To: DeCair, Sara[DeCair.Sara@epa.gov]
Cc: White, Rick[White.Rick@epa.gov]
From: Nesky, Anthony
Sent: Fri 9/25/2015 11:48:34 PM
Subject: RE: PAG wording simplification challenge--latest version
PAGWaterLanguage.docx

Dear Sara:

Here are two versions for you to look at. I'm not sure how the FDA DILs work, so you will have to check the discussion and walk me through it.

Tony Nesky

Center for Radiation Information and Outreach

Tel: 202-343-9597

nesky.tony@epa.gov

From: DeCair, Sara
Sent: Thursday, September 24, 2015 11:50 AM
To: Nesky, Anthony; Wieder, Jessica
Subject: PAG wording simplification challenge

Tony and Jessica,

I got feedback yesterday from Mike Flynn and Peter Grevatt (OGWDW Director) that the added redline language addressing how water and food PAGs are related but don't conflict is confusing to them.

I had chosen a subset of language that we'd put into the Internal Q&A (also attached) but if you see other ways to add or cut or simplify what it says in the proposal itself, that would be greatly appreciated.

I'm glad to set up a short meeting or conf call if it's easier to just talk thru - let me know.
Many thanks!!

S. (cell 202-738-2871)

To: DeCair, Sara[DeCair.Sara@epa.gov]; Wieder, Jessica[Wieder.Jessica@epa.gov]
Cc: White, Rick[White.Rick@epa.gov]
From: Nesky, Anthony
Sent: Thur 9/24/2015 7:33:42 PM
Subject: Re: The food-water relationship lingo

OK, we're getting there, slowly but surely. Question: Are the FDA PAGs adjusted to account for the fact that people will be drinking water with radionuclides in them--in other words, are the DILs for food lower than they would be because they know there will be a dose from drinking water in addition to food?

From: DeCair, Sara
Sent: Thursday, September 24, 2015 3:14 PM
To: Nesky, Anthony; Wieder, Jessica
Cc: White, Rick
Subject: Re: The food-water relationship lingo

I'm thinking of providing some of this as additional fodder for Alan to look at, and I'm very curious if Rick has input as a reader not previously in on all these PAGs conversations. The third sentence below is not true, but people do seem to think it. The FDA does a calculation of how much a diet is contaminated by giving a total diet mass (the denominator of the fraction) and that is the only place their guidance includes water. Their PAG does not work to protect against contaminated tap water since they didn't consider how it gets to people or what to recommend if it's over a guideline.

I can see how ODs are finding this confusing, but our Internal Q&A language is pretty strong!

From: Nesky, Anthony
Sent: Thursday, September 24, 2015 3:02 PM
To: DeCair, Sara; Wieder, Jessica
Cc: White, Rick
Subject: Re: The food-water relationship lingo

I sent it, but maybe my Outlook crashed. Try this:

Taken together, the FDA food PAGs and EPA drinking water PAGs account for all

doses from ingestion. Both PAGs are implemented through calculation of derived levels (known as derived intervention levels (DILs) in FDA and derived response levels (DRLs) in EPA). The FDA DIL calculations for food are protective because they account for all ingestion doses, including dose from drinking water covered by the EPA PAG. The EPA DRL calculations account for water added to beverages and to foods during preparation, but not the water intrinsic in food, which is covered by the FDA PAG.

In application, these are pre-set default intervention levels for both PAGs that are subject to change should incident-specific circumstances warrant it. When actual contamination levels are known, incident-specific factors might be used. Both PAGs are calculated to ensure that individuals will have no significant health risk from ingesting radioactive contamination.

From: DeCair, Sara
Sent: Thursday, September 24, 2015 2:59 PM
To: Nesky, Anthony
Subject: Re: The food-water relationship lingo

Sorry, no I didn't see an earlier message. It is one of OSWER's showstopper comments, and frankly everyone I've briefed, including the PAG Subcmte, asked about the interaction since FDA includes water as part of the diet (total mass, for their fraction calculation).

Peter's suggestion was verbal yesterday about Mike's interest in cumulative dose, that emergency managers should consider other pathways when they decide things about water. I thought that was pretty smart (and yes each of these things are marching orders from ODs).

From: Nesky, Anthony
Sent: Thursday, September 24, 2015 2:56 PM
To: DeCair, Sara
Subject: Re: The food-water relationship lingo

Did you receive my earlier email? Why do we need a discussion of the FDA PAG in the EPA PAG Manual? Also, do I have Peter's suggestion?

From: DeCair, Sara
Sent: Thursday, September 24, 2015 2:50 PM
To: Nesky, Anthony; Wieder, Jessica; Perrin, Alan
Subject: The food-water relationship lingo

I'm adding Alan since he heard Mike's concerns twice recently, and might be able to guide this editing process...

Jessica took a cut at simplifying the addition to our water proposal, and I've done a bit of editing on it. Anybody have an brilliant ideas on how to make this better? Note below, Alan, where I also try to address the considering other pathways suggestion that Peter gave us yesterday...

Whereas the FDA food PAG applies to food, EPA's drinking water PAG accounts for possible contamination in the drinking water supply. FDA's PAG includes water as part of the total diet calculation, including how food is prepared, and the proposed drinking water PAG focuses on drinking water consumption. FDA is one of the agencies that helped craft the drinking water PAG. Both PAGs are in terms of dose to be avoided. It is important to have both PAGs to address a variety of potential radiological emergency scenarios. Actions to protect against ingestion of contaminants in foods and water are handled differently, through embargoes, product recalls, public notifications or restrictions on water uses. Emergency response officials must consider potential doses from other pathways (e.g., airborne plume, ground shine) when making protective action decisions.

Thanks for any input you have! ~Sara

To: DeCair, Sara[DeCair.Sara@epa.gov]; Wieder, Jessica[Wieder.Jessica@epa.gov]
Cc: White, Rick[White.Rick@epa.gov]
From: Nesky, Anthony
Sent: Thur 9/24/2015 7:02:08 PM
Subject: Re: The food-water relationship lingo

I sent it, but maybe my Outlook crashed. Try this:

Taken together, the FDA food PAGs and EPA drinking water PAGs account for all doses from ingestion. Both PAGs are implemented through calculation of derived levels (known as derived intervention levels (DILs) in FDA and derived response levels (DRLs) in EPA). The FDA DIL calculations for food are protective because they account for all ingestion doses, including dose from drinking water covered by the EPA PAG. The EPA DRL calculations account for water added to beverages and to foods during preparation, but not the water intrinsic in food, which is covered by the FDA PAG.

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Sent: Thursday, September 24, 2015 2:59 PM
To: Nesky, Anthony
Subject: Re: The food-water relationship lingo

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Peter's suggestion was verbal yesterday about Mike's interest in cumulative dose, that emergency managers should consider other pathways when they decide things about water. I thought that was pretty smart (and yes each of these things are marching orders from ODs).

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To: DeCair, Sara
Subject: Re: The food-water relationship lingo

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Sent: Thursday, September 24, 2015 2:50 PM
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Whereas the FDA food PAG applies to food, EPA's drinking water PAG accounts for possible contamination in the drinking water supply. FDA's PAG includes water as part of the total diet calculation, including how food is prepared, and the proposed drinking water PAG focuses on drinking water consumption. FDA is one of the agencies that helped craft the drinking water PAG. Both PAGs are in terms of dose to be avoided. It is important to have both PAGs to address a variety of potential radiological emergency scenarios. Actions to protect against ingestion of contaminants in foods and water are handled differently, through embargoes, product recalls, public notifications or restrictions on water uses. Emergency response officials must consider potential doses from other pathways (e.g., airborne plume, ground shine) when making protective action decisions.

Thanks for any input you have! ~Sara

To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Nesky, Anthony
Sent: Thur 9/24/2015 6:59:16 PM
Subject: Fw: The food-water relationship lingo

Also, I am confused. Is it EPA's PAG or the FDA PAG that accounts for water used for food protection?

From: Nesky, Anthony
Sent: Thursday, September 24, 2015 2:56 PM
To: DeCair, Sara
Subject: Re: The food-water relationship lingo

Did you receive my earlier email? Why do we need a discussion of the FDA PAG in the EPA PAG Manual? Also, do I have Peter's suggestion?

From: DeCair, Sara
Sent: Thursday, September 24, 2015 2:50 PM
To: Nesky, Anthony; Wieder, Jessica; Perrin, Alan
Subject: The food-water relationship lingo

I'm adding Alan since he heard Mike's concerns twice recently, and might be able to guide this editing process...

Jessica took a cut at simplifying the addition to our water proposal, and I've done a bit of editing on it. Anybody have an brilliant ideas on how to make this better? Note below, Alan, where I also try to address the considering other pathways suggestion that Peter gave us yesterday...

Whereas the FDA food PAG applies to food, EPA's drinking water PAG accounts for possible contamination in the drinking water supply. FDA's PAG includes water as part of the total diet calculation, including how food is prepared, and the proposed drinking water PAG focuses on drinking water consumption. FDA is one of the agencies that helped craft the drinking water PAG. Both PAGs are in terms of dose to be avoided. It is important to have both PAGs to address a variety of potential radiological emergency scenarios. Actions to protect against ingestion of contaminants in foods and water are

handled differently, through embargoes, product recalls, public notifications or restrictions on water uses. Emergency response officials must consider potential doses from other pathways (e.g., airborne plume, ground shine) when making protective action decisions.

Thanks for any input you have! ~Sara

To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Wieder, Jessica
Sent: Thur 9/24/2015 5:24:39 PM
Subject: Re: PAG wording simplification challenge

Let me know if there is anything I can help with for late next week regarding the OSWER comments.

Jessica Wieder
U.S. Environmental Protection Agency
Radiation Protection Program
202-343-9201
m: 202-420-9353

Sent from my iPhone

On Sep 24, 2015, at 1:05 PM, DeCair, Sara <DeCair.Sara@epa.gov> wrote:

> I think once I am able to get Mike Flynn through the concept satisfactorily, I will run it past Mike Noska and Bill Cunningham. What you put below is a good cut at it and I'm thinking of using the last part as a springboard to another thing I need to address: What if more than one (or all) the exposure pathways are involved? Peter G. suggested a mention of how local emergency officials will have to consider other doses as they make decisions. We are hard at work addressing OSWER and ODs input...
>
> Tony, if you have ideas, do share them and I will show you both an updated version in a little bit once I've monkeyed with it a little.
>
> Process-wise, I'm trying to get new language through us and OW and up to ODs by Tuesday, and they are trying to meet with OSWER as soon as next Thursday or Friday! Scheduling miracles and an approved CR will be required of course.
>
> Thanks, Jessica!

From: Wieder, Jessica
Sent: Thursday, September 24, 2015 12:48 PM
To: DeCair, Sara; Nesky, Anthony
Subject: Re: PAG wording simplification challenge

A call with you and Mike Noska might be helpful. Unfortunately, after today, I am on vacation until next Wednesday.

Just to get us started, what do you think about what I have below. I tried to stay out of the weeds. Is it worth mentioning that FDA was part of the federal intergancy group that approved the drinking water PAG?

EPA's authorities are separate from FDA's. Whereas the FDA food PAG is relevant for food, EPA's drinking water PAG accounts for possible contamination in the drinking water supply. It is important to have both sets of PAGs to address a variety of potential radiological emergency scenarios (e.g., a drinking water supply was targeted or became heavily contaminated or there is specific concern about a specific radionuclide uptake in a crop or dairy product).

While FDA's PAGs includes water as part of the total diet (including how food is prepared), the EPA PAG focuses on drinking water consumption. FDA was one of the member agencies that helped create the drinking water PAG. It is important to remember that both EPA drinking water and FDA food PAGs are doses to be avoided and that should be applied by emergency planners and responders as needed for specific scenarios.

Jessica Wieder
U.S. EPA
Radiation Protection Program
Center for Radiation Information and Outreach
w: 202-343-9201
c: 202-420-9353

From: DeCair, Sara
Sent: Thursday, September 24, 2015 11:50 AM
To: Nesky, Anthony; Wieder, Jessica
Subject: PAG wording simplification challenge

Tony and Jessica,

I got feedback yesterday from Mike Flynn and Peter Grevatt (OGWDW Director) that the added redline language addressing how water and food PAGs are related but don't conflict is confusing to them.

I had chosen a subset of language that we'd put into the Internal Q&A (also attached) but if you see other ways to add or cut or simplify what it says in the proposal itself, that would be greatly appreciated.

I'm glad to set up a short meeting or conf call if it's easier to just talk thru - let me know. Many thanks!!

S. (cell 202-738-2871)

To: Nesky, Anthony[Nesky.Tony@epa.gov]; DeCair, Sara[DeCair.Sara@epa.gov]
From: Wieder, Jessica
Sent: Thur 9/24/2015 5:07:36 PM
Subject: Re: Mike Flynn's briefing to ADD: Could you please review/edit paragraphs on DW PAG and Southern Expsoure exercise by COB Thursday?
PAGs and SE15 paragraph.docx

Here are my edits. Tony, you might want to send the SE15 exercise write up to Ray Clark for review.

Jessica Wieder
U.S. EPA
Radiation Protection Program
Center for Radiation Information and Outreach
w: 202-343-9201
c: 202-420-9353

From: Nesky, Anthony
Sent: Wednesday, September 23, 2015 3:44 PM
To: Wieder, Jessica; DeCair, Sara
Subject: Mike Flynn's briefing to ADD: Could you please review/edit paragraphs on DW PAG and Southern Expsoure exercise by COB Thursday?

Mike Flynn has to give a briefing to the Acting Deputy Director, and we need to pull together a one-pager on key RPD activities. I put together paragraph on the drinking water PAG and the Southern Exposure Exercise. Could you please check them and add any next steps and milestones? Could you get it to me by COB tomorrow? Thanks!

Tony

Protective Action Guides (PAGs) for Drinking Water

The Protective Action Guide (PAG) manual contains radiation dose guidelines that would trigger public safety measures, such as evacuation or staying indoors, to minimize or prevent radiation exposure during an emergency. Emergency response organizations use the PAG Manual guidance in their response plans. EPA will propose a drinking water PAG in response to

comments submitted by a number of response organizations during the 2013 comment period on the updated PAG Manual. The proposed drinking water PAG will be a health-based tipping point at which alternative drinking water should be provided. EPA is developing a two-tiered-approach: 500 millirem projected dose in the first year for the general population, and 100 millirem projected dose in the first year for more sensitive populations. RPD and the Office of Water jointly developed the drinking water PAG, and are now working to address OSWER comments. Jessica/Sara what are the next steps?

Southern Exposure Exercise

ORIA personnel participated in the full-scale Southern Exposure 15 exercise, which simulated a nuclear power reactor accident that results in significant off-site radioactive releases in South Carolina. Participants included EPA, FEMA, NRC, FEMA, and all levels of state and local governments. ORIA personnel helped plan the exercise, and participated in sample analysis, dose calculation, contamination mapping, and public information functions. The MERL was dispatched to the exercise. ORIA personnel also participated in the second, "tabletop" phase of the exercise, dealing with relocation of homes and businesses, waste management, and monitoring/sampling to support long-term decision-making.

To: Wieder, Jessica[Wieder.Jessica@epa.gov]; DeCair, Sara[DeCair.Sara@epa.gov]
Cc: White, Rick[White.Rick@epa.gov]
From: Nesky, Anthony
Sent: Thur 9/24/2015 4:59:31 PM
Subject: Re: PAG wording simplification challenge

We might have to meet on this next week. I took a stab at shortening the section. It is my interpretation, which you will have to check for accuracy.

Here it is:

> Taken together, the FDA food PAGs and EPA drinking water PAG account for all doses from ingestion. Both PAGs are implemented through calculation of derived levels (known as derived intervention levels (DILs) in FDA and derived response levels (DRLs) in EPA). The FDA DIL calculations for food are protective because they account for all ingestion doses, including dose from drinking water covered by the EPA PAG. The EPA DRL calculations account for water added to beverages and to foods during preparation, but not the water intrinsic in food, which is covered by the FDA PAG.
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> In application, these are pre-set default intervention levels for both PAGs that are subject to change in response to incident-specific circumstances. When actual contamination levels are known, incident-specific factors might be used. Both PAGs are calculated to ensure that individuals will have no significant health risk from ingesting radioactive contamination.

I have an overarching question: what do we need to say about the FDA PAG in our EPA PAG Manual?

From: Wieder, Jessica
Sent: Thursday, September 24, 2015 12:48 PM
To: DeCair, Sara; Nesky, Anthony
Subject: Re: PAG wording simplification challenge

A call with you and Mike Noska might be helpful. Unfortunately, after today, I am on vacation until next Wednesday.

Just to get us started, what do you think about what I have below. I tried to stay out of the weeds. Is it worth mentioning that FDA was part of the federal intergancy group that approved the drinking water PAG?

EPA's authorities are separate from FDA's. Whereas the FDA food PAG is relevant for food, EPA's drinking water PAG accounts for possible contamination in the drinking water supply. It is important to have both sets of PAGs to address a variety of potential radiological emergency scenarios (e.g., a drinking water supply was targeted or became heavily contaminated or there is specific concern about a specific radionuclide uptake in a crop or dairy product).

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Jessica Wieder
U.S. EPA
Radiation Protection Program
Center for Radiation Information and Outreach
w: 202-343-9201
c: 202-420-9353

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Sent: Thursday, September 24, 2015 11:50 AM
To: Nesky, Anthony; Wieder, Jessica
Subject: PAG wording simplification challenge

Tony and Jessica,

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I'm glad to set up a short meeting or conf call if it's easier to just talk thru - let me know.
Many thanks!!

S. (cell 202-738-2871)

To: Wieder, Jessica[Wieder.Jessica@epa.gov]; DeCair, Sara[DeCair.Sara@epa.gov]
From: Nesky, Anthony
Sent: Wed 9/23/2015 7:44:23 PM
Subject: Mike Flynn's briefing to ADD: Could you please review/edit paragraphs on DW PAG and Southern Expsoure exercise by COB Thursday?

Mike Flynn has to give a briefing to the Acting Deputy Director, and we need to pull together a one-pager on key RPD activities. I put together paragraph on the drinking water PAG and the Southern Exposure Exercise. Could you please check them and add any next steps and milestones? Could you get it to me by COB tomorrow? Thanks!

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To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Daly, Eric
Sent: Thur 9/17/2015 6:02:01 PM
Subject: October Rad Training-Rad Removal Action Levels and RadResponder
CERCLA Radiation_general_ASN mtg 2014.pptx
Two CERCLA Radiation Risk Assessment Overview guides -Toolkit and Q&A_OG....pptx
WhyNotResradt.ppt

Great!!! Thanks so much. I have been working with Lyndsey N. more than Oleg on this because Oleg was away all last month when I needed to start developing my action memos for Niagara Falls Boulevard Site and Holy Trinity Cemetery. I am really struggling on what direction we are going in how to justify our removal actions. Any advice would be welcomed.

Here are some of my notes so far. I attached some of Stuart Walker slides I was provided and about to watch.

This is about the training but more importantly right now….finishing my Action Memos that need to be approved in less than two weeks. My presentation on the new sites will be based on what decisions we come up on which of the three paths we take.

1. Use UMTRCA Standards of 5pCi/g

2. Calculate a risk based cleanup value using 10^-4 to 10^-6 risk in the PRG Calculator.

3. Calculate a dose based cleanup value in ResRad and relate it back to a risk based number. If I recall, HQ frowns upon this because ResRad is not conservative in their calculations.

Attached are three presentations that Stuart Walker sent out. All three really layout the overall idea of how radiation risk is handled in OSWER for remedial projects. I'm not sure if it will help but it might clear up some of our questions.

From the slides, the overall idea is that if an ARAR isn't established/relevant then the PRG Calculator is used. I have used the PRG calculator and you can put in your own risk factors manually (e.g. 10^-4 to 10^-6 usually set for remedial). Stuart hates ResRad (there's even a powerpoint that's titled "Why Not ResRad." I would think the number(s) we use for our cleanup level would also be the number we would use for final status survey, right?

I stumbled upon this when reading some guidance on soil cleanup criteria. Our sites (i.e. NFB and HTC) meets these requirement.

See reference below. Some of the verbiage in here may be used in our Action Memo.

http://www.epa.gov/superfund/health/conmedia/soil/cleanup.htm

From: DeCair, Sara
Sent: Thursday, September 17, 2015 1:36 PM
To: Daly, Eric <Daly.Eric@epa.gov>
Subject: RE: October Rad Training-Rad Removal Action Levels and RadResponder

Sure enough, I'm planning to be there and can cover both things. I've even got Brendan coming from Chainbridge to help with the RR session, which is awesome, he's a good teacher and he knows how far Region 2 has already gotten.

Once I start the rad levels presentation, I'll want to talk with you and maybe Oleg to see if I'm hitting the right things. That training is less than a month away so I'd better get going, huh?

Cheers! I'm glad to get to come up and visit you all! I've never been to Edison, if you can believe it.

From: Daly, Eric
Sent: Thursday, September 17, 2015 1:31 PM
To: DeCair, Sara
Subject: October Rad Training-Rad Removal Action Levels and RadResponder
Importance: High

Hi Sara:

How are you doing? Has Christopher Royce contacted you about presenting at our October Rad Training/Exercise? Specifically, a brief presentation on the shift towards using remedial action levels in determining rad removal action eligibility? Also, we will be discussing and trying to use RadResponder during our exercise. Christopher recommended you speaking on that and/or Chainbridge personnel.

Please let me know.

I hope all is well with you and the family.

Regards,

Eric

"We must, indeed, all hang together, or assuredly we shall all hang

separately", Benjamin Franklin

Eric M. Daly
On-Scene Coordinator/Radiological Response Specialist
US Environmental Protection Agency- Region II

ERRD/RPB/PPS
2890 Woodbridge Avenue
Edison, NJ 08837
daly.eric@epa.gov
732-321-4350

To: Schultheisz, Daniel[Schultheisz.Daniel@epa.gov]; Rosnick, Reid[Rosnick.Reid@epa.gov]
Cc: DeCair, Sara[DeCair.Sara@epa.gov]; Rosencrantz, Ingrid[Rosencrantz.Ingrid@epa.gov]
From: Lee, Raymond
Sent: Tue 9/15/2015 6:33:18 PM
Subject: Re: A new task

FYI - the headers for the dates are as follows:

The first column is projected OP to OMB, and then second column is planned signature date.

From: Lee, Raymond
Sent: Tuesday, September 15, 2015 2:31 PM
To: Schultheisz, Daniel; Rosnick, Reid
Cc: DeCair, Sara; Rosencrantz, Ingrid
Subject: Re: A new task

Hi all,

Based on the newest info that Alan/Andrea sent to Britney on Monday, this is the latest that need to be incorporated into the action plan files. I don't have the latest files so I'm assuming Reid, Ingrid and Sara can update them and get the final versions to Andrea:

5198	Protective Action Guidance for Radiological Incidents	Notice	11/15/2015	02/15/2016	As part of its mission to protect human health and the environment, the Environmental Protection Agency (EPA) publishes protective action guides to help federal, state, local and tribal emergency response officials make radiation protection decisions during emergencies. EPA, in coordination with a multi-agency working group within the Federal Radiological Preparedness Coordinating Committee (FRPCC), is proposing updates to the 1992 Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, also referred to as 'The PAG Manual' or 'PAGs' (EPA 400-R-92-001, May 1992).	

5281	NESHAP for Operating Uranium Mill Tailings - Amendments (Subpart W)	Final Rule	01/05/2016	05/06/2016	NESHAP Subpart W protects human health and the environment by setting radon emission standards and work practices for operating uranium mill tailings impoundments. EPA is in the process of reviewing this standard. If necessary, the agency will revise the NESHAP requirements for radon emissions from operating uranium mill tailings.	OP approved downtier to Tier 3 on 8/26/15

5319	Revisions to Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings	Final Rule	08/08/2016	12/15/2016	The cross-media standards found in 40 CFR Part 192 – which apply to pollutant emissions and site restoration associated with uranium ore processing and disposal of waste materials – must be adopted by the Nuclear Regulatory Commission, their Agreement States, and the Department of Energy. The Agency is revising the existing rule to take into particular account the significant changes in 5633 industry extraction technologies and their potential impacts to groundwater.	

Thanks and let me know if you need anything else. I'm in some training but have access to a computer/webmail.

Ray

From: Schultheisz, Daniel
Sent: Tuesday, September 15, 2015 2:22 PM
To: Rosnick, Reid
Cc: Lee, Raymond
Subject: RE: A new task

Ray, can you help Reid with the dates? Thanks.

From: Rosnick, Reid
Sent: Tuesday, September 15, 2015 2:20 PM
To: Schultheisz, Daniel
Subject: RE: A new task

I can't get into Reg Tracker.

From: Schultheisz, Daniel
Sent: Tuesday, September 15, 2015 2:14 PM
To: Rosnick, Reid; Rosencrantz, Ingrid; Lee, Raymond
Subject: A new task

Per Alan:

Please make sure the Action Plans for subpart W and 192 reflect the dates in the reg tracker (they probably should). Then send the Action Plan to Andrea, with copy to Alan. Mike will be meeting with Janet later today. Thanks.

To: DeCair, Sara[DeCair.Sara@epa.gov]; Perrin, Alan[Perrin.Alan@epa.gov]
From: Wieder, Jessica
Sent: Thur 9/3/2015 5:31:49 PM
Subject: Re: FR is a bit edited: Drinking Water PAG
Water PAG FR Notice draft 9-3-2015 jw.docx

Sara - Attached are my thoughts, but I wont be offended if you don't include them.

As you know, I wish we didn't have to include this language. We have never had a public or press question regarding cumulative risk. Adding this may be inviting questions.

Jess

Jessica Wieder
U.S. EPA
Radiation Protection Program
Center for Radiation Information and Outreach
w: 202-343-9201
c: 202-420-9353

From: DeCair, Sara
Sent: Thursday, September 3, 2015 11:30 AM
To: Wieder, Jessica; Perrin, Alan
Subject: FR is a bit edited: Drinking Water PAG

Jessica, Alan,

I did some rearranging and added a few words you'll be interested in – see Section D of this FR Notice. I asked Lisa Christ to take the next look, but I'm hoping for your thoughts as well. Thank you!

Sara

From: DeCair, Sara
Sent: Thursday, September 03, 2015 11:29 AM
To: Christ, Lisa
Subject: FYI note from 8/27: OSWER Review of Drinking Water PAG

Importance: High

Lisa,

FYI, Mike is wanting us to address all of the items Barbara lists below. I've got them well in hand, and I think the attached updated draft FR now addresses the cumulative risk thing, which we'll have to see how we all feel about…

Alan didn't have anything further on this FR so I think it's for your eyes next. I switched the point of contact to you, but would be glad to have it be me, or both of us.

If we hear anything from OSWER today, I'll touch base (but I'd be a bit surprised). Cheers,

Sara

202-343-9108

From: Hostage, Barbara
Sent: Thursday, August 27, 2015 9:29 AM
To: Tulis, Dana; Cheatham, Reggie; Woolford, James; Stalcup, Dana; Scozzafava, MichaelE; Fitz-James, Schatzi; Kudarauskas, Paul; Raffaele, Kathleen; Foster, Stiven; Cogliano, Gerain
Subject: FW: OSWER Review of Drinking Water PAG
Importance: High

fyi

From: Hostage, Barbara
Sent: Thursday, August 27, 2015 9:14 AM
To: Flynn, Mike
Cc: Grevatt, Peter
Subject: OSWER Review of Drinking Water PAG

Importance: High

Good morning, Mike.

I was just drafting this email message to you when I received your email this morning.

It was very nice seeing/speaking with you and Peter on Monday.

We look forward to seeing the redline/strikeout version of the revised draft.

We will also provide our comments on the draft Q& A document that Sara Decair shared with us on Monday afternoon.

Finally, we would like to request to review/comment on the FR notice which will announce the Draft DW PAG for review/comment.

We are particularly interested in the "charge questions" that will focus reviewer's comments on the important elements contained in the draft PAG (e.g., the feasibility/implementability of a 2-tiered PAG vs. a single value PAG, including what a possible single value might be).

In addition, OSWER scientific staff would like more detailed information/additional discussion regarding the FDA PAG, the relationship between the FDA PAG and the EPA PAG, and the question of cumulative risk (OSWER Overarching comments #6 & #7).

Lastly, with respect to the schedule, we certainly understand and appreciate your offices' interest to move as quickly as possible in order to meet your goal of finalizing the PAG document by the end of 2016. OSWER will work closely with you, and as expeditiously as possible, to resolve our questions and concerns, given OSWER's many other high visibility priorities such as the Gold King Mine spill. That being said, we will need to make sure that OSWER leadership is involved in the path forward. And, as I mentioned at Monday's meeting, Dana Tulis will be out of the office until September 16th and would like an opportunity to personally review any revised PAG, FR notice, Q & A's.

It is my hope that we can use the time before Dana returns to answer any questions/resolve any further concerns we (OSWER) may have.

I want to thank you and your staff for the time and consideration in addressing OSWER concerns.

Please let me know if you have any questions.

Barbara Hostage, Director

Policy Analysis and Regulatory Management Staff (PARMS)
Office of Program Management (OPM)
Office of Solid Waste and Emergency Response (OSWER)

EPA West Room 4130A
Phone Number: 202-566-1933
Fax Number: 202-566-1934
Mail Code: 5103T

To: DeCair, Sara[DeCair.Sara@epa.gov]; Perrin, Alan[Perrin.Alan@epa.gov]
Cc: Rosnick, Reid[Rosnick.Reid@epa.gov]; Rosencrantz, Ingrid[Rosencrantz.Ingrid@epa.gov]
From: Lee, Raymond
Sent: Wed 9/2/2015 4:18:04 PM
Subject: RE: Reg tracker and PAG project plan dates match up
OAR-ORIA Reg Tracker August 7 2014.docx

Awesome Sara! Good to know. Reid and Ingrid, I'm cc'ing you on this and including the file I sent to Sara so that you guys can also take a look at what we have in the system. Please let me know if you have any edits to these milestones so that I can get them back for the reg. tracker report (**due tomorrow by noon**) and also in the ADP system via Lotus Notes (**due COB Friday**).

Thanks!

Ray

P.S. Reid, I cc'd you on the request for an update on the downtiering the other day. Haven't heard anything still!

Ray Lee | Center for Radiation Information and Outreach (CRIO) | US EPA | Phone 202.343.9463 | Fax 202.343.2305 | lee.raymond@

From: DeCair, Sara
Sent: Wednesday, September 02, 2015 11:31 AM
To: Perrin, Alan; Lee, Raymond
Subject: Reg tracker and PAG project plan dates match up

Good job to us, our dates in the still-possible Project Plan meet up perfectly with the OAR-ORIA Reg Tracker that Ray maintains. I'm still hopeful we can get to OP by 9/28 and that OMB would start review by Nov. 1, so signature on an FR by Mar. 2016. We'll see!

Sara D. DeCair

http://www.epa.gov/radiation/rert/pags.html

202-343-9108

Room 1416 B in WJC West

To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Wieder, Jessica
Sent: Thur 8/27/2015 1:16:09 PM
Subject: Try this language

Every PAG is developed with the same three basic principles in mind: avoid acute effects, minimize cancer risk, and ensure the actions taken are not more dangerous than the risk being avoided. Each PAG provides guidance on safety measures to keep cumulative doses as low as possible during an emergency while allowing for the decision-making flexibility needed to address different types of large scale radiological releases. PAGs are doses to be avoided; they do not represent "acceptable" routine exposures.

Jessica Wieder

U.S. EPA

Radiation Protection Program

Center for Radiation Information and Outreach

w: 202-343-9201

c: 202-420-9353

To: Wieder, Jessica[Wieder.Jessica@epa.gov]
Cc: White, Rick[White.Rick@epa.gov]; DeCair, Sara[DeCair.Sara@epa.gov]
From: Nesky, Anthony
Sent: Wed 8/19/2015 7:39:14 PM
Subject: Suggested Edits to PAG Technical Fact Sheet
Technical Fact Sheet for DW PAG_7-16-15tnedits.docx

Dear Jess:

Here are my suggested edits for the Technical Fact Sheet for the proposed Drinking Water PAG. Edits are in redline/strikeout.

Tony Nesky

Center for Radiation Information and Outreach

Tel: 202-343-9597

nesky.tony@epa.gov

To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Hudson, Scott
Sent: Wed 8/19/2015 4:56:45 PM
Subject: RE: For Monday: Check our water math

Hi Sara:

Just FYI – John is on leave this week, and deploying w/ ASPECT for the next couple weeks. He'll probably get back to you soon, he's good like that, but just to inform you, he's not in the office until well into Sept.

scott

From: DeCair, Sara
Sent: Wednesday, August 19, 2015 11:11 AM
To: Cardarelli, John
Cc: Kudarauskas, Paul; Kappelman, David; Hudson, Scott; Veal, Lee; Hernandez-Quinones, Samuel
Subject: For Monday: Check our water math

John,

I hope your week off was restful and that you might have a few minutes to review our math so we're all on the same page going forward with this drinking water proposal. We talked with Scott and Stuart on Tuesday, and I think they're cool with what we've done. In the attached spreadsheet, you'll see there is a most limiting concentration derived from all the age groups other than adult, which we choose as the DRL for the lower tier. FRMAC has agreed they can reproduce this in their assessment manual, where the rest of the PAGs DRLs are.

Note too that we use the corresponding age group's intake rate for each calculation, then pick the most restrictive. The adult DRLs are more straightforward. While we know a complicated approach may take more explaining, we feel pretty strongly that this gives us the conservatism needed to strike the right balance for a wide possible range of emergencies. We can also envision using one tier or a combo of these assumptions or actual inputs to adjust based on the situation.

To a great extent, those choices are up to state/locals and likely, Office of Water, who gets pulled into every large drinking water situation.

Let us know if you run into questions, and feel free to call my cell anytime: 202-738-2871

S.

Sara D. DeCair

http://www.epa.gov/radiation/rert/pags.html

202-343-9108

Room 1416 B in WJC West

To: DeCair, Sara[DeCair.Sara@epa.gov]; Gillam, Connie[Gillam.Connie@epa.gov]
From: Lee, Raymond
Sent: Wed 8/19/2015 3:23:16 PM
Subject: RE: Review my Action Memo?

Hi Sara,

As far as a format/organiziational standpoint, I went through the memo and everything looks good to me! The action memo template has not changed since 2013 so everything should be good to go on that front. It has all the headers and sections that are required.

Thanks,

Ray

Ray Lee | Center for Radiation Information and Outreach (CRIO) | US EPA | Phone 202.343.9463 | Fax 202.343.2305 | lee.raymond@

From: DeCair, Sara
Sent: Wednesday, August 19, 2015 10:24 AM
To: Lee, Raymond; Gillam, Connie
Subject: Review my Action Memo?

Ray, Connie,

I wonder if you would both take a look at the attached Action Memo that will accompany our FR package for a drinking water PAG proposal up to OP in the next few weeks. Do you see any problems with format, organization or anything I've missed? I used the example from our 2013 PAG process… thank you very much for any input! If you could get back to me by Monday morning, that would be ideal.

Sara

Sara D. DeCair

http://www.epa.gov/radiation/rert/pags.html

202-343-9108

Room 1416 B in WJC West

To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Pawel, David
Sent: Tue 8/18/2015 8:11:13 PM
Subject: Trigger Levels Report PAG for Drinking Water 4-2014 w Pawel comments.doc
Trigger Levels Report PAG for Drinking Water 4-2014 w Pawel comments.doc

Hi Sara,

I didn't have a chance to get into as much detail as I'd like, but here's some initial comments I thought to send you before we meet.

1) Already mentioned to you that risk estimates are based on FGR 13. It is my understanding that a preliminary FGR16 (to replace FG13) should be completed by the end of September. Does it make sense, or is it possible, to wait until then to make sure that the risk estimates in this report are not obsolete upon arrival?

2) More work is needed to make sure the definitions of basic terms at the beginning of the report are accurate. For example, the weighting factors used to calculate effective dose are subjectively derived and incorporate non-cancer (as well as cancer) risk. The statement about the thyroid cancer weight is simply not accurate.

3) In general, I would refrain from referring to risks or doses associated with 1 Bq. It might cause less confusion if risk and dose per Bq are described more in terms of slope factors, i.e., factors when multiplied by activity (Bq) yield estimates of risk or dose.

4) Re Table 5: I would be inclined to base main results on mean drinking water ingestion rates. Note that people who drink two to three times as much water as the national average would not necessarily have twice the dose for tissues of concern.

5) The presentation is clear, but some editing is needed.

David

U.S. EPA Superfund Radiation Policy and Guidance

Stuart Walker
U.S. Environmental Protection Agency
Office of Superfund Remediation
and Technology Innovation (OSRTI)

Presented to
Florence Gabillaud-Poillion of ASN
in Arlington, Virginia on 17 July, 2014

EPA

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EPA Addresses Site Cleanup Under Several Laws, Programs

- Comprehensive Environmental Response, Compensation & Liability Act, CERCLA or "Superfund"
- National Contingency Plan (NCP) is regulation for CERCLA
- National Priorities List (NPL) guides EPA on which sites need further attention

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CERCLA Programs

- Removal actions – short-term response actions
  - » Emergency
  - » Time-Critical
  - » Non-Time Critical (addressed by remedial program)
- Remedial – long-term response actions (focus of this talk)

EPA

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Purpose

- Provide brief description of CERCLA process
- Provide overview of CERCLA remedy (long-term cleanup) selection requirements:
  - » Focus on radionuclides
- Provide overview of key EPA CERCLA guidance and tools that specifically address radionuclides
  - » Radionuclides are also addressed with other hazardous substances under general EPA CERCLA guidelines

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Part 1.
What does Superfund Address

EPA

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Superfund NPL (remedial) sites: Number and Progress *(old data)*

- 1,304 NPL sites
  - » 66 are radiation sites
- 59 mores sites proposed for NPL
  - » 1 is a radiation site
- 1,124 NPL sites are “construction completion”
  - » 38 are radiation sites
- 360 Sites have been deleted from NPL
  - » 9 are radiation sites

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What does a Superfund Site look like?

- There are many different types of Superfund sites.
  - » See following 4 pages for examples of radioactively contaminated sites.

EPA

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Nuclear Metals Inc. - Massachusetts

EPA

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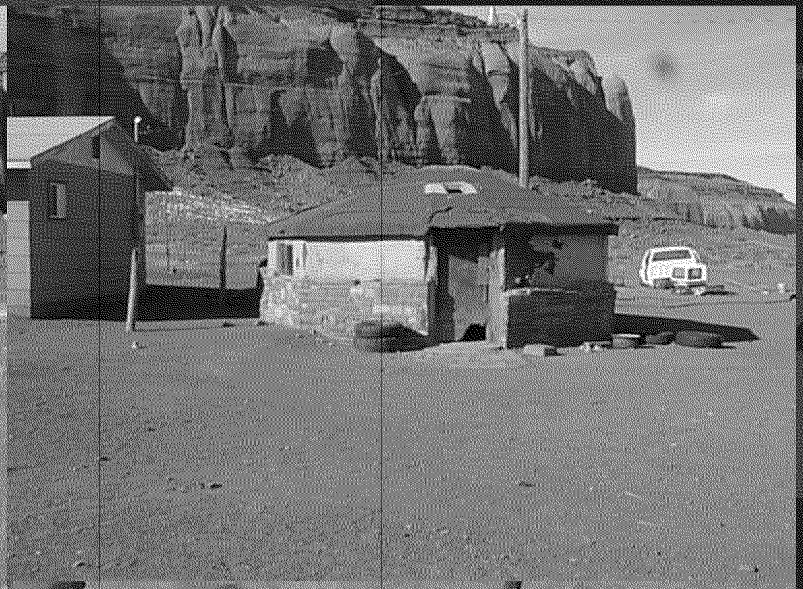
Abandoned Uranium Mines Project – Navajo Nation



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Welsbach/General Gas Mantle – New Jersey

EPA

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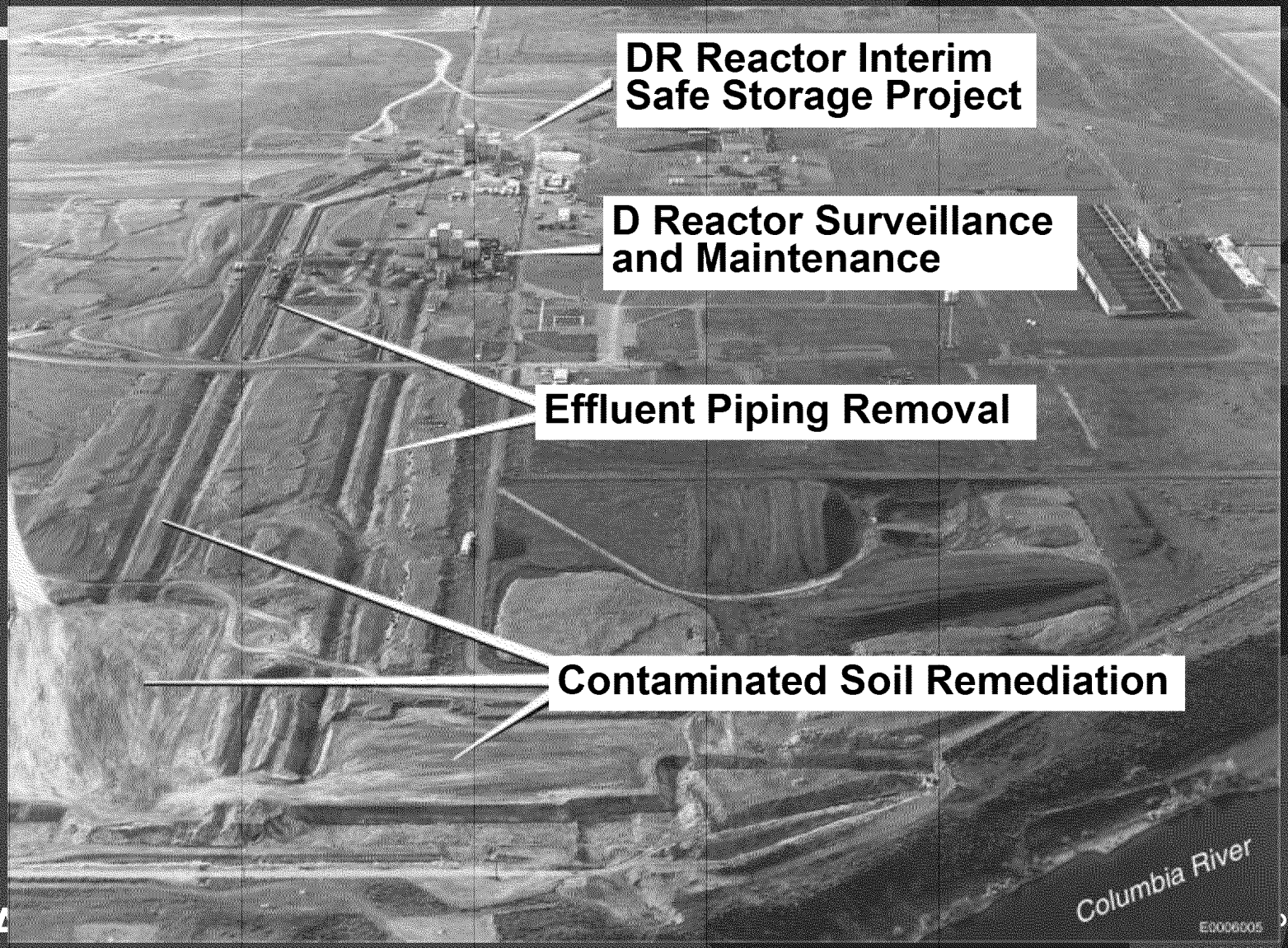
Hanford –
D Reactor / DR Reactor Remediation



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CERCLA Decision-making

- CERCLA cleanup decisions are made site-specifically
  - » Must comply with law (CERCLA) and regulations (NCP)
- EPA Regional site managers
  - » Removals – On Scene Coordinators (OSCs)
  - » Remedial (and NTC-removals) – Remedial Project Managers (RPMs)

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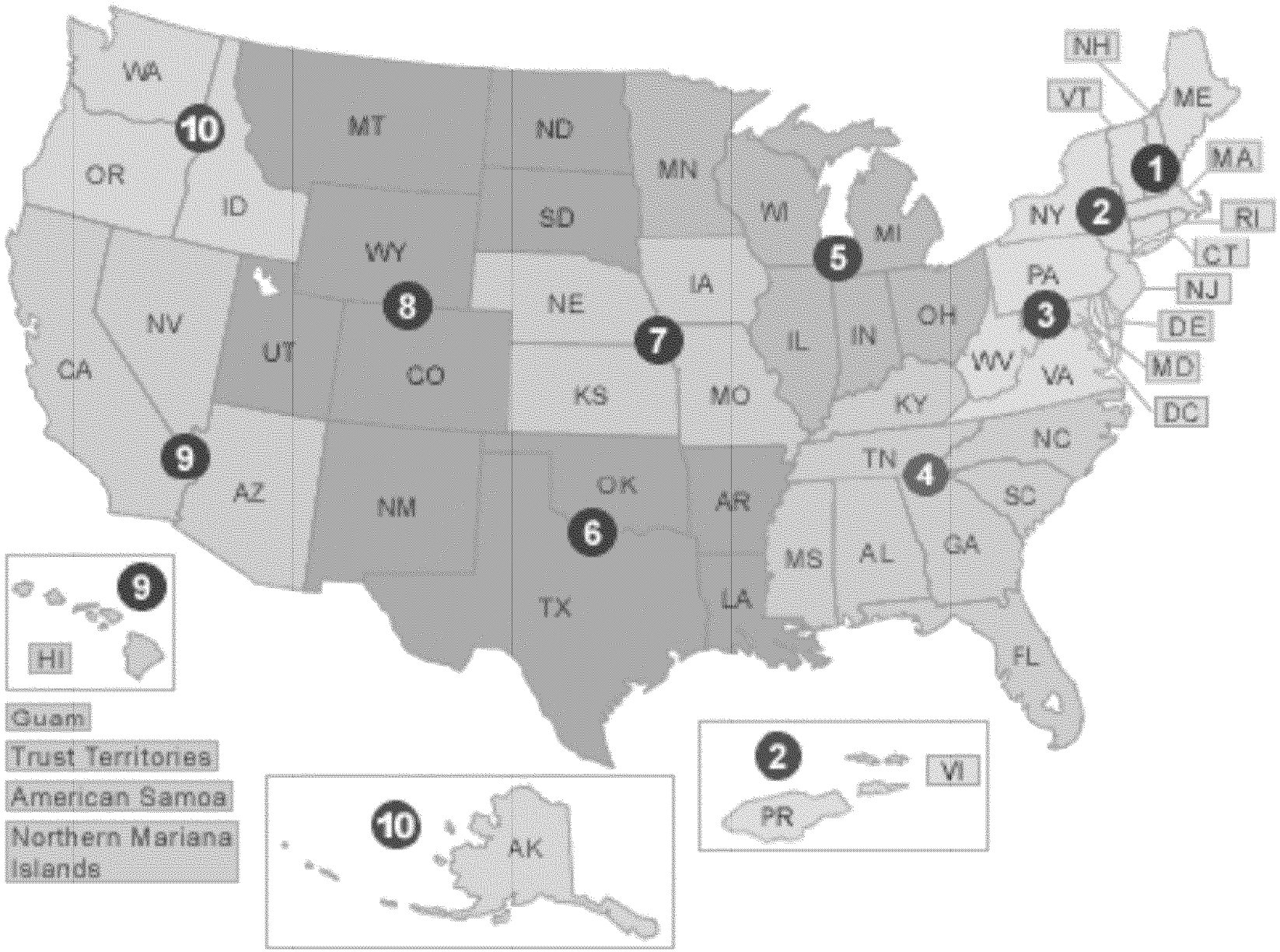
EPA Regions



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Part 2.
Regulatory Framework

EPA

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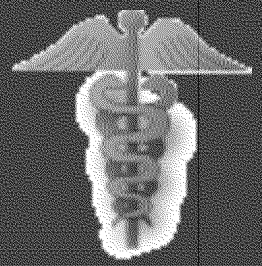
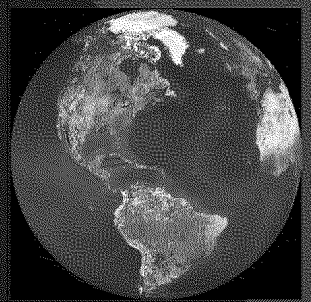
Nine CERCLA Remedy Selection Criteria

- Two threshold criteria (both must be met)
  1. Protect human health and the environment
  2. Comply (attain or waive) with other federal and state laws: Applicable or Relevant and Appropriate Requirements (ARARs)
     - Protect current or future sources of drinking water (e.g., attain MCLs or more stringent state standards)





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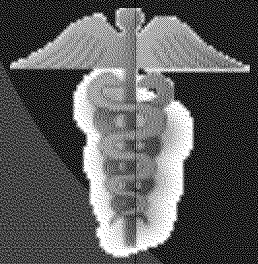
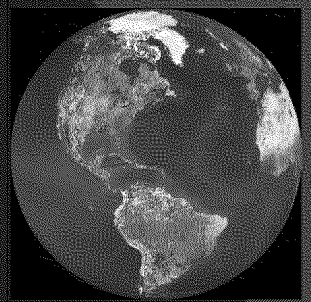
Nine CERCLA Remedy Selection Criteria (continued)

- 6 CERCLA ARAR waivers
  1. Interim Measure
  2. Greater Risk to Health and the Environment
  3. Technical Impracticability
  4. Equivalent Standard of Performance
  5. Inconsistent Application of State Requirements
  6. Fund Balancing





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Nine CERCLA Remedy Selection Criteria (continued)

- Five balancing criteria (used to evaluate between potential remedies that meet threshold criteria)
  1. Long-term effectiveness and permanence
  2. Reduction of waste toxicity, mobility, or volume
  3. Short-term effectiveness
  4. Implementability
  5. Cost

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Nine CERCLA Remedy Selection Criteria (continued)

- Two modifying criteria (information from public comment period that may modify remedial action)
  1. State acceptance
  2. Community acceptance

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CERCLA Cleanup Levels

- ARARs often determine cleanup levels
- Where ARARs are not available or protective, EPA sets site-specific cleanup levels that
  - » For carcinogens, represent an increased cancer risk of 1×10^{-6} to 1×10^{-4}
    - —10^{-6} used as "point of departure"
    - —PRGs are established at 1×10^{-6}
  - » For non-carcinogens, will not result in adverse effects to human health (hazard index (HI) <1)
- Address ecological concerns
- To-be-considered (TBC) material may help determine cleanup level

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CERCLA Cleanup Levels Are NOT Based On

- NRC decommissioning requirements (e.g., 25, 100 mrem/yr dose limits) 10 CFR 20 Subpart E
  - » If used as an ARAR, 10^{-6} still used as point of departure, and 10^{-4} to 10^{-6} risk range must be met
- Guidance outside risk range and/or if expressed as a dose (# mrem/year). This includes:
  - » DOE orders, NRC guidance (e.g., NUREGs), ICRP guidance, IAEA guidance, NCRP guidance, ANSI/HPS guidance, EPA/DHS PAGs, and Federal guidance

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Part 3.
Guidance for EPA staff

EPA

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Site consistency

- To help facilitate compliance with NCP and cleanup sites, EPA Headquarters provides:
  - » Guidance documents
  - » Models (calculators)
  - » Training (developed with State led ITRC)
- Available for free on the internet

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Guidance: CERCLA Cleanup

- *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination* (8/22/97) OSWER Directive 9200.4-18
- Radioactive contaminants at CERCLA sites are governed by the NCP like all other contaminants
  - » Cleanups based on ARARs or risk range
  - » Groundwater restored to beneficial reuse
  - » Use reasonably anticipated land use

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EPA/ITRC CERCLA Policy and Guidance Training

- Four modules provide:
  1. Radiation Regulatory Background and Case Studies
  2. Overview of CERCLA Requirements
  3. EPA CERCLA Radiation Guidance and Tools
  4. Challenges of Long-Term Management of Radiation Sites

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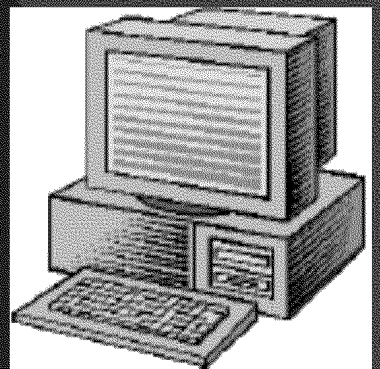
EPA/ITRC CERCLA Policy and Guidance Training, cont.

- Five Live Internet rad CERCLA Policy Training sessions have been conducted
  - » 838 total participants, including 163 EPA employees
- An archived version of a live training session is available at:
  - » http://www.clu-in.org/conf/itrc/radscleanup_060507/
- Archived version was accessed by users 3,282 times between January 1, 2008 and August 26, 2009.



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Common Rad ARARs

- Radium and thorium in soil (40 CFR Part 192 (UMTRCA))
  - » 5 pCi/g [0.185 Bq/g] *over* background
- Radon in buildings (40 CFR Part 192 (UMTRCA))
  - » 0.02 working levels of radon-220 and -222 decay products
- Outdoor radon (40 CFR Part 192 (UMTRCA) 40 CFR Part 61 (CAA))
  - » 20 pCi/m²-s [0.74 Bq/m²-s] of radon-222

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Common Rad ARARs (continued)

- NRC Low Level Waste (10 CFR Part 61 (AEA))
  - » 25 mrem/yr [0.25 mSv/yr] whole body, 75 mrem/yr [0.75 mSv/yr] to the thyroid, and 25 mrem/yr [0.25 mSv/yr] to any critical organ other than the thyroid
    - —This is different dose methodology than 25, 100 mrem/yr [0.25, 1 mSv/yr] NRC decommissioning standard
- State water quality standards

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Common Rad ARARs (continued)

- Federal drinking water MCLs (40 CFR Part 141 (SDWA))
  - » 5 pCi/l [0.185 Bq/l] of radium-226 and -228 combined
  - » 4 mrem/yr [0.04 mSv/yr] from beta particles and photon emitters to total body or any internal organ
  - » 15 pCi/l [0.555 Bq/l] for gross alpha particle activity (excluding radon and uranium)
  - » 30 micrograms per liter of uranium
- Uranium in groundwater (40 CFR Part 192 (UMTRCA))
  - » 30 pCi/l [1.11 Bq/l] of uranium-234 and -238 combined
- State MCLs if more stringent than federal

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Guidance: UMTRCA Soil ARAR

- *Use of Soil Cleanup Criteria in 40 CFR Part 192 as Remediation Goals for CERCLA sites* (2/12/98) OSWER Directive 9200.4-25
- Guidance on radium and thorium subsurface soil cleanup levels
- Attain 5 pCi/g [0.185 Bq/g], not 15 pCi/g [0.555 Bq/g], in subsurface
  - » 15 pCi/g [0.555 Bq/g], is “finding tool” for UMTRCA sites where subsurface contamination is high,
  - » and was expected to achieve 5 pCi/g [0.185 Bq/g] or less, therefore
  - » 15 pCi/g [0.555 Bq/g], is “relevant and appropriate” at CERCLA sites only when it will achieve 5 pCi/g [0.185 Bq/g] or less

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Risk-based Cleanup Levels for Radioactive Contamination

- Radiation cleanup levels expressed as risk levels, **not** mrem [mSv]
- Superfund uses "slope factors" in Health Effects Assessment Summary Tables (HEAST) instead of dose conversation tables to estimate cancer risk from radioactive contaminants
  - » HEAST has been updated with new information from Federal Guidance 13
    - —Based on information in ICRP 72
    - —Soon to be updated by ICRP 107

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Guidance: Risk Assessment Q&A

Old Superceded

- *Radiation Risk Assessment at CERCLA Sites: Q&A* (12/99) OSWER Directive 9200.4-31P
- Provides overview of **then** current EPA guidance for radiation risk assessment
- Written for users familiar with Superfund but not radiation
- Adds some new guidance
  - » Dose assessment only for ARAR compliance
  - » No dose-based TBCs (including ***No*** 15 mrem/yr [0.15 mSv/yr])
  - » Direct exposure rate may supplement sampling

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New 2014 Risk Assessment Q&A

- *Radiation Risk Assessment at CERCLA Sites: Q&A* (5/2014) OSWER Directive 9200.4-40
- Provides overview of **current** EPA guidance for radiation risk assessment
- Written for users familiar with Superfund but not radiation

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Summary of Key Policy Points of New 2014 Risk Assessment Q&A

1. Still do not use dose based (expressed as # millirem per year (mrem/yr) guidance as TBCs
   - » Including NRC, DOE, or international guidance
2. Dose based ARARs not protective if greater than 12 mrem/yr, instead of 15 mrem/yr
3. Use EPA Superfund risk assessment models (PRG calculators) **not** DOE models (RESRAD)
4. Don't use MARSSIMM area averaging survey method for rad when using Not To Exceed for chemicals

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Reflect Superfund Recommended guidance issued since 1999

1. Rad SSG User Guide 2000
2. Rad SSG TBD 2000
3. PRG calculator 2002
4. Common Rads found at Superfund sites 2002
5. DCC calculator 2004
6. SF Rad Risk Assessment & How You Can Help 2005
7. BPRG calculator 2006
8. SPRG calculator 2009
9. BDCC calculator 2010
10. SDCC calculator 2010
11. CPM calculator 2014?
12. Eco calculator 2014?

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Update Policies Based on Newer Science

- For an effective dose standard ARAR to be considered protective, it should be 12 mrem/yr or less.
  - » Change from 15 mrem/yr based on risk to dose estimate in Federal Guidance 13
  - » Cleanup levels not based on an ARAR continue to be based on cancer risk range (10-4 to 10-6) <u>not</u> dose

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Update Policies Based on Newer Science, cont.

- To comply with UMTRCA indoor radon standard as an ARAR, users may assume the following concentrations correspond to 0.02 Working Levels:
  - » 5 pCi/l of Rn-222
  - » 7.5 pCi/l of Rn-220
- The methodology for making these conversions is discussed in ICRP "Lung Cancer Risk from Radon and Progeny"

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More consistency on Risk Assessments (Rad & Chem)

- Explain what type of circumstances these Superfund guidance and tools are recommended
- Reiterate more strongly that risk assessments (e.g., models used) should be consistent with chemicals at site and with other regional sites
- Don't use a steady state model for chemical and a transfer/dynamic model for radionuclides
  - » Such as using RSL calculator for chemicals then RESRAD for radionuclides

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More consistency on Surveys (Rad & Chem)

- Explain what type of circumstances these Superfund guidance and tools are recommended
- Reiterate more strongly that site surveys (e.g., characterization and confirmation) should be consistent with chemicals at site and with other regional sites
- Don't use not-to-exceed (NTE) for chemicals and area averaging (AA) for radionuclides for residential
  - » NTE for residential cleanup of chemicals but AA approach like MARSIMM for the radionuclides

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Guidance: Rad SSG

- Soil Screening Guidance for Radionuclides [rad SSG] documents (10/00) OSWER Directives 9355.4-16A and 9355.4-16
  - » User Guide
  - » Technical Background Document
- Guidance to screen out areas, pathways, and/or radionuclides early in the process
- Consistent with 1996 chemical SSG
  - » 1×10^{-6} and MCLs (leaching from soil)
  - » Residential land use
  - » Survey procedures for site characterization
  - » Evaluates 5 soil to groundwater models
  - » Accounts for technical differences of radiation

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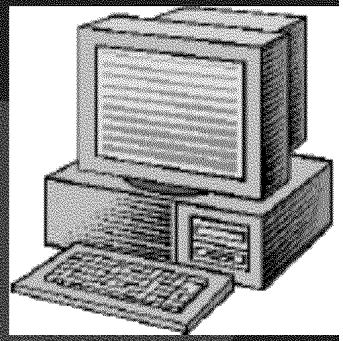
Guidance: Rad PRG Calculator

- Calculator to establish PRGs, when:
  - » ARAR is either not available or sufficiently protective (e.g., 25 mrem/yr [0.25 mSv/yr] or more)
- Electronic equations (risk and leaching to groundwater) also are on Internet
  - » 1×10^{-6} and MCLs (leaching from soil)
  - » Accounts for technical differences of radiation (e.g., gamma, plant uptake)



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Guidance: Rad PRG Calculator (continued)

- Eight (soon ten) scenarios/land uses available

1. Residential
2. Agricultural
3. Indoor workers
4. Outdoor workers
5. Fish ingestion
6. Tap water
7. Soil to groundwater
8. Air
9. Recreator
10. Construction worker

- Chemical SSL Internet equations should be used for chemical toxicity of uranium
- EPA developed Internet-based training with States (ITRC) on calculator and radiation risk assessment
  - » http://www.clu-in.org/conf/itrc/rads_051507/

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Guidance: ARAR Dose Calculator

- Calculator to establish Dose Compliance Concentrations (DCC) for single dose limit ARARs requiring a dose assessment
- Eight (soon ten) scenarios/land uses available

1. Residential
2. Agricultural
3. Indoor workers
4. Outdoor workers
5. Fish ingestion
6. Tap water
7. Soil to water
8. Air
9. Recreator
10. Construction worker

- Equations similar to those for PRG calculator, except dose conversion factors used instead of slope factors

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EPA/ITRC Radiation Risk Training

- Four modules provide:
  1. Background and Regulatory Case Studies
  2. Existing Practices in Radiation Risk Assessment
  3. **Use of Radiation PRG Calculator *(tutorial on using PRG and ARAR dose calculator)***
  4. **Case Study Application for PRG Calculator**

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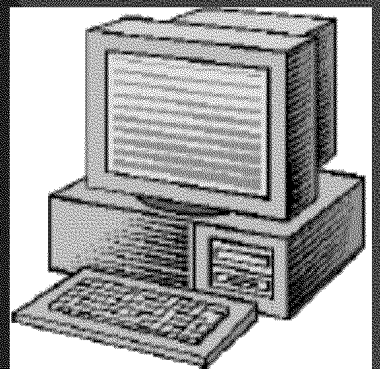
EPA/ITRC Radiation Risk Training, cont.

- Eight Live Internet rad CERCLA Policy Training sessions have been conducted
  - » 1,047 total participants, including 165 EPA employees
- An archived version of a live training session is available at:
  - » http://www.clu-in.org/conf/itrc/rads_051507/
- Archived version was accessed by users 1,710 times between January 1, 2008 and August 26, 2009.



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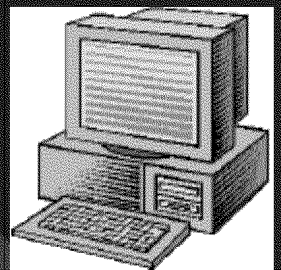
Guidance: Building PRG (BPRG) Calculator

- Calculator to establish $1x10^{-6}$ risk based PRGs for the reuse of radioactively contaminated buildings.
- Equations and parameters are derived from latest EPA chemical methodology (e.g., assessment at WTC)
  - » Adjusted to account for technical differences posed by radiation
- EPA and ITRC Internet-based training on BPRG calculator and D&D
  - » http://www.clu-in.org/conf/itrc/radsdd_040308/



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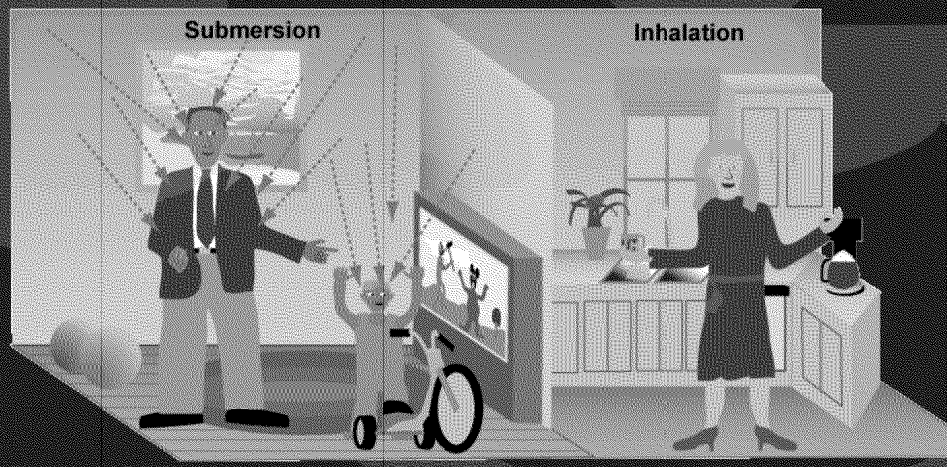
Guidance: Building PRG (BPRG) Calculator (continued)

- BPRG calculator includes 2 land use scenarios
  - » Residential
  - » Indoor worker
- Both land uses include 3 exposure routes
  - » Settled dust
  - » Ambient air
  - » Direct external exposure
    - —5 Room sizes and 4 receptor locations, both
      - –Surface
      - –Volumetric



EPA

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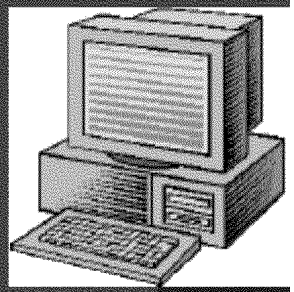
Building Dose Cleanup Concentrations (BDCC) ARAR Dose Calculator

- BDCC Purpose: to establish BCCs for Inside Buildings for single dose limit ARARs (# mrem/yr)
- BDCC includes 2 land use scenarios (Residential, Indoor Worker)
- 2 land uses include 3 exposure routes (Settled dust, Fixed Direct External 3-D, Ambient Air)
- Equations similar to those used for BPRG calculator, except dose conversion factors used instead of slope factors



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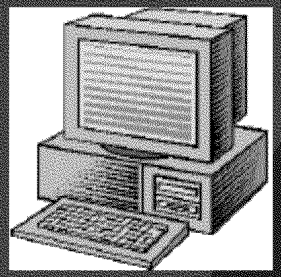
Surfaces PRG (SPRG) Calculator

- Establish 1 x 10^{-6} risk based PRGs for radioactively contaminated ***outside*** hard surfaces (e.g., slabs, pavement, sidewalks, sides of buildings)
- Derived from rad PRG and BPRG calculators



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SPRG Exposure Scenarios

- SPRG includes 3 land use scenarios
  - » Residential
  - » Indoor Worker
  - » Outdoor Worker
- 3 land uses include 3 exposure routes
  - » Settled dust (pave and unpaved street level)
  - » Fixed Direct External 3-D (street level)
    - —Surface and Volumetric
  - » Fixed Direct External 2-D (slabs)
    - —Surface and Volumetric

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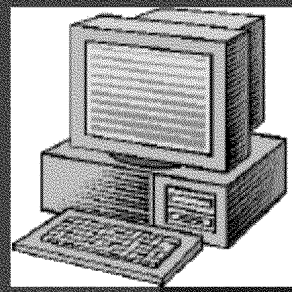
Surface Dose Cleanup Concentrations (SDCC) ARAR Dose Calculator

- SDCC Purpose: to establish DCCs for Outside Hard Surfaces for single dose limit ARARs (# mrem/yr)
- SDCC includes 3 land use scenarios (Residential, Indoor Worker, Outdoor Worker)
- 3 land uses include 3 exposure routes (Settled dust, Fixed Direct External 3-D, Fixed Direct External 2-D (slabs))
- Equations similar to those used for SPRG calculator, except dose conversion factors used instead of slope factors



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EPA/ITRC Radiation D&D Training

- Four modules provide:
  1. Introduction and Regulatory Basis for D&D
  2. Factors for Implementing D&D
  3. **Preliminary Remediation Goal (PRG) Calculators *(tutorial on using BPRG, SPRG, BDCC, and SDCC calculators)***
  4. Case Studies and Lessons Learned

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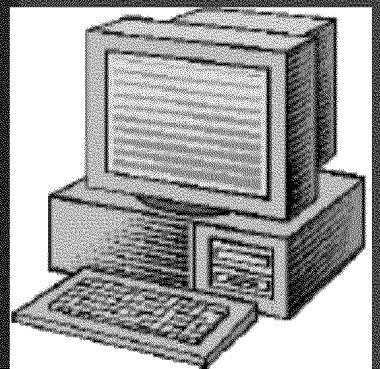
Radiation D&D Training, cont.

- Five Live Internet rad CERCLA Policy Training sessions have been conducted
  - » 731 total participants, including 101 EPA employees
- An archived version of a live training session is available at:
  - » http://www.clu-in.org/conf/itrc/radsdd_040308/
- Archived version was accessed by users 2,046 times between January 1, 2008 and August 26, 2009.



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Guidance: Uranium in Groundwater

- *Use of Uranium Drinking Water Standards Under 40 CFR 141 and 40 CFR 192 as Remediation Goals for Groundwater at CERCLA Sites* (11/6/01) OSWER Directive 9283.1-14
- Guidance on the use of MCL and UMTRCA **uranium standards as ARARs for groundwater**
- When both standards are ARARs, must attain or waive both
  1. 30 micrograms per liter of total uranium
  2. 30 pCi/l [1.11 Bq/l] of uranium-234 and 238 combined
- Use MCL ARAR point of compliance for UMTRCA
- Includes a list of radionuclides under 4 mrem/year beta and 15 pCi/l [0.555 Bq/l] alpha MCLs

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Guidance under Development for the Superfund Remedial Program

1. MNA for inorganics (metals and radionuclides)
2. Counts Per Minute (CPM) calculator
3. Radionuclide Ecological Benchmark calculator

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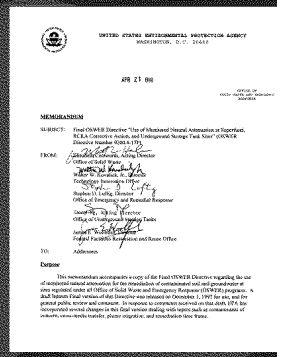
MNA for Inorganics (metals and radionuclides) Policy document

- Will complement 1999 overall MNA policy document "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites"
  - » Will help clarify policy issues unique to inorganics not addressed in 1999
- 3 Volume ORD MNA for inorganics documents will be technical support document for this policy document
  - » Also complemented by 2010 ITRC guidance on MNA for inorganics


UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

APR 21 2010

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

MEMORANDUM

SUBJECT: Final OSWER Directive "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites" (OSWER Directive Number 9200.4-17P)

FROM: Elizabeth Cotsworth, Acting Director
Office of Solid Waste
Walter W. Kovalick, Jr., Director
Technology Innovation Office
Stephen D. Luftig, Director
Office of Emergency and Remedial Response
Daniel W. Ashley, Director
Office of Underground Storage Tanks
Jennifer Hubbard, Director
Federal Facilities Restoration and Reuse Office

TO: Addressees

Purpose

This memorandum accompanies a copy of the Final OSWER Directive regarding the use of monitored natural attenuation for the remediation of contaminated soil and groundwater at sites regulated under all Office of Solid Waste and Emergency Response (OSWER) programs. A draft Interim Final version of that Directive was released on December 1, 1997 for use, and for general public review and comment. In response to comments received on that draft, EPA has incorporated several changes in this final version dealing with topics such as contaminants of concern, cross-media transfer, plume migration, and remediation time frame.

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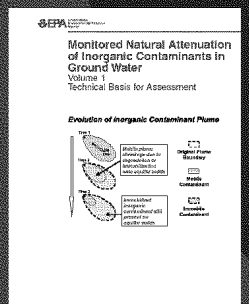
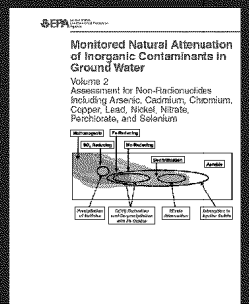
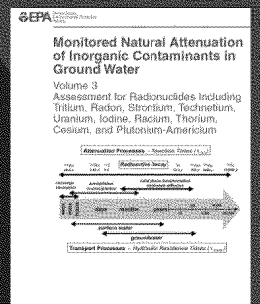
Technical Background Documents for MNA Guidance for Inorganics

- 3 Technical Reports "Monitored Natural Attenuation of Inorganic Contaminants in Ground Water"
  - » "Volume 1 - Technical Basis for Assessment" 2007
  - » "Volume 2 - Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium" 2007
  - » "Volume 3 - Assessment for Radionuclides Including Americium, Cesium, Iodine, Plutonium, Radium, Radon, Strontium, Technecium, Thorium, Tritium, Uranium" 2010







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CPM Calculator Scenarios

- The CPM calculator has three major sub calculators based on the field survey scenario:

1. Ground based scanning of surface contamination
2. Ground based scanning of volumetric contamination
3. Air based scanning of contamination *(under consideration)*

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CPM tool caveats

- The CPM tool is intended to facilitate use of Real-Time measurement techniques to supplement sampling **NOT** replace sampling
- The CPM tool only addresses gamma emitters
- The CPM tool assumes uniform contamination

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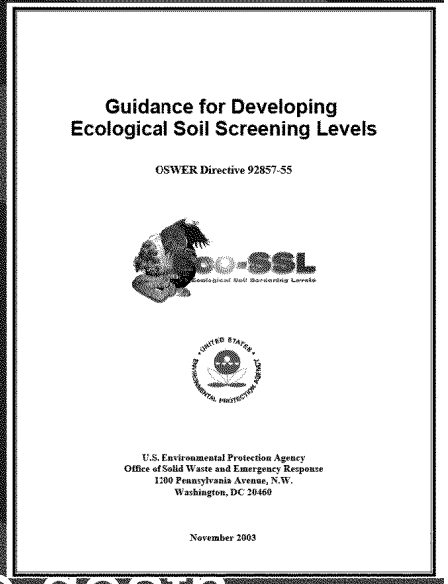
Radionuclide Ecological Benchmark (REB) Calculator

- Establish risk-based Biota Concentration guides (BCGs), or ecological benchmarks, for radioactively contaminated sites
- Fits with Superfund framework for developing eco benchmarks
- Derived from DOE Graded Approach guidance
  - » Includes same dose levels for tissue death
  - » Strong recommendation to look at chemical eco effects



Guidance for Developing
Ecological Soil Screening Levels

OSWER Directive 92857-55

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460

November 2003

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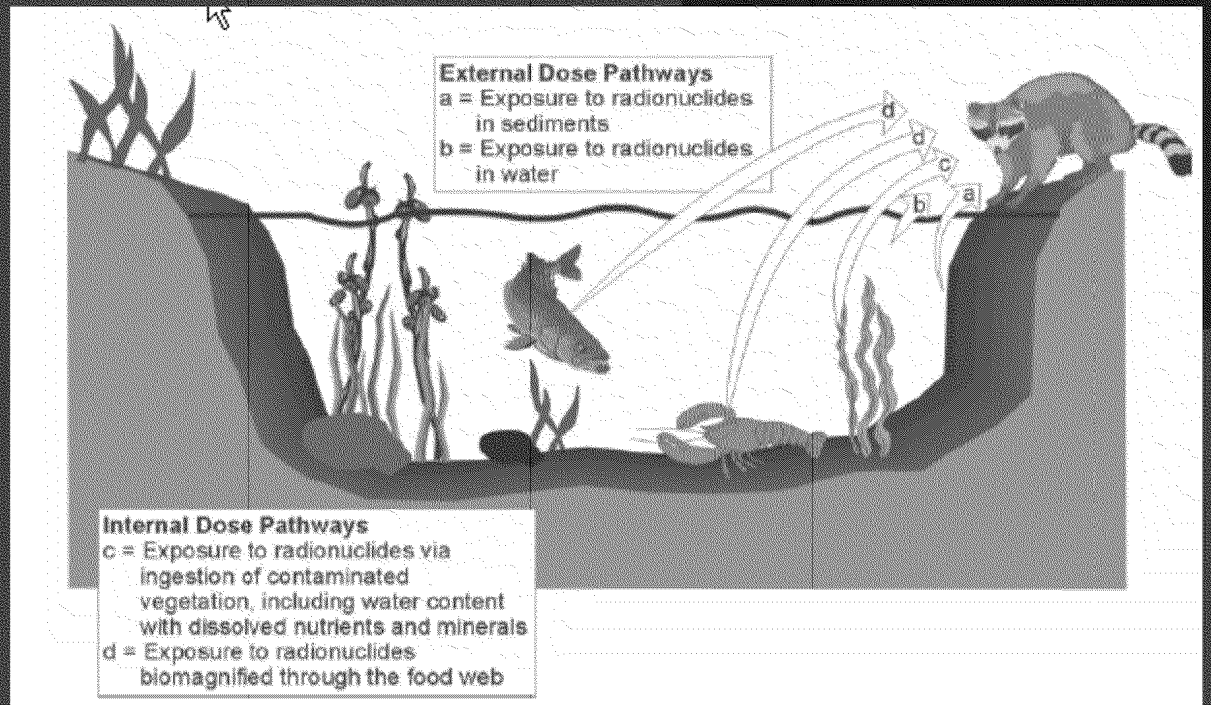
REB Exposure Scenarios

- Includes 12 animal or plant benchmark scenarios
  - » 6 generic composite only
  - » 6 species-specific/site-specific



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Part 3.
Involving Stakeholders at Superfund Remedial Program Sites

EPA

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Community Involvement

- EPA has many tools to facilitate meaningful involvement by communities near sites
- EPA hosts a community involvement national conference
- EPA has 2 tools designed specifically for use at radiation sites that are based on earlier tools for chemical sites

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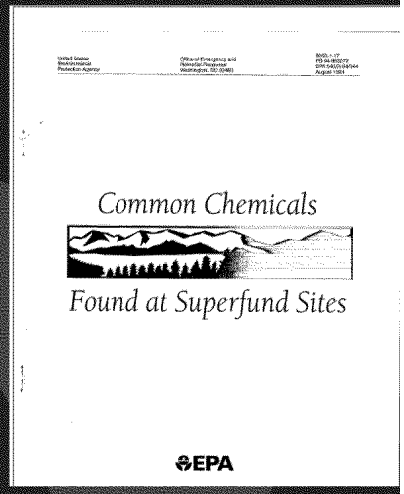
Booklet: Common Chemicals

- *Common Chemicals Found at Superfund Sites* (8/94) OSWER Directive 9203.1-17
- Booklet for the general public. It contains information on
  - » Health effects of chemicals commonly found at Superfund sites
  - » EPA policies for cleaning up these chemicals

    Note this booklet has been superceded by a website



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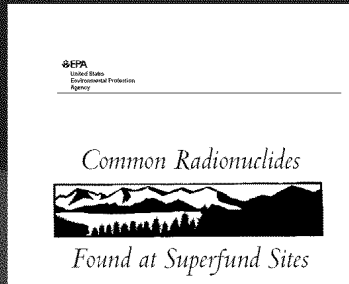
Booklet: Common Radionuclides

Old Superceded

- *Common Radionuclides Found at Superfund Sites* (7/02) OSWER Directive 9200.1-34
- Booklet for the general public. It contains information on
  - » Health effects of radionuclides commonly found at Superfund sites
  - » EPA policies for cleaning up these radionuclides



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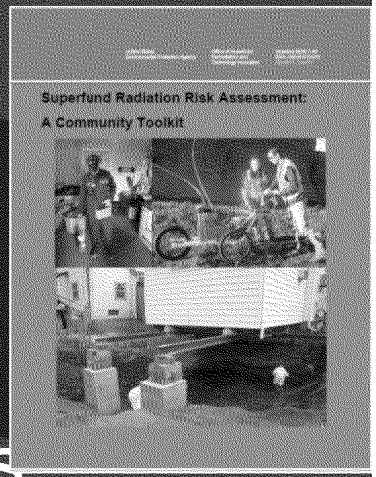
Toolkit: Radiation Risk Assessment

New

- *Superfund Radiation Risk Assessment: A Community Toolkit* (issued June 2014)
- Collection of 22 fact sheets for the general public. It contains fact sheets on
  - » Superfund and Radiation
  - » Superfund risk assessment process at radiation sites
  - » Each of the 6 PRG and DCC calculators
  - » Replacement for the Common Rad booklet fact sheets



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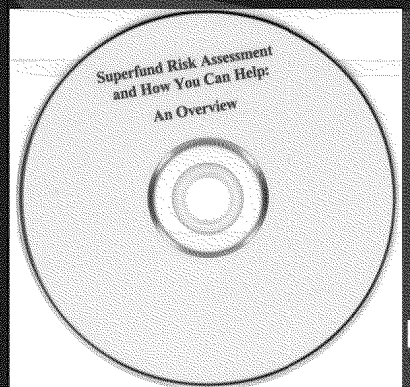
Video: Chemical Risk Assessment

- *Superfund Risk Assessment and How you can Help, an Overview* (1999) OSWER Directive 9285.7-29A
- Video for the general public. It contains information on:
  - » The Superfund risk assessment process when addressing chemical contamination
  - » How the public is involved site-specifically



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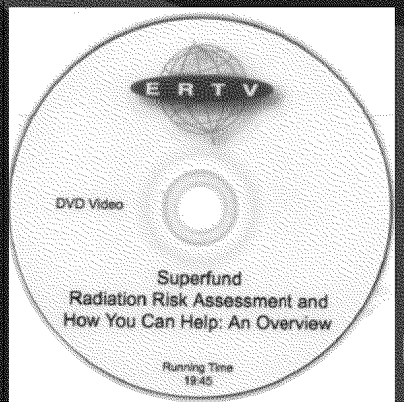
Video: Radiation Risk Assessment

- *Superfund Radiation Risk Assessment and How you can Help, an Overview* (3/05) OSWER Directive 9200.4-37
- Video for the general public. It contains information on:
  - » The Superfund risk assessment process when addressing radioactive contamination
  - » How the public is involved site-specifically



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For More Copies or Information

- Guidance documents are on Superfund Radiation Webpage:
  - » http://www.epa.gov/superfund/health/contaminants/radiation/index.htm

  EPA/ITRC training on EPA Superfund radiation approach
  - » http://www.clu-in.org/conf/itrc/radscleanup_060507/
- Guidance documents for overall cleanup level issues are on Superfund Remedy Decisions Webpage:
  - » http://www.epa.gov/superfund/policy/remedy/sfremedy/index.htm
- For further information or questions, Stuart Walker
  - » Phone: (703) 603-8748
  - » Fax: (703) 603-9133
  - » Email: Walker.Stuart@epa.gov

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EPA

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TRIGGER LEVELS ASSOCIATED WITH ALTERNATIVE PROTECTIVE ACTION GUIDES FOR DRINKING WATER

Prepared by
John Mauro, PhD, CHP
Steve Marschke
SC&A, Inc.

Reviewed by
The Cadmus Group, Inc.

We would like to express our appreciation for the assistance provided by Dr. Joyce Lipsztein and Dr. Richard Leggett in the preparation of this report.

TABLE OF CONTENTS

Key Definitions....3

1.0 Introduction....6

2.0 Models and Assumptions....9

3.0 Model Input Parameters....11

- 3.1 Effective Dose Coefficients (Sv/Bq Ingested)....11
- 3.2 Effective Whole Body Dose (Sv/Bq) to Offspring Due to Ingestion of Radionuclides by the Mother between Conception and Birth....11
- 3.3 Risk Coefficients (RCs)....12

4.0 Results – Examples....16

- 4.1 Example 1: Cs-137 Dose and Risk to an Infant (100 day old)....16
- 4.2 Example 2: Cs-137 Dose and Risk to an Adult....17
- 4.3 Example 3: Cs-137 Dose In Utero....17

5.0 Results – Complete Sets of Tables....19

References....21

Appendix 1: All Age Groups....22

Appendix 2: DEVELOPING EMBRYO AND FETUS*....25

Appendix 3: Infant....27

Appendix 4: 1 Year Old....29

Appendix 5: 5 Year Old....31

Appendix 6: 10 Year Old....33

Appendix 7: 15 Year Old....35

Appendix 8: Adult....37

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KEY DEFINITIONS

Rad

A rad is the amount of absorbed radiation that delivers 100 ergs of energy per gram of absorbing medium.

For example, it is not unusual for a radionuclide to emit 1 MeV of photon or electron radiation each time it disintegrates. Since 1 MeV = 1.6E-6 ergs and the amount of energy required to break a chemical bond and create a free electron and a positively charged molecule (an ion pair) is typically about 30 to 40 eV, one rad will create about 2E12 ion pairs per gram of tissue exposed. These ion pairs are the cause of the damage associated with exposure to ionizing radiation, which at high whole body doses (>25 rad) can result in observable clinical damage, death at doses above about 400 rad, and a lifetime cancer risk of about between 0.0005 and 0.001 per rad delivered to the whole body.

rem and mrem

A rem is an expression of the amount of ionizing radiation absorbed by tissue multiplied by the a quality factor that takes into consideration the relative potential amount of damage the radiation might cause; a mrem (millirem) is 0.001 rem.

For example, for an internally deposited radionuclide, such as Cs-137, each time an atom of Cs-137 decays inside the body, it emits a certain amount of ionizing radiation in the form of beta particles (essentially electrons) and gamma rays (i.e., energetic photons). When this energy is deposited in tissue, the molecules that comprise living tissue are ionized, which results in an increased risk of cancer. The product of the absorbed dose to tissue (which is expressed in terms of rad) with the quality factor is referred to as the dose equivalent, expressed in units of rem or millirem. If 100 ergs per gram of any combination of beta particles ot photons is deposited into a gram of tissue, the absorbed dose to the exposed tissue is 1 rad and the dose equivalent to that tissue is 1 rem. If the energy deposited in tissue is in due to an alpha particle, the quality factor is 20 and the dose equivalent is 20 rem because the damage caused by the energy of an alpha particle in a gram of tissue is about 20 times greater than the same amount of energy of beta and photon radiation deposited in a gram of tissue is 20 times greater. If that energy is deposited uniformly in every gram of tissue in the body (whether alpha, beta or gamma), the exposure is defined as a whole body dose or effective dose.

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Sv	A sievert (Sv) is 100 rem. Sv is the International System of Units (SI) derived unit of ionizing radiation dose (the rem and mrem are older, non-SI units).
Effective dose	When ionizing radiation is deposited in tissue, it can be deposited in only a small part of the body or uniformly throughout the body. The potential for harm associated with 1 rem (100 ergs/g) deposited in only a portion of the body is less than the potential for harm if the entire body experiences 1 rem. In order to establish risk equivalency between a partial and a whole body dose when only a portion of the body is exposed, the dose equivalent to the tissue experiencing the exposure is multiplied by a tissue weighting factor which converts the tissue dose to an effective whole body dose, or simply referred to as the effective dose. For example, if a person ingests I-131, most of the internal dose will be delivered to the thyroid gland. The tissue weighting factor for the thyroid gland is 0.04. This means that the risk of cancer from the exposure of only the thyroid gland is about 0.04 of the risk of cancer if that same dose was delivered to the entire body. Hence, if one rem is delivered to the thyroid gland due to the ingestion of I-131, the effective whole body dose is 0.04 rem. If Cs-137 is ingested, it is distributed to the whole body so there is no need to apply a tissue weighting factor because the whole body is uniformly exposed.
Ci, pCi, and dps	A curie (Ci) is an expression of the amount of radioactivity that corresponds to that amount of radioactive material (atoms or grams) that has a decay rate of 3.7E10 disintegrations per second (dps). A picocurie (pCi) is one trillionth (i.e., 10^{-12}) of a Ci.
Bq	One becquerel (Bq) is the amount of a radioactive material (atoms or grams) that decays at a rate of 1 disintegration per second.
DCF	**Throughout this report, the terms dose and dose conversion factor (DCF) are used. If a person were to ingest a given radionuclide, the radionuclide might remain in his or her body for a long time. Hence, when we refer to a dose of 500 mrem delivered due to the ingestion of contaminated water for a one year period, the actual dose is the dose delivered to that person over his or her lifetime due to the radionuclides ingested in that year. Hence 500 mrem is actually 500 mrem lifetime dose commitment.** **Dose conversion factor, expressed in terms of Sv/Bq or mrem/Bq, actually is an expression of the lifetime dose**

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commitment due to the ingestion of one Bq of a given radionuclide. If the Bq is ingested in one day or one year, that dose rate is referred to as 1 Bq/day or per year, but the actual dose is delivered over a lifetime. For long lived radionuclides, like U-238, it could take an entire lifetime for uranium to be entire cleared from the body. For relatively short-lived radionuclides, such as I-131, the iodine is entirely cleared in a relative short period of time. It is still referred to as a lifetime dose commitment, but the dose is actually all delivered in a relatively short period of time because it decays away relatively quickly.

LET

Linear Energy Transfer (LET) is an expression of the energy lost by a charged particle per unit distance traveled in a material (in KeV per micron traveled in an absorbing medium), such as living tissue. In general, for the same amount of energy deposited in a gram of tissue, the damage caused by high LET radiation, such as alpha particles and neutrons, is much greater than that same amount of energy deposited by beta and photon radiation. The reason for the difference in potential damage is the number of ions produced per unit path traveled by the high LET particle is much denser than that for low LET radiation, making it more difficult for the body to repair the damage caused by the radiation. For example, the carcinogenic risks associated with a rad of alpha particle exposure is estimated to be about 20 times greater than a rad of beta or photon exposure.

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1.0 INTRODUCTION

During the early stages of a radiological emergency, such as following an accident at a nuclear power plant or other type of incident where drinking water supplies could become contaminated with a variety of radionuclides, it may become necessary for emergency response personnel to interdict drinking water resources for some time period until there is assurance that the concentration of radionuclides in the drinking water resources have declined to an acceptable level, either through natural attenuation or treatment. As part of the planning process for such incidents, a relationship needs to be established between the concentration of a given radionuclide in a drinking water resource and the radiation dose and health risk members of the population might experience as a result of drinking contaminated water. This report presents the results of investigations that will help the U.S. Environmental Protection Agency (EPA) make judgments regarding when intervention might be needed.

A number of factors must be taken into consideration when making judgments regarding interdiction decision making. Of particular importance are the types of radionuclides of concern, the duration that members of the public might be exposed to contaminated drinking water, and the radiation dose and health risk that different members of a population might experience as a result of drinking water contaminated with radionuclides. In this particular investigation, the EPA has selected six radionuclides that require investigation, including Sr-90, Cs-137, and I-131, which are of particular interest with respect to nuclear power plant accidents, and Ir-192, Po-210, and Co-60, which are of interest because of their potential to be used in a dirty bomb or other incidents where drinking water resources might be contaminated. However, it is important to note that Sr-90, Cs-137, and I-131 are also of interest as radionuclides that might be used by terrorists or involved in some other type of incident where drinking water resources might be contaminated.

The concentration of a given radionuclide in drinking water that requires interdiction depends primarily on the radiation dose and health risk that members of an exposed population might experience. In this particular investigation, we are interested in the concentration of the above six radionuclides that could result in radiation exposures of 4, 10, 15, 25, 100, 250, 300, 400, and 500 mrem/yr.[1] These exposures were selected because they bracket the range of radiation exposures that might be of public health concern. For example, 4 mrem/yr is associated with the current drinking water standards as set for in 40 CFR 141. If radionuclides in drinking water resources are below the concentration that can result in a whole body dose below 4 mrem/yr, the water is considered safe for drinking by EPA. At the other extreme, 500 mrem, has been selected by the Food and Drug Administration (FDA) as the radiation dose where it is appropriate to interdict food that might become contaminated with radionuclides. Hence, this range of doses represents potential interdiction levels, or Protective Action Guides (PAGs), that might warrant interdiction of contaminated water supplies. It is noted that under some circumstances higher interdiction levels might warrant consideration, including 1 rem, 5 rem, and perhaps as high as 25 rem.

[1] These values are actually the lifetime effective dose commitment associated with radionuclides ingested during the course of year or any of the other ingestion time periods addressed in this report.

ED_001057_00009404

Interdiction decision making is complicated by the fact that, for the same quantity of a given radionuclide ingested in drinking water, different members of the public will experience different doses and health risks. For example, the dose and potential health risk that an adult might experience due to the ingestion of 1 Bq of a given radionuclide is different than the dose and health risk that a child might experience. In addition, since different members of the public consume different daily quantities of water, the amount of a given radionuclide that one member of the public might ingest in a day, such as an adult, will be different from the amount of that radionuclide that a child might ingest in a day for water containing the same concentration of a given radionuclide.

Ultimately, the radiation dose and health risk a given member of a population might experience from a given concentration of a radionuclide in drinking water will depend on the total amount of water consumed over the time period that the water resource is ingested. Hence, the radiation dose that a population might experience from drinking water contaminated with a given concentration of a radionuclide in water will be greater if the population is exposed for long periods of time, as opposed to short periods of time.

In light of these considerations, this report presents the concentrations of radionuclides in water and associated radiation health risks for the following array of circumstances and potential decision criteria (i.e., PAGs):

- Decision criteria or PAGs established at 4, 10, 15, 25, 100, 250, 300, 400, and 500 mrem/yr.
- Isotopes of interest: Sr-90, Cs-137, I-131, Ir-192, Po-210, Co-60.
- The dose and risk and conversion parameters contained in Federal Guidance Report 13 (FGR-13) (EPA 2002).
- Exposed subpopulations, including the embryo and fetus of pregnant women, infants, children, adults, elderly, and women of child bearing age. As discussed later in this report, dose conversion factors are not available separately for males or females or for pregnant women or the elderly in FGR-13 and International Commission on Radiological Protection (ICRP) publications . On the other hand, separate risk coefficients (RCs) are available for males and females and the elderly. With respect to the elderly, the dose commitment per unit intake of a given radionuclide is expected to be comparable to or less than the dose commitment per unit intake for other adults because of the shorter life expectancy of the elderly, which results in a shorter time period over which dose is delivered following intake. Hence, all other factors being equal regarding state of health and predisposition to cancer, if young adults are protected, so are the elderly. Rather than "children" generically, the sources support an evaluation of trigger levels and risks for 1 year olds, 5 year olds, 10 year olds, and 15 year olds.
- Consumption factors for exposure at different ages for each subpopulation as recommended in FGR 13. Since we were unable to make a distinction between males and females with respect to dose conversion factors, we had to make a choice regarding which drinking water values we should use: males, females, or the average for adults. In general, we chose to use the average for adults. However, in order to derive the doses to

ED_001057_00009404

the developing fetus, we used the water ingestion rate for pregnant women as provided in the *EPA Exposure Factors Handbook* (EPA 2011).

- Exposure durations of 30, 60, 90, and 365 days for each age group considered. In the case of the child in utero the maximum duration of the ingestion period for the pregnant women is 270 days because that is (approximately) the duration of the gestation period.

ED_001057_00009404

2.0 MODELS AND ASSUMPTIONS

The fundamental equations that are used to derive trigger levels in this report are as follows.

The first step in the process is to derive the quantity of radionuclide *i* ingested by age group *a* over a given time period, *T*.

$$I_{iaT} = C_i \times Ing_a \times T$$

Where:

I_{iaT} = The total intake of radionuclide *i* for age group *a* (pCi or Bq) over time period *T* (days)

C_i = The concentration of radionuclide *i* in drinking water (pCi/L or Bq/L). In this analysis, the concentration of the radionuclide is assumed to be constant over the time period *T* of interest. In the real world, the concentration of a given radionuclide in water will likely vary widely over a given time period of interest, especially over long time periods.

Ing_a = The daily ingestion rate of water for age group *a* as provided in FGR-13 (L/day).

T = The time period that the population is drinking contaminated water (days). In this analysis, the time periods of interest are 30, 60, 90, and 365 days.

The effective whole body dose (mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time period *T* is derived as follows:

$$D_{iaT} = I_{iaT} \times DCF_{ia}$$

Where:

D_{iaT} = Effective whole body dose (mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time period *T*

I_{iaT} = The total intake of radionuclide *i* for age group *a* (pCi or Bq) over time period *T*

DCF_{ia} = The effective dose coefficient (also referred to as the whole body dose conversion factor or DCF) for the ingestion of radionuclide *i* in drinking water and age group *a* (mrem/Bq or Sv/Bq) using the DCFs from FGR-13.

Risk, in this report, is expressed in terms of total cancer risk (morbidity) as opposed to fatal cancer risk (i.e., mortality). The lifetime risk of cancer due to the ingestion of radionuclide *i* by age group *a.*:

$$R_{iaT} = I_{iaT} \times RC_{ia}$$

Where:

R_{iaT} = The lifetime risk of cancer due to the ingestion of radionuclide *i* over time period *T* by age group *a* (life risk of cancer per Bq or per pCi ingested).

I_{iaT} = The total intake of radionuclide *i* for age group *a* (pCi or Bq) over time period *T*.

ED_001057_00009404

RC_{ia} = The lifetime risk coefficient for the ingestion of radionuclide *i* in drinking water and age group *a* [lifetime risk per pCi (or per Bq) ingested in water] using the RCs from FGR-13.

ED_001057_00009404

3.0 MODEL INPUT PARAMETERS

3.1 Effective Dose Coefficients (Sv/Bq Ingested)

Table 1 presents the effective whole body dose per Bq ingested of each radionuclide in water by each age group. The values apply to both males and females because DCFs are not provided separately for males and females. All the FGR 13 values are the average values for males and females.

Table 1. Dose Conversion Factors

Isotope	DCFs (Sv per Bq ingested at the age indicated) from FGR-13*					
	Infant (100 day old)	1 year old	5 year old	10 year old	15 year old	Adult
Sr-90	2.27E-07	7.24E-08	4.69E-08	5.97E-08	7.89E-08	2.77E-08
Y-90	3.13E-08	2.00E-08	9.97E-09	5.90E-09	3.34E-09	2.69E-09
Cs-137	2.11E-08	1.24E-08	9.69E-09	1.01E-08	1.34E-08	1.36E-08
I-131	1.84E-07	1.79E-07	1.04E-07	5.24E-08	3.42E-08	2.18E-08
Ir-192	1.34E-08	8.74E-09	4.59E-09	2.85E-09	1.71E-09	1.37E-09
Po-210	5.30E-06	1.79E-06	8.88E-07	5.25E-07	3.19E-07	2.45E-07
Co-60	5.43E-08	2.68E-08	1.69E-08	1.12E-08	7.94E-09	3.42E-09

* The values in this table were taken from the CD that accompanies FGR-13 (EPA 2002).

Doses on the order of 1E-5 to 1E-9 Sv/Bq imply that the ingestion of 1 Bq (i.e., the quantity of a radionuclide associated with 1 disintegration per second) is an extremely small quantity of radioactive material and is associated with a very small dose commitment.

For radionuclides like Po-210, which can be present in soluble or insoluble form in water, the DCFs for the soluble form are used because they have the higher DCFs and are more likely to reach receptors before they deposit or are filtered from the drinking water resource.

Although it is not among the six radionuclides of primary interest, Y-90 is also included in this table and other tables in this report because it is likely that Y-90, which is the progeny of Sr-90, will be present in equilibrium, or close to equilibrium, with Sr-90 in drinking water. If the Sr-90 is freshly separated, the Y-90 might not be initially present, because it has a 64-hour half-life, and it will take several weeks of growth before it achieves equilibrium with its parent, Sr-90. However, upon deposition in a drinking water resource, the Y-90 might already be present at levels close to equilibrium. The implications are that, when making use of these tables, a judgment will need to be made whether the DCFs and RCs for Sr-90 and Y-90 should be summed. However, since the DCFs and RCs for Y-90 are small compared to those for Sr-90, the additional dose or risk associated with Y-90 is small relative to that of Sr-90 and will not have a significant impact on interdiction decision making. The Y-90 values are provided here for completeness.

3.2 Effective Whole Body Dose (Sv/Bq) to Offspring Due to Ingestion of Radionuclides by the Mother between Conception and Birth

ED_001057_00009404

Table 2 presents the Dose Conversion Factors corresponding to the effective whole body dose that will be experienced by the offspring while in utero and after birth due to the ingestion of the indicated radionuclides by the mother from conception to birth. More precisely, these values represent the doses (in Sv) that the offspring will experience in utero and from age 0 to 70 if the mother ingests 1 Bq of the indicated radionuclide during the course of the 9-month period from conception to birth of the child. The dose conversion factors apply to both male and female offspring. The results presented in Appendix 2 were calculated using the "in utero" dose conversion factors only, representing the dose incurred by the offspring before birth. Alternatively, the "in utero" and "after birth" values could be summed to enable calculation of a total lifetime dose.

Table 2. Dose Conversion Factors for Offspring Exposed in Utero

Isotope	DCFs (Sv per Bq ingested by mother during pregnancy) from ICRP 88*	
	In Utero	After Birth through the Age of 70
Sr-90	2.8E-08	1.5E-08
Y-90	Not available	Not available
Cs-137	5.2E-09	4.8E-10
I-131	2.1E-08	2.1E-09
Ir-192	Not available	Not available
Po-210	1.1E-07	2.0E-08
Co-60	1.5E-09	4.1E-10

Source: ICRP 2012

This rather unique subject has been discussed in two relatively recent reports:

- NCRP 2013. "Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance," NCRP Report No. 174. National Council of Radiation Protection and Measurement.
- ICRP 2001. *Doses to Embryo and Fetus from Intakes of Radionuclides by the Mother*. ICRP Publication 88. Oxford, Pergamon Press.

A review of these documents helps to enrich our understanding of this important issue. It is quite conceivable that a woman might ingest radionuclides in water (or by inhalation or the ingestion or food) and accumulate a body burden before becoming pregnant. At the time of pregnancy, the radionuclides present in the woman's body can result in exposure of the developing embryo (conception to 8 weeks) and the developing fetus (from week 8 until birth) (ICRP 2001, Section 4.20.2, pg. 228). Of course, while the woman is pregnant, radionuclides ingested by the woman can expose the embryo and developing fetus to varying degrees. This report explicitly considers these exposure scenarios as part of investigations into alternative PAGs and trigger levels. Note, however, that the limiting exposure would occur if the woman ingests radionuclides while she is pregnant. Hence, this report is limited to that aspect of this exposure scenario.

3.3 Risk Coefficients (RCs)

ED_001057_00009404

Table 3 presents, for different isotopes and different age groups, the lifetime risk of cancer (fatal plus nonfatal) per Bq ingested in water at that age. If the isotope could exist in organic vs. inorganic form, inorganic was assumed. The values presented here apply to both males and females. However, in the case of these RCs, separate values can be developed for males and females, if so desired. (Risk Tab Ver. 2.2.1, the source of the information in the table, presents risk conversion factors for both males and females and for both--i.e., the average of the two values. We used the average. We could develop a separate set of risk tables for males and females and also a separate set for morbidity and mortality.)

Table 3. Lifetime Morbidity Risk Conversion Factors (per Bq ingested in water at the indicated age)

Isotope	In utero	Infant	1 yr old	5 yr old	10 yr old	15 yr old	Adult (age 25-70)
Sr-90	not available	1.35E-08	8.59E-09	5.13E-09	3.21E-09	3.36E-09	1.10E-09
Y-90	not available	1.11E-08	8.08E-09	4.25E-09	2.54E-09	1.44E-09	1.13E-10
Cs-137	not available	3.40E-09	2.49E-09	1.97E-09	1.99E-09	2.44E-09	6.17E-10
I-131	not available	2.15E-08	1.99E-08	1.06E-08	5.04E-09	2.96E-09	4.58E-10
Ir-192	not available	4.12E-09	3.04E-09	1.65E-09	1.01E-09	5.94E-10	5.34E-11
Po-210	not available	1.77E-07	9.51E-08	5.15E-08	3.18E-08	1.95E-08	6.73E-09
Co-60	not available	7.52E-09	5.22E-09	3.30E-09	2.16E-09	1.42E-09	1.33E-10

These values were taken from Risk Tab Ver. 2.2.1 by K.F. Eckerman & N.S. Nelson (Nov. 8, 2012).

The term morbidity risk is an expression of the probability that the individual will contract a cancer during his or her lifetime. Risk conversion factors express the additional lifetime risk of cancer a person might experience as a result of ingesting one Bq of a radionuclide. As may be noted, the additional cancer risks associated with the ingestion of 1 Bq is extremely small relative to the lifetime risk of cancer due to other (often unknown) causes. Note that the lifetime risk of cancer per Bq ingested is higher for young people than for old people.

Risk conversion factors for the developing embryo and developing fetus are not available from Risk Tab Ver. 2.2.1 or any other source consulted. Therefore, although the risk for exposure in the womb may be non-zero, we are unable to quantify it.

3.4 Water Ingestion Rate

Two sources were used to derive ingestion rates, FGR-13 (EPA 2002) and the *EPA Exposure Factors Handbook: 2011 Edition* (EPA 2011).

Table 4 presents the mean values for tap water consumption taken from Table 3-1 of FGR-13 (EPA 2002). Values are provided for males and females in various age groups. Most of the ingestion values used in this report were taken from this table, which was designed to be used in conjunction with other data from FGR-13. Since the ingestion rates for males are higher (and therefore more conservative) than those for females, we elected to use the values for males to represent each age group. We could have used the average drinking water value for each age

ED_001057_00009404

group, but then that would have underestimated the doses for males. If so desired, we can derive separates tables of risks for males and females.

Table 4. Drinking Water Ingestion Rates from FGR-13

Age (years)	Tap Water (L/day)*	
	Male	Female
0	0.191	0.188
1	0.223	0.216
5	0.542	0.499
10	0.725	0.649
15	0.900	0.712
20	1.137	0.754
50	1.643	1.119
75	1.564	1.179

*Values Extracted from EPA 2002, Table 3.1.

Table 5 presents the drinking water ingestion rates provided in "The Executive Summary" of the *EPA Exposure Factors Handbook: 2011 Edition* (EPA 2011). This table provides both mean and 95th percentile ingestion values for individuals (males and females aggregated) in various age groups, as well as in special cohorts such as pregnant and lactating women. The mean ingestion rate for pregnant women from this table (i.e., 0.819 L/day, which is slightly higher than for non-pregnant women) was used to calculate trigger levels for the developing fetus in Appendix 2 of this report.

Table 5. Per Capita Drinking Water Ingestion Rates from *EPA Exposure Factors Handbook* (2011)

Age	Mean mL/day	95th percentile mL/day
Children		
Birth to 1 month	184	839*
1 to<3 months	227*	896*
3 to <6 months	362*	1,056
6 months to <12 months	360	1,055
1 to <2 years	271	837
2 to <3 years	317	877
3 to <6 years	327	959
6 to <11 years	414	1,316
11 to <16 years	520	1,821
16 to <18 years	573	1,783
18 to <20 years	681	2,368
Adults		
>21 years	1,043	2,958
>65 years	1,046	2,730
Pregnant women	819*	2,503*
Lactating women	1,379*	3,434*

* Estimates are less statistically reliable, based on guidance published in NCHS 1993.

ED_001057_00009404

An important judgment needs to be made whether the trigger levels and risks provided in this report are for use in protecting the average member of a given age group or the 95th percentile members of a given age group. We used the mean drinking water values, which means that some people will experience slightly higher doses and risks and some will experience slightly lower doses and risks. If the 95th percentile drinking water values from Table 5 were to be used, 95% of the population would be protected at the indicated levels. Finally, other values in the calculation, including the effective dose coefficients and risk conversion factors, have a degree of uncertainty and individual variability. The values used in this report are those recommended by the EPA in FGR-13 and represent a best estimate for a given population group. The uncertainty and individual variability in these values are described in the published literature.

ED_001057_00009404

4.0 RESULTS – EXAMPLES

Using the models described in Section 2 and the input parameters in Section 3, we can derive the trigger levels and lifetime cancer risks associated with the ingestion of the six radionuclides in water (Sr-90, Cs-137, I-131, Ir-192, Po-210, and Co-60) for the different age groups, alternative PAGs (4, 10, 15, 25, 100, 250, 300, 400, and 500 mrem/yr), and the four different exposure time periods (30, 60, 90, and 365 days). These calculations are best performed using a spreadsheet. However, to aid the reader (and as part of the quality assurance check on the spreadsheet values), we will first perform selected calculations by hand for Cs-137. In these example calculations, the PAG is 500 mrem/yr and the time period of exposure is assumed to be 1 year.

4.1 Example 1: Cs-137 Dose and Risk to an Infant (100 day old)

Let us assume that a PAG is set at 500 mrem/yr (5 mSv or 0.005 Sv) and we are concerned with protecting an infant (100 day old) who might consume contaminated drinking water for 1 year. As described in Section 2, the basic equation used to perform this calculation is as follows:

$$D_{iaT} = C_i \times Ing_a \times T \times DCF_{ia}$$

Where:

D_{iaT} = Effective whole body dose (mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time period *T*.

DCF_{ia} = The effective dose coefficient (or effective whole body DCF) for the ingestion of radionuclide *i* in drinking water and age group *a* (mrem/Bq or Sv/Bq) using the DCFs from FGR-13.

C_i = The concentration of radionuclide *i* in drinking water (pCi/L or Bq/L). In this analysis, the concentration of the radionuclide is assumed to be constant over the time period *T* of interest. In the real world, the concentration of a given radionuclide in water will likely vary widely over a given time period of interest, especially if long time periods are involved.

Ing_a = The daily ingestion rate of water for age group *a* as provided in FGR-13 (L/day).

T = The time period that the population is drinking contaminated water (days). In this analysis, the time periods of interest are 30, 60, 90, and 365 days.

The equation takes the following form when deriving the radionuclide concentrations:

$$C_i = D_{iaT} \div (Ing_a \times T \times DCF_{ia})$$

Where:

D_{iaT} = 0.005 Sv (or 500 mrem)

Ing_a = 0.191 L/day for a male 100 day old child

T = 365 days

DCF_{ia} = 2.11E-08 Sv/Bq ingested

C_i = 0.005 Sv ÷ (0.191 l/day × 365 × 2.11E-08 Sv/Bq) = 3,399 Bq/L = 91,773 pCi/L

ED_001057_00009404

Hence, the trigger level would be 3,399 Bq/L, or 91,773 pCi/L, of Cs-137.

The lifetime risk of cancer to the child associated with this intake of Cs-137 in water is derived as follows:

$$R_{iaT} = I_{iaT} \times RC_{ia}$$

Where:

R_{iaT} = The lifetime risk of health detriment due to the ingestion of radionuclide *i* by age group *a* over time period *T*.

I_{iaT} = The total intake of radionuclide *i* for age group *a* (pCi or Bq) over time period *T*. (Calculated as the drinking water concentration, C_i in the previous equation, multiplied by the water ingestion rate, in this case for a newborn male from Table 4 above, multiplied by the time period, in this case 365 days.)

RC_{ia} = The lifetime risk coefficient for the ingestion of radionuclide *i* in drinking water and age group *a* [lifetime risk per pCi (or per Bq) ingested in water] using the RCs from FGR-13. Risk is expressed in terms of total cancer risk (morbidity), as opposed to fatal cancer risk (i.e., mortality).

R_{iaT} = 3,399 Bq/L × 0.191 L/day × 365 days × 3.40E-09/Bq = 8.06E-04 lifetime risk of cancer.

4.2 Example 2: Cs-137 Dose and Risk to an Adult

Performing the same exercise, we obtain the following results:

C_i = $D_{iaT} \div (Ing_a \times T \times DCF_{ia})$

C_i = 0.005 Sv ÷ 1.137 L/day × 365 days × 1.36E-08 Sv/Bq = 886 Bq/L = 23,922 pCi/L

R_{iaT} = 886 Bq/L × 1.137 L/day × 365 days × 6.02E-10/Bq = 2.2E-04 lifetime risk of cancer

Note that the concentration of Cs-137 in drinking water that is associated with a dose of 500 mrem for 1 year of exposure to a child is 3,399 Bq/L, while the concentration of Cs-137 in drinking water that results in 500 mrem to an adult from 1 year of exposure is 886 Bq/L. Hence, in order to achieve the same dose-based PAG, the concentration of Cs-137 in water must be about 3.8 times lower in order to protect an adult as opposed to a child (0–1 year old). This unexpected result is due to the fact that, even though the DCF for a child is about 1.6 times higher, adults ingest much larger quantities of water (1.137 versus 0.191 L/day). Therefore, the dose to the adult is limiting in this example.

4.3 Example 3: Cs-137 Dose In Utero

Performing the same exercise for in utero dose calculations, we obtain the following results:

C_i = $D_{iaT} \div (Ing_a \times T \times DCF_{ia})$

ED_001057_00009404

C_i = 0.005 Sv ÷ (0.819 L/day × 270 days × 5.2E-09 Sv/Bq) = 4,348 Bq/L = 117,396 pCi//L

An estimate of risk to the developing fetus is not provided for the reasons described elsewhere in this report.

ED_001057_00009404

5.0 RESULTS – COMPLETE SETS OF TABLES

In this section, we briefly describe and present the concentrations of radionuclides in water and associated lifetime risks of cancer for the following combination of alternative PAGs, isotopes, members of the exposed population, and time periods of exposure to contaminated water:

- PAGs established at 4, 10, 15, 25, 100, 250, 300, 400, and 500 mrem/yr.
- Isotopes of interest: Sr-90, Cs-137, I-131, Ir-192, Po-210, and Co-60.
- Exposed subpopulations: The data do not support analysis of all categories exactly as listed in the charge statement, but they support analysis that sheds at least some light on each category.
    - Embryo and fetus: Dose data are available for this population (with the exception of isotopes Y-90 and Ir-192); risk data are not. Ingestion rates for pregnant women are applied.
    - Infants: Dose data are available representing newborn infants (100 day old). Risk data representing both sexes in this age group are applied; drinking water ingestion rates for males in this age group are applied as more conservative than ingestion rates for females or the average.
    - Children: Dose data are available representing 1- 5-, 10-, and 15-year olds. Risk data representing both sexes in these age groups are applied; drinking water ingestion rates for males in these age groups are applied as more conservative than ingestion rates for females or the average.
    - Adults: Dose data are available for generic adults. Risk data representing both sexes in this age group are applied; drinking water ingestion rates for males in this age group are applied as more conservative than ingestion rates for females or the average.
    - Elderly: Dose data are not available specifically for the elderly population; general adult dose data may be consulted for the sake of comparison. The dose commitment per unit intake of a given radionuclide is expected to be comparable to or less than the dose commitment per unit intake for younger adults due to the shorter life expectancy after exposure and, therefore, the shorter time period over which dose is delivered following intake. Risk data and ingestion data for the elderly population are available (risk data for both sexes and ingestion rates for males would be applied, as in other population categories).
    - Women of child bearing age: Dose data are not available specifically for women of child-bearing age; general adult dose data may be consulted. Risk data and ingestion rates specific to this age and gender group are available and could be applied.
    - We also provide a set of tables with the results of the limiting age group for each radionuclide and each alternative PAG.

ED_001057_00009404

- Exposure durations of 30, 60, 90, or 365 days. (In the case of in utero exposure, a duration of 270 days, approximating full-term pregnancy, is used.)

We have organized the information into separate appendices, as follows:

Appendix 1 – All Age Groups: This appendix presents the most restrictive concentrations of radionuclides in water for each radionuclide and each alternative PAG. These are the lowest concentrations in water, among the different age groups, for each candidate PAG. Specifically, we sorted on the values of trigger levels among each age group that are most limiting (lowest concentration) for each isotope, each alternative candidate PAG, and each exposure duration. This appendix allows the user of these tables to quickly determine the trigger level for each radionuclide that is most protective for each candidate PAG, and each time period of exposure, and which age group is the limiting.

Appendix 2 – Developing Embryo and Fetus: This appendix presents the radionuclide concentrations in drinking water associated with specified doses for developing embryos and fetuses whose mothers consume the indicated radionuclides in drinking water over the specified time periods during gestation. (The figures represent only the dose incurred during gestation, not the lifetime dose that results from exposure in utero.) The longest ingestion period considered in this appendix is 270 days, or the approximate length of a full-term pregnancy. Note that trigger levels could not be calculated for Y-90 or Ir-192, and lifetime risks could not be calculated for any isotope in utero.

Appendix 3 – Infant (100 day old): This appendix presents the radionuclide concentrations in drinking water and associated lifetime risks for an infant who consumes the indicated radionuclides in drinking water over the specified time periods.

Appendix 4 – 1 Year Old: This appendix presents the radionuclide concentrations in drinking water and associated lifetime risks for a 1 year old who consumes the indicated radionuclides in drinking water over the specified time periods at that age.

Appendix 5 – 5 Year Old: This appendix presents the radionuclide concentrations in drinking water and associated lifetime risks for a 5 year old who consumes the indicated radionuclides in drinking water over the specified time periods at that age.

Appendix 6 – 10 Year Old: This appendix presents the radionuclide concentrations in drinking water and associated lifetime risks for a 10 year old who consumes the indicated radionuclides in drinking water at that age.

Appendix 7 – 15 Year Old: This appendix presents the radionuclide concentrations in drinking water and associated lifetime risks for a 15 year old who consumes the indicated radionuclides in drinking water at that age.

Appendix 8 – Adult: This appendix presents the radionuclide concentrations in drinking water and associated lifetime risks for an adult who consumes the indicated radionuclides in drinking water over the specified time periods. The FGR 13 CD provides DCFs for adults and does not

ED_001057_00009404

make a distinction among adults of different ages because the actual age when the adult ingests the drinking water has little effect on the trigger level or lifetime risk, until he or she is quite old; then the trigger levels decline due to declining DCFs because the time period over which the dose is delivered begins to decrease. Risks declines because of the latency period associated with cancer induction, which can extend beyond normal life expectancy.

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ED_001057_00009404

APPENDIX 1: ALL AGE GROUPS

Most Restrictive (i.e., Lowest)
Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	5.07E+02	1.27E+03	1.90E+03	3.17E+03	1.27E+04	3.17E+04	3.81E+04	5.07E+04	6.34E+04
Y-90	6.03E+03	1.51E+04	2.26E+04	3.77E+04	1.51E+05	3.77E+05	4.52E+05	6.03E+05	7.53E+05
Cs-137	2.33E+03	5.83E+03	8.74E+03	1.46E+04	5.83E+04	1.46E+05	1.75E+05	2.33E+05	2.91E+05
I-131	6.39E+02	1.60E+03	2.40E+03	4.00E+03	1.60E+04	4.00E+04	4.79E+04	6.39E+04	7.99E+04
Ir-192	1.41E+04	3.52E+04	5.28E+04	8.80E+04	3.52E+05	8.80E+05	1.06E+06	1.41E+06	1.76E+06
Po-210	3.56E+01	8.90E+01	1.33E+02	2.22E+02	8.90E+02	2.22E+03	2.67E+03	3.56E+03	4.45E+03
Co-60	3.47E+03	8.69E+03	1.30E+04	2.17E+04	8.69E+04	2.17E+05	2.61E+05	3.47E+05	4.34E+05

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.54E+02	6.34E+02	9.52E+02	1.59E+03	6.34E+03	1.59E+04	1.90E+04	2.54E+04	3.17E+04
Y-90	3.01E+03	7.53E+03	1.13E+04	1.88E+04	7.53E+04	1.88E+05	2.26E+05	3.01E+05	3.77E+05
Cs-137	1.17E+03	2.91E+03	4.37E+03	7.28E+03	2.91E+04	7.28E+04	8.74E+04	1.17E+05	1.46E+05
I-131	3.20E+02	7.99E+02	1.20E+03	2.00E+03	7.99E+03	2.00E+04	2.40E+04	3.20E+04	4.00E+04
Ir-192	7.04E+03	1.76E+04	2.64E+04	4.40E+04	1.76E+05	4.40E+05	5.28E+05	7.04E+05	8.80E+05
Po-210	1.78E+01	4.45E+01	6.67E+01	1.11E+02	4.45E+02	1.11E+03	1.33E+03	1.78E+03	2.22E+03
Co-60	1.74E+03	4.34E+03	6.51E+03	1.09E+04	4.34E+04	1.09E+05	1.30E+05	1.74E+05	2.17E+05

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.69E+02	4.23E+02	6.34E+02	1.06E+03	4.23E+03	1.06E+04	1.27E+04	1.69E+04	2.11E+04
Y-90	2.01E+03	5.02E+03	7.53E+03	1.26E+04	5.02E+04	1.26E+05	1.51E+05	2.01E+05	2.51E+05
Cs-137	7.77E+02	1.94E+03	2.91E+03	4.86E+03	1.94E+04	4.86E+04	5.83E+04	7.77E+04	9.71E+04
I-131	2.13E+02	5.33E+02	7.99E+02	1.33E+03	5.33E+03	1.33E+04	1.60E+04	2.13E+04	2.66E+04
Ir-192	4.69E+03	1.17E+04	1.76E+04	2.93E+04	1.17E+05	2.93E+05	3.52E+05	4.69E+05	5.87E+05
Po-210	1.19E+01	2.97E+01	4.45E+01	7.42E+01	2.97E+02	7.42E+02	8.90E+02	1.19E+03	1.48E+03
Co-60	1.16E+03	2.90E+03	4.34E+03	7.24E+03	2.90E+04	7.24E+04	8.69E+04	1.16E+05	1.45E+05

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.17E+01	1.04E+02	1.56E+02	2.61E+02	1.04E+03	2.61E+03	3.13E+03	4.17E+03	5.21E+03
Y-90	4.95E+02	1.24E+03	1.86E+03	3.10E+03	1.24E+04	3.10E+04	3.72E+04	4.95E+04	6.19E+04
Cs-137	1.92E+02	4.79E+02	7.18E+02	1.20E+03	4.79E+03	1.20E+04	1.44E+04	1.92E+04	2.39E+04
I-131	5.25E+01	1.31E+02	1.97E+02	3.28E+02	1.31E+03	3.28E+03	3.94E+03	5.25E+03	6.57E+03
Ir-192	1.16E+03	2.89E+03	4.34E+03	7.23E+03	2.89E+04	7.23E+04	8.68E+04	1.16E+05	1.45E+05
Po-210	2.93E+00	7.31E+00	1.10E+01	1.83E+01	7.31E+01	1.83E+02	2.19E+02	2.93E+02	3.66E+02
Co-60	2.86E+02	7.14E+02	1.07E+03	1.78E+03	7.14E+03	1.78E+04	2.14E+04	2.86E+04	3.57E+04

ED_001057_00009404

Most Restrictive (i.e., Lowest)
Drinking Water Risk for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.59E-06	3.97E-06	5.96E-06	9.93E-06	3.97E-05	9.93E-05	1.19E-04	1.59E-04	1.99E-04
Y-90	1.68E-06	4.20E-06	6.30E-06	1.05E-05	4.20E-05	1.05E-04	1.26E-04	1.68E-04	2.10E-04
Cs-137	1.81E-06	4.54E-06	6.81E-06	1.13E-05	4.54E-05	1.13E-04	1.36E-04	1.81E-04	2.27E-04
I-131	8.40E-07	2.10E-06	3.15E-06	5.25E-06	2.10E-05	5.25E-05	6.30E-05	8.40E-05	1.05E-04
Ir-192	1.56E-06	3.90E-06	5.85E-06	9.74E-06	3.90E-05	9.74E-05	1.17E-04	1.56E-04	1.95E-04
Po-210	1.10E-06	2.75E-06	4.12E-06	6.87E-06	2.75E-05	6.87E-05	8.24E-05	1.10E-04	1.37E-04
Co-60	1.56E-06	3.89E-06	5.83E-06	9.72E-06	3.89E-05	9.72E-05	1.17E-04	1.56E-04	1.94E-04

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.59E-06	3.97E-06	5.96E-06	9.93E-06	3.97E-05	9.93E-05	1.19E-04	1.59E-04	1.99E-04
Y-90	1.68E-06	4.20E-06	6.30E-06	1.05E-05	4.20E-05	1.05E-04	1.26E-04	1.68E-04	2.10E-04
Cs-137	1.81E-06	4.54E-06	6.81E-06	1.13E-05	4.54E-05	1.13E-04	1.36E-04	1.81E-04	2.27E-04
I-131	8.40E-07	2.10E-06	3.15E-06	5.25E-06	2.10E-05	5.25E-05	6.30E-05	8.40E-05	1.05E-04
Ir-192	1.56E-06	3.90E-06	5.85E-06	9.74E-06	3.90E-05	9.74E-05	1.17E-04	1.56E-04	1.95E-04
Po-210	1.10E-06	2.75E-06	4.12E-06	6.87E-06	2.75E-05	6.87E-05	8.24E-05	1.10E-04	1.37E-04
Co-60	1.56E-06	3.89E-06	5.83E-06	9.72E-06	3.89E-05	9.72E-05	1.17E-04	1.56E-04	1.94E-04

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.59E-06	3.97E-06	5.96E-06	9.93E-06	3.97E-05	9.93E-05	1.19E-04	1.59E-04	1.99E-04
Y-90	1.68E-06	4.20E-06	6.30E-06	1.05E-05	4.20E-05	1.05E-04	1.26E-04	1.68E-04	2.10E-04
Cs-137	1.81E-06	4.54E-06	6.81E-06	1.13E-05	4.54E-05	1.13E-04	1.36E-04	1.81E-04	2.27E-04
I-131	8.40E-07	2.10E-06	3.15E-06	5.25E-06	2.10E-05	5.25E-05	6.30E-05	8.40E-05	1.05E-04
Ir-192	1.56E-06	3.90E-06	5.85E-06	9.74E-06	3.90E-05	9.74E-05	1.17E-04	1.56E-04	1.95E-04
Po-210	1.10E-06	2.75E-06	4.12E-06	6.87E-06	2.75E-05	6.87E-05	8.24E-05	1.10E-04	1.37E-04
Co-60	1.56E-06	3.89E-06	5.83E-06	9.72E-06	3.89E-05	9.72E-05	1.17E-04	1.56E-04	1.94E-04

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.59E-06	3.97E-06	5.96E-06	9.93E-06	3.97E-05	9.93E-05	1.19E-04	1.59E-04	1.99E-04
Y-90	1.68E-06	4.20E-06	6.30E-06	1.05E-05	4.20E-05	1.05E-04	1.26E-04	1.68E-04	2.10E-04
Cs-137	1.81E-06	4.54E-06	6.81E-06	1.13E-05	4.54E-05	1.13E-04	1.36E-04	1.81E-04	2.27E-04
I-131	8.40E-07	2.10E-06	3.15E-06	5.25E-06	2.10E-05	5.25E-05	6.30E-05	8.40E-05	1.05E-04
Ir-192	1.56E-06	3.90E-06	5.85E-06	9.74E-06	3.90E-05	9.74E-05	1.17E-04	1.56E-04	1.95E-04
Po-210	1.10E-06	2.75E-06	4.12E-06	6.87E-06	2.75E-05	6.87E-05	8.24E-05	1.10E-04	1.37E-04
Co-60	1.56E-06	3.89E-06	5.83E-06	9.72E-06	3.89E-05	9.72E-05	1.17E-04	1.56E-04	1.94E-04

ED_001057_00009404

Age Group With the Most Restrictive Drinking Water Concentration

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old
Y-90	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Cs-137	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult
I-131	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old
Ir-192	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Po-210	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Co-60	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	15 yr old	15 yr old	15 yr old	10 yr old	15 yr old	10 yr old	15 yr old	15 yr old	15 yr old
Y-90	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Cs-137	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult
I-131	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old
Ir-192	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Po-210	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Co-60	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old
Y-90	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Cs-137	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult
I-131	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old
Ir-192	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Po-210	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Co-60	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old	15 yr old
Y-90	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Cs-137	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult	Adult
I-131	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old	5 yr old
Ir-192	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Po-210	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant
Co-60	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant	Infant

ED_001057_00009404

APPENDIX 2: DEVELOPING EMBRYO AND FETUS*

Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.57E+03	3.93E+03	5.89E+03	9.82E+03	3.93E+04	9.82E+04	1.18E+05	1.57E+05	1.96E+05
Y-90*									
Cs-137	8.46E+03	2.12E+04	3.17E+04	5.29E+04	2.12E+05	5.29E+05	6.35E+05	8.46E+05	1.06E+06
I-131	2.10E+03	5.24E+03	7.86E+03	1.31E+04	5.24E+04	1.31E+05	1.57E+05	2.10E+05	2.62E+05
Ir-192*									
Po-210	4.00E+02	1.00E+03	1.50E+03	2.50E+03	1.00E+04	2.50E+04	3.00E+04	4.00E+04	5.00E+04
Co-60	2.93E+04	7.33E+04	1.10E+05	1.83E+05	7.33E+05	1.83E+06	2.20E+06	2.93E+06	3.67E+06

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	7.86E+02	1.96E+03	2.95E+03	4.91E+03	1.96E+04	4.91E+04	5.89E+04	7.86E+04	9.82E+04
Y-90*									
Cs-137	4.23E+03	1.06E+04	1.59E+04	2.64E+04	1.06E+05	2.64E+05	3.17E+05	4.23E+05	5.29E+05
I-131	1.05E+03	2.62E+03	3.93E+03	6.55E+03	2.62E+04	6.55E+04	7.86E+04	1.05E+05	1.31E+05
Ir-192*									
Po-210	2.00E+02	5.00E+02	7.50E+02	1.25E+03	5.00E+03	1.25E+04	1.50E+04	2.00E+04	2.50E+04
Co-60	1.47E+04	3.67E+04	5.50E+04	9.17E+04	3.67E+05	9.17E+05	1.10E+06	1.47E+06	1.83E+06

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	5.24E+02	1.31E+03	1.96E+03	3.27E+03	1.31E+04	3.27E+04	3.93E+04	5.24E+04	6.55E+04
Y-90*									
Cs-137	2.82E+03	7.05E+03	1.06E+04	1.76E+04	7.05E+04	1.76E+05	2.12E+05	2.82E+05	3.53E+05
I-131	6.98E+02	1.75E+03	2.62E+03	4.37E+03	1.75E+04	4.37E+04	5.24E+04	6.98E+04	8.73E+04
Ir-192*									
Po-210	1.33E+02	3.33E+02	5.00E+02	8.33E+02	3.33E+03	8.33E+03	1.00E+04	1.33E+04	1.67E+04
Co-60	9.78E+03	2.44E+04	3.67E+04	6.11E+04	2.44E+05	6.11E+05	7.33E+05	9.78E+05	1.22E+06

270 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.75E+02	4.37E+02	6.55E+02	1.09E+03	4.37E+03	1.09E+04	1.31E+04	1.75E+04	2.18E+04
Y-90*									
Cs-137	9.40E+02	2.35E+03	3.53E+03	5.88E+03	2.35E+04	5.88E+04	7.05E+04	9.40E+04	1.18E+05
I-131	2.33E+02	5.82E+02	8.73E+02	1.46E+03	5.82E+03	1.46E+04	1.75E+04	2.33E+04	2.91E+04
Ir-192*									
Po-210	4.44E+01	1.11E+02	1.67E+02	2.78E+02	1.11E+03	2.78E+03	3.33E+03	4.44E+03	5.56E+03
Co-60	3.26E+03	8.15E+03	1.22E+04	2.04E+04	8.15E+04	2.04E+05	2.44E+05	3.26E+05	4.07E+05

* DCFs for Y-90 and Ir-192 for the developing fetus have not been developed. Hence these rows are left blank. This does not mean there are zero doses. We are not able to assign doses at this time.

ED_001057_00009404

Risks Associated with Exposure in Utero

Risk conversion factors are not available for in utero exposure; therefore lifetime risks cannot be quantified.

Though we suspect that there might be some level of health risk to the developing fetus due to exposures resulting from the ingestion of contaminated water by the mother during gestation, Table 1-1 NCRP Report No. 17 titled, *Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance* (2013) states that minimal non-stochastic health effects are anticipated at acute doses of low LET radiation below 15 rem during the most radiosensitive gestation time periods. Table 1-1 also states that "The lifetime risk of oncogenic effects following in utero irradiation appears to be lower than that following irradiation during childhood." Table 1-1 also states that "There is no data available that informs on which stages of pregnancy may be the most vulnerable to the oncogenic effects of radiation."

On this basis, we assume that exposures to other age groups are limiting or at least as radiosensitive with respect to health risk for chronic low levels of low LET radiation.

ED_001057_00009404

APPENDIX 3: INFANT

Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	8.31E+02	2.08E+03	3.12E+03	5.19E+03	2.08E+04	5.19E+04	6.23E+04	8.31E+04	1.04E+05
Y-90	6.03E+03	1.51E+04	2.26E+04	3.77E+04	1.51E+05	3.77E+05	4.52E+05	6.03E+05	7.53E+05
Cs-137	8.94E+03	2.24E+04	3.35E+04	5.59E+04	2.24E+05	5.59E+05	6.71E+05	8.94E+05	1.12E+06
I-131	1.03E+03	2.56E+03	3.85E+03	6.41E+03	2.56E+04	6.41E+04	7.69E+04	1.03E+05	1.28E+05
Ir-192	1.41E+04	3.52E+04	5.28E+04	8.80E+04	3.52E+05	8.80E+05	1.06E+06	1.41E+06	1.76E+06
Po-210	3.56E+01	8.90E+01	1.33E+02	2.22E+02	8.90E+02	2.22E+03	2.67E+03	3.56E+03	4.45E+03
Co-60	3.47E+03	8.69E+03	1.30E+04	2.17E+04	8.69E+04	2.17E+05	2.61E+05	3.47E+05	4.34E+05

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.16E+02	1.04E+03	1.56E+03	2.60E+03	1.04E+04	2.60E+04	3.12E+04	4.16E+04	5.19E+04
Y-90	3.01E+03	7.53E+03	1.13E+04	1.88E+04	7.53E+04	1.88E+05	2.26E+05	3.01E+05	3.77E+05
Cs-137	4.47E+03	1.12E+04	1.68E+04	2.79E+04	1.12E+05	2.79E+05	3.35E+05	4.47E+05	5.59E+05
I-131	5.13E+02	1.28E+03	1.92E+03	3.20E+03	1.28E+04	3.20E+04	3.85E+04	5.13E+04	6.41E+04
Ir-192	7.04E+03	1.76E+04	2.64E+04	4.40E+04	1.76E+05	4.40E+05	5.28E+05	7.04E+05	8.80E+05
Po-210	1.78E+01	4.45E+01	6.67E+01	1.11E+02	4.45E+02	1.11E+03	1.33E+03	1.78E+03	2.22E+03
Co-60	1.74E+03	4.34E+03	6.51E+03	1.09E+04	4.34E+04	1.09E+05	1.30E+05	1.74E+05	2.17E+05

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.77E+02	6.93E+02	1.04E+03	1.73E+03	6.93E+03	1.73E+04	2.08E+04	2.77E+04	3.46E+04
Y-90	2.01E+03	5.02E+03	7.53E+03	1.26E+04	5.02E+04	1.26E+05	1.51E+05	2.01E+05	2.51E+05
Cs-137	2.98E+03	7.45E+03	1.12E+04	1.86E+04	7.45E+04	1.86E+05	2.24E+05	2.98E+05	3.73E+05
I-131	3.42E+02	8.54E+02	1.28E+03	2.14E+03	8.54E+03	2.14E+04	2.56E+04	3.42E+04	4.27E+04
Ir-192	4.69E+03	1.17E+04	1.76E+04	2.93E+04	1.17E+05	2.93E+05	3.52E+05	4.69E+05	5.87E+05
Po-210	1.19E+01	2.97E+01	4.45E+01	7.42E+01	2.97E+02	7.42E+02	8.90E+02	1.19E+03	1.48E+03
Co-60	1.16E+03	2.90E+03	4.34E+03	7.24E+03	2.90E+04	7.24E+04	8.69E+04	1.16E+05	1.45E+05

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	6.83E+01	1.71E+02	2.56E+02	4.27E+02	1.71E+03	4.27E+03	5.12E+03	6.83E+03	8.54E+03
Y-90	4.95E+02	1.24E+03	1.86E+03	3.10E+03	1.24E+04	3.10E+04	3.72E+04	4.95E+04	6.19E+04
Cs-137	7.35E+02	1.84E+03	2.76E+03	4.59E+03	1.84E+04	4.59E+04	5.51E+04	7.35E+04	9.19E+04
I-131	8.43E+01	2.11E+02	3.16E+02	5.27E+02	2.11E+03	5.27E+03	6.32E+03	8.43E+03	1.05E+04
Ir-192	1.16E+03	2.89E+03	4.34E+03	7.23E+03	2.89E+04	7.23E+04	8.68E+04	1.16E+05	1.45E+05
Po-210	2.93E+00	7.31E+00	1.10E+01	1.83E+01	7.31E+01	1.83E+02	2.19E+02	2.93E+02	3.66E+02
Co-60	2.86E+02	7.14E+02	1.07E+03	1.78E+03	7.14E+03	1.78E+04	2.14E+04	2.86E+04	3.57E+04

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Drinking Water Risk for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.38E-06	5.95E-06	8.92E-06	1.49E-05	5.95E-05	1.49E-04	1.78E-04	2.38E-04	2.97E-04
Y-90	1.42E-05	3.55E-05	5.32E-05	8.87E-05	3.55E-04	8.87E-04	1.06E-03	1.42E-03	1.77E-03
Cs-137	6.45E-06	1.61E-05	2.42E-05	4.03E-05	1.61E-04	4.03E-04	4.83E-04	6.45E-04	8.06E-04
I-131	4.67E-06	1.17E-05	1.75E-05	2.92E-05	1.17E-04	2.92E-04	3.51E-04	4.67E-04	5.84E-04
Ir-192	1.23E-05	3.07E-05	4.61E-05	7.69E-05	3.07E-04	7.69E-04	9.22E-04	1.23E-03	1.54E-03
Po-210	1.34E-06	3.34E-06	5.01E-06	8.35E-06	3.34E-05	8.35E-05	1.00E-04	1.34E-04	1.67E-04
Co-60	5.54E-06	1.38E-05	2.08E-05	3.46E-05	1.38E-04	3.46E-04	4.15E-04	5.54E-04	6.92E-04

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.38E-06	5.95E-06	8.92E-06	1.49E-05	5.95E-05	1.49E-04	1.78E-04	2.38E-04	2.97E-04
Y-90	1.42E-05	3.55E-05	5.32E-05	8.87E-05	3.55E-04	8.87E-04	1.06E-03	1.42E-03	1.77E-03
Cs-137	6.45E-06	1.61E-05	2.42E-05	4.03E-05	1.61E-04	4.03E-04	4.83E-04	6.45E-04	8.06E-04
I-131	4.67E-06	1.17E-05	1.75E-05	2.92E-05	1.17E-04	2.92E-04	3.51E-04	4.67E-04	5.84E-04
Ir-192	1.23E-05	3.07E-05	4.61E-05	7.69E-05	3.07E-04	7.69E-04	9.22E-04	1.23E-03	1.54E-03
Po-210	1.34E-06	3.34E-06	5.01E-06	8.35E-06	3.34E-05	8.35E-05	1.00E-04	1.34E-04	1.67E-04
Co-60	5.54E-06	1.38E-05	2.08E-05	3.46E-05	1.38E-04	3.46E-04	4.15E-04	5.54E-04	6.92E-04

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.38E-06	5.95E-06	8.92E-06	1.49E-05	5.95E-05	1.49E-04	1.78E-04	2.38E-04	2.97E-04
Y-90	1.42E-05	3.55E-05	5.32E-05	8.87E-05	3.55E-04	8.87E-04	1.06E-03	1.42E-03	1.77E-03
Cs-137	6.45E-06	1.61E-05	2.42E-05	4.03E-05	1.61E-04	4.03E-04	4.83E-04	6.45E-04	8.06E-04
I-131	4.67E-06	1.17E-05	1.75E-05	2.92E-05	1.17E-04	2.92E-04	3.51E-04	4.67E-04	5.84E-04
Ir-192	1.23E-05	3.07E-05	4.61E-05	7.69E-05	3.07E-04	7.69E-04	9.22E-04	1.23E-03	1.54E-03
Po-210	1.34E-06	3.34E-06	5.01E-06	8.35E-06	3.34E-05	8.35E-05	1.00E-04	1.34E-04	1.67E-04
Co-60	5.54E-06	1.38E-05	2.08E-05	3.46E-05	1.38E-04	3.46E-04	4.15E-04	5.54E-04	6.92E-04

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.38E-06	5.95E-06	8.92E-06	1.49E-05	5.95E-05	1.49E-04	1.78E-04	2.38E-04	2.97E-04
Y-90	1.42E-05	3.55E-05	5.32E-05	8.87E-05	3.55E-04	8.87E-04	1.06E-03	1.42E-03	1.77E-03
Cs-137	6.45E-06	1.61E-05	2.42E-05	4.03E-05	1.61E-04	4.03E-04	4.83E-04	6.45E-04	8.06E-04
I-131	4.67E-06	1.17E-05	1.75E-05	2.92E-05	1.17E-04	2.92E-04	3.51E-04	4.67E-04	5.84E-04
Ir-192	1.23E-05	3.07E-05	4.61E-05	7.69E-05	3.07E-04	7.69E-04	9.22E-04	1.23E-03	1.54E-03
Po-210	1.34E-06	3.34E-06	5.01E-06	8.35E-06	3.34E-05	8.35E-05	1.00E-04	1.34E-04	1.67E-04
Co-60	5.54E-06	1.38E-05	2.08E-05	3.46E-05	1.38E-04	3.46E-04	4.15E-04	5.54E-04	6.92E-04

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APPENDIX 4: 1 YEAR OLD

Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.23E+03	5.58E+03	8.37E+03	1.39E+04	5.58E+04	1.39E+05	1.67E+05	2.23E+05	2.79E+05
Y-90	8.08E+03	2.02E+04	3.03E+04	5.05E+04	2.02E+05	5.05E+05	6.06E+05	8.08E+05	1.01E+06
Cs-137	1.30E+04	3.26E+04	4.89E+04	8.14E+04	3.26E+05	8.14E+05	9.77E+05	1.30E+06	1.63E+06
I-131	9.03E+02	2.26E+03	3.39E+03	5.64E+03	2.26E+04	5.64E+04	6.77E+04	9.03E+04	1.13E+05
Ir-192	1.85E+04	4.62E+04	6.93E+04	1.16E+05	4.62E+05	1.16E+06	1.39E+06	1.85E+06	2.31E+06
Po-210	9.03E+01	2.26E+02	3.39E+02	5.64E+02	2.26E+03	5.64E+03	6.77E+03	9.03E+03	1.13E+04
Co-60	6.03E+03	1.51E+04	2.26E+04	3.77E+04	1.51E+05	3.77E+05	4.52E+05	6.03E+05	7.54E+05

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.12E+03	2.79E+03	4.18E+03	6.97E+03	2.79E+04	6.97E+04	8.37E+04	1.12E+05	1.39E+05
Y-90	4.04E+03	1.01E+04	1.51E+04	2.52E+04	1.01E+05	2.52E+05	3.03E+05	4.04E+05	5.05E+05
Cs-137	6.52E+03	1.63E+04	2.44E+04	4.07E+04	1.63E+05	4.07E+05	4.89E+05	6.52E+05	8.14E+05
I-131	4.51E+02	1.13E+03	1.69E+03	2.82E+03	1.13E+04	2.82E+04	3.39E+04	4.51E+04	5.64E+04
Ir-192	9.24E+03	2.31E+04	3.47E+04	5.78E+04	2.31E+05	5.78E+05	6.93E+05	9.24E+05	1.16E+06
Po-210	4.51E+01	1.13E+02	1.69E+02	2.82E+02	1.13E+03	2.82E+03	3.39E+03	4.51E+03	5.64E+03
Co-60	3.01E+03	7.54E+03	1.13E+04	1.88E+04	7.54E+04	1.88E+05	2.26E+05	3.01E+05	3.77E+05

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	7.44E+02	1.86E+03	2.79E+03	4.65E+03	1.86E+04	4.65E+04	5.58E+04	7.44E+04	9.30E+04
Y-90	2.69E+03	6.73E+03	1.01E+04	1.68E+04	6.73E+04	1.68E+05	2.02E+05	2.69E+05	3.37E+05
Cs-137	4.34E+03	1.09E+04	1.63E+04	2.71E+04	1.09E+05	2.71E+05	3.26E+05	4.34E+05	5.43E+05
I-131	3.01E+02	7.52E+02	1.13E+03	1.88E+03	7.52E+03	1.88E+04	2.26E+04	3.01E+04	3.76E+04
Ir-192	6.16E+03	1.54E+04	2.31E+04	3.85E+04	1.54E+05	3.85E+05	4.62E+05	6.16E+05	7.70E+05
Po-210	3.01E+01	7.52E+01	1.13E+02	1.88E+02	7.52E+02	1.88E+03	2.26E+03	3.01E+03	3.76E+03
Co-60	2.01E+03	5.02E+03	7.54E+03	1.26E+04	5.02E+04	1.26E+05	1.51E+05	2.01E+05	2.51E+05

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.83E+02	4.59E+02	6.88E+02	1.15E+03	4.59E+03	1.15E+04	1.38E+04	1.83E+04	2.29E+04
Y-90	6.64E+02	1.66E+03	2.49E+03	4.15E+03	1.66E+04	4.15E+04	4.98E+04	6.64E+04	8.30E+04
Cs-137	1.07E+03	2.68E+03	4.02E+03	6.69E+03	2.68E+04	6.69E+04	8.03E+04	1.07E+05	1.34E+05
I-131	7.42E+01	1.86E+02	2.78E+02	4.64E+02	1.86E+03	4.64E+03	5.57E+03	7.42E+03	9.28E+03
Ir-192	1.52E+03	3.80E+03	5.70E+03	9.50E+03	3.80E+04	9.50E+04	1.14E+05	1.52E+05	1.90E+05
Po-210	7.42E+00	1.86E+01	2.78E+01	4.64E+01	1.86E+02	4.64E+02	5.57E+02	7.42E+02	9.28E+02
Co-60	4.96E+02	1.24E+03	1.86E+03	3.10E+03	1.24E+04	3.10E+04	3.72E+04	4.96E+04	6.19E+04

ED_001057_00009404

Drinking Water Risk for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.75E-06	1.19E-05	1.78E-05	2.97E-05	1.19E-04	2.97E-04	3.56E-04	4.75E-04	5.93E-04
Y-90	1.62E-05	4.04E-05	6.06E-05	1.01E-04	4.04E-04	1.01E-03	1.21E-03	1.62E-03	2.02E-03
Cs-137	8.03E-06	2.01E-05	3.01E-05	5.02E-05	2.01E-04	5.02E-04	6.02E-04	8.03E-04	1.00E-03
I-131	4.45E-06	1.11E-05	1.67E-05	2.78E-05	1.11E-04	2.78E-04	3.34E-04	4.45E-04	5.56E-04
Ir-192	1.39E-05	3.48E-05	5.22E-05	8.70E-05	3.48E-04	8.70E-04	1.04E-03	1.39E-03	1.74E-03
Po-210	2.13E-06	5.31E-06	7.97E-06	1.33E-05	5.31E-05	1.33E-04	1.59E-04	2.13E-04	2.66E-04
Co-60	7.79E-06	1.95E-05	2.92E-05	4.87E-05	1.95E-04	4.87E-04	5.84E-04	7.79E-04	9.74E-04

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.75E-06	1.19E-05	1.78E-05	2.97E-05	1.19E-04	2.97E-04	3.56E-04	4.75E-04	5.93E-04
Y-90	1.62E-05	4.04E-05	6.06E-05	1.01E-04	4.04E-04	1.01E-03	1.21E-03	1.62E-03	2.02E-03
Cs-137	8.03E-06	2.01E-05	3.01E-05	5.02E-05	2.01E-04	5.02E-04	6.02E-04	8.03E-04	1.00E-03
I-131	4.45E-06	1.11E-05	1.67E-05	2.78E-05	1.11E-04	2.78E-04	3.34E-04	4.45E-04	5.56E-04
Ir-192	1.39E-05	3.48E-05	5.22E-05	8.70E-05	3.48E-04	8.70E-04	1.04E-03	1.39E-03	1.74E-03
Po-210	2.13E-06	5.31E-06	7.97E-06	1.33E-05	5.31E-05	1.33E-04	1.59E-04	2.13E-04	2.66E-04
Co-60	7.79E-06	1.95E-05	2.92E-05	4.87E-05	1.95E-04	4.87E-04	5.84E-04	7.79E-04	9.74E-04

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.75E-06	1.19E-05	1.78E-05	2.97E-05	1.19E-04	2.97E-04	3.56E-04	4.75E-04	5.93E-04
Y-90	1.62E-05	4.04E-05	6.06E-05	1.01E-04	4.04E-04	1.01E-03	1.21E-03	1.62E-03	2.02E-03
Cs-137	8.03E-06	2.01E-05	3.01E-05	5.02E-05	2.01E-04	5.02E-04	6.02E-04	8.03E-04	1.00E-03
I-131	4.45E-06	1.11E-05	1.67E-05	2.78E-05	1.11E-04	2.78E-04	3.34E-04	4.45E-04	5.56E-04
Ir-192	1.39E-05	3.48E-05	5.22E-05	8.70E-05	3.48E-04	8.70E-04	1.04E-03	1.39E-03	1.74E-03
Po-210	2.13E-06	5.31E-06	7.97E-06	1.33E-05	5.31E-05	1.33E-04	1.59E-04	2.13E-04	2.66E-04
Co-60	7.79E-06	1.95E-05	2.92E-05	4.87E-05	1.95E-04	4.87E-04	5.84E-04	7.79E-04	9.74E-04

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.75E-06	1.19E-05	1.78E-05	2.97E-05	1.19E-04	2.97E-04	3.56E-04	4.75E-04	5.93E-04
Y-90	1.62E-05	4.04E-05	6.06E-05	1.01E-04	4.04E-04	1.01E-03	1.21E-03	1.62E-03	2.02E-03
Cs-137	8.03E-06	2.01E-05	3.01E-05	5.02E-05	2.01E-04	5.02E-04	6.02E-04	8.03E-04	1.00E-03
I-131	4.45E-06	1.11E-05	1.67E-05	2.78E-05	1.11E-04	2.78E-04	3.34E-04	4.45E-04	5.56E-04
Ir-192	1.39E-05	3.48E-05	5.22E-05	8.70E-05	3.48E-04	8.70E-04	1.04E-03	1.39E-03	1.74E-03
Po-210	2.13E-06	5.31E-06	7.97E-06	1.33E-05	5.31E-05	1.33E-04	1.59E-04	2.13E-04	2.66E-04
Co-60	7.79E-06	1.95E-05	2.92E-05	4.87E-05	1.95E-04	4.87E-04	5.84E-04	7.79E-04	9.74E-04

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APPENDIX 5: 5 YEAR OLD

Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.42E+03	3.54E+03	5.32E+03	8.86E+03	3.54E+04	8.86E+04	1.06E+05	1.42E+05	1.77E+05
Y-90	6.67E+03	1.67E+04	2.50E+04	4.17E+04	1.67E+05	4.17E+05	5.00E+05	6.67E+05	8.34E+05
Cs-137	6.86E+03	1.72E+04	2.57E+04	4.29E+04	1.72E+05	4.29E+05	5.15E+05	6.86E+05	8.58E+05
I-131	6.39E+02	1.60E+03	2.40E+03	4.00E+03	1.60E+04	4.00E+04	4.79E+04	6.39E+04	7.99E+04
Ir-192	1.45E+04	3.62E+04	5.43E+04	9.05E+04	3.62E+05	9.05E+05	1.09E+06	1.45E+06	1.81E+06
Po-210	7.49E+01	1.87E+02	2.81E+02	4.68E+02	1.87E+03	4.68E+03	5.62E+03	7.49E+03	9.36E+03
Co-60	3.93E+03	9.84E+03	1.48E+04	2.46E+04	9.84E+04	2.46E+05	2.95E+05	3.93E+05	4.92E+05

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	7.09E+02	1.77E+03	2.66E+03	4.43E+03	1.77E+04	4.43E+04	5.32E+04	7.09E+04	8.86E+04
Y-90	3.33E+03	8.34E+03	1.25E+04	2.08E+04	8.34E+04	2.08E+05	2.50E+05	3.33E+05	4.17E+05
Cs-137	3.43E+03	8.58E+03	1.29E+04	2.14E+04	8.58E+04	2.14E+05	2.57E+05	3.43E+05	4.29E+05
I-131	3.20E+02	7.99E+02	1.20E+03	2.00E+03	7.99E+03	2.00E+04	2.40E+04	3.20E+04	4.00E+04
Ir-192	7.24E+03	1.81E+04	2.72E+04	4.53E+04	1.81E+05	4.53E+05	5.43E+05	7.24E+05	9.05E+05
Po-210	3.74E+01	9.36E+01	1.40E+02	2.34E+02	9.36E+02	2.34E+03	2.81E+03	3.74E+03	4.68E+03
Co-60	1.97E+03	4.92E+03	7.38E+03	1.23E+04	4.92E+04	1.23E+05	1.48E+05	1.97E+05	2.46E+05

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.73E+02	1.18E+03	1.77E+03	2.95E+03	1.18E+04	2.95E+04	3.54E+04	4.73E+04	5.91E+04
Y-90	2.22E+03	5.56E+03	8.34E+03	1.39E+04	5.56E+04	1.39E+05	1.67E+05	2.22E+05	2.78E+05
Cs-137	2.29E+03	5.72E+03	8.58E+03	1.43E+04	5.72E+04	1.43E+05	1.72E+05	2.29E+05	2.86E+05
I-131	2.13E+02	5.33E+02	7.99E+02	1.33E+03	5.33E+03	1.33E+04	1.60E+04	2.13E+04	2.66E+04
Ir-192	4.83E+03	1.21E+04	1.81E+04	3.02E+04	1.21E+05	3.02E+05	3.62E+05	4.83E+05	6.04E+05
Po-210	2.50E+01	6.24E+01	9.36E+01	1.56E+02	6.24E+02	1.56E+03	1.87E+03	2.50E+03	3.12E+03
Co-60	1.31E+03	3.28E+03	4.92E+03	8.20E+03	3.28E+04	8.20E+04	9.84E+04	1.31E+05	1.64E+05

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.17E+02	2.91E+02	4.37E+02	7.28E+02	2.91E+03	7.28E+03	8.74E+03	1.17E+04	1.46E+04
Y-90	5.48E+02	1.37E+03	2.06E+03	3.43E+03	1.37E+04	3.43E+04	4.11E+04	5.48E+04	6.85E+04
Cs-137	5.64E+02	1.41E+03	2.11E+03	3.52E+03	1.41E+04	3.52E+04	4.23E+04	5.64E+04	7.05E+04
I-131	5.25E+01	1.31E+02	1.97E+02	3.28E+02	1.31E+03	3.28E+03	3.94E+03	5.25E+03	6.57E+03
Ir-192	1.19E+03	2.98E+03	4.46E+03	7.44E+03	2.98E+04	7.44E+04	8.93E+04	1.19E+05	1.49E+05
Po-210	6.15E+00	1.54E+01	2.31E+01	3.85E+01	1.54E+02	3.85E+02	4.62E+02	6.15E+02	7.69E+02
Co-60	3.23E+02	8.08E+02	1.21E+03	2.02E+03	8.08E+03	2.02E+04	2.43E+04	3.23E+04	4.04E+04

ED_001057_00009404

Drinking Water Risk for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.38E-06	1.09E-05	1.64E-05	2.73E-05	1.09E-04	2.73E-04	3.28E-04	4.38E-04	5.47E-04
Y-90	1.71E-05	4.26E-05	6.39E-05	1.07E-04	4.26E-04	1.07E-03	1.28E-03	1.71E-03	2.13E-03
Cs-137	8.13E-06	2.03E-05	3.05E-05	5.08E-05	2.03E-04	5.08E-04	6.10E-04	8.13E-04	1.02E-03
I-131	4.08E-06	1.02E-05	1.53E-05	2.55E-05	1.02E-04	2.55E-04	3.06E-04	4.08E-04	5.10E-04
Ir-192	1.44E-05	3.59E-05	5.39E-05	8.99E-05	3.59E-04	8.99E-04	1.08E-03	1.44E-03	1.80E-03
Po-210	2.32E-06	5.80E-06	8.70E-06	1.45E-05	5.80E-05	1.45E-04	1.74E-04	2.32E-04	2.90E-04
Co-60	7.81E-06	1.95E-05	2.93E-05	4.88E-05	1.95E-04	4.88E-04	5.86E-04	7.81E-04	9.76E-04

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.38E-06	1.09E-05	1.64E-05	2.73E-05	1.09E-04	2.73E-04	3.28E-04	4.38E-04	5.47E-04
Y-90	1.71E-05	4.26E-05	6.39E-05	1.07E-04	4.26E-04	1.07E-03	1.28E-03	1.71E-03	2.13E-03
Cs-137	8.13E-06	2.03E-05	3.05E-05	5.08E-05	2.03E-04	5.08E-04	6.10E-04	8.13E-04	1.02E-03
I-131	4.08E-06	1.02E-05	1.53E-05	2.55E-05	1.02E-04	2.55E-04	3.06E-04	4.08E-04	5.10E-04
Ir-192	1.44E-05	3.59E-05	5.39E-05	8.99E-05	3.59E-04	8.99E-04	1.08E-03	1.44E-03	1.80E-03
Po-210	2.32E-06	5.80E-06	8.70E-06	1.45E-05	5.80E-05	1.45E-04	1.74E-04	2.32E-04	2.90E-04
Co-60	7.81E-06	1.95E-05	2.93E-05	4.88E-05	1.95E-04	4.88E-04	5.86E-04	7.81E-04	9.76E-04

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.38E-06	1.09E-05	1.64E-05	2.73E-05	1.09E-04	2.73E-04	3.28E-04	4.38E-04	5.47E-04
Y-90	1.71E-05	4.26E-05	6.39E-05	1.07E-04	4.26E-04	1.07E-03	1.28E-03	1.71E-03	2.13E-03
Cs-137	8.13E-06	2.03E-05	3.05E-05	5.08E-05	2.03E-04	5.08E-04	6.10E-04	8.13E-04	1.02E-03
I-131	4.08E-06	1.02E-05	1.53E-05	2.55E-05	1.02E-04	2.55E-04	3.06E-04	4.08E-04	5.10E-04
Ir-192	1.44E-05	3.59E-05	5.39E-05	8.99E-05	3.59E-04	8.99E-04	1.08E-03	1.44E-03	1.80E-03
Po-210	2.32E-06	5.80E-06	8.70E-06	1.45E-05	5.80E-05	1.45E-04	1.74E-04	2.32E-04	2.90E-04
Co-60	7.81E-06	1.95E-05	2.93E-05	4.88E-05	1.95E-04	4.88E-04	5.86E-04	7.81E-04	9.76E-04

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.38E-06	1.09E-05	1.64E-05	2.73E-05	1.09E-04	2.73E-04	3.28E-04	4.38E-04	5.47E-04
Y-90	1.71E-05	4.26E-05	6.39E-05	1.07E-04	4.26E-04	1.07E-03	1.28E-03	1.71E-03	2.13E-03
Cs-137	8.13E-06	2.03E-05	3.05E-05	5.08E-05	2.03E-04	5.08E-04	6.10E-04	8.13E-04	1.02E-03
I-131	4.08E-06	1.02E-05	1.53E-05	2.55E-05	1.02E-04	2.55E-04	3.06E-04	4.08E-04	5.10E-04
Ir-192	1.44E-05	3.59E-05	5.39E-05	8.99E-05	3.59E-04	8.99E-04	1.08E-03	1.44E-03	1.80E-03
Po-210	2.32E-06	5.80E-06	8.70E-06	1.45E-05	5.80E-05	1.45E-04	1.74E-04	2.32E-04	2.90E-04
Co-60	7.81E-06	1.95E-05	2.93E-05	4.88E-05	1.95E-04	4.88E-04	5.86E-04	7.81E-04	9.76E-04

ED_001057_00009404

APPENDIX 6: 10 YEAR OLD

Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	8.33E+02	2.08E+03	3.12E+03	5.20E+03	2.08E+04	5.20E+04	6.24E+04	8.33E+04	1.04E+05
Y-90	8.42E+03	2.11E+04	3.16E+04	5.27E+04	2.11E+05	5.27E+05	6.32E+05	8.42E+05	1.05E+06
Cs-137	4.92E+03	1.23E+04	1.85E+04	3.08E+04	1.23E+05	3.08E+05	3.69E+05	4.92E+05	6.15E+05
I-131	9.49E+02	2.37E+03	3.56E+03	5.93E+03	2.37E+04	5.93E+04	7.11E+04	9.49E+04	1.19E+05
Ir-192	1.74E+04	4.36E+04	6.54E+04	1.09E+05	4.36E+05	1.09E+06	1.31E+06	1.74E+06	2.18E+06
Po-210	9.47E+01	2.37E+02	3.55E+02	5.92E+02	2.37E+03	5.92E+03	7.10E+03	9.47E+03	1.18E+04
Co-60	4.44E+03	1.11E+04	1.66E+04	2.77E+04	1.11E+05	2.77E+05	3.33E+05	4.44E+05	5.55E+05

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.16E+02	1.04E+03	1.56E+03	2.60E+03	1.04E+04	2.60E+04	3.12E+04	4.16E+04	5.20E+04
Y-90	4.21E+03	1.05E+04	1.58E+04	2.63E+04	1.05E+05	2.63E+05	3.16E+05	4.21E+05	5.27E+05
Cs-137	2.46E+03	6.15E+03	9.23E+03	1.54E+04	6.15E+04	1.54E+05	1.85E+05	2.46E+05	3.08E+05
I-131	4.74E+02	1.19E+03	1.78E+03	2.96E+03	1.19E+04	2.96E+04	3.56E+04	4.74E+04	5.93E+04
Ir-192	8.72E+03	2.18E+04	3.27E+04	5.45E+04	2.18E+05	5.45E+05	6.54E+05	8.72E+05	1.09E+06
Po-210	4.73E+01	1.18E+02	1.78E+02	2.96E+02	1.18E+03	2.96E+03	3.55E+03	4.73E+03	5.92E+03
Co-60	2.22E+03	5.55E+03	8.32E+03	1.39E+04	5.55E+04	1.39E+05	1.66E+05	2.22E+05	2.77E+05

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.78E+02	6.94E+02	1.04E+03	1.73E+03	6.94E+03	1.73E+04	2.08E+04	2.78E+04	3.47E+04
Y-90	2.81E+03	7.02E+03	1.05E+04	1.76E+04	7.02E+04	1.76E+05	2.11E+05	2.81E+05	3.51E+05
Cs-137	1.64E+03	4.10E+03	6.15E+03	1.03E+04	4.10E+04	1.03E+05	1.23E+05	1.64E+05	2.05E+05
I-131	3.16E+02	7.90E+02	1.19E+03	1.98E+03	7.90E+03	1.98E+04	2.37E+04	3.16E+04	3.95E+04
Ir-192	5.81E+03	1.45E+04	2.18E+04	3.63E+04	1.45E+05	3.63E+05	4.36E+05	5.81E+05	7.27E+05
Po-210	3.16E+01	7.89E+01	1.18E+02	1.97E+02	7.89E+02	1.97E+03	2.37E+03	3.16E+03	3.94E+03
Co-60	1.48E+03	3.70E+03	5.55E+03	9.25E+03	3.70E+04	9.25E+04	1.11E+05	1.48E+05	1.85E+05

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	6.84E+01	1.71E+02	2.57E+02	4.28E+02	1.71E+03	4.28E+03	5.13E+03	6.84E+03	8.55E+03
Y-90	6.92E+02	1.73E+03	2.60E+03	4.33E+03	1.73E+04	4.33E+04	5.19E+04	6.92E+04	8.66E+04
Cs-137	4.04E+02	1.01E+03	1.52E+03	2.53E+03	1.01E+04	2.53E+04	3.03E+04	4.04E+04	5.06E+04
I-131	7.80E+01	1.95E+02	2.92E+02	4.87E+02	1.95E+03	4.87E+03	5.85E+03	7.80E+03	9.75E+03
Ir-192	1.43E+03	3.58E+03	5.38E+03	8.96E+03	3.58E+04	8.96E+04	1.08E+05	1.43E+05	1.79E+05
Po-210	7.78E+00	1.95E+01	2.92E+01	4.86E+01	1.95E+02	4.86E+02	5.84E+02	7.78E+02	9.73E+02
Co-60	3.65E+02	9.12E+02	1.37E+03	2.28E+03	9.12E+03	2.28E+04	2.74E+04	3.65E+04	4.56E+04

ED_001057_00009404

Drinking Water Risk for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.15E-06	5.38E-06	8.07E-06	1.34E-05	5.38E-05	1.34E-04	1.61E-04	2.15E-04	2.69E-04
Y-90	1.72E-05	4.31E-05	6.46E-05	1.08E-04	4.31E-04	1.08E-03	1.29E-03	1.72E-03	2.15E-03
Cs-137	7.88E-06	1.97E-05	2.96E-05	4.93E-05	1.97E-04	4.93E-04	5.91E-04	7.88E-04	9.85E-04
I-131	3.85E-06	9.62E-06	1.44E-05	2.40E-05	9.62E-05	2.40E-04	2.89E-04	3.85E-04	4.81E-04
Ir-192	1.42E-05	3.54E-05	5.32E-05	8.86E-05	3.54E-04	8.86E-04	1.06E-03	1.42E-03	1.77E-03
Po-210	2.42E-06	6.06E-06	9.09E-06	1.51E-05	6.06E-05	1.51E-04	1.82E-04	2.42E-04	3.03E-04
Co-60	7.71E-06	1.93E-05	2.89E-05	4.82E-05	1.93E-04	4.82E-04	5.79E-04	7.71E-04	9.64E-04

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.15E-06	5.38E-06	8.07E-06	1.34E-05	5.38E-05	1.34E-04	1.61E-04	2.15E-04	2.69E-04
Y-90	1.72E-05	4.31E-05	6.46E-05	1.08E-04	4.31E-04	1.08E-03	1.29E-03	1.72E-03	2.15E-03
Cs-137	7.88E-06	1.97E-05	2.96E-05	4.93E-05	1.97E-04	4.93E-04	5.91E-04	7.88E-04	9.85E-04
I-131	3.85E-06	9.62E-06	1.44E-05	2.40E-05	9.62E-05	2.40E-04	2.89E-04	3.85E-04	4.81E-04
Ir-192	1.42E-05	3.54E-05	5.32E-05	8.86E-05	3.54E-04	8.86E-04	1.06E-03	1.42E-03	1.77E-03
Po-210	2.42E-06	6.06E-06	9.09E-06	1.51E-05	6.06E-05	1.51E-04	1.82E-04	2.42E-04	3.03E-04
Co-60	7.71E-06	1.93E-05	2.89E-05	4.82E-05	1.93E-04	4.82E-04	5.79E-04	7.71E-04	9.64E-04

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.15E-06	5.38E-06	8.07E-06	1.34E-05	5.38E-05	1.34E-04	1.61E-04	2.15E-04	2.69E-04
Y-90	1.72E-05	4.31E-05	6.46E-05	1.08E-04	4.31E-04	1.08E-03	1.29E-03	1.72E-03	2.15E-03
Cs-137	7.88E-06	1.97E-05	2.96E-05	4.93E-05	1.97E-04	4.93E-04	5.91E-04	7.88E-04	9.85E-04
I-131	3.85E-06	9.62E-06	1.44E-05	2.40E-05	9.62E-05	2.40E-04	2.89E-04	3.85E-04	4.81E-04
Ir-192	1.42E-05	3.54E-05	5.32E-05	8.86E-05	3.54E-04	8.86E-04	1.06E-03	1.42E-03	1.77E-03
Po-210	2.42E-06	6.06E-06	9.09E-06	1.51E-05	6.06E-05	1.51E-04	1.82E-04	2.42E-04	3.03E-04
Co-60	7.71E-06	1.93E-05	2.89E-05	4.82E-05	1.93E-04	4.82E-04	5.79E-04	7.71E-04	9.64E-04

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.15E-06	5.38E-06	8.07E-06	1.34E-05	5.38E-05	1.34E-04	1.61E-04	2.15E-04	2.69E-04
Y-90	1.72E-05	4.31E-05	6.46E-05	1.08E-04	4.31E-04	1.08E-03	1.29E-03	1.72E-03	2.15E-03
Cs-137	7.88E-06	1.97E-05	2.96E-05	4.93E-05	1.97E-04	4.93E-04	5.91E-04	7.88E-04	9.85E-04
I-131	3.85E-06	9.62E-06	1.44E-05	2.40E-05	9.62E-05	2.40E-04	2.89E-04	3.85E-04	4.81E-04
Ir-192	1.42E-05	3.54E-05	5.32E-05	8.86E-05	3.54E-04	8.86E-04	1.06E-03	1.42E-03	1.77E-03
Po-210	2.42E-06	6.06E-06	9.09E-06	1.51E-05	6.06E-05	1.51E-04	1.82E-04	2.42E-04	3.03E-04
Co-60	7.71E-06	1.93E-05	2.89E-05	4.82E-05	1.93E-04	4.82E-04	5.79E-04	7.71E-04	9.64E-04

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APPENDIX 7: 15 YEAR OLD

Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	5.07E+02	1.27E+03	1.90E+03	3.17E+03	1.27E+04	3.17E+04	3.81E+04	5.07E+04	6.34E+04
Y-90	1.20E+04	3.00E+04	4.50E+04	7.49E+04	3.00E+05	7.49E+05	8.99E+05	1.20E+06	1.50E+06
Cs-137	2.99E+03	7.47E+03	1.12E+04	1.87E+04	7.47E+04	1.87E+05	2.24E+05	2.99E+05	3.74E+05
I-131	1.17E+03	2.93E+03	4.39E+03	7.32E+03	2.93E+04	7.32E+04	8.78E+04	1.17E+05	1.46E+05
Ir-192	2.34E+04	5.85E+04	8.78E+04	1.46E+05	5.85E+05	1.46E+06	1.76E+06	2.34E+06	2.93E+06
Po-210	1.26E+02	3.14E+02	4.71E+02	7.84E+02	3.14E+03	7.84E+03	9.41E+03	1.26E+04	1.57E+04
Co-60	5.04E+03	1.26E+04	1.89E+04	3.15E+04	1.26E+05	3.15E+05	3.78E+05	5.04E+05	6.30E+05

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	2.54E+02	6.34E+02	9.52E+02	1.59E+03	6.34E+03	1.59E+04	1.90E+04	2.54E+04	3.17E+04
Y-90	5.99E+03	1.50E+04	2.25E+04	3.75E+04	1.50E+05	3.75E+05	4.50E+05	5.99E+05	7.49E+05
Cs-137	1.49E+03	3.74E+03	5.60E+03	9.34E+03	3.74E+04	9.34E+04	1.12E+05	1.49E+05	1.87E+05
I-131	5.85E+02	1.46E+03	2.20E+03	3.66E+03	1.46E+04	3.66E+04	4.39E+04	5.85E+04	7.32E+04
Ir-192	1.17E+04	2.93E+04	4.39E+04	7.32E+04	2.93E+05	7.32E+05	8.78E+05	1.17E+06	1.46E+06
Po-210	6.28E+01	1.57E+02	2.35E+02	3.92E+02	1.57E+03	3.92E+03	4.71E+03	6.28E+03	7.84E+03
Co-60	2.52E+03	6.30E+03	9.46E+03	1.58E+04	6.30E+04	1.58E+05	1.89E+05	2.52E+05	3.15E+05

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.69E+02	4.23E+02	6.34E+02	1.06E+03	4.23E+03	1.06E+04	1.27E+04	1.69E+04	2.11E+04
Y-90	4.00E+03	9.99E+03	1.50E+04	2.50E+04	9.99E+04	2.50E+05	3.00E+05	4.00E+05	5.00E+05
Cs-137	9.96E+02	2.49E+03	3.74E+03	6.23E+03	2.49E+04	6.23E+04	7.47E+04	9.96E+04	1.25E+05
I-131	3.90E+02	9.76E+02	1.46E+03	2.44E+03	9.76E+03	2.44E+04	2.93E+04	3.90E+04	4.88E+04
Ir-192	7.81E+03	1.95E+04	2.93E+04	4.88E+04	1.95E+05	4.88E+05	5.85E+05	7.81E+05	9.76E+05
Po-210	4.18E+01	1.05E+02	1.57E+02	2.61E+02	1.05E+03	2.61E+03	3.14E+03	4.18E+03	5.23E+03
Co-60	1.68E+03	4.20E+03	6.30E+03	1.05E+04	4.20E+04	1.05E+05	1.26E+05	1.68E+05	2.10E+05

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	4.17E+01	1.04E+02	1.56E+02	2.61E+02	1.04E+03	2.61E+03	3.13E+03	4.17E+03	5.21E+03
Y-90	9.85E+02	2.46E+03	3.69E+03	6.16E+03	2.46E+04	6.16E+04	7.39E+04	9.85E+04	1.23E+05
Cs-137	2.46E+02	6.14E+02	9.21E+02	1.53E+03	6.14E+03	1.53E+04	1.84E+04	2.46E+04	3.07E+04
I-131	9.62E+01	2.41E+02	3.61E+02	6.01E+02	2.41E+03	6.01E+03	7.22E+03	9.62E+03	1.20E+04
Ir-192	1.92E+03	4.81E+03	7.22E+03	1.20E+04	4.81E+04	1.20E+05	1.44E+05	1.92E+05	2.41E+05
Po-210	1.03E+01	2.58E+01	3.87E+01	6.45E+01	2.58E+02	6.45E+02	7.74E+02	1.03E+03	1.29E+03
Co-60	4.14E+02	1.04E+03	1.55E+03	2.59E+03	1.04E+04	2.59E+04	3.11E+04	4.14E+04	5.18E+04

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Drinking Water Risk for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.70E-06	4.26E-06	6.39E-06	1.06E-05	4.26E-05	1.06E-04	1.28E-04	1.70E-04	2.13E-04
Y-90	1.72E-05	4.31E-05	6.47E-05	1.08E-04	4.31E-04	1.08E-03	1.29E-03	1.72E-03	2.16E-03
Cs-137	7.28E-06	1.82E-05	2.73E-05	4.55E-05	1.82E-04	4.55E-04	5.46E-04	7.28E-04	9.10E-04
I-131	3.46E-06	8.65E-06	1.30E-05	2.16E-05	8.65E-05	2.16E-04	2.60E-04	3.46E-04	4.33E-04
Ir-192	1.39E-05	3.47E-05	5.21E-05	8.68E-05	3.47E-04	8.68E-04	1.04E-03	1.39E-03	1.74E-03
Po-210	2.45E-06	6.11E-06	9.17E-06	1.53E-05	6.11E-05	1.53E-04	1.83E-04	2.45E-04	3.06E-04
Co-60	7.15E-06	1.79E-05	2.68E-05	4.47E-05	1.79E-04	4.47E-04	5.37E-04	7.15E-04	8.94E-04

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.70E-06	4.26E-06	6.39E-06	1.06E-05	4.26E-05	1.06E-04	1.28E-04	1.70E-04	2.13E-04
Y-90	1.72E-05	4.31E-05	6.47E-05	1.08E-04	4.31E-04	1.08E-03	1.29E-03	1.72E-03	2.16E-03
Cs-137	7.28E-06	1.82E-05	2.73E-05	4.55E-05	1.82E-04	4.55E-04	5.46E-04	7.28E-04	9.10E-04
I-131	3.46E-06	8.65E-06	1.30E-05	2.16E-05	8.65E-05	2.16E-04	2.60E-04	3.46E-04	4.33E-04
Ir-192	1.39E-05	3.47E-05	5.21E-05	8.68E-05	3.47E-04	8.68E-04	1.04E-03	1.39E-03	1.74E-03
Po-210	2.45E-06	6.11E-06	9.17E-06	1.53E-05	6.11E-05	1.53E-04	1.83E-04	2.45E-04	3.06E-04
Co-60	7.15E-06	1.79E-05	2.68E-05	4.47E-05	1.79E-04	4.47E-04	5.37E-04	7.15E-04	8.94E-04

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.70E-06	4.26E-06	6.39E-06	1.06E-05	4.26E-05	1.06E-04	1.28E-04	1.70E-04	2.13E-04
Y-90	1.72E-05	4.31E-05	6.47E-05	1.08E-04	4.31E-04	1.08E-03	1.29E-03	1.72E-03	2.16E-03
Cs-137	7.28E-06	1.82E-05	2.73E-05	4.55E-05	1.82E-04	4.55E-04	5.46E-04	7.28E-04	9.10E-04
I-131	3.46E-06	8.65E-06	1.30E-05	2.16E-05	8.65E-05	2.16E-04	2.60E-04	3.46E-04	4.33E-04
Ir-192	1.39E-05	3.47E-05	5.21E-05	8.68E-05	3.47E-04	8.68E-04	1.04E-03	1.39E-03	1.74E-03
Po-210	2.45E-06	6.11E-06	9.17E-06	1.53E-05	6.11E-05	1.53E-04	1.83E-04	2.45E-04	3.06E-04
Co-60	7.15E-06	1.79E-05	2.68E-05	4.47E-05	1.79E-04	4.47E-04	5.37E-04	7.15E-04	8.94E-04

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.70E-06	4.26E-06	6.39E-06	1.06E-05	4.26E-05	1.06E-04	1.28E-04	1.70E-04	2.13E-04
Y-90	1.72E-05	4.31E-05	6.47E-05	1.08E-04	4.31E-04	1.08E-03	1.29E-03	1.72E-03	2.16E-03
Cs-137	7.28E-06	1.82E-05	2.73E-05	4.55E-05	1.82E-04	4.55E-04	5.46E-04	7.28E-04	9.10E-04
I-131	3.46E-06	8.65E-06	1.30E-05	2.16E-05	8.65E-05	2.16E-04	2.60E-04	3.46E-04	4.33E-04
Ir-192	1.39E-05	3.47E-05	5.21E-05	8.68E-05	3.47E-04	8.68E-04	1.04E-03	1.39E-03	1.74E-03
Po-210	2.45E-06	6.11E-06	9.17E-06	1.53E-05	6.11E-05	1.53E-04	1.83E-04	2.45E-04	3.06E-04
Co-60	7.15E-06	1.79E-05	2.68E-05	4.47E-05	1.79E-04	4.47E-04	5.37E-04	7.15E-04	8.94E-04

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APPENDIX 8: ADULT

Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.14E+03	2.86E+03	4.29E+03	7.15E+03	2.86E+04	7.15E+04	8.58E+04	1.14E+05	1.43E+05
Y-90	1.18E+04	2.95E+04	4.42E+04	7.36E+04	2.95E+05	7.36E+05	8.84E+05	1.18E+06	1.47E+06
Cs-137	2.33E+03	5.83E+03	8.74E+03	1.46E+04	5.83E+04	1.46E+05	1.75E+05	2.33E+05	2.91E+05
I-131	1.45E+03	3.63E+03	5.45E+03	9.09E+03	3.63E+04	9.09E+04	1.09E+05	1.45E+05	1.82E+05
Ir-192	2.31E+04	5.78E+04	8.68E+04	1.45E+05	5.78E+05	1.45E+06	1.74E+06	2.31E+06	2.89E+06
Po-210	1.29E+02	3.23E+02	4.85E+02	8.09E+02	3.23E+03	8.09E+03	9.70E+03	1.29E+04	1.62E+04
Co-60	9.27E+03	2.32E+04	3.48E+04	5.79E+04	2.32E+05	5.79E+05	6.95E+05	9.27E+05	1.16E+06

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	5.72E+02	1.43E+03	2.15E+03	3.58E+03	1.43E+04	3.58E+04	4.29E+04	5.72E+04	7.15E+04
Y-90	5.89E+03	1.47E+04	2.21E+04	3.68E+04	1.47E+05	3.68E+05	4.42E+05	5.89E+05	7.36E+05
Cs-137	1.17E+03	2.91E+03	4.37E+03	7.28E+03	2.91E+04	7.28E+04	8.74E+04	1.17E+05	1.46E+05
I-131	7.27E+02	1.82E+03	2.73E+03	4.54E+03	1.82E+04	4.54E+04	5.45E+04	7.27E+04	9.09E+04
Ir-192	1.16E+04	2.89E+04	4.34E+04	7.23E+04	2.89E+05	7.23E+05	8.68E+05	1.16E+06	1.45E+06
Po-210	6.47E+01	1.62E+02	2.43E+02	4.04E+02	1.62E+03	4.04E+03	4.85E+03	6.47E+03	8.09E+03
Co-60	4.63E+03	1.16E+04	1.74E+04	2.90E+04	1.16E+05	2.90E+05	3.48E+05	4.63E+05	5.79E+05

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	3.81E+02	9.53E+02	1.43E+03	2.38E+03	9.53E+03	2.38E+04	2.86E+04	3.81E+04	4.77E+04
Y-90	3.93E+03	9.82E+03	1.47E+04	2.45E+04	9.82E+04	2.45E+05	2.95E+05	3.93E+05	4.91E+05
Cs-137	7.77E+02	1.94E+03	2.91E+03	4.86E+03	1.94E+04	4.86E+04	5.83E+04	7.77E+04	9.71E+04
I-131	4.85E+02	1.21E+03	1.82E+03	3.03E+03	1.21E+04	3.03E+04	3.63E+04	4.85E+04	6.06E+04
Ir-192	7.71E+03	1.93E+04	2.89E+04	4.82E+04	1.93E+05	4.82E+05	5.78E+05	7.71E+05	9.64E+05
Po-210	4.31E+01	1.08E+02	1.62E+02	2.70E+02	1.08E+03	2.70E+03	3.23E+03	4.31E+03	5.39E+03
Co-60	3.09E+03	7.72E+03	1.16E+04	1.93E+04	7.72E+04	1.93E+05	2.32E+05	3.09E+05	3.86E+05

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	9.40E+01	2.35E+02	3.53E+02	5.88E+02	2.35E+03	5.88E+03	7.05E+03	9.40E+03	1.18E+04
Y-90	9.68E+02	2.42E+03	3.63E+03	6.05E+03	2.42E+04	6.05E+04	7.26E+04	9.68E+04	1.21E+05
Cs-137	1.92E+02	4.79E+02	7.18E+02	1.20E+03	4.79E+03	1.20E+04	1.44E+04	1.92E+04	2.39E+04
I-131	1.19E+02	2.99E+02	4.48E+02	7.47E+02	2.99E+03	7.47E+03	8.96E+03	1.19E+04	1.49E+04
Ir-192	1.90E+03	4.75E+03	7.13E+03	1.19E+04	4.75E+04	1.19E+05	1.43E+05	1.90E+05	2.38E+05
Po-210	1.06E+01	2.66E+01	3.99E+01	6.65E+01	2.66E+02	6.65E+02	7.97E+02	1.06E+03	1.33E+03
Co-60	7.62E+02	1.90E+03	2.86E+03	4.76E+03	1.90E+04	4.76E+04	5.71E+04	7.62E+04	9.52E+04

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Drinking Water Risk for Specified Dose (mrem) Over Specified Time

30 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.59E-06	3.97E-06	5.96E-06	9.93E-06	3.97E-05	9.93E-05	1.19E-04	1.59E-04	1.99E-04
Y-90	1.68E-06	4.20E-06	6.30E-06	1.05E-05	4.20E-05	1.05E-04	1.26E-04	1.68E-04	2.10E-04
Cs-137	1.81E-06	4.54E-06	6.81E-06	1.13E-05	4.54E-05	1.13E-04	1.36E-04	1.81E-04	2.27E-04
I-131	8.40E-07	2.10E-06	3.15E-06	5.25E-06	2.10E-05	5.25E-05	6.30E-05	8.40E-05	1.05E-04
Ir-192	1.56E-06	3.90E-06	5.85E-06	9.74E-06	3.90E-05	9.74E-05	1.17E-04	1.56E-04	1.95E-04
Po-210	1.10E-06	2.75E-06	4.12E-06	6.87E-06	2.75E-05	6.87E-05	8.24E-05	1.10E-04	1.37E-04
Co-60	1.56E-06	3.89E-06	5.83E-06	9.72E-06	3.89E-05	9.72E-05	1.17E-04	1.56E-04	1.94E-04

60 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.59E-06	3.97E-06	5.96E-06	9.93E-06	3.97E-05	9.93E-05	1.19E-04	1.59E-04	1.99E-04
Y-90	1.68E-06	4.20E-06	6.30E-06	1.05E-05	4.20E-05	1.05E-04	1.26E-04	1.68E-04	2.10E-04
Cs-137	1.81E-06	4.54E-06	6.81E-06	1.13E-05	4.54E-05	1.13E-04	1.36E-04	1.81E-04	2.27E-04
I-131	8.40E-07	2.10E-06	3.15E-06	5.25E-06	2.10E-05	5.25E-05	6.30E-05	8.40E-05	1.05E-04
Ir-192	1.56E-06	3.90E-06	5.85E-06	9.74E-06	3.90E-05	9.74E-05	1.17E-04	1.56E-04	1.95E-04
Po-210	1.10E-06	2.75E-06	4.12E-06	6.87E-06	2.75E-05	6.87E-05	8.24E-05	1.10E-04	1.37E-04
Co-60	1.56E-06	3.89E-06	5.83E-06	9.72E-06	3.89E-05	9.72E-05	1.17E-04	1.56E-04	1.94E-04

90 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.59E-06	3.97E-06	5.96E-06	9.93E-06	3.97E-05	9.93E-05	1.19E-04	1.59E-04	1.99E-04
Y-90	1.68E-06	4.20E-06	6.30E-06	1.05E-05	4.20E-05	1.05E-04	1.26E-04	1.68E-04	2.10E-04
Cs-137	1.81E-06	4.54E-06	6.81E-06	1.13E-05	4.54E-05	1.13E-04	1.36E-04	1.81E-04	2.27E-04
I-131	8.40E-07	2.10E-06	3.15E-06	5.25E-06	2.10E-05	5.25E-05	6.30E-05	8.40E-05	1.05E-04
Ir-192	1.56E-06	3.90E-06	5.85E-06	9.74E-06	3.90E-05	9.74E-05	1.17E-04	1.56E-04	1.95E-04
Po-210	1.10E-06	2.75E-06	4.12E-06	6.87E-06	2.75E-05	6.87E-05	8.24E-05	1.10E-04	1.37E-04
Co-60	1.56E-06	3.89E-06	5.83E-06	9.72E-06	3.89E-05	9.72E-05	1.17E-04	1.56E-04	1.94E-04

365 days

	4	10	15	25	100	250	300	400	500
Sr-90	1.59E-06	3.97E-06	5.96E-06	9.93E-06	3.97E-05	9.93E-05	1.19E-04	1.59E-04	1.99E-04
Y-90	1.68E-06	4.20E-06	6.30E-06	1.05E-05	4.20E-05	1.05E-04	1.26E-04	1.68E-04	2.10E-04
Cs-137	1.81E-06	4.54E-06	6.81E-06	1.13E-05	4.54E-05	1.13E-04	1.36E-04	1.81E-04	2.27E-04
I-131	8.40E-07	2.10E-06	3.15E-06	5.25E-06	2.10E-05	5.25E-05	6.30E-05	8.40E-05	1.05E-04
Ir-192	1.56E-06	3.90E-06	5.85E-06	9.74E-06	3.90E-05	9.74E-05	1.17E-04	1.56E-04	1.95E-04
Po-210	1.10E-06	2.75E-06	4.12E-06	6.87E-06	2.75E-05	6.87E-05	8.24E-05	1.10E-04	1.37E-04
Co-60	1.56E-06	3.89E-06	5.83E-06	9.72E-06	3.89E-05	9.72E-05	1.17E-04	1.56E-04	1.94E-04

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ENVIRONMENTAL PROTECTION AGENCY

[EPA-HQ-OAR-2008-0268; FRL-####-##]

Notice of Availability: Protective Action Guide (PAG) for Drinking Water after a Radiological Incident

AGENCY: Environmental Protection Agency (EPA).

ACTION: Notice of document availability for public comment.

SUMMARY: As part of its mission to protect human health and the environment, the Environmental Protection Agency (EPA) publishes protective action guides to help federal, state, local and tribal emergency response officials make radiation protection decisions during emergencies. EPA, in coordination with a multi-agency working group within the Federal Radiological Preparedness Coordinating Committee (FRPCC), is proposing an addition to the 2013 revised PAG Manual – Protective Action Guides and Planning Guidance for Radiological Incidents ("2013 revised PAG Manual" hereafter) to provide guidance on drinking water.

DATES: Comments must be received on or before [60 days after date of publication in the Federal Register].

ADDRESSES: Submit your comments, identified by Docket ID No. **EPA-HQ-OAR-2008-0268**, by one of the following methods—

- www.regulations.gov: Follow the on-line instructions for submitting comments.
- Email: to a-and-r-docket@epa.gov; Docket ID No. **EPA-HQ-OAR-2008-0268.**
- Fax: (202) 566-1741
- Mail: Air and Radiation Docket and Information Center, Environmental Protection Agency, Mail Code: 6102T, 1200 Pennsylvania Ave., NW, Washington, DC 20460

Instructions: Direct your comments to Attn: Docket ID No. **EPA-HQ-OAR-2008-0268.** The

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Agency's policy is that all comments received will be included in the public docket without change and may be made available online at www.regulations.gov, including any personal information provided, unless the comment includes information claimed to be Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Do not submit information that you consider to be CBI or otherwise protected through www.regulations.gov or e-mail. The www.regulations.gov website is an "anonymous access" system, which means EPA will not know your identity or contact information unless you provide it in the body of your comment. If you send an e-mail comment directly to EPA without going through www.regulations.gov, your e-mail address will be automatically captured and included as part of the comment that is placed in the public docket and made available on the Internet. If you submit an electronic comment, EPA recommends that you include your name and other contact information in the body of your comment and with any disk or CD-ROM you submit. If EPA cannot read your comment due to technical difficulties and cannot contact you for clarification, EPA may not be able to consider your comment. Electronic files should avoid the use of special characters, any form of encryption and be free of any defects or viruses. For additional information about EPA's public docket, visit the EPA Docket Center homepage at http://www.epa.gov/epahome/dockets.htm.

Docket: All documents in the docket are listed in the www.regulations.gov index. Although listed in the index, some information is not publicly available, e.g., CBI or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, will be publicly available only in hard copy. EPA has established a docket for this action under Docket ID No. **[EPA-HQ-OAR-2008-0268; FRL-####-##]**. Publicly available docket materials

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are available either electronically through www.regulations.gov or in hard copy at the Air and Radiation Docket in the EPA Docket Center, (EPA/DC) EPA West, Room 3334, 1301 Constitution Ave., NW, Washington, DC 20004. The EPA Docket Center Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566-1744 and the telephone number for the Air and Radiation Docket is (202) 566-1742. In accordance with EPA's regulations at 40 CFR Part 2 and in accordance with normal EPA docket procedures, if copies of any docket materials are requested, a reasonable fee may be charged for photocopying.

FOR FURTHER INFORMATION CONTACT: Lisa M. Christ, Standards and Risk Management Division, Office of Ground Water and Drinking Water , Mail Code 4607M, U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue NW, Washington, DC 20460; telephone number: (202) 564-8354; fax number: (202)-------; E-mail: *christ.lisa@epa.gov*.

SUPPLEMENTARY INFORMATION:

1. General Information

A. Does this Action Apply to me?

This action does not impose any requirements on anyone. It notifies interested parties of EPA's proposed drinking water protective action guide (PAG) and request for public comment. The drinking water PAG will help federal, state, local, tribal officials and public water systems make decisions about use of water during radiological emergencies. The drinking water PAG is non-regulatory guidance.

B. What authority does EPA have to provide Protective Action Guidance?

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The historical and legal basis of EPA's role in the 2013 PAG Manual begins with Reorganization Plan No. 3 of 1970, in which the Administrator of EPA assumed all the functions of the Federal Radiation Council (FRC), including the charge to "…advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with states." (Reorg. Plan No. 3 of 1970, sec. 2(a) (7), 6(a) (2); § 274.h of the Atomic Energy Act of 1954, as amended (AEA), codified at 42 U.S.C. § 2021(h)). Recognizing this role, FEMA directed EPA in their Radiological Emergency Planning and Preparedness Regulations to "establish Protective Action Guides (PAGs) for all aspects of radiological emergency planning in coordination with appropriate federal agencies." (44 CFR 351.22(a)). FEMA also tasked EPA with preparing "guidance for state and local governments on implementing PAGs, including recommendations on protective actions which can be taken to mitigate the potential radiation dose to the population."(44 CFR 351.22(b)). All of this information was to "be presented in the Environmental Protection Agency (EPA) 'Manual of Protective Action Guides and Protective Actions for Nuclear Incidents.'"(44 CFR 351.22(b)).

Additionally, section 2021(h) charged the Administrator with performing "such other functions as the President may assign to him [or her] by Executive order." Executive Order 12656 states that the Administrator shall "[d]evelop, for national security emergencies, guidance on acceptable emergency levels of nuclear radiation…." (Executive Order No. 12656, sec.1601(2)). EPA's role in PAGs development was reaffirmed by the *National Response Framework, Nuclear/Radiological Incident Annex* of June 2008.

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C. What is the PAG Manual: Protective Action Guides and Planning Guidance for Radiological Incidents?

In 2013, EPA revised the PAG Manual that provides federal, state and local emergency management officials with guidance for responding to radiological emergencies (78 FR 22257, April 15, 2013). A protective action guide (PAG) is the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. Emergency management officials use PAGs for making decisions regarding actions to protect the public from exposure to radiation during an emergency. Such actions include evacuation, shelter-in-place, temporary relocation, water and food restrictions.

The PAGs are based on the following essential principles, which also apply to the selection of any protective action during an incident—

- Prevent acute effects.
- Balance protection with other important factors and ensure that actions result in more benefit than harm.
- Reduce risk of chronic effects.

The PAG Manual is not a legally binding regulation or standard and does not supersede any environmental laws; PAGs are not intended to define "safe" or "unsafe" levels of exposure or contamination. As indicated by the use of non-mandatory language such as "may," "should" and "can," the Manual only provides recommendations and does not confer any legal rights or impose any legally binding requirements upon any member of the public, states or any federal agency. Rather, the PAG Manual provides projected radiation dose levels at which specific actions are recommended in order to reduce or avoid that dose. The 2013 revised PAG Manual is

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designed to provide flexibility to be more or less restrictive as deemed appropriate by decision makers based on the unique characteristics of the incident and the local situation.

D. What additional guidance is being proposed for the PAG Manual?

Drinking water protective action guidance was developed by a multi-agency Subcommittee of the Federal Radiological Preparedness Coordinating Committee and is published by EPA with concurrence from the Department of Energy, the Department of Defense; the Department of Homeland Security, including the Federal Emergency Management Agency; the Nuclear Regulatory Commission; the Department of Health and Human Services, including both the Centers for Disease Control and Prevention as well as the Food and Drug Administration; the U.S. Department of Agriculture; and the Department of Labor.

A large scale radiation contamination incident could impact the US, driving the need for a pre-established drinking water PAG. EPA is proposing a two-tiered intermediate phase drinking water PAG of 100 mrem projected dose in the first year for infants, children and pregnant or nursing women and 500 mrem projected dose in the first year for the general population. The government of Japan adopted a similarly two tiered drinking water advisory when responding to the radiation incident in Fukushima.

This proposed additional guidance recommends protective actions when drinking water may be impacted by a radiological or nuclear incident. A PAG is a health-based tipping point where actions are warranted to avoid radiation exposure. This guidance seeks to balance the goal of keeping radiation doses as low as possible with the practical and logistical challenges of providing alternative drinking water during the response to a disaster. In developing the drinking water PAG, the Agency considered potential cumulative exposure from a radiation incident.

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Ultimately, a PAG does not represent an "acceptable" routine exposure; A PAG is a dose to be avoided. Every PAG is developed with the same three principles: avoid acute effects, minimize cancer risk and ensure the actions taken are not more dangerous than the risk being avoided.

Under the Safe Drinking Water Act (SDWA), the Agency has established maximum contaminant levels (MCLs) for radiological contaminants in drinking water. The National Primary Drinking Water Regulations (NPDWR) for radionuclides are based on lifetime exposure criteria and assume 70 years of continued exposure to contaminants in drinking water. The Agency recognizes that within the SDWA framework, water systems in violation of drinking water standards have processes available to get back into compliance within a reasonable time frame. While the SDWA framework is appropriate for day-to-day normal operations, it does not provide the necessary tools to assist emergency responders with determining the need for an immediate protective action. EPA assumes that any drinking water system adversely impacted during a radiation incident will be able to achieve compliance with MCLs as soon as practicable.

E. When will the PAG Manual be finalized?

Once comments on this addition are adjudicated, drinking water guidance will be added to the full PAG Manual which will be issued in final form for incorporation into state, local, tribal and federal emergency response plans over a one-year implementation timeframe.

F. What Should I Consider as I Prepare My Comments for EPA?

1. *Submitting Confidential Business Information (CBI):*

Do not submit this information to EPA through www.regulations.gov or e-mail. Clearly mark all of the information that you claim to be CBI. For CBI information in a disk or CD ROM that

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you mail to EPA, mark the outside of the disk or CD ROM as CBI and then identify electronically within the disk or CD ROM the specific information that is claimed as CBI. In addition to one complete version of the comment that includes information claimed as CBI, a copy of the comment that does not contain the information claimed as CBI must be submitted for inclusion in the public docket. Information marked as CBI will not be disclosed except in accordance with procedures set forth in 40 CFR Part 2.

2. *Tips for Preparing Your Comments:*

When submitting comments, remember to—

- Identify the rulemaking by docket number, subject heading, ***Federal Register*** date and page number.
- Follow directions—EPA may ask you to respond to specific questions or organize comments by referencing the chapter number.
- Explain why you agree or disagree; suggest alternatives and substitute language for your requested changes.
- Describe any assumptions and provide technical information and data that you used.
- If you estimate potential costs or burdens, explain how you arrived at your estimate in sufficient detail to allow it to be reproduced.
- Illustrate your concerns with specific examples and suggest alternatives.
- Explain your views as clearly as possible, avoiding the use of profanity or personal threats.
- Make sure to submit your comments by the comment period deadline identified.

G. What Specific Comments are Being Sought?

While all comments regarding any aspect of the drinking water PAG guidance will be

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considered, please comment on the following issues specifically—

- Please comment on the appropriateness of the drinking water PAG, and the guidance for advance planning and implementation of the PAG.
- Please suggest additional guidance that would aid pre-incident planning and implementation specific to your community's drinking water supply systems.
- Please comment on how this guidance should be implemented in emergency response and recovery plans at all levels of government.
- In the future, calculations and derived response levels will be provided in the Federal Radiological Monitoring and Assessment Center (FRMAC) Assessment Manuals. Emergency planners are referred to FRMAC Monitoring and Sampling Methods to assess surface and drinking water impacts from a radiological emergency. See the Assessment and Monitoring & Sampling folders at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

After considering public comments, EPA intends to issue a final PAG Manual which will supersede the 1992 PAG Manual and the 2013 revised PAG Manual.

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Dated: __ __, 2015

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Ken Kopocis,
Acting Assistant Administrator,
Office of Water.

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Protective Action Guides (PAGs) for Drinking Water

The Protective Action Guide (PAG) manual contains radiation dose guidelines that would trigger public safety measures, such as evacuation or staying indoors, to minimize or prevent radiation exposure during an emergency. Emergency response organizations use the PAG Manual guidance in their response plans. EPA is actively working on a drinking water PAG proposal, which takes into account comments submitted during the 2013 comment period on the updated PAG Manual. The proposed drinking water PAG will be a health-based dose that should be avoided by providing a alternative drinking water. EPA is developing a two-tiered-approach: 500 millirem projected dose in the first year for the general population, and 100 millirem projected dose in the first year for more sensitive populations. RPD and the Office of Water jointly developed the drinking water PAG. Staff are currently adjudicating internal comments before moving to OMB review within the next several months.

Southern Exposure Exercise

ORIA personnel participated in the full-scale Southern Exposure 15 exercise, which simulated a nuclear power reactor accident that results in significant off-site radioactive releases in South Carolina. Participants included EPA, FEMA, NRC, DOE, and all levels of state and local government organizatiosn. ORIA personnel helped plan the exercise, and participated in field monitoring, sample analysis, dose calculation,, and public information functions. ORIA personnel also participated in the second, "tabletop" phase of the exercise, dealing with relocation of homes and businesses, waste management and monitoring/sampling to support long-term decision-making.

Web Content Tabs: Water Systems/ General Public/ Emergency Responders/ Primacy Agencies

Technical Fact Sheet

Proposed EPA Drinking Water Protective Action Guide

For Radiological Emergencies

The proposed drinking water protective action guide (PAG) is non-regulatory guidance to protect the public in the event of a radiological incident that affects drinking water supplies. The proposed drinking water PAG will help federal, state, local and public water system officials make decisions about use of water during radiological emergencies.

The proposed drinking water PAG is for use only during an emergency; it is not a substitute for compliance with EPA's National Primary Drinking Water Regulations (NPDWRs) for Radionuclides. EPA expects that any drinking water system adversely impacted during a radiation incident will take action to return to compliance as soon as practical.

What is a drinking water PAG?

- The drinking water PAG is a health-based tipping point where alternative water should be provided. The protective action is to restrict the use of contaminated water for drinking purposes and provide alternative drinking water for the affected community.
- The proposed drinking water PAG levels are projected doses to an individual. EPA is proposing a two-tiered drinking water PAG—
  - 500 millirems (mrem) projected dose in the first year for the general population.
  - 100 mrem projected dose in the first year for more sensitive individuals: infants, children, pregnant women and nursing mothers.
- PAGs are doses to be avoided; they do not represent "acceptable" routine exposures. The PAGs trigger safety measures to keep cumulative doses as low as possible during an emergency.

- **What actions could water systems take to protect the public from contaminated water?**
  - Develop a radiological emergency operations plan that is utility-specific. Advance planning can provide clarity and facilitate the decision-making process. [1]Guidance on developing emergency drinking water supplies is available from EPA
  - Treat contaminated water
  - Establish interconnections to neighboring systems
  - Blend water sources
  - Import water in tanker trucks
  - Import bottled water
- **When and how should water systems sample for radionuclides in water?**
  - Whenever practicable and when it's safe to do so, water systems should collect samples to analyze for radionuclides.

[1] Refer to EPA. *Planning for an Emergency Drinking Water Supply,* EPA 600/R-11/054, June 2011

- EPA has established [2]rapid analytical methods (non-regulatory) for particular radionuclides.
- EPA approved methods must be used for analysis when complying with the NPDWRs for radionuclides.

- **What are the radionuclides that are likely to be detected in drinking water following a radiological incident?**
  - The radionuclides that could contaminate water will depend on what type of incident that has happened. There are specific radionuclides, such as cesium-137, iodine-131, and srontium-90, which are of particular interest for radiological incident scenarios involving nuclear power plants.
  - Different radionuclides can be associated with other incidents that involve a radiological dispersal device (RDD) or improvised nuclear device (IND). Further guidance on types of radionuclides released associated with various types of incidents please visit: http://www.remm.nlm.gov/typesofevents.htm.
- **How does the drinking water PAG work with EPA's existing Safe Drinking Water Act regulations?**
  - The proposed drinking water PAGs are for use during emergencies only.
  - Immediately following a radiological incident, community water systems must also return to compliance with [3]radionuclide standards as soon as possible.

[2] The rapid analysis methods can be located at http://www.epa.gov/narel/rapid_methods.html

[3] For more information about EPA's regulations for radionuclides in drinking water, refer to the Radionuclides Rule: A Quick Reference Guide: http://water.epa.gov/lawsregs/rulesregs/sdwa/radionuclides/upload/2009_04_16_radionuclides_qrg_radionuclides.pdf

To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Mosser, Jennifer
Sent: Fri 5/8/2015 8:43:11 PM
Subject: RE: Discontinuation of RadNet Field Screening Measurements

Sounds good. We will call you.

From: DeCair, Sara
Sent: Friday, May 08, 2015 4:42 PM
To: Mosser, Jennifer
Subject: FW: Discontinuation of RadNet Field Screening Measurements

I think I'd better call in to the General since Lee has handed us 400 things to talk about – I'm leaving print copies on your chair of this field screen thing, my initial hotwash from VR, and the latest on PAGs from Alan (so he doesn't need a reminder, but maybe wants to chit chat and make sure Jon is up to date).

Can you just dial me on my cell (202-738-2871) once you're in Jon's office since I couldn't get in there today to see what the Polycomm number is?

S.

From: Veal, Lee
Sent: Friday, May 08, 2015 3:33 PM
To: DeCair, Sara; Mosser, Jennifer
Subject: Discontinuation of RadNet Field Screening Measurements

Sara and Jen,

I completely agree with the idea of discontinuing the in-field screening of RadNet filters. The system we are able to support nowadays allows us to take this step.

I spoke briefly with Scott Telofski this afternoon, and he tells me that John Griggs would like to make sure that Jon E and I are on board with this change before making it final.

Could you please share this with Jon on Monday at our general? I've attached a revised agenda for you.

Lee Ann B. Veal

Director, Center for Radiological Emergency Management

Radiation Protection Division

Office of Radiation and Indoor Air

Office: 202-343-9448

Cell: 202-617-4322

www.epa.gov/radiation

From: Telofski, Scott
Sent: Monday, March 23, 2015 1:26 PM
To: Veal, Lee
Cc: Griggs, John; Askren, Daniel R.
Subject: Discontinuation of RadNet Field Screening Measurements

Lee,

You may recall that at the February ICRU meeting we briefly discussed concerns about field screening of RadNet air filters and our desire to discontinue these field measurements. Dan and I developed some slides that go over the details of the concerns (attached to this e-mail), and John has asked that we send them to you, so that perhaps you and Jon Edwards can take a look at these slides. If that seems reasonable, then we'd like to schedule time to get your input once you've had an opportunity to look these over.

Thanks,

Scott

To: DeCair, Sara[DeCair.Sara@epa.gov]; Veal, Lee[Veal.Lee@epa.gov]; Edwards, Jonathan[Edwards.Jonathan@epa.gov]
From: Perrin, Alan
Sent: Fri 5/8/2015 1:56:04 PM
Subject: RE: Updated PAG proposal project plan - input by Monday?

Sounds good, with proposed calendar consensus, I can probably get it in front of Mike for a green light on scheduling. He planned to call J Woolford, if I have an opp I'll check on status. I certainly see no problem with OSRTI staff letting their mgmt know what they're reviewing.

On the OD's mtg, you might want to pose ? to Lisa on attendance from OW, i.e., are there other OW ODs that need to be at this brief? Understand the difficulty with Sam W – if it's a prob, maybe we can offer a quick individual meet or phone conv for him. -ap

Alan Perrin, Deputy Director
Radiation Protection Division, USEPA
ofc (202) 343-9775 | mbl (202) 279-0376

From: DeCair, Sara
Sent: Friday, May 08, 2015 9:02 AM
To: Perrin, Alan; Veal, Lee; Edwards, Jonathan
Subject: FW: Updated PAG proposal project plan - input by Monday?

FYI, Lisa is out today, returning Monday, so I expect to hear from her then. Andrea is on vacation, returning Wednesday May 13th so that will be the soonest she can help Debbie with starting the scheduling process.

Reggie won't be surprised by the briefing scheduling process, but Jim Woolford hasn't heard about this topic for a long time and my staff level contacts in his org, Lyndsey and Dave Kappelman, probably don't talk to him regularly. Shall I encourage them to have their bosses mention it in generals or something? Just a thought so we are not met with surprise and confusion?

One more thought – Lee had suggested OHS's Sam Wiggins as well and he would be a good

addition but I fear it will take forever to get it scheduled if we add him as well! It will be hard enough to get four ODs at the same time, by mid June.

Thx

From: DeCair, Sara
Sent: Thursday, May 07, 2015 5:23 PM
To: Christ, Lisa
Cc: Perrin, Alan; Cherepy, Andrea; Lee Veal
Subject: Updated PAG proposal project plan - input by Monday?

Lisa,

We are starting the process to schedule Peter and Mike's pre-brief and then joint ODs briefing planned for Jim Woolford and Reggie Cheatham of OSWER. If we're lucky, we can get those both scheduled in June and have OGC's review done by then too, so our final steps wouldn't be delayed.

Could you take a look at the attached Project Plan update (changes highlighted) and provide me any concerns or input by Monday? Mike asked that we do this now to ensure we are all on the same page. Then Andrea can help our scheduler, Debbie Cheng, get the meetings on our calendars.

Thank you so much!

Sara

Sara D. DeCair

http://www.epa.gov/radiation/rert/pags.html

202-343-9108

Room 1416 B in WJC West

Chapter ##: Protective Action Guide (PAG) for Drinking Water

1.0 INTRODUCTION

This chapter presents protective action guides and planning guidance for protection of the public in the event of a radiological incident that affects drinking water supplies. A PAG is the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended.

The protective action for the drinking water exposure pathway is to restrict the use of contaminated water for drinking purposes and to provide alternative drinking water for the affected community. The drinking water PAGs apply during the intermediate phase of an incident, which may last for weeks to months.

2.0 SUMMARY OF THE DRINKING WATER PAG

EPA is proposing a two-tier drinking water PAG be used during the year following a radiation incident: 500 mrem (5 mSv) projected dose[1] over the course of a year for the general population (defined as anyone over age 15, excluding pregnant women), and 100 mrem (1 mSv) projected dose over the course of a year for pregnant women, infants, and children age 15 and under.

EPA expects that any drinking water system adversely impacted during a radiation incident will take action to return to compliance with Safe Drinking Water Act (SDWA) levels as soon as practical within the first year after the incident. The proposed PAG is consistent with the other Protective Actions Guides currently in place for other media at the intermediate phase (viz., the 500 mrem PAG for internal exposure from ingestion of food[2,3]) and provides an additional level of protection for the most sensitive life stages.

EPA is also proposing Derived Response Levels (DRLs) in Table 1 for several radionuclides likely to appear in drinking water during a radiological contamination incident. DRLs are concentrations of radionuclides in drinking water that correspond to EPA's proposed PAGs of 100 mrem and 500 mrem. DRLs are essential because a PAG is not a quantity that can be measured directly in a medium such as drinking water. DRLs are expressed in units of Bq/L or pCi/L, and can be directly compared to modeled or measured radionuclide concentrations in drinking water supplies. In the absence of site-specific DRLs developed by emergency responders acquainted with local conditions, EPA recommends using these DRLs to guide actions to protect the public in the event of a radiological incident that affects drinking water supplies.

[1] All dose values expressed as Committed Effective Dose (CED).

[2] Food and Drug Administration (FDA). 1998. Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations to State and Local Agencies.

[3] Food and Drug Administration. 2004. Supporting Document for Guidance Levels for Radionuclides in Domestic and Imported Foods. Docket No. 2003D-0558.

Table 1. Derived Response Levels (DRLs) -- Drinking water concentrations corresponding to specified doses (mrem) of select radionuclides, assuming one year of exposure at constant levels (picoCuries per Liter)

	DRLs for Developing Embryos & Fetuses (Maternal Exposure), Infants, and Children Age 15 and Younger	DRLs for Adults (Excluding Pregnant Women)
Dose Level	**100 mrem**	**500 mrem**
Strontium (Sr)-90/Yttrium (Y)-90	1,043 pCi/L	11,755 pCi/L
Cesium (Cs)-137	6,140 pCi/L	23,940 pCi/L
Iodine (I)-131	1,314 pCi/L	14,935 pCi/L

Note: Y-90 is a radioactive decomposition product of Sr-90 and will normally be found alongside Sr-90 in the case of a Sr-90 release; therefore they are treated together. Solubility differences may cause less Yttrium to be present, however it is a conservative assumption to include both in DRLs. When calculating the combined DRL, note that the dose coefficients (see Table 4) are additive.

3.0 FACTORS CONSIDERED WHEN ESTABLISHING THE DRINKING WATER PAG

Section 1.3.2 of the draft revised PAG manual[4] provides the following three principles for establishing PAGs.

1. Prevent acute effects
2. Balance protection with other important factors and ensure that actions result in more benefit than harm
3. Reduce risk of chronic effects

The Agency crafted the drinking water PAG with these principles in mind. Specifically, consideration was given to the acute effects of exposure to radiation and lifetime risk of cancer based on age and drinking water intake. EPA made use of the risk conversion factors set forth in Federal Guidance Report No. 13[5] and considerations of risk to the unborn set forth in National Council on Radiation Protection (NCRP) Report No. 174.[6]

[4] EPA. 2013. Draft PAG Manual for Interim Use and Public Comment. Available online at: http://www.epa.gov/radiation/docs/er/pag-manual-interim-public-comment-4-2-2013.pdf. Accessed October 23, 2014.

[5] EPA. 1999. Cancer Risk Coefficients for Environmental Exposure to Radionuclides. Federal Guidance Report #13. Available online at: http://www.epa.gov/rpdweb00/docs/federal/402-r-99-001.pdf. Accessed October 23, 2014.

[6] Brent, R.L., Frush, D.P., Harms, R.W., and M.S. Linet. 2013. *Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance.* National Council on Radiation Protection. Report #174.

In preparing this draft document, the Agency reviewed existing PAGs, thresholds, criteria and guidelines that have been established and proposed for protecting human health from a radiological incident. EPA also gave careful consideration to feedback received from public stakeholders on an earlier draft PAG manual[7], as it relates to public health protection from radiation exposure in drinking water.

The drinking water PAG was developed based on risks associated with ingesting drinking water contaminated with radionuclides. EPA also considered the potential radiation dose people could receive from various other uses of contaminated water, including showering and bathing. In the United States, people typically shower and bathe using the same source of water that they use to drink, but these activities generally represent much smaller risk than drinking contaminated water. EPA believes that protection of a community's drinking water supply based on assumptions about ingestion will also protect the population from undue risk from contaminated water by other routes of exposure.

4.0 RATIONALE FOR INTERMEDIATE PHASE DRINKING WATER PAG

The draft intermediate phase drinking water PAG was developed in consideration of several key factors, including existing radiation protection standards, the drinking water maximum contaminant levels (MCL) for radionuclides, excess health risks associated with the radiation doses identified in the draft PAG, and standards that have been set in response to previous radiological incidents. The current non-occupational radiation protection standard of 100 mrem per year effective dose, as set forth in Nuclear Regulatory Commission (NRC) regulations (i.e., 10 CFR Part 20.1301), serves as a useful benchmark in decision making related to drinking water PAGs. Hence, 100 mrem provides a reasonable level of protection to the most sensitive life stages from exposure to radiation in drinking water during a radiological incident. The proposed adult drinking water PAG of 500 mrem is consistent with both the FDA food PAG[8] of 500 mrem and the 500 mrem one-year dose guide for drinking water established by the Department of Homeland Security.[9] There are clear benefits associated with selecting and implementing a consistent approach across environmental media, as discussed below.

Under the Safe Drinking Water Act (SDWA), the Agency has established MCLs for radiological contaminants in drinking water. The National Primary Drinking Water Regulations (NPDWR) for radionuclides, set forth in 40 CFR 141, effectively adopt a dose-based limit of 4 mrem/yr for beta particle and photon radioactivity. These requirements are based on lifetime exposure criteria, which assume 70 years of

[7] Public feedback on the draft PAG Manual was requested in the Federal Register Notice Vol. 78, No. 72, p. 22257, April 15, 2013.

[8] FDA. 2004.

[9] See Table 1 in 73 FR 45029, http://www.gpo.gov/fdsys/pkg/FR-2008-08-01/pdf/E8-17645.pdf.

continued exposure to contaminants in drinking water. The Agency determined that it is not appropriate to base response measures during short-term emergency incidents on lifetime exposure criteria. While the SDWA framework is appropriate for day-to-day normal operations, it does not provide the necessary tools to assist emergency responders with determining the need for an immediate protective action. Regardless of the cause of an incident, EPA expects that any drinking water system impacted during a radiation incident will take action to return to compliance with the National Primary Drinking Water Regulation (NPDWR) levels as soon as practical.

The International Commission on Radiation Protection[10] recommends reference levels (acute or annual) in the range of 20 to 100 mSv (2,000 to 10,000 mrem) for protection of human health in emergencies, and in the range of 1 to 20 mSv (100 to 2,000 mrem) for occupational exposure, exposure by caregivers, or residential radon exposure. EPA's proposed drinking water PAGs are at the lower end of the latter range.

Following the Fukushima nuclear plant releases in 2011, there was concern about levels of radioactive Iodine-131 (I-131) in drinking water. The Japanese authorities applied a two-tier set of provisional emergency standards to I-131 in water: 300 Bq/L for adults, and 100 Bq/L for infants (specifically for drinking water used to prepare baby formula). According to informational materials assembled by the World Health Organization in the wake of the incident,[11] these emergency drinking water standards were provisional regulation values established by the Japanese Food Sanitation Act, as indicated by the Nuclear Safety Commission of Japan. These standards were precautionary and took international guidance into consideration, including recommendations of the International Atomic Energy Agency and the International Commission on Radiological Protection. The infant standard, furthermore, was equivalent to the international guideline set by Codex Alimentarius[12] for infant food.

The Japanese adult drinking water emergency standard of 300 Bq/L corresponds to a dose of about 1 mrem/day, or 365 mrem over the course of a year (on the same order of magnitude as EPA's proposed PAG for the adult population), assuming a high-end default water ingestion rate of 2 L/day[13]. Assuming that an infant is exposed to an average of 100 Bq/L of I-131 in drinking water from birth until the age of 1, and consumes an average of 0.2 L/day over the course of the year, the dose is 134 mrem/yr.

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[10] International Commission on Radiological Protection (ICRP). 2007. *The 2007 Recommendations of the International Commission on Radiological Protection*, Annals of the ICRP, Volume 37, Nos.2-4, 2007, Publication 103, ISSN 0146-6453, ISBN 978-0-7020-3048-2, pp. 96-98

[11] World Health Organization (WHO). 2011. FAQs: Japan nuclear concerns. Page 9, water contamination. September 2011. Available online at: http://www.who.int/hac/crises/jpn/faqs/en/index8.html. Accessed October 22, 2014.

[12] http://www.codexalimentarius.org/about-codex/en/

[13] EPA. 2011a. *Exposure Factors Handbook 2011 Edition (Final).* EPA/600/R-09/052F, 2011.

4.1 Rationale for a establishing a separate PAG for pregnant women and children

In addition to a PAG of 500 mrem for the general population (i.e., anyone over age 15, excluding pregnant women), EPA proposes establishing a more stringent PAG of 100 mrem to inform protective actions for pregnant women and children. Fetuses, infants, and children are at greater risk from radiological exposures than adults due to the greater sensitivity of the developing body to the potential harmful effects of radiation and the longer dose commitment period for the longer-lived radionuclides that clear slowly from the body; a newborn that ingests radioactive material in water might be subject to the effects of that radiation for a longer period of time than an adult.

There are precedents for establishing a second, more protective threshold for radiological risks for younger members of the population due to the greater radiosensitivity of children versus adults. The Japanese authorities set an emergency standard for infants that was one-third the value for adults.

FDA's PAGs for thyroid blocking with potassium iodide and for ingestion of food both include separate guidelines for more sensitive age groups.

Fetuses, infants, and young children are not a homogenous group. There are considerable differences in the transmission of radiological drinking water contaminants to a fetus via the placenta, to an infant via formula, and to a child via direct consumption. There is also considerable variation in the sensitivities of various organs to radiological threats in developing bodies. Nevertheless, for the sake of making clear and executable decisions in the intermediate phase of emergency response, EPA believes it is important to propose a single PAG for these more sensitive members of the population. Keeping PAGs relatively simple helps to minimize confusion during their implementation.

5.0 INTERPRETING AND APPLYING THE PAGS

The drinking water PAGs are primarily intended to guide planning and decision-making efforts by local and state officials, including drinking water providers, during the intermediate phase of a radiological emergency when water supplies are particularly vulnerable to contamination from deposition of radioactive material from the atmosphere. Actions to protect water supplies may be implemented at other levels and at any time following a radiological incident, and even before an anticipated release occurs. The goal is to keep the dose to the public as low as reasonably achievable. Radiation doses should be reduced to below SDWA MCLs as soon as practical.

5.1 Interpreting the dual PAG

EPA is proposing a two-tier PAG: 500 mrem for the general population (anyone over age 15, excluding pregnant women) and 100 mrem for the developing fetus (i.e., water ingested by pregnant women), infants, and children.

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Since children are present among the general population, authorities may find it prudent to take the PAG of 100 mrem as a target for the whole population. Under some circumstances, authorities may find that it makes sense to make use of both targets simultaneously. For example: Emergency managers can use a two-tier approach to focus on protecting the most sensitive population with limited alternate water resources. If bottled water must be rationed, for example, authorities may make the bottled water available to infants, children, and pregnant women and instruct the rest of the population to use a public drinking water supply that will satisfy the 500 mrem PAG.

As stated above, the PAGs are intended as guidance, and local authorities should take into account local circumstances (e.g., incident scope and community needs) when implementing a course of action to protect the public.

5.2 Operationalizing PAGs as Derived Response Levels (DRLs)

The PAG specifies a radiation dose to avoid via drinking water exposure over the course of a year. In order to determine whether a PAG should be implemented, authorities will need to establish a relationship between the concentration of one or more radionuclides in a drinking water source and the radiation dose members of the population might experience as a result of drinking contaminated water. Incident-specific factors that may be taken into consideration include:

1. The radionuclides of concern
2. The rate and timing of entry of the radionuclides into a drinking water supply, via atmospheric deposition or by other means
3. The rate of radioactive decay and natural attenuation of the radionuclides
4. The potential, or estimated duration of public exposure to contaminated drinking water
5. The estimated daily consumption of contaminated drinking water
6. Radionuclide-specific dose conversion factors, to convert between drinking water concentrations and radiation doses

Those responsible for implementing PAGs will need to convert PAGs into Derived Response Levels (DRLs) in units of Bq/L or pCi/L. Section 7.0 of this document introduces DRLs and explains how they can be calculated. Selected dose conversion factors and standard estimates of daily drinking water consumption for various age groups are also provided, along with references to informational resources.

While the PAG Manual is primarily for advance planning, there are specific radionuclides including Cs-137, I-131, and Sr-90/Y-90, of particular interest for radiological incident scenarios where drinking water sources might be contaminated. Section 7.0 presents default DRLs for these radionuclides to aid emergency managers in making water restriction decisions involving these contaminants.

5.3 Practical Considerations

After deposition has ended, radionuclide concentrations present in a water supply may decline at rates determined by half-lives of the individual nuclides, or may decline faster by dilution with uncontaminated water, or may even increase after rainfall events. The concentration of radionuclides in drinking water as a function of time after the incident can be estimated or modeled based on knowledge of the incident and the properties of the drinking water supply, such estimates must be validated by monitoring. Monitoring is discussed in Section 6.1.

In many incidents, ground water supplies may be less vulnerable to contamination than surface water supplies, but this should be confirmed by monitoring. The potential for ground water to become contaminated will greatly depend on whether the ground water resource is close to the surface or is from a deep aquifer bounded by an aquitard, as well as on rainfall rate and the composition of the overlying soil (which will affect the rate at which contaminants deposited on soil will migrate to the ground water resource).

A PAG is intended as a point of reference to aid emergency response managers in their decision-making. After a particular situation stabilizes and becomes more clearly defined, local authorities may wish to modify the level of drinking water exposure they consider to be appropriate in order to implement longer-term dose reduction strategies. Decision makers may want to consider lower dose levels for a drinking water PAG, depending on the resources and needs of an individual community. EPA expects that any drinking water system adversely impacted during a radiation incident will take action to return to compliance with National Primary Drinking Water Regulations (NPDWR) levels as soon as practical within the first year after the incident.

Section 6.3, below, discusses protective actions that authorities can take to prevent drinking water radiation doses from exceeding PAG levels. Because radionuclides decay over time, early interventions, such as restricting use of contaminated water immediately after the incident, may be most effective in reducing the total radiation dose to the population. Such decisions may need to be made based on limited information. Authorities may find it prudent to take such action even before modeled estimates of total yearly dose have been calculated and validated.

6.0 PLANNING AND TAKING ACTION

In the case that a water supply may be affected by a radiological contamination incident and that projected radiation doses from drinking contaminated water could exceed the PAG levels in the first year, actions to protect the public should be taken by state and/or local authorities and the drinking water utility. Any of the actions described in Section 6.3 may be taken alone or in combination, depending on the nature of the emergency and characteristics of the local water system. Other actions that public authorities and/or drinking water providers should take include water monitoring (described in Section 6.1)

and public notification (described in Section 6.2). Preventive action, such as temporary closure of water system intake valves to prevent a contaminant plume from entering the system may be taken in advance of an anticipated release; it is not necessary to wait until drinking water contamination exceeds PAG levels. Emergency response plans will need to consider whether sufficient storage capacity is available to support the community's fire suppression and sanitation needs while the intake valves are closed.

Emergency planning provides the opportunity to develop state, local and utility-specific emergency plans and implementation procedures that reflect the unique needs of a particular community. Advance planning can provide clarity and facilitate the decision-making process during a radiological emergency.

6.1 Monitoring and Characterization of Contaminants

A comprehensive radiological surveillance program that monitors concentrations of radionuclides of interest in both source and finished drinking water will provide an indication of whether any action is necessary or if the actions being taken are effective.

The NPDWR for radionuclides requires community water systems (CWSs) to conduct monitoring at each entry point to the distribution system to ensure that every customer's water does not exceed the MCLs for radionuclides.[14] All CWSs are required to monitor for gross alpha, radium-226/228 and uranium. In addition, CWSs designated by the state as "vulnerable" and those using waters contaminated by effluents from nuclear facilities must also conduct monitoring for beta particle and photon radioactivity. To determine compliance with NPDWR requirements, systems sampling for radionuclides must use approved EPA methods.

In the event of a radiological contamination incident, state officials may require public water systems to immediately collect additional samples for radionuclides, including beta particle and photon activity. However, the agency recognizes that during an emergency situation it may be necessary to identify alternative sampling and analytical approaches to obtain data to inform short-term actions by emergency response personnel. Many states have Radiological Emergency Preparedness programs prepared to sample, analyze samples and advise emergency managers in a radiological emergency. Additionally, the Federal Radiological Monitoring and Assessment Center (FRMAC) can deploy field teams and dose assessment expertise to assist. See the National Response Framework, Nuclear/Radiological Incident Annex for information on roles and capabilities. If a water system is directed by the Primacy Agency to collect samples for compliance purposes, approved analytical methods must be used. [15]

In 2014, the EPA developed new rapid radioanalytical methods for selected radionuclides to expedite the analytical turnaround time while simultaneously meeting

[14] For more information about monitoring requirements for the Radionuclides Rule see the "Radionuclides Rule: A Quick Reference Guide" (EPA 816-F-01-003, June 2001) or "Implementation Guidance for Radionuclides" (EPA 816-F-00-002, March 2002).

[15] For more information see 40 CFR 141.26.

measurement quality objectives.[16] Emergency planning can help to prepare for challenges that may arise related to variability in environmental matrices and achieving sample representativeness and homogeneity relative to routine samples.

6.2 Public Notification

An emergency response plan should also include a strategy for keeping the community informed of the actions being taken and ensuring that people understand their respective roles and responsibilities. It is critical for water utilities to participate in the emergency response planning activities.

If compliance monitoring indicates that contamination levels exceed the MCL for any radionuclide, water systems are required to issue a Tier 2 Public Notification (i.e., within 30 days). However, States have the flexibility to elevate the notification if warranted to a Tier 1 Public Notification (i.e., within 24 hours).[17]

During a radiological event, water systems may be dealing with a number of requirements and operating procedures and may not be prepared to issue public notification. The state may issue public notification on behalf of the water system (40 CFR 141.210(a)). This would allow the state to develop and deliver a consistent message to all affected customers and also allows the system to concentrate its efforts on returning the system to operation and/or returning to compliance in the event of a radionuclides MCL violation. For more information see the Revised Public Notification Handbook (EPA 816-R-09-013, March 2010).

Authorities should be proactive in communicating about risks and uncertainties and providing clear instructions to the public. For any incident response requiring coordinated Federal support, refer to the National Response Framework and Emergency Support Function 15, External Affairs Annex, for roles and response protocols.

6.3 Protective Actions to Reduce Levels of Contamination

In the early phase, officials may take reasonable precautionary measures to protect water supplies as soon as notification of a radiological release or impending release is received. Then, as data are obtained from monitoring programs (including analysis of water samples collected upstream and downstream of a water system intake structure and within the distribution system) and observed concentrations are compared with PAGs or associated DRLs, officials can make informed decisions about the need to implement protective actions in the intermediate phase.

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[16] EPA. 2014. Rapid Radiochemical Methods Applicable to Selected Radionuclides for Environmental Remediation Following Radiological Incidents. Third Edition. Front matter available online at: http://www.epa.gov/narel/Docs/Preface%20to%203rd%20Edition%20%28Online%29%2004-16-14.pdf. Accessed October 21, 2014. Rapid methods are available online at: http://www.epa.gov/narel/rapid_methods.html

[17] For more information see 40 CFR 141.201(a)(3), Special public notices: Occurrence of a waterborne disease outbreak or other waterborne emergency.

Drinking water systems should take practical actions during the intermediate phase to reduce radioactivity dose levels experienced by drinking water customers. These actions should be guided by emergency drinking water plans[18] that include:

- Alternate drinking water options, such as interconnections with neighboring utilities or alternate local supplies;
- Treatment options, such as the use of point-of-use devices;
- Storage options prior to distribution, such as bulk storage of treated water in tanker trucks or warehousing for packaged water; and
- Distribution options, such as use of existing, non-impacted sections of the existing distribution system, or delivery of drinking water at local sites when the distribution system cannot be used.

In addition, while it might not be a viable option for all water systems, some utilities may be able to utilize existing reserve within their distribution systems for storage of uncontaminated drinking water. During the early phase of an incident recommendations to the public regarding conservation of this uncontaminated water may increase the available response options as the emergency situation progresses.

More detailed examples of possible actions to protect drinking water are discussed in the following sections:

6.3.1 Temporary Intake Valve Closures

If radionuclides are deposited in a river, some of the community's source water may become contaminated. If the deposition of radionuclides into the river can be controlled, it may be possible to temporarily shut the treatment system intake valves to allow the contaminant plume to flow past the intake and prevent contaminants from entering the distribution system. Emergency response plans will need to consider whether sufficient storage capacity is available to support the community's needs while the intake valves are closed. If the stored water supplies could be depleted before the affected valves can be reopened, treatment of the contaminated water while using available stored water supplies should be considered. If no treatment options are available, contaminated water could be temporarily replaced with other available water sources (purchased water, interconnection, new wells, etc.), and the utility will also need to plan for fire suppression and sanitation needs of the community.

6.3.2 Treat Contaminated Water

Systems could use treatment to remove radionuclides. While only a small percentage of all water systems are equipped to treat specifically for radionuclides, various treatment options exist for reducing radioactive contamination of drinking water. Treatment technologies that are able to help in reducing radioactivity in drinking water include

[18] For more information, see EPA. 2011b. *Planning for an Emergency Drinking Water Supply,* EPA 600/R-11/054, June 2011.

ED_001057_00009694

coagulation/filtration, ion exchange, lime softening and reverse osmosis. Their actual removal efficiency greatly depends on the radionuclide of interest, chemical form and the type of treatment employed. Another option available to certain systems could be the deployment of mobile treatment systems.

6.3.3 Activate Existing Connections to Neighboring Systems

If the water supply system is part of a larger, regional supply system, activation of existing connections to a neighboring area could be considered if these systems are not contaminated. Some water systems can establish connections with other systems for emergency purposes. As in many cases, this option may have already been considered during emergency planning. If this option is implemented, steps must be taken to ensure that the neighboring systems are not impacted by deposition and do not become contaminated from water backflow from the contaminated system.

6.3.4 Bypass Contaminated Sections of Distribution System

Running a pipeline to various distribution centers located throughout the affected community is a routine means of providing clean water. For example, when water mains must be repaired or cleaned of debris, community water needs have been met through the assembly of temporary pipes and hoses. This is a relatively simple procedure, requiring very little construction and technical expertise. For medium- to long-term emergencies, the construction of a temporary pipeline could be cost-effective. PVC pipe, fire hoses and steel pipe have been used to provide emergency drinking water for periods of up to 2 months when service has been disrupted by earthquakes, drought, or bacterial contamination.

6.3.5 Import Water in Tanker Trucks

If treated drinking water is available from a water system close to the affected area, it may be more efficient to arrange to transport from that location by truck, rail, or barge to distribution centers located throughout the affected community. Distribution center set up would need to consider people with limited transportation options or physical disabilities. The most significant obstacle for the use of this option is the cleanliness and availability of transport vehicles. State and local laws may also restrict this option.

6.3.6 Import Bottled Water

Importing bottled water into the affected community is another possible option. The water may come from a nearby water supply system or from a water bottling company. This option may be cost-effective during an emergency if water is needed quickly and if the length of the emergency does not merit long-term action, such as the construction of a temporary pipeline.

6.3.7 Ration Clean Water Supplies

Rationing uncontaminated water is also a possibility. This is particularly true if water

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reserves can provide each individual in the community with 1 L of water per day until the contaminated plume has passed, the contaminated water is treated, or the water supply system has returned to normal operating conditions. If this option is chosen, it is important that efficient methods for rationing are in place. Rationing water might also be required if water treatment capabilities are limited. Consider a scheme to ration water as part of emergency planning efforts.

7.0 DERIVED RESPONSE LEVELS (DRLS)

EPA developed the DRLs by calculating the radionuclide concentrations in drinking water that would result in projected radiation doses of 100 and 500 mrem dose, assuming one year of continuous exposure and standard drinking water intake rates for children and adults.

Several considerations should be kept in mind when using these pre-calculated DRLs. First, DRLs presented in Table 2 are calculated on the assumption that each radionuclide is the only radionuclide present in drinking water. DRLs are additive. In situations where multiple radionuclides are present, DRLs should be combined using a sum of fractions, to ensure that the total dose does not exceed the target threshold of 100 or 500 mrem. (An example calculation is provided in Section 7.1.) Second, Table 2 does not present DRLs for all radionuclides that may occur in drinking water following a contamination incident. DRLs will need to be calculated if radionuclides of concern are not included in Table 2.

Third, these DRLs were calculated using a simplifying assumption that radionuclide levels will remain constant over the course of one year. In fact, after the initial deposition event has occurred, concentrations may decline at rates determined by the half-lives of individual isotopes, or decline faster due to dilution with uncontaminated water, or could even increase after rainfall or subsequent deposition events. Some nuclides, like I-131, have half-lives measured in days, while others, like Cs-137, have half-lives measured in years. Early exceedance of the DRL does not preclude the possibility that doses will stay below PAGs as radionuclide concentrations in water decline by a combination of radioactive decay and natural attenuation. If the *average* concentrations of radionuclides do not exceed DRLs over the course of one year, doses will remain below the PAG.

Table 2. Dose response levels (DRLs) -- Drinking water concentrations corresponding to specified doses (mrem) of select radionuclides, assuming one year of exposure at constant levels

	DRLs for Developing Embryos & Fetuses (Maternal Exposure), Infants, and Children Age 15 and Younger	DRLs for Adults (Excluding Pregnant Women)

Dose Level	100 mrem	500 mrem
Sr-90/Y-90	1,043 pCi/L	11,755 pCi/L
Cs-137	6,140 pCi/L	23,940 pCi/L
I-131	1,314 pCi/L	14,935 pCi/L

Note: Y-90 is a radioactive decomposition product of Sr-90 and will normally be found alongside Sr-90 in the case of a Sr-90 release; therefore they are treated together. Solubility differences may cause less Yttrium to be present, however it is a conservative assumption to include both in DRLs. When calculating the combined DRL, note that the dose coefficients (see Table 4) are additive.

The DRLs provided in Table 2 were derived by calculating life stage-specific DRLs (as described in section 7.2) for seven different ages (fetus, plus ages 0, 1, 5, 10, 15, and adults), and then selecting the most limiting/protective result within each category. (The calculated values differ across individual lifestages because each life stage has a different dose conversion factor and drinking water ingestion rate.) The most limiting concentration for I-131 is for the 5 year old and the most limiting concentrations for Sr-90/Y-90 and Cs-137 are for the 15 year old.

7.1 Combining DRLs for Multiple Radionuclides

If multiple radionuclides are present in the water supply, then it is recommended that the obtained concentrations of each radionuclide be divided by the provided DRL values. This provides a fraction of the allowed concentration (and the projected dose) for each radionuclide. If the sum of the fractions is less than 1, the total dose is assumed to be below the PAG values. The sum of the fractions is expressed as follows:

$$F = \sum (C_i / DRL_i)$$

Where:

F = sum of the fractions

C_i = the concentration of radionuclide *i* in the water supply (pCi/L or Bq/L)

DRL_i = derived response level for the ith radionuclide (pCi/L or Bq/L)

So, for example, if Sr-90/Y-90 and Cs-137 are the only radionuclides present in the drinking water, and Sr-90/Y-90 are present at 1,540 pCi/L and Cs-137 is present at 10,600 pCi/L, the combined dose exceeds the PAG of 100 mrem for fetuses, infants,

and children:

$$F = \sum (C_i / DRL_i)$$
$$= (1{,}540 \text{ pCi/L} / 1{,}043 \text{ pCi/L}) + (10{,}600 \text{ pCi/L} / 6{,}140 \text{ pCi/L})$$
$$= 1.48 + 1.73$$
$$= 3.21$$

3.21 > 1, so the PAG is exceeded.

The same concentrations do not exceed the PAG of 500 mrem for adults:

$$F = \sum (C_i / DRL_i)$$
$$= (1{,}540 \text{ pCi/L} / 11{,}755 \text{ pCi/L}) + (10{,}600 \text{ pCi/L} / 23{,}940 \text{ pCi/L})$$
$$= 0.13 + 0.44$$
$$= 0.57$$

0. 57 < 1, so the PAG is not exceeded.

7.2 Calculation of DRLs

DRLs may be calculated with the help of the following equations.

The quantity of radionuclide *i* ingested by age group *a* over a given time period, *T*, is calculated as follows.

$$I_{iaT} = C_i \times Ing_a \times T$$

Where:

I_{iaT} = The total intake of radionuclide *i* for age group *a* (in pCi or Bq) over time period *T.*

C_i = The concentration of radionuclide *i* in drinking water (in pCi/L or Bq/L). A simplifying assumption is made that the concentration of the radionuclide is constant over the time period *T*.

Ing_a = The daily ingestion rate of water for age group *a*, in L/day. See Section 7.3 for guidance on daily water ingestion rates.

T = The time period that the population is drinking contaminated water (days). In this analysis, the time period of interest is 365 days.

The dose (mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time

period *T* is calculated as follows:

$$D_{iaT} = I_{iaT} \times DCF_{ia}$$

Where:

D_{iaT} = Dose (in mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time period *T*

I_{iaT} = The total intake of radionuclide *i* for age group *a* (in pCi or Bq) over time period *T*

DCF_{ia} = The dose conversion factor (also referred to as dose coefficient) for the ingestion of radionuclide *i* in drinking water and age group *a* (in mrem/pCi or Sv/pCi, or mrem/Bq or Sv/Bq). See section 7.4 for guidance on DCFs.

For each age group *a* and radionuclide *i*, substituting the applicable PAG for the dose D_{iaT} and then solving for C_i yields the applicable DRL.

7.3 Water Ingestion Rates

Table 3 presents mean values for tap water consumption taken from the CD supplement to FGR-13.[19] Other sources of estimated drinking water ingestion rates are available (e.g., EPA's *Exposure Factors Handbook*[20]), but the ingestion rates presented in FGR-13 were specifically designed (e.g., in the selection of age ranges) to be used in conjunction with other data from FGR-13. Values are provided for males and females in various age groups. Since the ingestion rates for males are higher (and therefore more conservative) than those for females, EPA elected to use the intake values for males to represent each age group in the calculation of DRLs in Table 2.

Table 3. Mean Drinking Water Ingestion Rates from FGR-13

Age (years)	Tap Water (L/day)	
	Male	**Female**
0	0.191	0.188
1	0.223	0.216
5	**0.542**	0.499
10	0.725	0.649
15	**0.900**	0.712

[19] EPA. 2002. Federal Guidance Report 13. Cancer Risk Coefficients for Environmental Exposure to Radionuclides: CD Supplement, EPA-402-C-99-001, Rev. 1.

[20] EPA. 2011a.

ED_001057_00009694

20	**1.137**	0.754
50	1.643	1.119
75	1.564	1.179

Source: CD Supplement to FGR-13, Table 3.1.

7.4 Dose Coefficients, or Dose Conversion Factors (DCF) (Sv/Bq Ingested)

The effective whole body dose per Bq ingested of various radionuclides in water, for various age groups, can be found on the CD supplement to FGR-13.[21] These dose conversion factor (DCF) values apply to both males and females. Table 4 presents DCFs for a few representative radionuclides of interest.

[21] EPA. 2002.

Table 4. Dose Conversion Factors

Isotope	DCFs (Sv per Bq ingested at the age indicated) from FGR-13					
	Infant (100 day old)	1 year old	5 year old	10 year old	15 year old	Adult
Sr-90	2.27E-07	7.24E-08	4.69E-08	5.97E-08	7.89E-08	2.77E-08
Y-90	3.13E-08	2.00E-08	9.97E-09	5.90E-09	3.34E-09	2.69E-09
Cs-137	2.11E-08	1.24E-08	9.69E-09	1.01E-08	1.34E-08	1.36E-08
I-131	1.84E-07	1.79E-07	1.04E-07	5.24E-08	3.42E-08	2.18E-08

Source: CD Supplement to FGR-13.

To: Flynn, Mike[Flynn.Mike@epa.gov]; Cherepy, Andrea[Cherepy.Andrea@epa.gov]
Cc: Perrin, Alan[Perrin.Alan@epa.gov]; DeCair, Sara[DeCair.Sara@epa.gov]
From: Edwards, Jonathan
Sent: Thur 10/16/2014 9:50:45 PM
Subject: FW: draft water PAG briefing for AAs
Joint AAs Briefing 10-16-2014_draft.docx

Mike-- Attached please find the latest draft of the PAGs materials for the AAs (with ORIA review and comment up through Alan and me) -- Sara is now passing the materials on to OW for their review/input/concurrence and so I want to provide this "early" copy to you for any reactions that you or Andrea may have…..please let us know what you think… thanks, Jon

From: DeCair, Sara
Sent: Thursday, October 16, 2014 5:08 PM
To: Christ, Lisa; Hernandez-Quinones, Samuel; Ellis, Jerry
Cc: Veal, Lee; Perrin, Alan; Edwards, Jonathan
Subject: draft water PAG briefing for AAs

Lisa and Sam, for your review and input. I wonder if the order of some of the Rationale bullets could flow better. I did the edits in Track Changes, but it's a lot easier to read with No Markup! Let me know how we should finalize this, so we can provide read-aheads by Friday, Oct. 24th.

Next up, I'll send you my latest PAGs 101 briefing. Thanks so much,

Sara

Sara D. DeCair

http://www.epa.gov/radiation/rert/pags.html

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new office

Room 1416 B in WJC West

To: DeCair, Sara[DeCair.Sara@epa.gov]
Cc: Wieder, Jessica[Wieder.Jessica@epa.gov]
From: Nesky, Anthony
Sent: Thur 10/16/2014 4:23:00 PM
Subject: Edited Water PAG Chapter
Draft Chapter Drinking Water PAG-tnedits.docx

Dear Sara:

Here is my suggested version of the water PAG chapter. You will recognize 95% of the language, but I rearranged so many ideas that a redline/strikeout version is not readable. I suggest you do a side-by-side comparison to check that I retained all important concepts. We can sit down and do a systematic comparison with the previous version if you would like.

Tony Nesky

Center for Radiation Information and Outreach

Tel: 202-343-9597

nesky.tony@epa.gov

Tribal Update – Radiation Protection Division
Radiation Protection Division Training
October 20, 2014

Multi-Agency Radiation Survey and Site Investigation Manual Training MARSSIM) - OIRA will offer MARSSIM training this fall via webinar. Free to tribal government personnel. Also will be offering the MARSSIM and Multi-Agency Radiation Survey and Assessment of Materials and Equipment (MARSAME) training courses as DVD-based self-study course. **Contact: Katherine Snead**

Protection Action Guides (PAGS) - PAGs suggest precautions that state and local authorities can take during an emergency to keep people from receiving an amount of radiation that might be dangerous to their health. **[Should we include this? Is there anything we are doing with PAGs and Tribes?] Contact: Sara DeCair**

Tribal Radiation Education - ORIA tested tribal radiation education materials that were developed by ORIA. Designed for middle school students in American Indian and Alaskan Native communities, these classroom activities are intended to increase awareness and greater understanding of radiation health risks. The materials focus on real-life public health and environmental issues (E.g., uranium mining) encountered on tribal lands. During November 2013, initial pilot testing occurred in Anchorage, Alaska at the 39th Bilingual Multicultural Education/Equity Conference. Roll out of the educational materials, alongside ORIA's General Radiation Education Activities, is expected to take place FY14/15. **Contact: Angela Shogren**

Tribal Consultation on RPD Rulemakings - Tribal consultation on EPA rulemakings will continue. Currently consulting with the Ute Mountain Ute tribe on Subpart W (radon emissions at operating mills) and will be inviting tribes to consult on 40 CFR 190 (Environmental Radiation Protection Standards for Nuclear Power Operations) and 40 CFR 192 (in-situ recovery of uranium). On Subpart W, On July 10, 2014 members of ORIA HQ and Region 8 met in consultation with the Chairman of the Ute Mountain Ute Tribe to discuss the NESHAP proposed rule limiting radon emissions from operating uranium mill tailings. The Tribe discussed many areas of importance, including ground-water contamination, air quality issues and the proximity of tribal lands to the White Mesa uranium mill. Follow-up discussions with the Tribe will begin in August. **Contact: Subpart W – Reid Rosnick; 40 CFR 190 – Brian Littleton; 40 CFR 192 – Ingrid Rosencrantz**

Ad Hoc Tribal Support - ORIA will continue to support tribes in addressing unique radiation problems, concerns and issues as needed with technical assistance, guidance and training. **Contact:** Ingrid Rosencrantz

Chapter ##: Protective Action Guide for Drinking Water

1.1 Introduction

This chapter presents PAGs for protection of the public in the event of a radiological incident that affects drinking water supplies. The PAG is a level of projected exposure at which protective action should be taken to prevent, reduce, or limit a person's radiation dose during a radiological incident.

The drinking water PAG is for use during the intermediate phase of an incident, which may last for weeks to months.

Protective actions for drinking water include interdiction of water supplies, water treatment, and provision of alternate water supplies. More detailed examples of possible protective actions to protect drinking water are discussed in section XXX.

The PAG for drinking water is dual-tier: 75 mrem projected dose in the first year for pregnant women, infants and children under nine years of age; and 500 mrem projected dose in the first year for the general population. Emergency managers can use the two-tier approach to protect the most sensitive populations while being practical with limited alternate water resources. Emergency managers can make incident-specific decisions using these levels as appropriate for the incident scope and community needs. Protection against all exposures, above or below the PAG level, should be balanced against detriments from the protective action itself.

Early Phase Considerations

Actions to protect the water supply may be implemented at any time following a radiological incident. During the early stages of a radiological emergency, public officials may choose to take immediate precautionary measures such as closing water intakes, using available stored water, or restricting water supplies. Precautionary measures may be left in place until data are available to determine whether or not protective actions are needed.

The goal is to keep the dose to the public as low as reasonably achievable.

Projected doses for the drinking water PAG are calculated assuming one-year exposure criteria. This approach is consistent with other PAGs in place for the intermediate phase. EPA assumes that any drinking water system adversely impacted during a radiation incident will be able to achieve compliance with Safe Water Drinking Act (SDWA) Maximum Contaminant Levels (MCLs) within the first year after the incident. The drinking water PAG is emergency planning guidance which does not supersede EPA's SDWA MCLs. Actions should be taken to reduce radiation doses below SDWA MCLs as soon as practicable.

1.2 Rationale for Intermediate Phase Drinking Water PAG

EPA has established a PAG level for drinking water after determining that that it is not appropriate to base life-saving response measures for short-term emergencies on the SDWA's lifetime[1] exposure criteria. While water systems in violation of drinking water standards have processes available to get back into compliance within a reasonable

[1] Lifetime criteria assumes 70 years of continued exposure to contaminants in drinking water.

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The drinking water PAG for the general population is 500 mrem in the first year. EPA recommends a more stringent PAG of 75 mrem in the first for pregnant women and children 5 years and under because they are two to three times more sensitive to radiation. In addition for many infants, 100 percent of their diet consists of commercially available powdered infant formulas mixed with drinking water, compared to adults whose water intake is a much smaller percentage of their diet.

EPA's drinking water PAGs are more protective than those recommended by international advisory bodies. According to the International Commission on Radiation Protection, PAG levels for protection of people should be selected in the lower part of the 100 to 2,000 mrem/year recommended range. The Commission considers that a dose rising towards 10,000 mrem will almost always justify protective measures.

The World Health Organization set drinking water guidance for Japanese citizens after the Fukushima nuclear plant releases in 2011. A concentration of 300 Bq/L of I-131 in water for adults was given as a provisional regulation value for food and drink ingestion which was established by the Japanese Food Sanitation Act, as indicated by the Nuclear Safety Commission of Japan. These standards were precautionary and took international guidance into consideration, including recommendations of the International Atomic Energy Agency and the International Commission on Radiological Protection.

Japan set a concentration limit of 100 Bq/L of I-131 for drinking water used to prepare baby formula. This level is equivalent to the international guideline set by Codex Alimentarius for infant food. The Codex was crafted especially for situations where foods will be exported to other countries after a nuclear incident, to balance the need to continue international trade with radiation protection for consumers. The Codex levels (given in concentration) are for the first year after an incident, but can be extended beyond the first year.

1.3 Drinking Water Protective Actions

Protective actions against ingestion of radiologically contaminated drinking water involve water restrictions, provision of alternate water supplies, and water treatment. A number of factors must be taken into consideration when making a decision to restrict use of drinking water. Of particular importance are the types of radionuclides of concern, the duration that members of the public might be exposed to contaminated drinking water, and the radiation dose and health risk that different members of a population might experience as a result of drinking water contaminated with radionuclides. Suggested default assumptions are provided in Section ####.

The following are practical actions water systems could take during the intermediate phase to provide drinking water to customers.

Temporary Intake Valve Closures

If radionuclides are deposited over a river, a section of the water can become contaminated and can be repeatedly contaminated as rain re-deposits radioactive particles. As this section flows down the river, this section of contaminated water is called a plume. This scenario calls for closing down any source intake valves along the path of the plume of

contaminated water. While the intake valve is closed, no highly contaminated water can enter the water supply system; therefore the contaminated water is allowed to flow by the system intake structures.

During this time, if the system's characteristics are adequate, existing storage capacity can be depended upon. If the stored water supplies could be depleted before the affected valves can be reopened, treatment of the contaminated water while using available stored water supplies should be considered. This assumes that the treatment technology will be in place or readily accessible. In the event of no treatment options, contaminated water could be temporarily replaced with other available water sources (e.g., purchased water, interconnection, new wells, etc.).

Activate Existing Connections to Neighboring Systems

If the water supply system is part of a larger, regional supply system, activation of existing connections to a neighboring area could be considered. Most large water systems can establish connections with other large systems for emergency purposes. As in many cases, this option may have already been considered during emergency planning. If this option is implemented, steps must be taken to ensure that the "clean" systems do not become contaminated from water backflow.

Smaller water supply systems (i.e., that serve between 10,000 and 75,000 people), or sparsely populated or rural areas, may not be connected to a neighboring system. In this case, regionalization may be a part of emergency planning to explore. This involves connecting smaller systems to larger systems, thus forming a regional water supply system.

Establish Pipeline Connections to Closest Sources/Systems

Running a pipeline from a "clean" water supply system to various distribution centers located throughout the affected community is a routine means of providing clean water. For example, when water mains must be repaired or cleaned of debris, community water needs have been met through the assembly of temporary pipes and hoses. This is a relatively simple procedure, requiring very little construction and technical expertise. For medium- to long-term emergencies, the construction of a temporary pipeline could be cost-effective. PVC pipe, fire hoses and steel pipe have been used to provide emergency drinking water for periods of up to two months when service has been disrupted by earthquakes, drought, or bacterial contamination.

Import Water in Tanker Trucks

If an uncontaminated source of water is close to the affected area, it may be more efficient to arrange to transport water from that source by truck, rail, or barge to distribution centers located throughout the community. The most significant obstacle for the use of this option is the cleanliness and availability of transport vehicles. State and local laws may also affect this option.

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Import Bottled Water

Importing bottled water into the affected community is another possible option. The water may come from a nearby water supply system or from a water bottling company. This option may be cost-effective during an emergency if water is needed quickly and if the length of the emergency does not merit long-term action, such as the construction of a temporary pipeline.

Ration Clean Water Supplies

Rationing uncontaminated water is also a possibility. This is particularly true if water reserves can provide each individual in the community with one liter (0.264 gallons, about one quarter) of water per day until the contaminated plume has passed, the contaminated water is treated, or the water supply system has returned to normal operating conditions. If this option is chosen, it is important that efficient methods for rationing are in place. Rationing water might also be required if water treatment capabilities are limited. Consider a process to ration water as part of emergency planning efforts.

Treat Contaminated Water

While only a small percentage of all water systems are equipped to treat specifically for radionuclides, various treatment options exist for reducing radioactive contamination of drinking water. However, typical technologies commonly in place a water systems to treat for other contaminants are able to help in reducing radioactivity in drinking water. These technologies include coagulation/filtration, ion exchange, lime softening and reverse osmosis. Their actual removal efficiency greatly depends on the radionuclide of interest and the type of treatment employed.

Any of these actions may be taken alone or in combination, depending upon the nature of the emergency and the characteristics of the local water system. Consideration of these and other options during emergency planning provides the opportunity to develop state and local emergency plans and implementation procedures that reflect the unique needs of a particular community. Advance planning can provide clarity during the process of making key decisions quickly during a radiological emergency

1.4 Projecting Radiation Doses in Drinking Water with Derived Response Levels (DRLs)

EPA PAGs are expressed in terms of projected dose: of 75 mrem (0.075 rem) projected dose[2] in the first year for pregnant women, infants and children under nine years; and of 500 mrem (0.5 rem) projected dose in the first year for the general population[3]. As dose is not directly measurable, this manual provides information on Derived Response Levels (DRLs), which are the concentrations of radionuclides in drinking water that correspond to these PAGs. The DRLs are compared to analytical results from drinking water samples to determine if PAG levels have been exceeded.

[2] All dose values expressed as Cumulative Effective Dose Equivalent (CEDE)

[3] General population excludes pregnant women.

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In developing the DRLs, EPA took into consideration the specific drinking water intake rates for children and adults. Using DRLs to informing protective actions makes it very unlikely that the public will be exposed to radiation doses beyond the PAG levels. Table 3 provides DRLs for radionuclides likely to appear in drinking water during a radiological contamination incident.

The DRLs in Table 3 are provided as a point of reference to aid emergency response managers in their decision-making. EPA recommends use of site-specific DRLs whenever possible. After an emergency situation stabilizes and becomes more clearly defined, local authorities may wish to modify the level of drinking water exposure they consider to be appropriate as part of an optimized, longer-term, dose-reduction strategy. In other words, the dose level associated with the drinking water pathway may be controlled to levels below 75 or 500 mrem, depending on the needs of an individual community.

1.4.1 Models and Assumptions

The DRLs or radionuclide concentrations may be calculated using the following equation as follows.

The first step in the process is to derive the quantity of radionuclide i ingested by age group a over a given time period, T.

$$I_{iaT} = C_i \times Ing_a \times T$$

Where:

I_{iaT} = The total intake of radionuclide *i* (pCi or Bq) for age group *a* over time period *T* (days)

C_i = The concentration of radionuclide *i* (pCi/L or Bq/L) in drinking water. It is assumed that the concentration of the radionuclide is constant over the time period *T*.

Ing_a = The daily ingestion rate of water for age group *a* as provided in FGR-13 (L/day).

T = The time period that the population is drinking contaminated water (days). In this analysis, the time period of interest is 365 days.

The effective whole body dose (mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time period *T* is derived as follows:

$$D_{iaT} = I_{iaT} \times DCF_{ia}$$

Where:

D_{iaT} =Effective whole body dose (mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time period *T*

I_{iaT} = The total intake of radionuclide *i* (pCi or Bq) for age group *a* over time

period *T*

DCF_{ia} = The effective dose coefficient (also referred to as the whole body dose conversion factor or DCF) for the ingestion of radionuclide *i* in drinking water and age group *a* (mrem/Bq or Sv/Bq) using the DCFs from *Federal Guidance Report 13* (FGR-13).

1.4.2 Effective Dose Coefficients (Sv/Bq Ingested)

Table 1 presents the effective whole body dose per Bq ingested of each radionuclide in water by each age group, these values apply to both males and females. All the values from *Federal Guidance Report 13* (FGR-13) are the average values for males and females. Table 1 presents a few representative radionuclides of interest, a more comprehensive list of DCFs for other radionuclides is available in FGR-13.

Table 1. Dose Conversion Factors

Isotope	DCFs (Sv per Bq ingested at the age indicated) from FGR-13*					
	Infant (100 day old)	1 year old	5 year old	10 year old	15 year old	Adult
Sr-90	2.27E-07	7.24E-08	4.69E-08	5.97E-08	7.89E-08	2.77E-08
Cs-137	2.11E-08	1.24E-08	9.69E-09	1.01E-08	1.34E-08	1.36E-08
I-131	1.84E-07	1.79E-07	1.04E-07	5.24E-08	3.42E-08	2.18E-08

* The values in this table were taken from the CD that accompanies FGR-13 (EPA 2002).

Doses on the order of 1E-5 to 1E-9 Sv/Bq imply that the ingestion of one Bequerel (1 Bq) --the quantity of a radionuclide associated with 1 disintegration per second) is an extremely small quantity of radioactive material and is associated with a very small dose commitment.

1.4.3 Water Ingestion Rate

Table 2 presents the mean values for tap water consumption taken from Table 3-1 of *Federal Guidance Report 13* (FGR-13) (EPA 2002), which was designed to be used in conjunction with other data from FGR-13... Values are provided for males and females in various age groups. Since the ingestion rates for males are higher (and therefore more conservative) than those for females, EPA elected to use the values for males to represent each age group.

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Table 2. Drinking Water Ingestion Rates from FGR-13

Age (years)	Tap Water (L/day)*	
	Male	**Female**
0	0.191	0.188
1	0.223	0.216
5	0.542	0.499
10	0.725	0.649
15	0.900	0.712
50	1.643	1.119

*Values Extracted from EPA 2002, Table 3.1.

1.4.5 Tables of Derived Concentration Levels

Drinking Water Concentration (pCi/L) for Specified Dose (mrem) Over one year exposure. A complete list with additional radionuclides is currently under development. Once finished it will be inserted here.#####

Table 3: Derived Concentration Levels (DRLs) for Selected Radionuclides

	DRLs for Children and Infants	DRLs for the General Populatio n
Dose Level	75 mrem	500 mrem
Sr-90	1.71E+03	8.54E+03
Cs-137	1.84E+04	9.19E+04
I-131	2.11E+03	1.05E+04

1.4.6 Derived Concentration Levels for Multiple Radionuclides

In the case multiple radionuclides are found in the water supply, then it is recommended that the obtained concentrations of each radionuclide be divided by the provided DRL values. This provides a fraction of the allowed concentration in water for each

radionuclide. If the sum of the fraction is one or less, the total dose is assumed to be below the PAG dose values. Sum of the fraction is expressed as follows:

Where:

F = sum of the fractions

C_i = the concentration of radionuclide, i in the water supply (pCi/L)

DRL_i = derived response level for the ith radionuclide (pCi/L)

1.5 Planning Considerations for Drinking Water Protective Actions

The drinking water PAG is intended to guide planning and decision-making efforts during the intermediate phase of a radiological emergency when surface4 water supplies are particularly vulnerable to contamination from deposition of radioactive material from the atmosphere.

In some scenarios, little contamination from the environment may appear in drinking water, but sampling and monitoring must be conducted to assess this. Emergency response plans should include a comprehensive radiological surveillance program. This program will monitor the concentration of radionuclides in the drinking water and will provide an indication of whether any action is necessary or if the actions being taken are effective. The surveillance program should monitor the concentration of radionuclides of interest on both source and finished drinking water.

The emergency response plan should also include a strategy for keeping the community informed of the actions being taken. The public should be advised to continue to use drinking water unless otherwise informed by state officials.

Drinking water utilities should assess options for provision of emergency drinking water and develop an emergency drinking water plan[5] that includes:

- Alternate source water options, such as interconnections with neighboring utilities or alternate local sources.
- Treatment options, such as the use of satellite locations or point-of-use devices.
- Storage options prior to distribution, such as bulk storage of treated water in tanker trucks or warehousing for packaged water.
- Distribution options, such as use of existing, non-impacted sections of the existing distribution system, or delivery of drinking water at local sites when the distribution

[4] Although less likely there is the potential for some incidents to contaminate ground water sources.

[5] For more information, see Planning for an Emergency Drinking Water Supply (EPA 600/R-11/054, June 2011)

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system cannot be used.

In addition while it might not be a viable option for all water systems, there are some that are able to incorporate reserve and storage capacity. During the early phase (four to five days) of an incident it is unlikely that contamination could affect water which is directly available for consumption through distribution systems. It would take some time for radionuclides to be deposited from the plume into the supply system water source and then subsequently be distributed, so recommendations to the public about tap water should reflect these considerations.

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To: Wilds, Edward[Wilds.Edward@epa.gov]; Brozowski, George[brozowski.george@epa.gov]; Mosser, Jennifer[Mosser.Jennifer@epa.gov]; Ralston, Lowell[Ralston.Lowell@epa.gov]; Aquino, Marcos[Aquino.Marcos@epa.gov]; Melody Geer[mgeer@trininc.com]; Povetko, Oleg[Povetko.Oleg@epa.gov]; Ferguson, Rafaela[Ferguson.Rafaela@epa.gov]; DeCair, Sara[DeCair.Sara@epa.gov]; Rosenblum, Shelly[Rosenblum.Shelly@epa.gov]
Cc: Kimberly Wood[krw@trininc.com]
From: Melody Geer
Sent: Wed 8/27/2014 4:18:43 PM
Subject: Updates to QRGs
QRG 1 - Terminology - R4 - August 2014.pdf
QRG 2 - Accident Types - R1 - August 2014.pdf
QRG 3 - 2013 Draft PAG Manual Overview - R1 - August 2014.pdf
QRG 4 - Calcs for Public decisions - R1 - August 2014.pdf
QRG 5 - Incident Phases-Exposure Pathways-Protective Actions - R1 - August 2014.pdf
QRG 6 - 1992 PAG Manual Overview - R0 - August 2014.pdf
QRG 7 - FDA Food DILs - R0 - August 2014.pdf
QRG 8 - NPP Types and Emerg Planning - R0 - August 2014.pdf
QRG 9 - Radiation Units - Traditional and SI - R1 - August 2014.pdf
QRG 10 - Emergency Worker Protection - R0 - August 2014.pdf

Attached are all 10 of the QRGs that I have updated.

Marcos and Lowell sent me a few comments that have been incorporated, as appropriate.

The newest QRG (10) is a revision from a previous QRG on emergency worker dose control. I have incorporated information from the 2013 Draft PAG Manual and hope that I have captured the necessary information.

Comments are welcome.

Thanks,

Melody Geer

Program Manager, TEA

melodygeer@gmail.com

mgeer@trininc.com

980-241-2724

To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Danielle Murray
Sent: Mon 8/11/2014 5:47:17 PM
Subject: RE: 3 (easy!) changes to PAG Manual
Walk-through of Doc 8.11.14 005.docx

Sara, sorry for the delay, here are all the edits.

Danielle Murray

Operations and HR Analyst

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703-848-8842 ext.103

703-848-9001 (f)

From: DeCair, Sara [mailto:DeCair.Sara@epa.gov]
Sent: Friday, August 08, 2014 3:01 PM
To: Danielle Murray
Subject: 3 (easy!) changes to PAG Manual

Danielle,

I went through and made about 100 tiny tweaks and got the comments out of the Manual that are already addressed. I spell checked, replaced a few words and updated the header. All to get it ready for managers review starting next week. But I could NOT get the additional language inserted where I need it for Early Phase Basis and for KI! It totally trashed the formatting no matter what I tried, so I attempted to un-do the damage and would like for you to drop the indicated paragraphs in, from the attachments.

Also, after some deleting it's time to do away with Section 3.8 (I mean just make it all 3.7 for Reentry Matrix).

So these three things are the only three comments in the Manual and if you can get this back to me as soon as you can on Monday, I'd be thrilled! Many, many thanks –

S.

Sara D. DeCair

http://www.epa.gov/radiation/rert/pags.html

202-343-9108

new office

Room 1416 B in WJC West

1200 Pennsylvania Ave., NW

Washington, D.C.

To: DeCair, Sara[DeCair.Sara@epa.gov]
From: Snead, Kathryn
Sent: Thur 7/10/2014 5:44:43 PM
Subject: FW: Could you review this cost-benefit Work Assignment?
IGCE OPT PER 3 for Trinity PAG Cost Benefit Prelim Analysis 6-11-2014.xls
WA Cost-Benefit Preliminary Analysis 6-11-2014.doc

Sara,

Sorry I missed this earlier. Do you still need help with this?

Kathryn Snead

Center for Radiological Emergency Response

Office of Radiation and Indoor Air

Environmental Protection Agency

1200 Pennsylvania Ave., NW

Washington, DC 20460

202-343-9228 (W)

202-536-7896 (C)

From: DeCair, Sara
Sent: Wednesday, June 11, 2014 3:19 PM
To: Anoma, Valentine; Snead, Kathryn
Subject: Could you review this cost-benefit Work Assignment?

Val, Kathryn,

I've been hoping to do a preliminary sensitivity analysis through our contract support for ages now, to see how each of the factors used in developing the PAGs back in the 1980s/90s have

changed, to see if we need to go ahead with a full blown reanalysis, and craft new PAG levels. This WA is to do the first cut at seeing how much each of the considered factors have changed, to see if it would be worth doing the full thing.

Could you review it for clarity, wording, realism and any other things you think might make a better product for us? It is very short, only 3 pages, and calls for a very quick turnaround in the next few months. This is my first try at this type of work, so I'm very grateful for any and all comments you could provide, maybe by the end of next week, June 18th?

Many, many thanks, please let me know if you can't review and I'll try someone else.

Sara

Sara D. DeCair

http://www.epa.gov/radiation/rert/pags.html

202-343-9108

To: DeCair, Sara[DeCair.Sara@epa.gov]
Cc: vta.economist@yahoo.com[vta.economist@yahoo.com]
From: Anoma, Valentine
Sent: Wed 6/25/2014 4:13:17 PM
Subject: RE: Could you review this cost-benefit Work Assignment?
PAGS WA Cost-Benefit Preliminary Analysis 6-11-2014 (3).doc

Sara,

I am attaching a response to the PAG Work Assignment with necessary comments. If you would like, please let me know if you have 10 – 20 minutes so that I can explain to you what they mean.

Val

From: DeCair, Sara
Sent: Wednesday, June 25, 2014 8:32 AM
To: Anoma, Valentine
Subject: FW: Could you review this cost-benefit Work Assignment?

Thanks!!

From: DeCair, Sara
Sent: Wednesday, June 11, 2014 3:19 PM
To: Anoma, Valentine; Snead, Kathryn
Subject: Could you review this cost-benefit Work Assignment?

Val, Kathryn,

I've been hoping to do a preliminary sensitivity analysis through our contract support for ages now, to see how each of the factors used in developing the PAGs back in the 1980s/90s have changed, to see if we need to go ahead with a full blown reanalysis, and craft new PAG levels.

This WA is to do the first cut at seeing how much each of the considered factors have changed, to see if it would be worth doing the full thing.

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Many, many thanks, please let me know if you can't review and I'll try someone else.

Sara

Sara D. DeCair

http://www.epa.gov/radiation/rert/pags.html

202-343-9108

The Advisory Team for the Environment, Food and Health

The Advisory Team for the Environment, Food and Health (or "Advisory Team") is a federal interagency group of subject matter experts in radiological health and related matters. The mission of the Advisory Team is to provide protective action recommendations to decision makers at all levels following accidents or incidents that result in the release of radioactive material to the environment, from the early phase through the late phase. The Advisory Team provides coordinated advice and recommendations on the environment, food, water and both human and animal health. The Advisory Team is comprised of representatives from four agencies: EPA, USDA, CDC and FDA. Advisory Team members provide not only technical subject matter expertise, but also organizational knowledge of their respective agencies.

The Advisory Team utilizes data products from the Interagency Modeling and Atmospheric Assessment Center (IMAAC) and the Federal Radiological Monitoring and Assessment Center (FRMAC) to make its recommendations. A major function of the Advisory Team is to interpret published guidance on radiation protection, known as Protective Action Guides or PAGs, in the context of the specific contamination or exposure scenario. These guidance documents include protective action guides from the EPA for the general public and emergency workers (known as "EPA 400"; currently under revision); guidance from the FDA on acceptable levels of contamination in food and animal feed; guidance from the FDA on the use of potassium iodide (KI) for the protection of the thyroid following releases of radioactive iodine, and; guidance from the Department of Homeland Security on long term recovery following incidents involving radiological dispersal devices (RDDs) or improvised nuclear devices (INDs).

The Advisory Team is specifically listed in the Nuclear/Radiological Incident Annex to the National Response Framework as a key federal response asset. The Advisory Team is currently chaired by the FDA. According to current procedures, the Advisory Team may be activated by DHS, coordinating agencies, and State/Local Tribal governments by contacting the CDC Director's Emergency Operations Center at 1-770-488-7100. The Advisory Team may also be requested directly through the FDA Emergency Operations Center at 1-866-300-4374. The Advisory Team will likely also be activated by DOE upon activation of the FRMAC. The Advisory Team operates in two modes: by actively deploying subject matter experts to the incident site to integrate into the JFO and by maintaining a remote pool of experts at their respective headquarters, who serve as reach back resources for the field.

The Advisory Team's customers may include the Incident Command/Unified Command, DHS, the Joint Field Office/Unified Coordination Group, the coordinating agency and/or State/Local/Tribal government officials, as needed. The Advisory Team expects to integrate into the incident command structure through the Planning Section, where it can provide technical advice to the IC/UC. The Advisory Team also maintains close liaison with the FRMAC due to their mutual interests in data collection, dose assessment and guidance development. The Advisory Team also expects to liaise with other organizations in the field and the National Capital Region as needed and as resources permit.

4/25/2013

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LIMITS OF SCOPE

This guidance does not address or impact site cleanups occurring under other statutory authorities such as the United States Environmental Protection Agency's (EPA) Superfund program, the Nuclear Regulatory Commission's (NRC) decommissioning program, or other federal or state cleanup programs.

As indicated by the use of non-mandatory language such as "may," "should" and "can," this Manual only provides recommendations and does not confer any legal rights or impose any legally binding requirements upon any member of the public, states, or any other federal agency.

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CHAPTER 1 – OVERVIEW

1.1. PLANNING GUIDANCE AND PROTECTIVE ACTION GUIDES

The U.S. Environmental Protection Agency (EPA) has developed this Manual to assist public officials in planning for emergency response to radiological incidents. For purposes of this document, a radiological incident is an event or a series of events, deliberate or accidental, leading to the release or potential release into the environment of radioactive materials in sufficient quantity to warrant consideration of protective actions. This Manual provides radiological protection criteria for application to all incidents that would require consideration of protective actions, with the exception of nuclear war.

During an incident with an uncontrolled source of radiation, protection of the public from unnecessary exposure to radiation may require some form of intervention that will disrupt normal living. Such intervention is termed a protective action. Examples of protective actions include:

- Evacuating an area;
- Sheltering-in-place within a building or protective structure;
- Administering potassium iodide (KI) as a supplemental action;
- Relocation;
- Acquiring an alternate source of drinking water;
- Interdiction of food/milk.

This Manual provides recommended numerical protective action guides (PAGs) for the principal protective actions available to public officials during a radiological incident. A PAG is defined for purposes of this document as the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. PAGs are guides to help officials select protective actions under emergency conditions during which exposures would occur for relatively short time periods. They are not meant to be applied as strict numeric criteria, but rather as guidelines to be considered in the context of incident-specific factors. PAGs do not establish an acceptable level of risk for normal, nonemergency conditions, nor do they represent the boundary between safe and unsafe conditions. The PAGs are not legally binding regulations or standards and do not supersede any environmental laws. For information on roles, responsibilities and authorities during emergency response and recovery, please refer to the National Response Framework: http://www.fema.gov/national-response-framework and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008a,b).

Some protective actions are not associated with a numerical PAG. For example, the control of access to areas is a protective action implemented in concert with other protective actions; it does not have its own PAG. Any reasonable action to reduce radiation dose is encouraged even if it is not associated with a PAG, such as recommending that individuals use ad hoc respiratory protection with a handkerchief or piece of folded cloth. Or in areas where PAGs are not exceeded, but airborne radioactivity is present, people might be asked to stay indoors to the extent practicable to reduce their exposures. To further develop radiological emergency plans, brief planning guides have been provided for reentry to relocation areas, the cleanup planning process and considerations for radioactive waste disposal.

1.2. APPLICABILITY

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Protective actions may be recommended for a wide range of incidents, but generally apply to incidents involving relatively significant releases of radionuclides. Radiological incidents with potential for significant releases include:

- A fire in a majority facility such as a nuclear manufacturing plant;
- An accident at a federal nuclear weapons complex facility;
- An accident at a commercial nuclear power plant (NPP);
- A transportation accident involving radioactive material;
- A terrorist act involving a radiological dispersal device (RDD) or yield-producing Improvised Nuclear Device (IND).

Each type of incident would pose a unique threat to public health and should be planned for and managed accordingly. Emergency response planning for a given facility or scenario should consider:

- The radionuclides involved;
- The dynamics of the release including size and magnitude;
- The feasibility of specific protective actions;
- The timing of notification, response and protective action implementation.

The decision to advise members of the public to take a protective action during a radiological incident involves a complex judgment in which the radiological risk must be weighed against the action's inherent risks. This decision may have to be made under emergency conditions, with limited information and little time to analyze options. Advance planning reduces the complexity of the decision-making process during an incident. The planning process can identify the viability of responses to various incidents, the courses of action that can be set in motion in advance and the decisions that can only be made during an actual emergency. While many aspects of protective actions can be considered well in advance of an emergency, the situations and conditions that exist at the time of emergency must be considered if the most effective action is to be selected.

The unpredictable locations of certain radiological incidents make advance planning challenging. For example, an RDD could detonate anywhere and spread radiological contaminants over a wide variety of surfaces and terrain. Emergency planners should be prepared to apply PAGs to a wide scope of facilities and circumstances.

1.3. BACKGROUND ON THE UPDATED PAGS

This Manual updates the "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents" (EPA-400-R-92-001, May 1992), published by the U.S. EPA (EPA 1992b) (hereinafter referred to as the "1992 PAG Manual"). The guidance in this Manual was developed cooperatively with the Federal Radiological Preparedness Coordination Committee (FRPCC), with representation from the EPA; the Department of Energy (DOE); the Department of Defense (DoD); the DHS' Federal Emergency Management Agency (FEMA); the Nuclear Regulatory Commission (NRC); the Department of Health and Human Services (HHS), including the Centers for Disease Control and Prevention (CDC) and the Food and Drug Administration (FDA); the Department of Agriculture (USDA); and the Department of Labor (DOL).

1.3.1. Legal Basis

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The historical and legal basis of EPA's role in developing this guidance begins with Reorganization Plan No. 3 of 1970, in which the Administrator of EPA assumed all the functions of the Federal Radiation Council (FRC), including the charge to "…advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with states" (Reorg. Plan No. 3 of 1970, sec. 2(a) (7), 6(a) (2); § 274.h of the Atomic Energy Act of 1954, as amended (AEA), codified at 42 U.S.C. § 2021(h)). Recognizing this role, FEMA directed EPA in their Radiological Emergency Planning and Preparedness Regulations to "establish Protective Action Guides (PAGs) for all aspects of radiological emergency planning in coordination with appropriate federal agencies" (44 Code of Federal Regulations (CFR) §351.22(a)). FEMA also tasked EPA with preparing "guidance for state and local governments on implementing PAGs, including recommendations on protective actions which can be taken to mitigate the potential radiation dose to the population" (44 CFR §351.22(b)). All of this information was to "be presented in the EPA Manual of Protective Action Guides and Protective Actions for Nuclear Incidents" (44 CFR §351.22(b)).

Additionally, section 2021(h) charged the Administrator with performing "such other functions as the President may assign to him [or her] by Executive Order." Executive Order 12656 states that the Administrator shall "develop, for national security emergencies, guidance on acceptable emergency levels of nuclear radiation…." (Executive Order No. 12656, sec.1601(2)). EPA's role in the development of PAGs was also recognized in the "Nuclear/Radiological Incident Annex of the National Response Framework" of June 2008.

1.3.2. Interaction with FRC 5 and 7

1992 PAG Manual, Appendix C; C.1.1 Existing Federal Guidance
In the 1960's, the Federal Radiation Council (FRC) defined PAGs and established limiting guides for ingestion of strontium-89, strontium-90, cesium-137, and iodine-131 (FR-64; FR-65). That guidance applied to restricting the use of food products that had become contaminated as the result of release of radioactivity to the stratosphere from weapons testing. During the period immediately following an incident at any domestic nuclear facility, when the critical source of exposure is expected to be a nearby airborne plume, the principal protective actions are evacuation or sheltering. The PAGs developed here thus do not supersede previous guidance, but provide additional guidance for prompt exposure pathways specific to a domestic nuclear incident.
(check this vis a vis FDA Food PAG, and perhaps explain separation from PAGs on web where these are)

1.3.3. Technical Basis

The FRC introduced the concept of a PAG in a series of recommendations issued in the 1960s. A key concept about PAGs is that the decision to implement protective actions should be based on the projected dose that would be avoided if the protective actions were implemented. Developers of the EPA PAGs considered the following three principles in establishing exposure levels for the PAGs—

1. Prevent acute effects.
2. Balance protection with other important factors and ensure that actions result in more benefit than harm.
3. Reduce risk of chronic effects.

These principles apply to the determination of any PAG. Principles 1 and 2 have been proposed for use by the international community as essential ~~bases~~ basis for decisions to intervene during an incident. Principle 3 has been recognized as an appropriate additional consideration (IAEA 1989). Although it is important during emergency planning to consider a range of source terms to assess the costs associated with their implementation, the PAGs are pre-determined for use in emergencies without regard to the

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magnitude or type of radiological release.

1.3.4. Changes in Scenarios since the Issuance of the 1992 PAG Manual

EPA's 1992 PAG Manual provided emergency management officials at the federal, state, tribal and local levels with the technical basis to plan responses to radiological emergencies. The 1992 PAG Manual was written to accommodate the worst release scenario deemed likely at the time – a major accident at a commercial NPP that would result in a significant off-site release of radioactive material. ("Site" and "off-site" in this Manual refer to locations where the radiological incident occurs and are not limited to facility-type incidents.) Certain characteristics typify NPPs, including: fixed locations at which an accident might occur; a known suite of radionuclides on site, the dose from which is dominated by short-lived radioisotopes; tight regulatory controls and requirements; skilled operational personnel who plan for and exercise emergency responses; state and local involvement in emergency planning; well-developed and zoned emergency evacuation plans and routes; and advance notice (generally hours to days) from deteriorating plant conditions prior to accidental release of radioactive material into the environment. Therefore, the 1992 PAG Manual provided decision-makers with radiation dose-based PAG values for various exposure pathways (such as whole body, skin dose and food ingestion) and associated protective actions that were adapted to the mix of radionuclides and operational environments associated with commercial NPPs.

In late 1991, EPA conducted a symposium titled "Implementing Protective Actions for Radiological Incidents at Other Than Nuclear Power Reactors," to evaluate PAGs for incidents other than accidents at NPPs and concluded that the PAGs could be applied to all radiological incidents (EPA 1992a). Since then, new radiological and nuclear scenarios involving terrorist use of radioactive materials have gained status in radiological emergency response planning.

In 2008, the Department of Homeland Security (DHS) published "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents" (DHS 2008). An RDD is a device or mechanism that is intended to spread radioactive material from the detonation of conventional explosives or other means. An IND is a crude, yield-producing nuclear weapon fabricated from diverted fissile material. Incidents like these may occur anywhere with little or no warning. The DHS guidance, developed cooperatively with EPA, DOE, DoD, DOL, HHS, Department of Commerce (DOC), and the NRC, affirms the applicability of existing 1992 EPA PAGs to terrorist acts, while acknowledging that the PAGs were inadequate for early response planning needs specific to an IND. To address this gap, "Planning Guidance for Response to a Nuclear Detonation" (NSS 2010) was subsequently published.

This Manual substantively incorporates late phase cleanup guidance provided in the 2008 DHS document and refers readers to additional planning resources.

1.3.5. Key Changes to PAGs in this Updated Manual

This updated Manual applies PAGs and protective actions to an expanded range of sources of potential radiological releases, including commercial nuclear power facilities, uranium fuel cycle facilities, nuclear weapons facilities, transportation accidents, radiopharmaceutical manufacturers and users, space vehicle launch and reentry, RDDs and INDs.

Dosimetry for all the PAGs was updated using the International Commission on Radiological Protection (ICRP) Publication 60 series (ICRP 1991). The PAGs in this Manual may be implemented using calculated, measurable values contained in the Federal Radiological Monitoring and Assessment Center (FRMAC) Assessment Manuals (DOE 2010a, b),[1] though using other incident-specific dose assessment methodologies is encouraged, where appropriate. For simplicity, specific organ dose thresholds for

[1] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

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evacuation and sheltering were removed.

This Manual incorporates several related guidance documents published subsequent to the 1992 guidance, including FDA's 1998 update of the PAGs for interdiction of food. This Manual also incorporates FDA's 2001 decision to lower the PAG for administration of stable iodine to 5 rem (50 millisieverts (mSv)) projected child thyroid dose. ~~Finally,~~ this update removes the intermediate phase relocation PAG of 5 rem (50 mSv) over 50 years to avoid confusion with long-term cleanup. ~~All other~~ Most of the PAGs and corresponding protective actions from the 1992 PAG Manual remain unchanged.

Recommended limits of exposure for emergency workers also remain unchanged from the 1992 PAG Manual. The emergency worker guides in this manual are consistent with federal and state regulations. Responsible officials should use judgment when doses may exceed regulatory limits and must advise workers of the risks Table 1-1 presents PAGs with their principal associated protective actions or planning guides.

To further develop radiological emergency plans, brief planning guides have been provided for reentry to relocation areas, a cleanup planning process and considerations for radioactive waste disposal. In this Manual, the term reentry is used for emergency workers and members of the public going into relocation areas temporarily, under controlled conditions.

1.4. RADIOLOGICAL INCIDENT PHASES AND APPLICABILITY OF PROTECTIVE ACTIONS

Emergency planners divide responses to radiological incidents into three phases of activity—

- **Early Phase** — The beginning of a radiological incident ~~when~~ for which immediate decisions for effective use of protective actions are required and must therefore be based primarily on the status of the radiological incident and the prognosis for worsening conditions. When available, predictions of radiological conditions in the environment based on the condition of the source or actual environmental measurements may be used. Protective actions based on the PAGs may be preceded by precautionary actions during the period. This phase may last from hours to days.
- **Intermediate Phase** — The period beginning after the source and releases have been brought under control (has not necessarily stopped but is no longer growing) and reliable environmental measurements are available for use as a basis for decisions on protective actions and extending until these additional protective actions are no longer needed. This phase may overlap the early phase and late phase and may last from weeks to months.
- **Late Phase** — The period beginning when recovery actions designed to reduce radiation levels in the environment to acceptable levels are commenced and ending when all recovery actions have been completed. This phase may extend from months to years. A PAG level, or dose to avoid, is not appropriate for long-term cleanup.

The phases cannot be represented by precise periods of time – and may even overlap – but to view them in terms of activities, rather than time spans, can provide a useful framework for emergency response planning.

In the early phase, sheltering-in-place and evacuation are the principal protective actions. These actions are meant to avoid inhalation of gases or particulates in an atmospheric plume and to minimize external radiation exposures. Administration of prophylactic drugs may be employed depending on the specific radionuclides released; in particular, KI, also called "stable iodine"—may be administered as a supplementary protective action in incidents involving the release of significant quantities of radioactive iodine, such as NPP incidents. Some protective actions may begin prior to the release of radioactive material when there is advance notice.

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Planning considerations for reentry to relocation areas for specific tasks are suggested and basic planning guidance for late phase cleanup is provided in Chapters 3 and 4.

1.4.1. Implementation of Protective Action Guides and Protective Actions

Immediately upon becoming aware that an incident is about to occur or has occurred that may result in exposure of the population, responsible authorities should make a preliminary evaluation to determine the nature and potential magnitude of the incident. This evaluation should determine whether conditions indicate a significant possibility of a major release and, to the extent feasible, determine potential exposure pathways, populations at risk and projected doses. The incident evaluation and recommendations should then be presented to emergency response authorities for consideration and implementation.

During the early phase, the sequence of events includes—evaluation of conditions at the location of the incident, notification of responsible authorities, prediction or evaluation of potential consequences to the general public, recommendations for action and implementation of actions for the protection of the public.

In the intermediate phase, dose projections used to support decisions about protective actions may be based on measurements of environmental radioactivity and dose models. When conditions warrant relocation of populations, the collection of extensive radiological and cost-of-cleanup data will be necessary to form the decision basis for cleanup and recovery of the affected areas.

Table 1-1. Planning Guidance and Protective Action Guides for Radiological Incidents

Phase	Protective Action Recommendation	Protective Action Guide or Planning Guide
Early (Chapter 2)	Sheltering-in-place or evacuation of the public[a]	1 to 5 rem (10 mSv to 50 mSv) projected dose/4 days[b]
	Administration of prophylactic drugs KI[c]	5 rem (50 mSv) projected child thyroid dose[d] from radioactive iodine
	Limit emergency worker exposure	5 rem (50 mSv)/year (or greater under exceptional circumstances)[e]
Intermediate (Chapter 3)	Relocation of the public	2 rem (20 mSv) projected dose first year[b] Subsequent years, 0.5 rem (5 mSv)/year projected dose
	Food interdiction[f]	0.5 rem (5 mSv)/year projected dose, or 5 rem (50 mSv)/year to any individual organ or tissue, whichever is limiting
	Limit emergency worker exposure	5 rem (50 mSv)/year[b]
	Reentry	Operational Guidelines[g] (Stay times and concentrations) for specific activities (see Section 3.7)
Late (Chapter 4)	Cleanup	Brief description of planning process
	Waste Disposal	Brief description of planning process

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[a] Should begin at 1 rem (10 mSv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering may begin at lower levels if advantageous.

[b] Projected dose- the sum of the effective dose from external radiation exposure (i.e., groundshine and cloudshine) and the committed effective dose from inhaled radioactive material.

[c] Provides thyroid protection from ~~internal exposure~~ radioactive iodines only. {FDA 2001, FDA 2002 and links to PAG web page}. [Links for the documents above need to be added]For information on other radiological prophylactics and treatment, refer to..." radioactive iodines only. For other information on radiological prophylactics and treatment, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm063807.htm http://www.bt.cdc.gov/radiation and www.orau.gov/reacts

[d] Thyroid equivalent dose. For more information, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm072265.htm.

[e] When radiation control options are not available, or, due to the magnitude of the incident, are not sufficient, doses to emergency workers above 5 rem (50 mSv) may be unavoidable and are generally approved by competent authority. For further discussion see Chapter 2, Section 2.6.

[f] For more information on food and animal feeds guidance, the complete FDA guidance may be found at http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM094513.pdf

[g] For extensive technical and practical implementation information please see "Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident" (DOE 2009)

Protective actions may already be designated in existing emergency response plans. Under NRC regulations, large commercial NPPs must maintain detailed radiological response plans for an emergency planning zone (EPZ) within a 10 mile (16.1 km) radius of the plant and for a separate ingestion pathway EPZ within a 50 mile (80.5 km) radius. ~~Emergency Responders~~ Emergency Worker should be prepared to select and implement appropriate protective actions when standing response plans are not available or applicable.

1.4.2. Early Phase Protective Action Guides and Protective Actions

In the early phase, there may be little or no data on actual releases to the environment and responders may have to rely on crude estimates of airborne releases. Decision time frames are short and preparation is critical to make prudent decisions when data are lacking or insufficient.

The principal protective actions for the early phase are evacuation and sheltering-in-place. These protective actions would be taken if whole body doses are projected to exceed 1 to 5 rem (10 to 50 mSv) over four days. The decision to evacuate must weigh the anticipated radiation dose to individuals in the affected population against the feasibility of evacuating within a determined time frame and the risks associated with the evacuation itself. For example, evacuating a population of 50,000 carries with it a statistical risk of injury or death from transportation hazards or increased exposure. Evacuation also takes time. In the case of an accident at an NPP, there ~~may~~ will likely be time for an orderly and relatively safe evacuation. In the case of a fire or explosion of an RDD in an urban area, evacuating a large group of people could leave them exposed to the plume and actually increase radiation dose. Sheltering-in-place may be warranted in situations where evacuation poses a greater risk of exposure or physical harm.

In addition, there are actions that are advisable, but not associated with a numerical PAG. For example, individuals should be instructed to cover airways (nose and mouth) with available filtering material when airborne radionuclides may be present. Decontamination is another protective action that may be utilized in the early phase and may include washing of contaminated individuals, removing contaminated clothing and decontaminating surfaces of critical areas and objects. Further, in areas where airborne radioactivity is present but PAGs are not exceeded, officials can consider asking people to stay indoors to the extent practicable. In such cases, individuals are not prevented from carrying out necessary tasks (e.g., seeking medical care, purchasing food). Similar to actions used in major cities on high pollution days, these measures can be effective to reduce radiation doses when prolonged releases occur, as was the case for the Fukushima accident in Japan.

In cases where significant quantities of radioiodine may have been released, administration of the radioprotectant KI should be considered as a supplementary protective action if the projected child

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thyroid dose exceeds 5 rem (50 mSv). This PAG is lower than the 1992 guidance. The lower dose, which FDA adopted in 2001, is for protection of children based on early studies of Chernobyl exposure data.

The choice of protective action will be based on the status of the incident site and the prognosis for worsening conditions. In the early phase, precautionary actions based on worst-case scenarios may be used before implementation of protective actions based on PAGs. For example, in the case of RDD detonation, governments may instruct affected populations to shelter in place as a precautionary action while radiation levels are being measured to determine appropriate PAG-based protective actions. Officials should plan for rapid broadcast and dissemination of protective action orders to the public.

When available, predictions of radiological conditions in the environment based on an estimate of the source or actual environmental measurements may be used. Nuclear facilities, for example, have continuous, real-time radioactive effluent monitoring capabilities to monitor radioactive material released to the environment and may have a network of off-site measurement stations.

1.4.3. Conservatism built into the PAGs

Conservatism is built into the PAG levels themselves, as described in Sections __ and __ about the risk-benefit balancing process used to derive the PAGs. Additionally, assumptions made to generate default DPs and DRLs in FRMAC Assessment, Appendix C ensure protectiveness for all members of the public, including sensitive subpopulations such as young children. For example, Early Phase derived levels are based on the assumption that a person is outdoors twenty-four hours a day for four days being exposed to the plume. Intermediate Phase derived levels also conservatively do not account for shielding provided by being indoors part of each day of the projection year. People are assumed to remain in the contaminated area during the entire time (not going to work or school in uncontaminated area, for instance.) Another example of conservatism is that it is assumed radionuclides are in the chemical and physical form that yields the highest dose, and that the particle size is one micrometer mean aerodynamic diameter. These conservatisms allow dose assessors to project whole body doses (TED) to a reference person, for simplicity, and then decision makers can make protective action decisions that apply to entire communities including children, adults and the elderly. {Real example from WHO dose estimates in Japan…?}

Certain guidelines that lend themselves to different PAGs for different subpopulations are the PAGs for potassium iodide, food and water. These guidelines provide age-specific recommendations because of the radiosensitivity of the thyroid and young children with respect to ingestion and inhalation doses in particular. Taking protective actions like use of KI, avoiding certain foods or using alternative sources of drinking water can be relatively simple to implement by the parents of younger children. Clear public messages can convey which age groups should take which action, unlike how an evacuation or relocation order should apply to entire households or neighborhoods.

An evaluation of dose consequences to several age groups across many radiological scenarios was done and, for the Early phase including the plume, child whole body doses are typically no more than 15% higher than adult whole body doses. That margin is well within the conservatism discussed above, so that separate PAGs or projections need not be required. Therefore, basing evacuation, shelter in place and relocation dose projections on an adult is protective for all age groups. Sensitive age groups should be evaluated separately for KI, food and water decisions. (this is already done, or soon to be, for water…) Keeping calculations and decision making simple in the face of a disaster can enable timely actions to protect communities.

1.4.4. Intermediate Phase Protective Action Guides and Protective Actions

Intermediate phase activities are intended to reduce or avoid dose to the public, to control worker exposures, to control the spread of radioactive contamination and to prepare for late phase cleanup operations.

During the intermediate phase, relocation is the principal protective action against whole body external exposure from deposited material and internal exposure from inhalation of radioactive particulates.

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People may need to be relocated for weeks or months.

It is necessary to distinguish between evacuation and relocation. Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure from the plume or deposited activity. Relocation is the removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Site-specific conditions may allow some groups evacuated in an emergency to return, while others may have to relocate. In other cases, some groups that were not previously evacuated may have to relocate (see Section 3.3.1 for more details).

Intermediate phase PAGs are based on doses projected in the first and a limited number of subsequent years. The PAG for relocation of the public is 2 rem (20 mSv) in the first year and 0.5 rem (5 mSv) in any subsequent year. (Note: Relocation PAGs are treated separately from food and water ingestion. That is, projection of intermediate phase doses should not include these ingestion pathways. In some instances, however, where withdrawal of food and/or water from use would, in itself, create a, health risk, relocation may be an appropriate alternative protective action. In this case, the ingestion dose should be considered along with the projected dose from deposited radionuclides via other pathways, for decisions on relocation.) When projected doses are less than the relocation PAG of 2 rem (20 mSv) in the first year, focused environmental decontamination and cleanup may be able to reduce doses to populations that are not relocated. Decontamination and focused cleanup techniques can range from simple actions such as the scrubbing and flushing of surfaces with uncontaminated water to the removal and disposal of soil and contaminated debris.

Keeping projected subsequent doses below the 0.5 rem (5 mSv) PAG for out years – the second year and beyond – may be achieved through the decay of shorter half-life radioisotopes (as in the case of an accident at an NPP), through environmental decontamination and cleanup efforts or through other means of controlling public exposures, such as limiting access to certain areas. Information on food and animal feeds protective action guidance is contained in FDA's "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies" (FDA 1998). Workers and members of the public may be allowed to re-enter relocation area for tasks related to critical infrastructure and key resources, to care for animals and to assess the condition of closed zones. Reoccupancy may be allowed under dose constraints acceptable to the community. In this Manual, the term reoccupancy refers to households and communities moving back into relocation areas where the cleanup process is still ongoing, based on radiation levels acceptable to those communities.

EPA is not proposing a specific drinking water PAG at this time. EPA has established enforceable drinking water standards for radionuclides under the Safe Drinking Water Act (SDWA). EPA recommends that, to the extent practicable, emergency measures for drinking water be based on the National Primary Drinking Water Regulations (NPDWR) for Radionuclides. The Radionuclides Rule provides states with flexibility when responding to radiological events. If a public water system exceeds the radionuclides standard it must work to get back into compliance as soon as feasible. States have the authority to determine if other corrective actions are needed (e.g. providing alternative water). Guidance on monitoring, notification and protective actions is provided in Chapter 3, along with several online resources for drinking water system operators.

However, in light the Fukushima nuclear power plant accident, in which some Japanese drinking water supplies were impacted, the Agency recognizes a short-term emergency drinking water guide may be useful for public health protection The Agency requests input on the appropriateness of, and possible values for, a drinking water PAG.

While the NPDWR provide for a regulatory standard of 4 mrem/year (beta, photon emitters) based on life-time exposure, international organizations have developed technical approaches and methodologies that have produced a range of emergency guidelines related to drinking water (e.g., the World Health

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Organization[2], the International Atomic Energy Agency[3]), as have other federal agencies (e.g. the Department of Homeland Security[4], the Food and Drug Administration[5]) and non-federal organizations. EPA is seeking input on an approach and technical rationale for a drinking water PAG designed to help officials select protective actions under emergency conditions when exposures would occur over shorter time periods than those envisioned in the NPDWR.

During the intermediate phase, government officials may convene to discuss late phase cleanup and site restoration strategies. All actions taken during the early and intermediate phases should be considered with respect to the impact they may have on late phase remediation, such as avoiding the use of fixatives that could hinder surface decontamination at a later date.

1.4.5. Late Phase

The late phase, as used in this Manual, is the period beginning when cleanup and recovery actions have begun and ending when all recovery actions have been completed. This phase may extend from months to years.

The late phase cleanup process, as described in this guidance, begins sometime after the commencement of the intermediate phase and proceeds independently of intermediate phase protective action activities. The transition is characterized by a change in approach, from strategies predominantly driven by urgency, to strategies aimed at both reducing longer-term exposures and improving living conditions. The late phase involves the final cleanup of areas and property at which contamination directly attributable to the incident is present. It is in the late phase that final cleanup decisions are made and final recovery efforts following a radiological incident are implemented.

Unlike the early and intermediate phases of a radiological incident, decision makers will have more time and information during the late phase to allow for better data collection, stakeholder involvement and options analysis. Community members will influence decisions such as if and when to allow people to return home to contaminated areas. There will be populations, who were not relocated or evacuated, living in contaminated areas where efforts to reduce exposures will be ongoing. Implicit in these decisions is the ability to balance health protection with the desire of the community to resume normal life.
Radiation protection considerations must be addressed in concert with health, environmental, economic, social, psychological, cultural, ethical, political and other considerations. Many federal, state, and local agencies have important roles to play. It is recognized that experience from existing programs, such as the U.S. EPA's Superfund program, the U.S. NRC's process for decommissioning and decontamination to terminate a nuclear facility license and other national recommendations may be useful for designing cleanup and recovery efforts that could apply to a radiological incident. The cleanup process described in Chapter 4, however, does not rely on and does not affect any authority, including the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. 9601 et seq. and the National Contingency Plan (NCP), 40 CFR Part 300. For information on roles, responsibilities and authorities during emergency response and recovery please refer to the National Response Framework: http://www.fema.gov/national-response-framework and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008a, b).

The late phase or cleanup process described in Chapter 4 consists of multiple steps, namely 1) characterization and stabilization, 2) development of goals and strategies and 3) implementation and reoccupancy; meaningful stakeholder involvement should be integrated *throughout* the process.

[2] See http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/ and http://www.who.int/hac/crises/jpn/faqs/en/index8.html
[3] See http://www-pub.iaea.org/MTCD/publications/PDF/Pub1467_web.pdf.
[4] See http://ogcms.energy.gov/73fr45029.pdf
[5] See http://www.fda.gov/downloads/MedicalDevices/.../UCM094513.pdf.

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While radioactive waste handling and disposal will be an ongoing endeavor during the entire emergency response, brief planning guidance is provided in Chapter 4, the late phase. This guidance addresses both locations that may be identified by state and local officials and locations owned by the federal government, and lists criteria for evaluating their suitability for disposal, as well as actions that can be taken to facilitate their use. Legal and other considerations are also discussed. This guidance assumes that on-site disposal at a location affected by the incident, where appropriate, will be one of the locations of choice. Though recommended as the first consideration for discussion post-accident or attack, this guidance assumes that existing non-federal radioactive waste disposal capacity already available to impacted states and their regions is overwhelmed or otherwise eliminated from consideration, which drives the need to identify other disposal options or develop new disposal capacity.

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KEY POINTS IN CHATER 1 – OVERVIEW

- A PAG is the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. PAGs are guides to help officials select protective actions under emergency conditions when exposures would occur over relatively short time periods.
- EPA provides the PAG Manual to assist public officials with their radiological emergency response planning activities. The PAG Manual is a guidance document, not a legally binding regulation and does not affect or supersede any environmental laws. The PAG recommendations do not represent the boundary between safe and unsafe conditions.
- PAGs may be implemented to protect the public in a wide variety of radiological emergencies, including terrorist incidents and accidents involving nuclear power plants, transportation and the space program.
- PAGs are appropriate for implementation in the early and intermediate phases of radiological incidents. The early phase—lasting hours to days—is the period beginning at the projected (or actual) initiation of a release when immediate decisions for effective use of protective actions are required and must therefore be based primarily on the status of the release and the prognosis for worsening conditions. Little environmental data may be available in the early phase. The intermediate phase—lasting weeks to months—is the period beginning after the source and releases have been brought under control and environmental measurements are available for use as a basis for decisions on protective actions.
- Reentry and reoccupancy decisions will be made using incident-specific circumstances and the Operational Guidelines (DOE 2009).
- Cleanup and waste disposal decisions may be informed by planning guidance provided in Chapter 4.
- What's new in this updated Manual—
  - The PAGs in this Manual are implemented using the calculations and methods in the FRMAC Assessment Manual. Dosimetry in that Manual has been updated using the ICRP Publication 60 series (ICRP 1991).
  - EPA adopts the FDA guidance issued in 2001 that recommended lowering the projected thyroid dose at which the administration of KI is warranted as a supplementary protective action.
  - EPA adopts the 1998 FDA Food PAGs.
  - Planning guidance has been provided for reentry, late phase cleanup and waste disposal.

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Chapter 2 – Early Phase Protective Action Guides

2.1. INTRODUCTION

Decisions regarding protective actions for workers and the public during radiological incidents are risk management decisions and the recommendations in this Manual are provided in that context. Rapid action may be required to protect members of the public in the event of an incident involving a large release of radioactive materials into the environment. In all cases, all practical and reasonable means should be used to reduce or eliminate exposures.

This chapter presents PAGs for use in the early phase of a radiological incident. A PAG is the projected dose to an individual from a release of radioactive material at which a specific protective action should be taken to reduce or avoid that dose. The early phase begins at the actual or projected start of a release—most likely before ambient environmental and radiological data become available for quantitative risk-based actions. The exact duration of the early phase depends upon site conditions, but one should plan to project doses for four days.

Many radiological emergency scenarios would involve airborne releases, so this chapter provides guidance for estimating projected doses from exposure to an airborne plume of radioactive material and for implementing protective actions. Dose calculations for implementing the PAGs are made using the dose conversion factors (DCFs) and derived response level (DRL) methods referenced in the FRMAC Assessment Manuals (DOE 2010a, b).[6] Other calculation methods to implement PAGs may be appropriate.

2.2. EXPOSURE PATHWAYS DURING THE EARLY PHASE

During the early phase of an incident, there are three main exposure pathways from airborne releases—

- **Direct exposure** to radioactive materials in an atmospheric plume. The contents of such a plume will depend on the source of radiation involved and conditions of the incident. For example, in the case of an incident at an NPP, the plume may contain radioactive noble gases, radioiodines and radioactive particulate materials. Many of these materials emit gamma radiation that can expose people in the vicinity of the passing plume.
- **Inhalation** of radionuclides from immersion in a radioactive atmospheric plume and inhalation of ground-deposited radionuclides that are resuspended into a breathing zone. Inhaled radioactive particulates, depending on their solubility in body fluids, may remain in the lungs or move via the bloodstream to other organs, prior to elimination from the body. Some radionuclides become concentrated in a single body organ, with only small amounts going to other organs. For example, a significant fraction of inhaled radioiodines will move through the bloodstream to the thyroid gland.
- **Deposition** of radioiodine and particulates from a radioactive plume. Deposited materials can continue to emit "groundshine" (e.g., beta and gamma radiation) after the plume has passed causing continued exposure to skin and internal body organs. ~~Deposited materials can continue to emit beta and gamma radiation as "groundshine" after the plume has passed causing continued exposure to skin and internal body organs~~. Similarly, skin and clothes may become contaminated.

A plume may deposit materials on surfaces, posing a risk of longer-term exposures via ingestion, direct external exposure and inhalation pathways. If the release contains large quantities of radioactive iodines or particulates, the resulting long-term exposure to this "groundshine" can be more significant than external exposure from the passing plume if the exposure time to the ground contamination is long in comparison to the plume passage time. The early phase PAGs assume four days of exposure to ground

[6] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

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contamination to address this possibility. Doses from groundshine can be readily measured by field monitoring teams dispatched at the onset of a significant radioactive release. Holding a detector probe horizontal and three feet above the contaminated surface provides a direct measurement of groundshine dose. Such assessments can confirm dose projections based upon effluent release data and the adequacy of protective actions in the early phase. More detailed analyses (e.g., isotopic) would be needed to support long-term dose projections in the intermediate phase. Doses for groundshine can be calculated during the intermediate phase (see Chapter 3). Exposure pathways that contribute less than ten percent to the total dose incurred need not be considered during the early phase.

2.2.1. The Establishment of Exposure Patterns

It is unlikely that sufficient environmental data will be available for accurate dose projections during and immediately following the early response to a radiological incident. Dose projections are needed to determine whether protective actions should be implemented in additional areas during the early phase.

For dose projections in the early phase there are two sources of data: current data from initial environmental measurements or estimates of the source term and estimated data using modeled or historical atmospheric transport data. Source term measurements, or exposure rates or concentrations measured in the plume at a few selected locations, may be used to estimate the extent of the exposed area in a variety of ways, depending on the types of data and computation methods available. The most accurate method of projecting doses is through the use of an atmospheric diffusion and transport model that has been verified for use at the site in question or for similar site conditions. A variety of computer software packages can be used to estimate dose in real time, or to extrapolate a series of previously-prepared isopleths for unit releases under various meteorological conditions. The latter can be adjusted for the estimated source magnitude or environmental measurements at a few locations during the incident. If the model projections have some semblance of consistency with environmental measurements, extrapolation to other distances and areas can be made with greater confidence. If projections using a sophisticated site-specific model are not available, a simple but crude method is to measure the plume centerline exposure rate[7] at ground level (measured at approximately 1 m height) at a known distance downwind from the release point and then to calculate exposure rates at other downwind locations by assuming that the plume centerline exposure rate is a known function of the distance from the release point.

The following relationship can be used for this calculation:

$$D_2 = D_1 (R_1/R_2)_y$$

where D_1 and D_2 are exposure rates at the centerline of the plume at distances R_1 and R_2 from the release, respectively and y is a constant that depends on atmospheric stability. For stability classes[8] A and B, y = 2; for stability classes C and D, y = 1.5; and for stability classes E and F, y = 1. Classes A and B (unstable) occur with light winds and strong sunlight and classes E and F (stable) with light winds at night. Classes C and D generally occur with winds stronger than about 10 mph. This method of extrapolation is risky because the measurements available at the reference distance may be unrepresentative, especially if the plume is aloft and has a looping behavior. In the case of an elevated plume, the ground level concentration increases with distance from the source and then decreases, whereas any high-energy gamma radiation from the overhead cloud continuously decreases with distance. For these reasons, this method of extrapolation will perform best for surface releases or if the point of measurement for an elevated release is sufficiently distant (usually more than 1 mile) from the point of release for the plume to have expanded to ground level. The accuracy of this method will be

[7] The centerline exposure rate can be determined by traversing the plume at a point sufficiently far downwind that it has stabilized (usually more than one mile from the release point) while taking continuous exposure rate measurements.

[8] Pasquill stability classes categorize atmospheric turbulence into six stability classes named A, B, C, D, E and F, class A being the most unstable or most turbulence and class F the most stable or least turbulence. Pasquill, F. 1961. The Estimation of the Dispersion of Windborne Material. The Meteorological Magazine 90, No. 1063, 33-49.

improved by the use of measurements from many locations averaged over time.

2.3. THE PROTECTIVE ACTION GUIDES AND PROTECTIVE ACTIONS FOR THE EARLY PHASE: EVACUATION, SHELTERING-IN-PLACE AND ADMINISTRATION OF POTASSIUM IODIDE

The principal protective actions for the early phase are evacuation or sheltering-in-place. Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure from the plume or deposited activity. Sheltering-in-place is the action of staying or going indoors immediately. The administration of KI (stable iodine) to partially block the uptake of radioiodines by the thyroid is a supplemental protective action.

In addition, washing the body and changing clothing as soon as possible after significant exposure to a radioactive plume of any composition may be recommended protective actions. Changing of clothing is recommended primarily to provide protection from beta radiation from radioiodines and particulate materials deposited on the clothing.

The PAGs and corresponding protective actions for response during the early phase of an incident are summarized in Table 2-1. Evacuation or sheltering-in-place will be justified when the projected dose to an individual is 1 rem (10 mSv) projected over four days. This conclusion is based primarily on EPA's determination concerning acceptable levels of risk of health effects from radiation exposure in an emergency situation, while weighing costs and risks associated with any protective action. The basis for the PAGs for the early phase is given in Appendix C of the 1992 PAG Manual, available online as a historical reference at http://www.epa.gov/radiation/rert/pags.html.

Table 2-1. PAGs and Protective Actions for the Early Phase of a Radiological Incident

Protective Action Response	PAG (projected dose)	Comments
Sheltering-in-place or evacuation of the public[a]	1 to 5 rem (10 mSv to 50 mSv) over four days[b]	Evacuation (or, for some situations, sheltering-in-place) should be initiated when projected dose is 1 rem (10 mSv).
Supplementary administration of prophylactic drugs – KI[c]	5 rem (50 mSv) projected dose to child thyroid from exposure to iodine[d]	KI is most effective if taken prior to exposure. May require approval of state medical officials (or in accordance with established emergency plans).

[a]Should begin at levels below 1 rem (10 mSv) if advantageous except when practical or safety considerations warrant using 5 rem (50 mSv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering may begin at lower levels if advantageous.
[b]Calculated dose is the projected sum of the effective dose from external radiation exposure (i.e., groundshine and plume suubmersion) and the committed effective dose from inhaled radioactive material.
[c]Provides thyroid protection from radioactive iodines only. For other information on radiological prophylactics and treatment, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness, http://www.emergency.cdc.gov/radiation or http://www.orau.gov/reacts.
[d]~~Thyroid equivalent dose (see Section 2.3.5).~~ Thyroid dose (see Section 2.3.4)

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2.3.1. Thyroid Based Evacuation

This revised PAG Manual does not include a footnote from the 1992 PAG Manual Early Phase PAG table, which noted that 'thyroid and skin may be 5 and 50 times larger, respectively.' That footnote effectively provided organ dose based evacuation thresholds in addition to the whole-body dose PAG range of 1 to 5 rem. Because of the factors described above, these organ dose based Early Phase PAGs are not necessary.

Regarding sensitive subpopulations, child thyroid doses typically are about twice as high as adult thyroid doses. The former range recommended for thyroid dose-based evacuation (5 to 25 rem adult thyroid dose) is well covered by projections of whole body dose, with evacuation recommended at 1 to 5 rem adult TED. The conservatism built into the PAG levels when they were set ensures protection of the whole community when evacuation is based on these PAGs. Planners should consider instituting public messaging templates in advance to address concerns the public may have about how protective the PAG recommendations are for all members of an impacted community.

The PAG Manual is guidance, and intentionally not prescriptive. This set of recommendations does not preclude an emergency manager from setting local or state protective action guidelines for actions based on specific organ or age group dose levels, as warranted by specific needs of that community

2.1.1.

2.1.3. Basis for Early Phase PAGs

For a full description of the risk-benefit analysis used to set the PAG levels, refer to the 1992 PAG Manual, Appendices B, C and E. The Manual is available online in a searchable format. Below is a short summary on the basis for the Early Phase evacuation/sheltering PAG of 1 to 5 rem over 4 days.

PAGs are intended to apply to all individuals in a population other than workers performing emergency services. However, there may be identifiable groups that have different average sensitivity to radiation or, because of their living situation, will receive higher or lower doses. In addition, some groups may be at greater risk from taking a given protective action. Special circumstances and age groups (e.g., fetal dose) were considered, when appropriate, in establishing values for the PAGs.

The following four principles provided the basis for establishing values for Protective Action Guides:

1. Acute effects on health (those that would be observable within a short period of time and which have a dose threshold below which they are not likely to occur) should be avoided.
2. The risk of delayed effects on health (primarily cancer and genetic effects, for which linear non-threshold relationships to dose are assumed) should not exceed upper bounds that are judged to be adequately protective of public health, under emergency conditions, and are reasonably achievable.
3. PAGs should not be higher than justified on the basis of optimization of cost and the collective risk of effects on health. That is, any reduction of risk to public health achievable at acceptable cost should be carried out.
4. Regardless of the above principles, the risk to health from a protective action should not itself exceed the risk to health from the dose that would be avoided.

EPA considered the acceptable range of costs for avoiding a statistical death from pollutants other than radiation and using a rounded value from the BEIR III risk of 0.0003 cancer deaths per person-rem. Further evaluation of thyroid, skin and fetal dose consequences was conducted as well.

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2.1.4. Evacuation vs. Sheltering-in-Place

Evacuation can be 100 percent effective in avoiding dose if completed before plume arrival. Evacuation is appropriate when its risks and secondary effects are less severe than the risk of the projected radiation dose

Evacuation and sheltering-in-place provide different levels of dose reduction from the principal exposure pathways: direct gamma exposure and inhalation. Both sheltering and evacuation may be implemented during the same response in different areas or timeframes. Evacuation, if completed before plume arrival, can be 100 percent effective in avoiding radiation exposure. A decontamination station, with simple decontamination actions, may need to be collocated at shelters during the pre-evacuation period. This may reduce the spread of contamination and provide for greater protection during evacuation. Medical stations should also be collocated at shelters during the pre-evacuation period to ensure simple triage capabilities are met and to manage the distribution of prophylactic drugs. The effectiveness of evacuation will depend on many factors, such as how rapidly it can be implemented and the nature of the incident. For incidents where the principal source of dose is inhalation, evacuation could increase exposure if it is implemented during the passage of a short-term plume, because the air inside a vehicle rapidly equalizes with the outside air even when all of the windows and vents are closed. ~~since vehicles used to transport evacuees provide little protection against exposure~~ (DOE 1990). Below 1 rem evacuation is not recommended because of risks associated. ~~Evacuation will seldom be justified at less than 1 rem (10 mSv) over the first four days.~~

Sheltering-in-place is a low-cost, low-risk protective action that can provide protection with an efficiency ranging from zero to almost 100 percent, depending on the type of release, the type of shelter available, the duration of the plume passage and climatic conditions. Because of these advantages, planners and decision makers may consider implementing sheltering-in-place when projected doses are below 1 rem (10 mSv) over the first four days. More guidance on the unique challenges posed by an IND can be found in the "Planning Guidance for Response to a Nuclear Detonation" (NSS 2010).[9]

Sheltering-in-place may be preferred for special populations (e.g., those who are not readily mobile) as a protective action at projected doses of up to 5 rem (50 mSv) over four days. When environmental, physical, or weather hazards impede evacuation, sheltering-in-place may be justified at projected doses up to 5 rem (50 mSv) for the general population (and up to 10 rem (100 mSv) for special populations). It is also comparatively easy to communicate with populations that have sheltered-in-place. Dose projections use a four-day exposure duration, but sheltering in place duration is intentionally not specified. Incident-specific decisions must be made to determine how long people should shelter in place.

Selection of evacuation or sheltering-in-place is far from an exact science, particularly in light of time constraints that may prevent thorough analysis at the time of an incident. The selection process should be based on realistic or "best estimate" dose models and should take into account the unavoidable dose incurred during evacuation and potential failure scenarios for sheltering-in-place (e.g., leaking ventilation system).

Sheltering-in-place should be preferred to evacuation whenever it provides equal or greater protection.
Sheltering-in-place followed by informed evacuation may be most protective.

Advance planning and exercises can facilitate the decision process. In a commercial NPP incident, early decisions should be based on information from the response plans for the EPZ and on actual conditions at the nuclear facility (see Section 2.3.5). For transportation accidents, RDDs, INDs and other incident

[9] See http://www.epa.gov/rpdweb00/docs/er/planning-guidance-for-response-to-nuclear-detonation-2-edition-final.pdf

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scenarios for which EPZs are not practicable, best estimates of dose projections should be used for deciding on evacuation, sheltering-in-place or a combination thereof.

~~2.1.5. General Guidance for Evacuation and Sheltering-in-Place~~ Considerations for Evacuation

- The following is a summary of planning guidance for evacuation and sheltering-in-place—Evacuation may be the only effective protective action close to the plume source.
- Evacuation will be most effective if it is completed before arrival of the plume.
- Evacuation may increase exposure if carried out during the plume passage.
- Evacuation is also appropriate for protection from groundshine in areas with high exposure rates from deposited materials when suitable shelter is not available.
- Sheltering-in-place may be appropriate for areas not designated for immediate evacuation—
  - It may provide protection equal to or greater than evacuation for rapidly developing releases (e.g., RDDs) if followed by evacuation.
  - It positions the public to receive additional instructions.
  - Since it may be implemented rapidly, sheltering-in-place may be the protective action of choice (followed with evacuation when feasible) if rapid evacuation is impeded by:
    - severe environmental conditions, e.g., severe weather or floods;
    - uncertainty in contamination levels along routes;
    - health constraints, e.g., patients and workers in hospitals and nursing homes;
    - long mobilization times that may be associated with certain individuals, such as industrial and farm workers, or prisoners and guards;
    - physical constraints to evacuation, e.g., inadequate roads or blockage due to debris.
- If a major release of radioiodine or particulate materials occurs, inhalation dose may be a controlling criterion for protective actions—
  - Breathing air filtered through common household items (e.g., folded handkerchiefs or towels) may help reduce exposures.
  - After confirmation that the plume has passed, continued sheltering-in-place should be re-evaluated. Shelters may ~~should~~ be opened to vent any airborne radioactivity trapped inside and people should remain sheltered until official notice about leaving high exposure areas as soon as possible to avoid exposure to deposited radioactive material.

2.1.6. Considerations for ~~Evacuation and~~ Sheltering In Place

Advance planning is essential to identify potential problems that may occur in an evacuation. An NRC case study cites the following aspects of planning as contributing to efficiency and effectiveness of evacuation (NRC 2005)—

- High level of cooperation among agencies.
- Use of multiple forms of emergency communications.
- Community familiarity with alerting methods, the nature of the hazard and evacuation procedures.
- Community communication.
- Well-trained ~~emergency responders~~ emergency workers.

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The NRC 2005 study included an evaluation of 50 incidents of public evacuation involving 1,000 or more people. The evacuations studied were initiated in response to natural disasters, technological hazards and malevolent acts occurring between January 1, 1990 and June 30, 2003. The report indicated that public familiarity with alerting methods and door-to-door notification were statistically significant factors for the efficiency of evacuation. The report also indicated that many communities are making improvements to response capabilities by modernizing communication systems, improving traffic flow, local education awareness and developing interagency and cross-boundary coordination plans.

~~Regardless of size,~~ Large or small population groups can be evacuated effectively with minimal risk of injury or death. In the NRC report, only six of the 50 cases studied involved deaths from the hazard and of those six, only one involved death from the evacuation itself (NRC 2005).

However, in 2005, not long after this report was published, the gulf coast of the United States was hit by a series of hurricanes that resulted in the evacuation of approximately 5 million people. During the evacuation that accompanied Hurricane Rita in Houston, Texas, 106 people were reported to have died as a direct result of the evacuation. It is estimated that at least two-thirds of the evacuees did not need to evacuate but did so because of poor communication, fear and poor traffic management (NRC 2008).

The emergency planning process for radiological incidents should include effective traffic management plans and communications plans, including pre-scripted messages, provisions for evacuation of special needs populations, such as children in schools and child care facilities, people in institutions and people who have impaired mobility or lack personal transportation.

The degree of protection provided by structures is affected by factors such as attenuation of gamma radiation (shielding) by structural components (the mass of walls, ceilings, etc.) and outside/inside air exchange rates (see Figure 2-1). The use of large structures, such as shopping centers, schools, churches and commercial buildings, as collection points during evacuation mobilization will generally provide greater protection against gamma radiation than use of small structures. As with evacuation, delay in taking shelter during plume passage will result in higher exposure to radiation.

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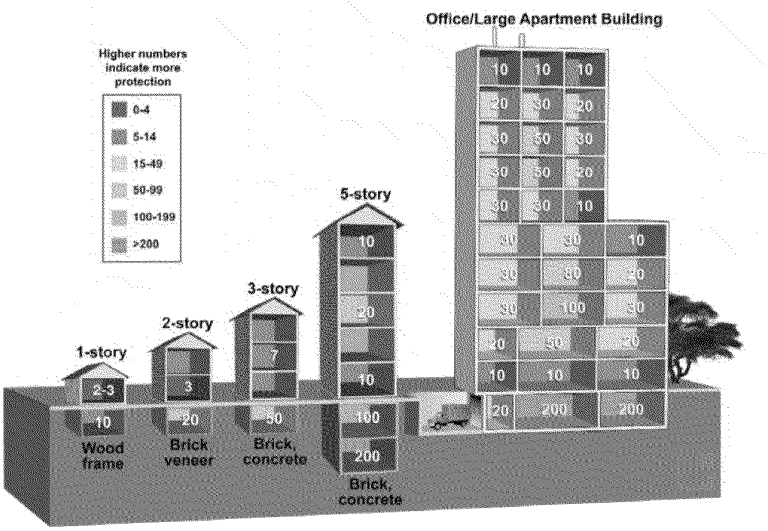
Figure 2-1: Exposure reduction from external radiation from nuclear fallout as a function of building type and location.



The numbers represent dose reduction factors. A dose reduction factor of 10 indicates that a person in that area would receive 1/10th of the dose of a person in the open. A dose reduction factor of 200 indicates that a person in that area would receive 1/200th of the dose of a person out in the open.
Figure taken from *Planning Guidance for Response to a Nuclear Detonation*, *Second Edition*, National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats, June 2010, courtesy of Lawrence Livermore National Laboratory. The protection factors in this figure are specific to nuclear detonation fallout, but the variations in factors throughout typical buildings may be informative for other airborne radiological releases.

2.1.7. Consideration for Potassium Iodide (KI)

[NEW WORDING FROM KI DOCUMENT][10] [11] [12]

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2.1.8. PAGs and Nuclear Facilities Emergency Planning Zones (EPZ)

Under NRC regulations, before a nuclear power reactor may be issued a license, the NRC must find that licensee, state and local emergency plans are adequate and that they can be implemented. For nuclear power reactors, there is a plume exposure EPZ within a 10 mile (16.1 km) radius of the plant and for a separate ingestion pathway EPZ within a 50 mile (80.5 km) radius. The sizes of these EPZs were developed by the NRC/EPA Task Force Report on Emergency Planning, NUREG-0396/EPA 520/1-7-016 and are based, in part, on the numerical values of the PAGs for the plume exposure and ingestion pathway EPZ. The licensee develops and maintains a detailed emergency plan for its facility while state and local authorities within the EPZ develop and maintain detailed emergency response plans for their respective jurisdictions. Guidance to these licensees, states and local agencies for developing these emergency response plans, including guidance on arrangements for implementing immediate protective actions is primarily contained in NUREG-0654/FEMA-REP-1 (NRC 1980)[13] and supplemented with other guidance issued by NRC (for licensees) and FEMA (for off-site response organizations).

Planning for incidents at other types of nuclear facilities should be developed using similar considerations. Emergency preparedness requirements for non-power reactors (e.g., test and research facilities) are provided in 10 CFR Part 50 Appendix E with supporting guidance in NRC Regulatory Guide 2.6, "Emergency Planning for Research and Test Reactors." Emergency preparedness requirements for fuel cycle and materials facilities are provided in 10 CFR Parts 30, 40, and 70 with supporting guidance in NRC Regulatory Guide 3.67, "Standard Format and Content for Emergency Plans for Fuel Cycle and Materials Facilities." Because of the relatively limited number and diverse nature of these facilities, the size of the EPZs, is determined, if needed, on a case-by-case basis for reactors with an authorized power level less than 250 MW thermal.

Within an EPZ, an area should be pre-designated for immediate response based on specified plant conditions prior to a release, or, given a release, prior to the availability of information on quantities of radioactive materials released. The shape of this area will depend on local topography, as well as political and other boundaries. Additional areas of the EPZ, particularly in the downwind direction, may require evacuation or sheltering-in-place, as determined by dose projections. The size of these areas will be based on the potential magnitude of the release and on an angular spread determined by meteorological conditions and any other relevant factors.

The pre-designated areas for immediate protective action may be reserved for use only in the most severe incidents and in cases when the facility operator cannot provide a quick estimate of projected dose based on actual releases. For lesser incidents, or if the facility operator is able to provide prompt off-site dose projections, the area for immediate protective action may be specified at the time of the incident instead of using a pre-designated area. Regardless of the basis for the initial protective action, radiological assessments need to continue through the duration of the event and if warranted, the initial protective actions extended into additional geographical areas.

Such prompt off-site dose projections may be possible when the facility operator can estimate the potential off-site dose based on information at the facility, using relationships developed during planning that relate abnormal plant conditions and meteorological conditions to potential off-site doses. After the release starts and the release rate is measurable, or when plant conditions or measurements can be used to estimate the characteristics and rate of the release, then these factors, along with atmospheric stability, the accuracy of these methods for estimating projected dose will be uncertain prior to confirmatory field

[13] Immediate protective actions based on in-plant conditions and EPZs established by NUREG-0654/FEMA-REP-1 are not applicable to naval nuclear propulsion plants. The largest naval reactors are rated at less than one-fifth of a large U.S. commercial NPP. In addition, since reactor power is directly linked to propulsion requirements, naval nuclear propulsion plants typically operate at low power when the ship is close to shore where high speeds are not required and are normally shut down when in port. Therefore, less than about 1% of the radioactivity contained in a typical commercial NPP could be released from a naval nuclear propulsion plant, limiting the possible dose to the general public and the size of the area of potential concern. Therefore, there is no need for towns and cities to have special emergency response plans such as those required for cities near commercial NPPs.

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measurements because of unknown or uncertain factors affecting environmental pathways, inadequacies of computer modeling and uncertainty in the data for release terms.

The EPZs should be large enough to cover affected urban and rural areas and accommodate the various organizations needed for emergency response.[14]Although the size of the EPZ is based on the maximum distance at which a PAG might be exceeded, the actual boundary of an EPZ should be demarcated by features readily identifiable by people within that area. Such boundaries generally include major topographical features (e.g., rivers, roads, transmission line corridors, rail rights of way) and political boundaries. The EPZ should be further subdivided, using similarly identifiable features, to facilitate implementing protective actions when the entire EPZ is not affected. Maps, showing the boundaries of the EPZ and the sub-areas and evacuation routes should be provided to the public within the EPZ on a periodic basis in a format that will likely be available if the emergency occurs (e.g., inserted sections in local phone directories, wall calendars, etc.) EPZs are not necessary at those facilities where it is not possible for PAGs to be exceeded off-site.

2.2. DOSE PROJECTIONS

The PAGs in this chapter are specified in terms of the projected whole body dose. This projected dose is the sum of the effective dose from external exposure to the plume and the committed effective dose from inhaled radionuclides. Guidance is also provided on the thyroid equivalent dose. Further references to effective or organ dose equivalent refer to these two quantities, respectively. The FRMAC Assessment Manuals (DOE 2010a, b)[15] provide detailed methods for estimating projected dose. These methods require knowledge of, or assumptions for, the intensity and duration of exposure and make use of standard assumptions on the relation, for each radioisotope, between exposure and dose. Exposure and dose projections should be based on the best estimates available. The FRMAC methods and models may be modified as necessary for specific sites for improved accuracy. Emergency response organizations are encouraged to use the most current, applicable tools and methods for implementing PAGs.

2.2.1. Dose Projection during the Early Phase

PAGs are expressed in terms of projected dose. The calculation of projected doses should be based on realistic dose models, to the extent practicable. Public protection decisions should be based upon the dose that can be avoided (i.e., avoidable dose) by taking some protective action (e.g., evacuation, sheltering). Unavoidable dose or doses incurred before the start of the protective action being considered generally should not be included in evaluating the need for protective action. Similarly, doses that may be incurred at later times than those affected by the specific protective action should not be included. As noted earlier, the projection of doses in the early phase needs to include only those exposure pathways that contribute a significant fraction (i.e., more than 10 percent) of the dose to an individual.

In the early phase of an incident, parameters other than projected dose may provide a more appropriate basis for decisions to implement protective actions. When a facility is operating outside its design basis and a substantial release to the environment has started, or is imminent but has not yet occurred, data adequate to directly estimate the projected dose may not be available. Emergency response plans should anticipate specific conditions at the source of a potential release and the possible consequences off-site. Emergency response plans for NPPs and facilities should make use of emergency action levels (EALs), based on in-plant conditions, to trigger notification and initial protective action recommendations to off-site officials.[16]Once the initial protective actions have been implemented, accident assessment should continue. Although initial assessments may be uncertain, the subsequent assessments will be less

[14] The development of EPZs for nuclear power facilities is discussed in the NUREG 0396.

[15] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

[16] Immediate protective actions based on in-plant conditions are not applicable to naval nuclear propulsion plants. See Footnote 7 for additional information. In addition, because of differences in design and operation, EALs based on in-plant conditions are not applicable to naval nuclear propulsion plants.

ED_001057_00010141

uncertain as additional information on facility condition and prognosis, effluent radiation monitor data and environmental data become available. The results of these continuing radiological assessments, including dose projections, should be used as the basis for refining the initial protective actions. In the case of transportation accidents, an RDD or IND, or other incidents that are not related to a facility, it may not be practicable to establish EALs.

Doses that may be incurred from ingestion of food and water, long-term radiation exposure (i.e., longer than four days), radiation exposure to deposited radioactive materials, or long-term inhalation of resuspended materials are chronic exposures for which neither emergency evacuation nor sheltering-in-place are appropriate protective actions. PAGs for the intermediate phase cover these exposure pathways (see Chapter 3).

2.2.2. Duration of Exposure

The projected dose for comparison to the early phase PAGs is calculated for exposure during the first four days following the anticipated (or actual) start of a release. The objective is to encompass the entire period of exposure to the plume and deposited material prior to implementation of any further, longer-term protective action such as relocation. For planning purposes, the four-day period is chosen as the duration of exposure during the early phase because it is a reasonable estimate of the time necessary to make measurements, reach decisions and prepare to implement further protective actions (such as relocation) if necessary. However, officials at the site at the time of the emergency may decide that a different time frame is more appropriate.

For example, doses incurred through ingestion pathways or long-term exposure to deposited radioactive materials take place over a longer time period. Protective actions for such exposures should be based on guidance addressed in Chapter 3.

The projected dose from each radionuclide in a plume is proportional to the time-integrated concentration of the radionuclide in the plume at each location. This concentration will depend on the rate and the duration of the release and meteorological conditions. Release rates will vary with time and this time-dependence cannot usually be predicted accurately. In the absence of more specific information, the release rate may be assumed to be constant.

Another factor affecting the estimation of projected dose is the duration of the plume at a particular location. For purposes of calculating projected dose from most pathways, exposure will start at a particular location when the plume arrives and will end when the plume is no longer present. Exposure from deposited materials will continue for an extended period as long as people are present. Other factors such as the aerodynamic diameter and solubility of particles, shape of the plume and terrain may also affect estimated dose and may be considered on a site- or source- specific basis.

Prediction of time frames for releases is difficult because of the wide range associated with the spectrum of potential incidents. Therefore, planners should consider the possible time periods between an initiating event and arrival of a plume and the duration of releases in relation to the time needed to implement competing protective actions (i.e., evacuation and sheltering-in-place). Analyses of commercial nuclear power reactors (NRC 1975) have shown that some incidents may take several days to develop to the point of a release while others may begin as early as a half hour after an initiating event. Furthermore, the duration of a release may range from less than 1 hour to several days, with the major portion of the release likely occurring within the first day.

Wind speed also influences radiological exposure rates from a plume. As a general rule, air concentration is inversely related to the wind speed at the point of release. Concentrations are also affected by the turbulence of the air, which tends to increase with wind speed and sunlight and by wandering of the plume, which is greater at the lower wind speeds. This results in higher concentrations generally being associated with low winds near the source and with moderate winds at larger distances. Higher wind

ED_001057_00010141

speed also shortens the travel time of the plume. Planning information on time frames for releases from nuclear power facilities may be found in references NRC 1978 and EPA 1978. Time frames for releases from other facilities will depend on the characteristics of the facility.

2.2.3. Derived Response Levels and Dose Conversion Factors

A Derived Response Level (DRL) is a level of radioactivity in an environmental medium that would be expected to produce a dose equal to its corresponding PAG. Depending on the exposure pathway, many factors such as ground roughness, weathering and resuspension may be required to calculate the Dose Parameter (DP) that converts an environmental measurement into a projected dose over a given time period (e.g., Early Phase). ~~A Dose Conversion Factor (DCF) is any factor used to change an environmental measurement to dose in the units of concern. Depending on the exposure pathway, other factors besides the DCF may be required to convert an environmental measurement into a dose~~.

The FRMAC Assessment Manuals ~~(DOE 2010a, b)~~[17] provide guidance in calculating DRLs and DPs ~~DCFs~~ based on the ICRP dosimetry models (ICRP 60 series). In addition, the FRPCC encourages the use of computational tools such as DOE's Turbo FRMAC and NRC's Radiological Assessment System for Consequence Analysis (RASCAL) as well as other appropriate or more current tools to implement the PAGs.

2.2.4. Higher PAGs for Special Circumstances

Hazardous environmental conditions (e.g., severe weather or a competing disaster) could create transportation risks from evacuation that would be higher than normal. It is therefore appropriate to allow higher projected doses for evacuation decisions under these circumstances. In the absence of any definitive information on such higher risks from evacuation, we have arbitrarily assumed that it would be appropriate to increase the recommended projected dose for evacuation of the general population under hazardous environmental conditions up to a factor of five higher than that used under normal environmental conditions.

It is also recognized that people who are not readily mobile are at higher risk from evacuation than are average members of the population. It would be appropriate to adopt higher PAGs for evacuation of individuals who would be at greater risk from evacuation itself than for the typically healthy members of the population, who are at low risk from evacuation. In the absence of definitive information on the higher risk associated with the evacuation of this group, we have arbitrarily assumed that it is appropriate to adopt PAGs a factor of five higher for evacuation of high risk groups under normal environmental conditions. If both conditions exist, (high risk groups and hazardous environmental conditions) projected doses up to ten times higher than the PAGs for evacuation of the general population under normal conditions may be justified. These doses are expected to satisfy Principle 4 without violating Principles 1 and 3. Although they violate Principle 2, Principle 4 becomes, for such cases, the overriding consideration.

2.3. EMERGENCY WORKER PROTECTION

These emergency worker guidelines were developed for a wide range of possible radiological scenarios, from a small transportation accident that may impact a single roadway to an IND that could potentially impact a large geographic region. Therefore, the 5, 10 and 25 rem (50, 100 and 250 mSv) guidelines (Table 2-2) should not be viewed as inflexible limits applicable to the range of early phase emergency actions covered by this guidance. Because of the range of impacts and case-specific information needed, it is impossible to develop a single turn-back dose level for all responders to use in all events, especially those that involve lifesaving operations. Indeed, with proper preparedness measures (training, personal protective equipment (PPE), etc.) most radiological emergencies addressed by this document, even lifesaving operations, may be manageable within the 5 rem (50 mSv) occupational limit. Moreover, Incident Commanders should make every effort to employ the ''as low as reasonably achievable'' (ALARA) principle after an incident. Still, in some incidents doses above the annual occupational 5 rem

[17] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

ED_001057_00010141

(50 mSv) dose limit may be unavoidable. For instance, in the case of a catastrophic incident, such as an IND, Incident Commanders may need to consider raising the lifesaving and valuable property (i.e., necessary for public welfare) emergency worker guidelines in order to prevent further loss of life and prevent the spread of massive destruction. It is essential that emergency workers have full knowledge of the associated risks prior to initiating emergency action and medical evaluation of emergency workers after such exposure.

Worker and public protection guidance and standards for normal operations are developed through risk management approaches and are implemented in federal and state regulations (e.g., 10 CFR Part 20; 10 CFR Part 835; 29 CFR Part 1910.1096). However, many factors or decision criteria in a radiological emergency differ from those in normal operations. Although there are times when implementation of standards or guidelines can cause or enhance other risks, these secondary risks can be controlled. Standards for normal operations provide a margin of safety that is greater than that in guidelines for emergency response because that margin can be provided in a manner that ensures no significant increase in public health risk or detriment to the public welfare. Currently, the development of standards and guidelines for normal operations is done in a manner that provides reasonable assurance that implementation of the standards will not cause more risk than it averts.

Response organizations need to develop plans and protocols that address radiation protection during a radiological incident and that ensure appropriate training is provided to responders and decision makers. Detailed reports on radiation risk, risk management decision making, training and public communication should be consulted in the development of plans, protocols and training materials and may be obtained from organizations such as ICRP, the National Council on Radiation Protection and Measurements (NCRP), International Atomic Energy Agency (IAEA), the American Nuclear Society (ANS) and the Health Physics Society (HPS). Detailed information on the risks of radiological emergency response and worker protection procedures can be found in the FRMAC "Radiological Emergency Response Health and Safety Manual" (DOE 2001) and the NCRP's "Management of Terrorist Events Involving Radioactive Material, Report No. 138" (NCRP 2001) and "Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers, Report No. 165" (NCRP 2010).

"Higher doses could be received by ~~emergency responders~~ emergency workers performing what NCRP Report No. 165, "Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers" calls "Time-Sensitive Mission-Critical" activities that could result in radiation doses higher than 25 rem. NCRP Report No. 165 expands the discussion on a Decision Dose of 50 rad. A Decision Dose can be used by the Incident Commander as a tool to address the need to and the consequences of exposing ~~emergency responders~~ emergency workers to higher doses to accomplish Mission Critical actions. This is especially important in an Improvised Nuclear Device (IND) incident."

2.4. CONTROLLING OCCUPATIONAL EXPOSURE AND DOSES TO ~~emergency responders~~ EMERGENCY WORKERS

This section provides guidance on occupational doses of radiation during an emergency response. In many radiological incidents, actual exposure of workers, including emergency responders, may be controlled to low doses when proper precautions are taken. During some emergencies, radiation exposures to responders may be unavoidable and may have the potential to exceed limits used for normal operations.

However, even in emergency conditions, every reasonable effort should be made to control doses to levels that are as low as practicable (consider NCRP 138[18] and NCRP 165[19] for recommendations that support ALARA).

[18] "Management of Terrorist Events Involving Radioactive Material, Report No. 138" (NCRP 2001).
[19] "Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers, Report No. 165" (NCRP 2010).

ED_001057_00010141

2.4.1. Maintaining the ALARA Principle

To minimize the risks from exposure to ionizing radiation, employers of ~~emergency responders~~ emergency workers should prepare emergency response plans and protocols in advance to keep worker exposures ALARA, an acronym for "as low as is reasonably achievable" means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the activity is undertaken. Plans and protocols should include the following health physics and industrial hygiene practices to the maximum extent possible—

- Minimizing the time spent in the contaminated area.
- Maintaining the maximum distance from sources of radiation.
- Shielding of radiation sources.
- Tailoring of hazard controls to the work performed.
- Properly selecting and using respirators (see 29 CFR Part 1910.134) and other PPE.
- Using prophylactic medications, where medically appropriate, that either block the uptake or reduce the retention time of radioactive material in the body.

The incident commander's staff should be prepared to identify, to the extent possible, all hazardous conditions or substances and to perform appropriate site hazard analysis. Emergency management plans should include protocols to control worker exposures, establish exposure guidelines in advance and outline procedures for worker protection. Emergency procedures should include provisions for exposure monitoring, worker training commensurate with the hazards involved in response operations and ways to control them and medical monitoring.

2.4.2. Understanding Dose and Risk Relationships

~~response worker~~ Emergency worker guidelines are based on cumulative dose constraint levels. These are based on an assumption that doses acquired in response to a radiological incident would be ''once in a lifetime'' doses and that future radiological exposures would be substantially lower.

Recommendations in this document provide a guideline level of 5 rem (50 mSv) for worker protection and alternative ~~response worker~~ emergency worker guidelines (see Table 2-2) for certain activities where exposures below 5 rem (50 mSv) cannot be maintained. For most radiological incidents, radiation control measures (e.g., minimizing time, maximizing distance, using shielding) will prevent doses from reaching the 5 rem (50 mSv) occupational exposure guide while performing typical emergency response activities such as transportation, firefighting and medical treatment of contaminated victims at hospitals. However, in those situations in which victims are injured or trapped in high radiation areas or can only be reached via high radiation areas, exposure control options may be unavailable or insufficient and doses above 5 rem (50 mSv) may be unavoidable.

Decisions to take response actions that could result in doses in excess of 5 rem (50 mSv) can only be made at the time of the incident, under consideration of the actual situation. In such situations, incident commanders and other responders need to understand the risk posed by such exposures in order to make informed decisions. The ~~response worker~~ emergency worker Guidelines for life and property saving activities in Table 2-2 are provided to assist such decision-making. These guidelines apply to doses incurred over the duration of an emergency and are assumed to be once in a lifetime.

Emergency personnel may be exposed to increased radiation during the unique catastrophic event of an IND detonation resulting in firestorm and widespread destruction of structures. The emergency intervention needed to prevent further destruction and loss of life may result in increased exposure. Exceeding the ~~response worker~~ emergency worker Guidelines in Table 2-2 may be unavoidable in responding to such events. ~~emergency responders~~ Emergency workers undertaking a mission covered under the ~~response worker~~ emergency worker guidelines should be informed when radiation control measures may not prevent doses from exceeding the 5 rem (50 mSv), general occupational exposure guideline and should be made ~~fully~~ aware of ~~the sub-chronic and chronic~~ risks involved, including

ED_001057_00010141

numerical estimates of the risk of delayed health effects.

Table 2-2. ~~response worker~~ Emergency Worker Guidelines

Guideline	Activity	Condition
5 rem (50 mSv)	All occupational exposures	All reasonably achievable actions have been taken to minimize
10 rem (100 mSv)[a]	Protecting valuable property necessary for public welfare (e.g., a power plant).	Exceeding 5 rem (50 mSv) unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose.
25 rem (250 mSv)[b]	Lifesaving or protection of large populations	Exceeding 5 rem (50 mSv) unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose.
>25 rem (250 mSv)	Lifesaving or protection of large populations	Only on a voluntary basist for people fully aware of the risks involved (See Tables 2-3 and 2-4)"

[a] For potential doses >5 rem (50 mSv), medical monitoring programs should be considered.
[b] In the case of a very large incident, such as an IND, incident commanders may need to consider raising the property and lifesaving ~~response worker~~ emergency worker guidelines to prevent further loss of life and massive spread of destruction.

The 25 rem (250 mSv) lifesaving ~~response worker~~ emergency worker guidelines provide assurance that exposures will not result in detrimental deterministic health effects (i.e., prompt or acute effects). However, it could increase the risk of stochastic (chronic) effects, such as the risk of cancer. Response actions that could cause exposures in excess of the 25 rem (250 mSv) ~~response worker~~ emergency worker Guideline should only be undertaken with an understanding of the potential acute effects of radiation to the exposed responder (see Table 2-3) and only when the benefits of the action clearly exceed the associated risks.

The estimated risk of fatal cancer[20] for workers exposed to 10 rem (100 mSv) is slightly less than the corresponding general population risk of 0.6 percent (6 cases per thousand exposed). Workers exposed to 25 rem (250 mSv) have an estimated risk of fatal cancer of 1.5 percent (15 cases per thousand exposed). Because of the latency period of cancer, younger workers face a larger risk of fatal cancer than older workers (for example, when exposed to 25 rem (250 mSv), 20 to 30-year-olds have a 9.1 per thousand risk of premature death, while 40 to 50-year-olds have a 5.3 per thousand risk of premature death).[21]

More specific risk determinations can be made when there is adequate information about the

[20] Risk per dose of a fatal cancer is assumed to be about $6x10^{-4}$ per rem ($6x10^{-5}$ per mSv). Cancer incidence is assumed to be about $8x10^{-4}$ per rem ($8x10^{-5}$ per mSv). (EPA 1999)

[21] The numerical estimate of cancer risk presented above (from Federal Guidance #13) was obtained by linear extrapolation using the nominal risk estimates based on data from human exposures at high doses and high dose rates. Other methods of extrapolation to the low-dose region could yield higher or lower numerical estimates of cancer deaths. Studies of human populations exposed at low doses are inadequate to demonstrate the actual magnitude of risk at low doses (about 0.1 Sv or 10 rem and below). There is scientific uncertainty about cancer risk in the low-dose region below the range of epidemiological observation and the possibility of no risk cannot be excluded. (EPA 1999)

contaminants and the potential for human exposure. EPA's Federal Guidance Report #13 (EPA 1999) and Health Effects Assessment Summary Tables have risk factors for specific radionuclides.

Table 2-3. Acute Radiation Syndrome [a]

Feature or Illness	Effects of Whole Body Absorbed Dose from external radiation or internal absorption, by dose range in rad				
	0-100 (0-1 Gy)	100-200 (1-2 Gy)	200-600 (2-61 Gy)	600-800 (6-8 Gy)	>800 (>8 Gy)
Nausea, Vomiting	None	5-50%	50-100%	75-100%	90-100%
Time of Onset		3-6 h	2-4 h	1-2 h	<1 h to minutes
Duration		<24 h	<24 h	<48 h	<48 h
Lymphocyte Count	Unaffected	Minimally Decreased	<1000 at 24 h	<500 at 24 h	Decreases within hours
Central Nervous System Function	No Impairment	No Impairment	Cognitive impairment for 6-20 h	Cognitive impairment for > 20 h	Rapid incapacitation
Mortality	None	Minimal	Low with aggressive therapy	High	Very High: Significant neurological symptoms indicate lethal dose

Source: Medical Management of Radiological Casualties, Second Edition, Armed Forces Radiobiology Research Institute. Bethesda, MD, April 2003.
[a] Percentage of people receiving whole-body doses within a few hours expected to experience acute health effects.

Prior to 5 rem (50 mSv) guideline being exceeded, workers should be provided the following—

- Site specific training, if no prior training was available, with respect to the risk associated with exposure to ionizing radiation (incident commanders and responders should consider having someone on each team with radiation safety experience).
- A thorough explanation of the latent risks associated with receiving exposures greater than 5 rem (50 mSv).

If the 5 rem (50 mSv) guideline is exceeded, workers should be provided with a medical follow-up and monitoring should be considered.

In addition, these guidelines represent dose constraint levels (e.g., when this level of dose is accumulated, the responder should not take part in the later stages of the response that may significantly increase their dose). Incident commanders and responders need a thorough understanding of the worker exposure guidelines for radiological emergency response, including the associated risks and specific worker protection procedures. The FRMAC "Radiological Emergency Response Health and Safety Manual" (FRMAC 2001) provides detailed information. Additional resources for advance planning are available on the Radiological Emergency Medical Management (REMM) web site: http://www.remm.nlm.gov/.

2.4.3. Occupational Safety Regulations for Radiological Emergency Response

The Occupational Safety and Health Act, requires employers to be responsible for the health and safety of their employees during routine and emergency operations. The primary occupational safety and health

ED_001057_00010141

standard for emergency response is the Hazardous Waste Operations and Emergency Response (HAZWOPER) standard (29 CFR Part 1910.120).

Many U.S. states operate their own OSHA-approved state plans, which are required to be "at least as effective as" Federal OSHA standards and may impose additional or more stringent requirements.[22] Some states operate "complete" plans that cover both the private sector and state and local government employees, while others cover state and local government employees only. EPA's Worker Protection Standard (40 CFR 311) applies the HAZWOPER standard to state and local workers in states that do not have occupational health and safety plans.

In addition to the Occupational Safety and Health Act, several federal agencies (DOE, NRC and OSHA) and Agreement States issue occupational radiation safety standards (see Table 2-4). The occupational standards are not guidelines but instead are regulatory limits that cannot be exceeded except under certain conditions. These occupational limits allow workers to receive radiation exposure during the course of performing their jobs.
Federal and state radiation safety standards recognize that it may be necessary to exceed dose limits to take critical lifesaving actions.

Table 2-4. Regulations for Worker Protection

Agency	Statutory Requirement	Title
Occupational Safety and Health Administration[1]	29 CFR 1910.120	Safety and Health-- HAZWOPER
	29 CFR 1910. 1096	Ionizing Radiation
Environmental Protection Agency[1]	40 CFR 311	Occupational Radiation Protection
Nuclear Regulatory Commission[2]	10 CFR 20	Standards for Protection Against Radiation
Department of Energy[3]	10 CFR 835	Radiation Protection Regulations

1. All states are either regulated by federal regulations or by respective state regulations. 40 CFR 311 applies the HAZWOPER standard in states that do not have their own occupational health and safety program.
2. NRC employees are covered by NRC Management Directive 10.131, "Protection of NRC Employees Against Ionizing Radiation." Section VI, Guidance for Emergency Exposure Controls During Rescue and Recovery Activities, deals specifically with radiation exposure control during emergencies
3. These requirements apply to all DOE employees and contractors (except for Naval Nuclear Propulsion Program (NNPP)) who may be exposed to ionizing radiation as a result of their work for DOE, including work relating to emergency response activities. The NNPP has established requirements consistent with those contained in 10 CFR 835.

2.5. CONTAMINATION LIMITS AND MONITORING OF THE ENVIRONMENT AND POPULATIONS

Areas under the plume can be expected to contain deposited radioactive materials if aerosols or particulate materials were released during the incident. In extreme cases, individuals and equipment may be highly contaminated and monitoring stations will be required for emergency monitoring, decontamination of individuals and medical evaluations. Equipment should be checked and decontaminated as necessary to avoid the spread of contamination to other locations. This monitoring service would be required for only a few days following plume passage until all such people have been evacuated or relocated.

~~People working in the parts of the restricted areas in which their dose from the residual radioactivity~~

[22] For a list of state plans, see: http://www.osha.gov/dcsp/osp/index.html

ED_001057_00010141

~~would exceed 2 mrem (20 μSv) in any hour or 100 mrem (1 mSv) in a year should operate under the controlled conditions established for occupational exposure.~~

Adults may reenter restricted areas under controlled conditions in accordance with occupational exposure standards. The need for monitoring stations should be evaluated along highways, which serve as the major evacuation or transportation routes, to control surface contamination at exits from the more highly contaminated areas. Decontamination and other measures should be implemented to maintain low-exposure rates at monitoring stations.

~~A contaminated item should not be released to an unrestricted area. Based on incident and locality-specific considerations, it may be acceptable to release contaminated materials if the level of surface-contamination is less than two times (2x) the existing background levels. As an alternative to-decontamination, contaminated items (i.e., not people or animals) may be retained in the restricted area-while the radiological contamination decays.~~

A contaminated item should not be released to an unrestricted area. Based on incident and locality specific considerations, it may be acceptable to release contaminated materials if the level of surface contamination is below acceptable release criteria. As an alternative to decontamination, contaminated items (i.e., not people or animals) may be retained in the restricted area while the radiological contamination decays

In some extreme cases, decontamination may be impractical. Evacuating a large area requires resources, and decontamination may conflict with priority use of those resources. Screening and decontamination can slow egress, which could result in increased dose to the evacuees. Emergency managers should refer to CDC's "Population Monitoring in Radiation Emergencies: A guide for state and local public health planners" for more information. These simple initial screening guides are more general than FEMA REP-21 and REP-22 on use of handheld instruments and portal monitors for screening the public.

2.6. SURFACE CONTAMINATION CONTROL

Surface contamination must be controlled both before and after relocation protective actions are implemented. The principal exposure pathways for loose surface contamination on people, clothing and equipment are:

- internal doses from ingestion by direct transfer;
- internal doses from inhalation of resuspended materials;
- beta dose to skin from contaminated skin or clothing or from nearby surfaces;
- dose to the whole body from external gamma radiation;
- internal dose from absorption of contamination into wounds.

The contamination limit should be influenced by the potential for the contamination to be ingested, inhaled or transferred to other locations. Therefore, it is reasonable to establish lower limits for surfaces where contamination is loose than for surfaces where the contamination is fixed (except for skin). The expected period of exposure from fixed contamination on skin would be longer so a lower limit would be justified.

It is not practical to set contamination limits significantly lower than residual contamination levels in uncontrolled areas. Although the contamination levels recommended in this manual are accordingly set high, consideration should be given as the event progresses to using lower contamination control levels (and more sensitive monitoring instruments) once people are removed from areas causing high external doses. Such efforts will minimize cross-contamination of people located outside of the affected areas. For events involving fixed nuclear facilities, some evacuation reception centers or shelters will have walk-through portal monitors.

ED_001057_00010141

"2x background is merely a simplified basis for responders to set their own instrument trigger levels based on practical circumstances at the time and location of each screening center. NCRP 161, "Population Monitoring and Radionuclide Decorporation Following a Radiological or Nuclear Incident (NCRP Report No. 166), National Council on Radiation Protection and Measurements, Bethesda, MD, 2011." and Koenig paper [cite properly] provide the basis for these simplified initial screening levels."

2.6.1. Priorities for Control of Contaminated Areas

The following priorities are recommended—

1. Do not delay urgent medical care for decontamination efforts or for time-consuming protection of attendants, such as donning of additional anti-contamination clothing.
2. In early phase scenarios where it might not be practical or would interfere with other life-saving and public health protection priorities, do not waste effort trying to contain contaminated wash water and be sure to notify sewage treatment plants.
3. Do not allow monitoring and decontamination to delay an ordered evacuation.
4. *When early screening is needed after a major incident* — After plume passage, it may be necessary to establish emergency contamination monitoring stations in areas not qualifying as low background areas. Gamma exposure rates in such areas should be less than 5 millirem (50 μSv) per hour. These monitoring stations should be used only during the early phase after major atmospheric releases to monitor people emerging from possible high exposure areas. The stations should be set up to provide simple (rapid) decontamination if needed and to evaluate whether affected people should undergo more extensive decontamination or other special care. Table 2-5 provides guidance on surface contamination levels for use if such centers are needed.
5. Establish monitoring and personnel decontamination (e.g., bathing) facilities at evacuation centers or other locations in low background areas (less than 0.1 millirem (1 μSv) per hour). *Encourage self-decontamination:* Encourage evacuated people who were exposed in areas where release of particulate materials would have warranted evacuation to change and bag the clothes they were wearing and store them in an area away from people and pets until authorities provide further instructions on their disposition, to wash other exposed surfaces such as cars and trucks and their contents and then report to these centers for monitoring. For more specific considerations on control of contaminated areas refer to "Population Monitoring in Radiation Emergencies: A Guide for State and Local Public Health Planners" (CDC 2007).[23] Table 2-6 provides surface contamination guidance. These screening levels are examples derived primarily on the basis of easily measurable radiation levels using portable instruments.
6. After the relocation area has been established, consider the need to set up monitoring and decontamination stations at exits from the more highly contaminated parts of the area. Low levels of contamination may be undetectable because of high background radiation levels at these locations. Monitoring should be done at lowest practical background levels. Nevertheless, these individuals should be advised to bathe and change clothes at their first opportunity—no later than within the next 24 hours. If, after decontamination, people still exceed the limits for the station, they should be sent for further decontamination or for medical or other special attention.

Table 2-5. Recommended surface contamination screening levels for emergency screening of people and objects at monitoring station ~~in high background radiation areas~~ with elevated background area (0.1 mR/h to 1 mR/h or 1 to 10 μSv/h Gamma Exposure Rate))[a]

Condition	Appropriate detection instrument reading	Recommended Action

[23] See: Population Monitoring and Radionuclide Decorporation Following a Radiological or Nuclear Incident (NCRP Report No. 166), National Council on Radiation Protection and Measurements, Bethesda, MD, 2011.

ED_001057_00010141

Before Decontamination	<2x existing background	~~Unconditional release~~ Release for further screening outside affected area
	>2x existing background	Decontaminate. Equipment may be stored or disposed of as appropriate.
After Decontamination	<2x existing background	~~Unconditional release~~ Release for further screening outside affected area
	>2x existing background	Continue to decontaminate or refer to low background monitoring and decon station. Equipment may be stored for decay or disposed of as appropriate.

[b] Monitoring stations in such high exposure rate areas are for use only during the early phase of an incident involving major atmospheric releases of particulates. Otherwise use Table 2-6.

Table 2-6. Recommended Surface Contamination Screening Levels for People[a] and Objects at Monitoring Stations in ~~Low~~ Background Radiation Areas (<0.1 mR/h Gamma Exposure Rate)[b]

Condition	Appropriate detection instrument reading	Recommended Action
Before decontamination	<2x existing background	Unconditional release
	>2x existing background	~~Decontaminate~~ Partial Decontamination
After simple[c] decontamination effort	<2x existing background	Unconditional release
	>2x existing background	Full decontamination
After full[d] decontamination effort	<2x existing background	Unconditional release
	>2x existing background	Continue to decontaminate people Release animals and equipment
After additional full decontamination effort	<2x existing background	Unconditional full release
	>2x existing background	Send people for further evaluation ~~Release animals and equipment~~

[a] People reporting to monitoring stations in low background radiation areas have been previously instructed to change and bag clothes, wash other exposed surfaces such as cars and their contents and then report to these centers for monitoring.
[b] Levels higher than 2x existing background (not to exceed the meter reading corresponding to 0.1 mR/h) may be used to speed the monitoring of evacuees in very low background areas.
[c] Washing hands and face and localized wiping are examples of a partial decontamination effort.
[d] Changing clothes and/or showering are examples of a full decontamination effort.

ED_001057_00010141

KEY POINTS IN CHAPTER 2 – EARLY PHASE

- The principal protective actions for the early phase are evacuation or sheltering-in-place. Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure from the plume or deposited activity. Sheltering-in-place refers to the use of a readily available structure that will provide protection from exposure to the plume.
- The PAG for evacuation or sheltering-in-place is a projected whole body dose of 1 to 5 rem (10 – 50 mSv) total effective dose (TED) over four days.
- Evacuation is appropriate when its risks and secondary effects are less severe than the risk of the projected radiation dose. Evacuation will be most effective in avoiding dose if completed before plume arrival.
- In general, sheltering-in-place should be preferred to evacuation whenever it provides equal or greater protection. After confirmation that the plume has passed, continued sheltering-in-place should be re-evaluated by public officials.
- The administration of KI to partially block the uptake of radioiodines by the thyroid is a supplemental protective action. The PAG for administration of KI is 5 rem (50 mSv) projected child thyroid dose. Other medical countermeasures are available, as well.
- Dose calculations for PAGs are made using the DCF DP and DRL calculation methods referenced in the FRMAC Assessment Manuals. Emergency response organizations are encouraged to use the most current, applicable tools and methods for implementing the PAGs.~~Dose calculations for PAGs are made using the DCF and DRL calculation methods referenced in the FRMAC Assessment Manuals. Emergency response organizations are encouraged to use the most current, applicable tools and methods for implementing the PAGs.~~
- ~~response worker~~ emergency worker guidelines of 5, 10 or 25 rem (50, 100 or 250 mSv) are based on the urgency of activities and knowledge of the risks involved.

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CHAPTER 3 – INTERMEDIATE PHASE PROTECTIVE ACTION GUIDES

3.1. INTRODUCTION

This chapter presents PAGs for the intermediate phase and provides guidance for the implementation of corresponding protective actions. A PAG is the projected dose to an individual from the release of radioactive material at which a specific protective action should be taken to reduce or avoid that dose. The intermediate phase is defined as the period beginning after the source and releases have been brought under control and environmental measurements are available for use as a basis for decisions on protective actions and extending until these protective actions are terminated. The intermediate phase may last from weeks to months; but is assumed to last for one year for purposes of dose projection.

During the early phase, decisions must be made and implemented quickly by state and local officials before federal assistance is available. In contrast, many decisions and actions during the intermediate phase may be taken after federal resources are present, as described in the Nuclear/Radiological Incident Annex of the National Response Framework (FEMA 2008 a, b). Decisions will be made during the intermediate phase concerning whether particular areas or properties from which people have been evacuated will be decontaminated and reoccupied or the occupants relocated for an extended period.

This chapter provides the PAGs and corresponding protective actions for use by state and local officials in developing their radiological emergency response plans to protect the public from exposure to radiation from deposited radioactive materials. Due to the wide variety of types of radiological incidents and radionuclide releases that could occur, it is not practical to provide implementing guidance for every possible situation.

This chapter also provides guidance for translating radiological conditions in the environment into projected doses that serve as the basis for decisions to take appropriate protective actions and basic planning guidance on reentry as informed by the Operational Guidelines (DOE 2009).

3.2. EXPOSURE PATHWAYS DURING THE INTERMEDIATE PHASE

During the intermediate phase, the principal exposure pathways for the public occupying areas contaminated with deposited radioactive materials are:

- **Exposure of the whole body** to external gamma radiation from deposited radioactive materials (groundshine). External gamma radiation is the expected dominant pathway for reactor accidents and incidents involving RDDs and INDs;
- **Internal exposure** from the inhalation of resuspended materials;
- **Internal exposure** from the ingestion of food and water.

Other potentially significant exposure pathways include exposure to beta radiation from surface contamination and direct ingestion of contaminated soil. These pathways are not expected to be controlling for NPP incidents (Aaberg 1989).

3.3. THE PROTECTIVE ACTION GUIDES AND PROTECTIVE ACTIONS FOR THE INTERMEDIATE PHASE: RELOCATION AND DOSE REDUCTION

The principal protective actions for reducing exposure of the public to deposited radioactive materials are:

- Relocation;
- Decontamination;
- Shielding;
- Time limits on exposure;

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- Control of the spread of surface contamination.

The most effective of these actions is relocation—the removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Relocation is highly disruptive and therefore only implemented when the dose is sufficiently high to warrant it. The PAG for relocation is 2 rem (20 mSv) projected over the first year of exposure. After the first year, the PAG for relocation is 0.5 rem (5 mSv) per year.

The PAG level for relocation applies to doses that can be avoided by relocation; doses already incurred prior to relocation are not included in the calculations. PAGs for protection from deposited radioactivity during the intermediate phase are summarized in Table 3-1. The basis for these values is presented in detail in Chapters 4 and 7 and Appendix E of the 1992 PAG Manual, available online as a historical reference at http://www.epa.gov/radiation/rert/pags.html. The decision to relocate will be considered on a case-by-case basis. Efforts to decontaminate and remediate the contaminated area and the shielding offered by buildings and the residency factor attributable to the building, must be considered to see if the second year PAG (0.5 rem (5 mSv) in a year) will be exceeded.

Avoiding exceedance of the relocation PAGs may not be easy for the radionuclides most likely associated with RDDs because of their longer half-lives. If these radionuclides are released, it may be necessary to relocate people in the affected areas even if exposure is less than 2 rem (20 mSv) in the first year provided decontamination and remediation measures during the first year are unsuccessful.

In most scenarios, relocation decisions will be based on doses from external exposure to the whole body from deposited materials and internal exposure from inhalation of resuspended contamination.

~~In most scenarios, relocation decisions will be based on doses from whole-body and internal exposure from inhalation of resuspended contamination.~~ Food and milk ingestion dose should be considered separately with decisions based on the FDA PAGs.[24]The FRMAC Assessment Manual provides guidance in calculating Ingestion Derived Response Levels that indicate the levels of deposited radioactive materials that may result in food exceeding the FDA PAGs

~~In most scenarios, relocation decisions will be based on doses from whole-body and internal exposure from inhalation of resuspended contamination. Food and milk ingestion dose should be considered separately with decisions based on the FDA PAGs.[21]~~

Other protective actions, such as simple dose reduction techniques, can be applied in areas where levels of deposited radioactivity are not high enough to warrant relocation. Dose reduction actions can range from the simple—scrubbing or flushing surfaces, removal and disposal of small spots of highly contaminated soil (e.g., from settlement of water) and spending more time than usual in lower exposure rate areas (e.g., indoors)—to the difficult and time consuming processes of removal, disposal and replacement of contaminated surfaces. The simple processes would probably be most appropriate in contaminated areas outside the relocation area. Many of these can be carried out by the residents with support from officials for monitoring and guidance on appropriate actions and disposal. The more difficult processes will be appropriate for recovery of areas where contamination is fixed (not removable) and from which the population is relocated.

Large areas may have to be restricted under these PAGs. As the land area increases, protective actions become more difficult and costly to implement, especially when the affected area is densely populated.

[24] Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies, FDA 1998, available online: http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM094513.pdf

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There may be situations where full implementation of early and intermediate phase protective actions is impracticable (e.g., a release in a large city). Informed judgment must be exercised to assure priority of protection for individuals in areas having the highest exposure rates.

Table 3-1. Protective Action Guides for Exposure to Deposited Radioactivity during the Intermediate Phase of a Radiological Incident

Protective Action Recommendation	PAG (Projected Dose)[a]	Comments
Relocate the general population[b]	≥ 2 rem (20 mSv) in the first year, 0.5 rem (5 mSv)/year in the second and subsequent years	Projected dose over one year
Apply simple dose reduction techniques[c]	~~< 2 rem (20 mSv)~~ < 2 rem projected in the first year	These protective actions should be taken to reduce doses to as low as practicable levels

[a]Projected dose refers to the dose that would be received in the absence of shielding from structures or the application of dose reduction techniques. These PAGs may not provide adequate protection from some long-lived radionuclides (see Section 3.7).
[b]People previously evacuated from areas outside the relocation zone defined by this PAG may return to occupy their residences.
Cases involving relocation of people at high risk from such action (e.g., patients under intensive care) may be evaluated individually.
[c]Simple dose reduction techniques include scrubbing or flushing hard surfaces, minor removal of soil from spots where

3.3.1. Removal of the 50 year Relocation PAG

For simplicity, the Relocation PAG of 5 rem over 50 years has been removed from this guidance. It is rarely, if ever, the driver for extending Relocation area beyond that prompted by the first or second year Relocation PAGs in scenarios that have been analyzed. Additionally, dose projections over fifty years after a radiological incident for various age groups showed no significant differences for individuals exposed at 3 months age versus adult. A response organization may wish to project fifty-year doses to inform decision making, but should consider weathering, decay, credit for time spent indoors, and to the extent it can be predicted, dose reduction from mitigation activities. To keep emergency management decisions as simple as possible, however, the recommended Relocation PAGs are 2 rem projected over the first year, and 0.5 rem projected over any subsequent year.

3.3.2. The Population Affected

The PAGs for relocation are intended for use in establishing the boundary of a relocation area within an area where radioactive materials have been deposited. The relocation PAGs have been established at a level that will provide adequate protection for the general population, including higher risk groups such as children and fetuses. People residing in contaminated areas outside the relocation area will be at some risk from radiation dose. Therefore, guidance on the reduction of dose during the first year to residents outside this zone is also provided. Monitoring and simple dose reduction efforts are recommended in these areas to reduce doses to the extent practical. Such actions are unlikely to be practical where the dose reduction achieved is less than 10 percent.

Affected populations may perceive that intermediate phase protective actions are not consistent with those taken in the early phase. Early-phase decisions on sheltering-in-place and evacuation may have been implemented prior to verification of the path of the plume. Therefore, some people may have been

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evacuated from areas where validated doses are much lower than were projected. Others who were in the path of the plume may have been sheltered or not protected at all. During the intermediate phase of the response, dose projections may be revised based on environmental measurements. People should be relocated from areas where the projected dose exceeds the PAG for relocation without regard to prior evacuation status.

3.3.3. Basis for Intermediate Phase PAGs

For a full description of the risk-benefit analysis used to set the PAG levels, refer to the 1992 PAG Manual, Appendices B, C and E. The Manual is available online in a searchable format. Below is a short summary on the basis for the Intermediate Phase relocation PAGs

.

In a prior section, for early phase (evacuation) PAGs, analysis was provided for the risks of health effects as a function of dose (Principles 1 and 2). Considerations for selection of PAGs for the intermediate phase of a nuclear incident differ from those for selection of PAGs for the early phase primarily with regard to implementation factors (i.e., Principles 3 and 4). Specifically, they differ with regard to cost of avoiding dose, the practicability of leaving infirm persons and prisoners in the restricted zone, and avoiding dose to fetuses. Although sheltering is not generally a suitable alternative to relocation, other alternatives (e.g., decontamination and shielding) are suitable.

For several assumed cumulative annual doses, the cost per day divided by the risk of fatality avoided by relocation was plotted for a radionuclide mixture from a hypothetical nuclear power plant accident. The cost per day of relocation is assumed to be constant, but with some nuclides decaying rapidly, the cost effectiveness of relocation diminishes over time. Drawing only general trends from this, the cost analysis supports relocation at doses as low as one rem for the first week and two rem for up to 25 days after an accident.

Based on the avoidance of acute effects alone (Principle 1) relocation of the general population and fetuses at 50 rem and 10 rem, respectively, is justified. However, on the basis of control of chronic risks (Principle 2) a lower upper bound is appropriate. Five rem is taken as an upper bound on acceptable risk for controllable lifetime exposure to radiation, including avoidable exposure to accidentally deposited radioactive materials.

Analyses based on Principle 3 (cost/risk) indicate that considering cost alone would not drive the PAG to values less than 5 rem. Analyses in support of Principle 4 (risk of the protective action itself) provide a lower bound for relocation PAGs of 0.15 rem. Based on the above, 2 rem projected committed effective dose equivalent from exposure in the first year is selected as the PAG for relocation. Implementation of relocation at this value will provide reasonable assurance that, for a reactor accident, a person relocated from the outer margin of the relocation zone will, by such action, avoid an exposure rate which, if continued over a period of one year, would result in a dose of about 1.2 rem. This assumes that 0.8 rem would be avoided without relocation through normal partial occupancy of homes and other structures.

Contrary to the situation for evacuation during the early phase of an incident, it is generally not practical to leave a few persons behind when most members of the general population have been relocated from a specified area for extended periods of time. It will usually be practicable to reduce these risks by establishing a high priority for efforts other than relocation to reduce the dose in cases where pregnant women reside near the boundary of the restricted zone. Move to planning considerations…?

The implementation of simple dose reduction techniques will further reduce dose to persons who are not relocated from contaminated areas. Table E-6 summarizes the estimated maximum dose that would be received by these persons for various reactor accident categories with and without the application of simple dose reduction techniques. In the case of non-reactor accidents, decay and weathering effects differ, it may be necessary to base relocation decisions on the second and subsequent year dose projections.

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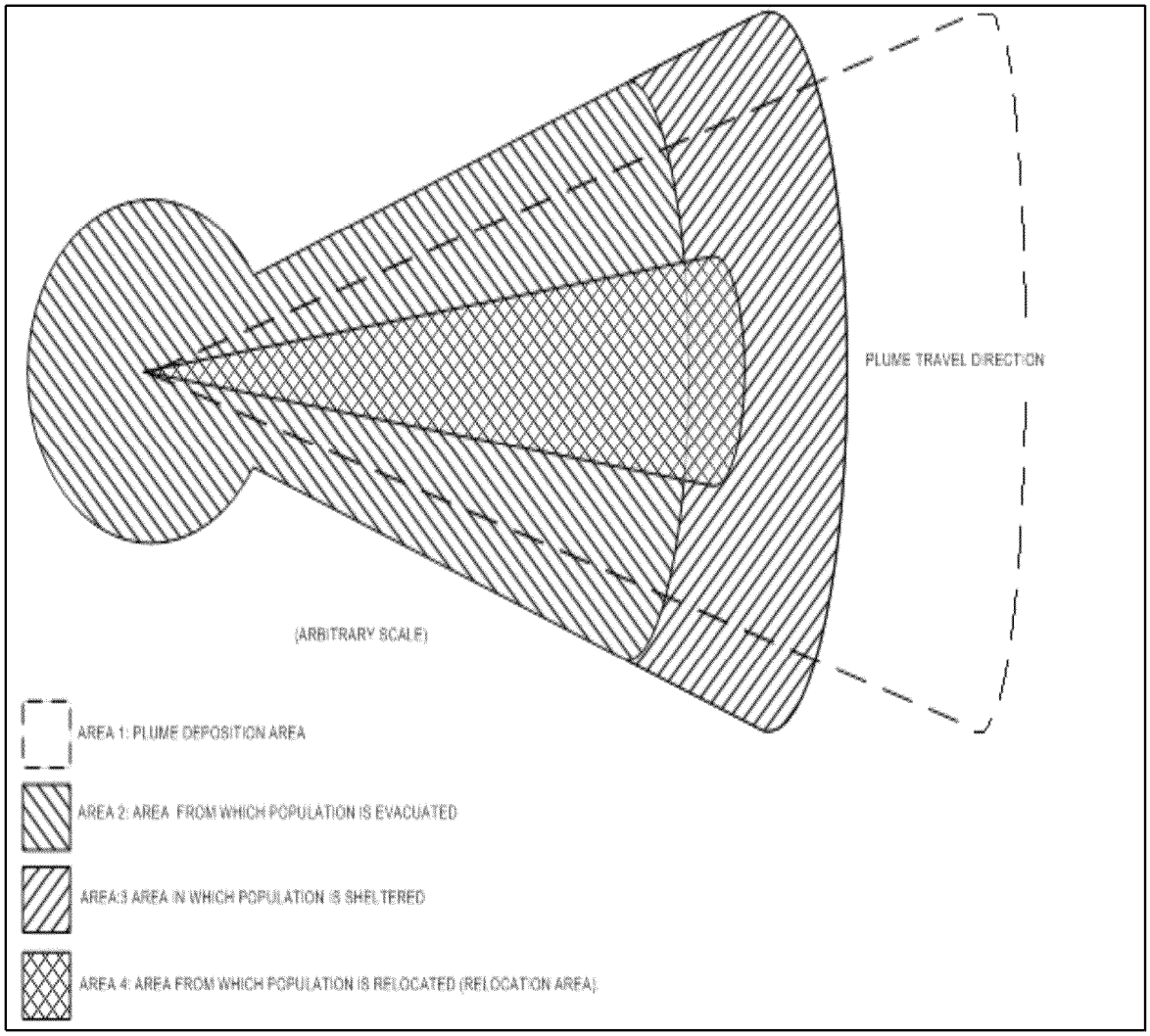

Figure 3-1. Generalized Protective Action Areas for NPP Incident

3.3.4. Areas Involved

Figure 3-1 provides a generalized example of the areas affected by different protective actions. Area 1 represents the plume deposition area. (In reality, variations in meteorological conditions would almost certainly produce a more complicated shape, but the same principles would apply.)

In situations such as an NPP accident, where early warning is given prior to a release of radioactive materials, people may already have been evacuated from Area 2 and sheltered in Area 3. People who have been evacuated from Area 2 or sheltered in Area 3 may go home if environmental monitoring verifies that their residences are outside the plume deposition area (Area 1).

Area 4 is the relocation area where projected doses are equal to or greater than the relocation PAG. People residing just outside the boundary of the relocation area may receive a dose approaching the PAG for relocation if decontamination or other dose reduction efforts are not implemented.

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Area 1, with the exception of the relocation area, represents the area of contamination that may continue to be occupied by the general public during the intermediate phase. Nevertheless, there will be contamination levels in this area that will require continued monitoring and dose reduction efforts other than relocation. Incident-specific levels below the PAGs may be used to control exposure to contamination. The relative positions of the boundaries shown in Figure 3-1 depend on areas evacuated and sheltered and the radiological and meteorological characteristics of the release. For example, Area 4 (the relocation area) could fall entirely inside Area 2 (area evacuated), so that the only people to be relocated would be those residing in Area 4 who were either missed in the evacuation process or who, because of mobility constraints for their evacuation, had remained sheltered during plume passage.

Establishing the boundary of a relocation area creates three groups of affected people—

- People who have already been evacuated from an area that is now designated as a relocation area and who now must be assigned relocation status.
- People who were not previously evacuated, but who reside inside the relocation area and should now relocate.
- People who were previously evacuated, but reside outside the relocation area and may now return home. A gradual return is recommended.

Small adjustments to the boundary of the relocation area established based on the PAG may be justified based on ease of implementation. For example, the use of a convenient natural boundary could be a logical reason for adjustment of the relocation area. However, such decisions should be supported by demonstration that exposure rates to people not relocated can be promptly reduced by methods other than relocation to meet the PAG, as well as the longer dose objectives addressed in Section 3.6.

The relocation PAG applies principally to personal residences but may impact other facilities as well. For example, it could impact work locations, hospitals and park lands as well as the use of highways and other transportation facilities. For each type of facility, the occupancy time of individuals should be taken into account to determine the criteria for using a facility or area. It might be necessary to avoid continuous use of homes in an area because radiation levels are too high. However, a factory or office building in the same area could be used because occupancy times are shorter. Similarly, a highway could be used at higher contamination levels because the exposure time of highway users would be considerably less than the time spent at home.

3.3.5. Priorities

In most cases, protective actions during the intermediate phase will be carried out over a relatively long period of time (e.g., months). Setting priorities will be important, especially when the affected area is so large that it is impractical to relocate members of the public from areas that barely exceed the relocation PAGs. The following priorities are appropriate—

- First, protect all people from doses that could cause acute health effects from all exposure pathways, including previous exposure to the plume.
- Conduct radiological surveys to verify or adjust estimates of radiological impacts.
- Recommend that affected people reduce their exposures by using simple decontamination techniques and remaining indoors.

3.4. SEQUENCE OF EVENTS

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The high-priority decisions on whether to relocate people from high exposure rate areas requires exposure rate measurements and dose analyses. Monitoring and dose assessment will be an ongoing process, with priority given to the areas with the highest exposure rates.

Following passage of the airborne plume, a number of tasks must be accomplished for the timely protection of the public. The general sequence of events is itemized below, but the time frames will overlap.

1. Determine the areas where the projected first-year dose will exceed the 2 rem (20 mSv) relocation PAG and relocate people from those areas, with priority given for people in the highest exposure rate areas.
2. Allow previously evacuated people to return as quickly as possible to areas where field gamma measurements indicate that exposure rates are near normal background levels. If there is a possibility that particles from high deposition areas could drift into the occupied areas, establish a buffer zone to restrict residential use until radiological measurements and assessments confirm that it is no longer necessary. Buffer zones are set with the understanding that conservatism is inherent in the PAGs.
3. Based on isodose-rate boundary (see Section 3.4.1), assign any evacuees who reside within the relocation area to be relocated. Evacuated people whose residence is in the area between the boundary of the plume deposition and the boundary to the relocation area may return gradually as dose projections allow.
4. Evaluate the dose reduction effectiveness of simple decontamination techniques and of sheltering-in-place in response to exposure from partial occupancy of residences and workplaces. Results of these evaluations may influence recommendations for reducing exposure rates for people who are not relocated from areas near, but outside, the relocation area.
5. Control access to and egress from the relocation area. This would be accomplished through control points at roadway accesses to the relocation area.
6. Establish monitoring and decontamination stations to support control of the relocation area.
7. Implement simple decontamination techniques in contaminated areas outside the relocation area, giving priority to areas with higher exposure rates.
8. Collect data needed to establish long-term radiation protection criteria for decontamination and dose reduction and data to determine the effectiveness of various decontamination or other dose reduction techniques.
9. Begin operations to clean up and recover contaminated property in the relocation area.
10. If not already done, evaluate whether food grown or produced within the plume deposition area need to be interdicted per the FDA PAGs and evaluate drinking water systems within the plume deposition area. Provide guidance on planting or harvesting specific agricultural products.

3.4.1. Establishment of Isodose-Rate Lines

As soon as federal or other assistance is available for aerial and ground monitoring, a concentrated effort should begin to establish isodose-rate lines on maps and identify boundaries of the relocation area. Standard maps should be developed on which all response organizations would record monitoring data. Records on monitoring and decontamination of the public and workers should also be collected.

Aerial monitoring can be used to collect data for establishing general patterns of radiation exposure rates and may form the primary basis for the development of dose lines out to the limit of aerial detectability.

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Initially during the early phase, detectability is limited to exposure rate changes of a few times natural background levels. Later during the intermediate phase, more sensitive measurements detect levels of radioactivity that are a small fraction of the natural background. Periodic air sample measurements will also be needed to verify the contribution to dose from inhalation of resuspended materials.

Gamma exposure rates measured at one meter (39 inches) will vary within a very small area because different surfaces have different deposition rates (e.g., smooth surfaces versus heavy vegetation). Rinsing or precipitation could also reduce levels in some areas and raise levels in others where runoff settles. In general, where exposure rates vary within designated areas, dose projections should be estimated using an appropriate average exposure rate.

3.4.2. Dose Projection

The FRMAC Assessment Manuals[25] provide detailed guidance for dose projection and calculating DRLs and DPs ~~DCF~~s (DOE 2010a, b). The FRMAC Assessment Manuals incorporate the ICRP dosimetry models (ICRP 60 series). In addition, the FRPCC encourages the use of computational tools such as DOE's Turbo FRMAC and NRC's RASCAL or other appropriate tools and methods to implement the PAGs.

The primary dose of interest in the intermediate phase is the sum of the effective dose from external exposure and the committed effective dose from inhalation. The exposure periods of interest are the first year and subsequent years after the incident. Other pathways should also be evaluated and their contributions considered, if significant. For example, anytime alpha-emitting radionuclides are involved, the inhalation of resuspended material must be considered. Although beta exposure will contribute to skin dose, its contribution to the overall risk of health effects from the radionuclides expected to be associated with reactor incidents should not be controlling in comparison to the whole body gamma dose (Aaberg 1989). However, the skin beta dose may be important for particulates deposited or transferred to the skin, as may be the case for an RDD that contains Strontium-90.

The dominant intermediate phase exposure pathway for incidents involving alpha-emitters (e.g. a weapons accident) is inhalation of resuspended material. For these incidents, dispersal of alpha-emitting material must be monitored carefully using proper measurement techniques. It is possible that there will be little or no associated gamma radiation or beta activity.

Calculation of the projected gamma dose from measurements will require knowledge of the principal radionuclides contributing to exposure and their relative abundances. Radiological characteristics can be compiled either through the use of portable gamma spectrometers or by radionuclide analysis of environmental samples. Several measurement locations may be required to determine whether any selective radionuclide deposition occurred as a function of meteorology, surface type, distance from the point of release, or other factors. In accordance with the Nuclear/Radiological Incident Annex to the National Response Framework, DOE, EPA and other federal agencies have the capability to assist state officials in performing environmental measurements, including determination of radiological characteristics of deposited materials (FEMA 2008 a, b).

The gamma exposure rate may decrease rapidly if deposited materials include a significant fraction of short-lived radionuclides. Therefore, the relationship between instantaneous exposure rate and projected first- and second-year annual doses will change as a function of time. These relationships must be established for the particular mix of deposited radioactive materials present at the time of the gamma exposure rate measurement. Over time, residual doses from gamma emitters will depend largely upon the

[25] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

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half-lives of the radionuclides involved and could potentially remain significant over many years. It should be noted that natural attenuation as well as nuclear decay can affect long term dose assessments.

Projected dose considers exposure rate reduction from radioactive decay and, generally, weathering. When one also considers the anticipated effects of shielding from normal part time occupancy in homes and other structures, people who are not relocated should receive a dose substantially less than the projected dose. For commonly assumed reactor source-terms, it is estimated that 2 rem (20 mSv) projected dose in the first year will be reduced to about 1.2 rem (12 mSv) by this factor. The application of simple decontamination techniques shortly after the incident can be assumed to provide a further 30 percent or more reduction so that the maximum first year dose to people who are not relocated is expected to be less than 1 rem (10 mSv). Taking account of decay rates assumed to be associated with releases from NPP incidents (SNL 1982) and shielding from partial occupancy and weathering, a projected dose of 2 rem (20 mSv) in the first year is likely to amount to an actual dose of 0.5 rem (5 mSv) or less in the second year. The application of simple dose reduction techniques would reduce the dose further. Calculations supporting these projections are summarized in Table E-6 of the 1992 PAG Manual.[26]

Keeping below the 0.5 rem (5 mSv) PAG for ~~out~~ subsequent-years—the second year and beyond—may be achieved through natural decay of shorter half-life radioisotopes, through decontamination efforts, or through other means of controlling public exposures (such as limiting access to certain areas). In the case of an RDD, in which a longer half-life radioisotope would likely be utilized, reductions in dose may prove difficult to achieve without longer term measures (see Chapter 4).

Exposure from ingestion of food and water is considered independently of decisions for relocation and decontamination. In rare instances, however, where withdrawal of food or water from use would pose a health risk in itself, relocation may be an appropriate protective action against exposure via ingestion. In this case, the dose from ingestion should be considered along with the projected dose from other exposure pathways for decisions on relocation.

3.4.3. Projected External Gamma Dose

Projected whole body external gamma doses at 1 meter height at particular locations during the first year and second year after the incident are the parameters of interest (DOE 1988). Measurements made at 1 meter to project whole-body dose from gamma radiation should be made with instruments of the "closed window" type to avoid the detection of beta radiation. The environmental information available for calculating these doses is expected to be the current gamma exposure rate at 1 m height and the relative abundance of each radionuclide contributing significantly to that exposure rate. Calculation models are available for predicting future exposure rates as a function of time with consideration of radioactive decay and weathering.

Relocation decisions can generally be made on the basis of the first year projected dose. However, projected doses during the second year are needed for decisions on protective actions for people who are not relocated. DCFs are therefore needed to convert environmental measurements to projected dose during the first year and second year following the incident (See FRMAC Assessment Manuals). Of the many types of environmental measurements that can be made to project whole body external gamma dose, gamma exposure rate in air is the easiest to make and is the most directly linked to gamma dose rate. However, analyses of a few environmental samples (particularly, soil samples) must be coupled with the gamma exposure rate to properly project decreasing dose rates.

In addition, measurements should be conducted to determine the dose reduction factors associated with simple, rapid, decontamination techniques so that these factors can be used in calculating dose to people who are not relocated. However, assumptions about these factors should not be included in calculating

[26] The 1992 PAG Manual is available as a historical reference online at: <http://www.epa.gov/radiation/rert/pags.html>

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projected dose for decisions on relocation. Only dose reductions already accomplished can be considered.

3.4.4. Exposure Limits for People Reentering the Relocation Area

After the relocation area is established, people will need to reenter for a variety of reasons, including recovery activities, retrieval of property, security patrol, operation of vital services and, in some cases, care and feeding of farm and other animals. It may be possible to quickly decontaminate access ways to vital institutions and businesses in certain areas so that they can be occupied by adults either for living (i.e., institutions such as nursing homes and hospitals) or for employment. Clearance for occupancy of such areas will require dose reduction to meet exposure limits (EPA 1987). Dose projections should include both external exposure from deposited material and inhalation of resuspended deposited material for the duration of the planned exposure. People working in areas inside the emergency relocation area should operate under the controlled conditions established for occupational exposure (EPA 1987). The worker dose limitation does not need to include ongoing doses received from living in a contaminated area outside the relocation area. It is also not necessary to consider dose received previously from the plume or groundshine during the early phase of the radiological incident.

3.5. PROTECTIVE ACTION GUIDANCE FOR FOOD AND DRINKING WATER

Information on food and animal feeds protective action guidance is contained in FDA's "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies" (FDA 1998).

EPA is not proposing a specific drinking water PAG at this time. EPA has established enforceable drinking water standards for radionuclides under the Safe Drinking Water Act (SDWA). EPA recommends that to the extent practicable, emergency measures for drinking water be based on the National Primary Drinking Water Regulations (NPDWR) for Radionuclides. The Radionuclides Rule provides states with flexibility when responding to radiological events. If a public water system exceeds the radionuclides standard it must work to get back into compliance as soon as feasible. States have the authority to determine if other corrective actions are needed (e.g. providing alternative water).

However, the Agency recognizes a short-term emergency drinking water guide may be useful for public health protection in light of the Fukushima nuclear power plant accident, which impacted some Japanese drinking water supplies. Input on the appropriateness of, and possible values for, an intermediate phase emergency drinking water PAG is being sought during the public review of this Manual.

While the NPDWR provide for a regulatory standard of 4 mrem/year (beta, photon emitters) based on life-time exposure, international organizations have developed technical approaches and methodologies that have produced a range of emergency guidelines related to drinking water (e.g., the World Health Organization[27], the International Atomic Energy Agency[28]) as have other federal agencies (e.g., the Department of Homeland Security[29], the Food and Drug Administration[30]) and non-federal organizations. EPA is seeking input on an approach and technical rationale for a drinking water PAG designed to help officials select protective actions under emergency conditions when exposures would occur over shorter time periods than those envisioned in the NPDWR.

3.5.1. Monitoring & Characterization of Contaminants

The Radionuclides Rule requires community water systems (CWS) to monitor at each entry point to the distribution system to ensure that every customer's water does not exceed the maximum contaminant

[27] See: http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/ and http://www.who.int/hac/crises/jpn/faqs/en/index8.html.

[28] See: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1467_web.pdf.

[29] See: http://ogcms.energy.gov/73fr45029.pdf

[30] See: http://www.fda.gov/downloads/MedicalDevices/.../UCM094513.pdf

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levels (MCLs) for radionuclides. All CWS are required to monitor for gross alpha, radium-226/228 and uranium. In addition, CWS designated by the state as "vulnerable" or if they use waters contaminated by effluents from nuclear facilities must also conduct monitoring for beta particle and photon radioactivity.

In the event of a radiological event, the state, at its own discretion, may exercise regulatory flexibility and require systems to collect samples for radionuclides, including beta particle and photon activity (40 CFR 141.26(c)). For more information about monitoring requirements for the Radionuclides Rule see the "Radionuclides Rule: A Quick Reference Guide" (EPA816-F-01-003, June 2001)[31] or "Implementation Guidance for Radionuclides" (EPA 816-F-00-002, March 2002).[32]

To determine if there is radiological contamination of drinking water sources and the extent to which such contamination is occurring, systems sampling for radionuclides must use approved EPA methods.[33]

3.5.2. Public Notification

If water sample monitoring indicates that contamination levels exceed the MCL for any radionuclide, water systems are required to issue a Tier 2 Public Notification (i.e., within 30 days).

States have the flexibility to elevate the notification if warranted to a Tier 1 Public Notification (i.e., within 24 hours) (40 CFR 141.201(a)(3) Special public notices: Occurrence of a waterborne disease outbreak or other waterborne emergency.

During a radiological event, water systems may be dealing with a number of requirements and operating procedures and may not be prepared to issue public notification. The state may issue public notification on behalf of the water system (40 CFR 141.210(a)). This would allow the state to develop and deliver a consistent message to all affected customers and also allows the system to concentrate its efforts on returning the system to operation and/or returning to compliance in the event of a radionuclides MCL violation. For more information see the Revised Public Notification Handbook (EPA 816-R-09-013, March 2010).[34]

3.5.3. Corrective Actions to Reduce Levels of Contamination

Water distribution systems all incorporate reserve and storage capacity. During the early phase of an incident it is unlikely that contamination could affect water which is directly available for consumption through distribution systems. It would take some time for radionuclides to be deposited from the plume into the supply system water source and then subsequently be distributed. During the early phase, recommendations to the public (i.e., about drinking tap water) should reflect these considerations. The public should be advised that the water is safe to drink unless otherwise informed by state officials. Some useful and practical actions water systems can take during the intermediate phase to provide drinking water to customers are described below.

Wait for Flow-By

If radionuclides are deposited over a river, a section of the water can become contaminated and can be repeatedly contaminated as rain re-deposits radioactive particles. As this section flows down the river, this section of contaminated water is called a plume. This action calls for closing down any source intake valves along the path of the plume of contaminated water. While the intake valve is closed, no

[31] See: http://www.epa.gov/ogwdw/radionuclides/pdfs/qrg_radionuclides.pdf

[32] See: http://water.epa.gov/lawsregs/rulesregs/sdwa/radionuclides/upload/2009_04_16_radionuclides_guide_radionuclides_stateimplementation.pdf

[33] A list of EPA approved analytical methods for Radionuclides is available at: http://www.epa.gov/ogwdw/methods/pdfs/methods/methods_radionuclides.pdf

[34] See: http://water.epa.gov/lawsregs/rulesregs/sdwa/publicnotification/upload/PNrevisedPNHandbookMarch2010.pdf.

ED_001057_00010141

contaminated water can enter the water supply system, therefore the contaminated water is allowed to flow by the system. During this time, the system's existing storage capacity can be depended upon. If the stored water supplies could be depleted before the affected valves can be reopened, treatment of the contaminated water while using available stored water supplies should be considered. This assumes that the treatment technology will be in place or readily accessible. In the event of no other option, contaminated water could be temporarily replaced with large quantities of purchased uncontaminated water.

Treat Contaminated Water

Various treatment options exist for reducing or eliminating the contamination of drinking water by man-made radionuclides. Only a small percentage of all water systems treat specifically for radionuclides. However, typical technologies used to treat water for other contaminants can reduce the concentration of radioactivity. These technologies include coagulation/filtration, ion exchange, lime softening and reverse osmosis. Their actual removal efficiency depends on the radionuclide and the type of treatment.[35]

Activate Existing Connections to Neighboring Systems

If the water supply system is part of a larger, regional supply system, activation of existing connections to a neighboring area could be considered. Most large water systems can establish connections with other large systems for emergency purposes. As in many cases, this option may have already been considered during emergency planning. If this option is implemented, steps must be taken to ensure that the "clean" systems do not become contaminated from water backflow.

Smaller water supply systems (i.e., that serve between 10,000 and 75,000 people), or sparsely populated or rural areas, may not be connected to a neighboring system. In this case, regionalization may be a part of emergency planning to explore. This involves connecting smaller systems to larger systems, thus forming a regional water supply system. This is obviously a long-term proposition, but it does have the added advantage of reducing system vulnerability to water shortages or water quality problems other than those resulting from a radiological incident.

Establish Pipeline Connections to Closest Sources/Systems

Running a pipeline from a "clean" water supply system to various distribution centers located throughout the affected community is a routine means of providing clean water. For example, when water mains must be repaired or cleaned of debris, community water needs have been met through the assembly of temporary pipes and hoses. This is a relatively simple procedure, requiring very little construction and technical expertise. For medium- to long-term emergencies, the construction of a temporary pipeline could be cost-effective. PVC pipe, fire hoses and steel pipe have been used to provide emergency drinking water for periods of up to 2 months when service has been disrupted by earthquakes, drought, or bacterial contamination.

Import Water in Tanker Trucks

If an uncontaminated source of water is close to the affected area, it may be more efficient to arrange to transport water from that source by truck, rail, or barge to distribution centers located throughout the community. The most significant obstacle for the use of this option is the cleanliness and availability of transport vehicles. State and local laws may also affect this option.

Import Bottled Water

Importing bottled water into the affected community is another possible option. The water may come from a nearby water supply system or from a water bottling company. This option may be cost-effective during an emergency if water is needed quickly and if the length of the emergency does not merit long-term action, such as the construction of a temporary pipeline.

[35] Additional information about treatment options and compliance guidance is available at the following website: http://water.epa.gov/lawsregs/rulesregs/sdwa/radionuclides/compliancehelp.cfm.

ED_001057_00010141

Ration Clean Water Supplies

Rationing uncontaminated water is also a possibility. This is particularly true if water reserves can provide each individual in the community with 1 L (0.264G, about 1 qt) of water per day until the contaminated plume has passed, the contaminated water is treated, or the water supply system has returned to normal operating conditions. If this option is chosen, it is important that efficient methods for rationing are in place. Rationing water might also be required if water treatment capabilities are limited. Consider a scheme to ration water as part of emergency planning efforts.

3.6. LONGER-TERM OBJECTIVES OF THE PROTECTIVE ACTION GUIDES FOR THE INTERMEDIATE PHASE

It is an objective of the PAGs to ensure that doses in any single year after the first will not exceed 0.5 rem (5 mSv). For source terms from NPP incidents, the PAG of 2 rem (20 mSv) projected dose in the first year is expected to meet this longer-term objective through radioactive decay, weathering and normal part-time occupancy in structures. If the release contains long-lived radionuclides, decontamination of areas outside the relocation area may be required during the first year to meet these objectives. For situations where it is impractical to meet these objectives through decontamination, relocation should be considered even if the projected first-year dose is lower than the relocation PAG.

Based on the relocation PAGs, reentry guidance can be found in the Reentry Matrix in Section 3.8, as well as in the Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident, Group C (DOE 2009). After the population has been protected in accordance with the PAGs for relocation, return for occupancy of the relocation areas should be governed on the basis of cleanup criteria and late phase cleanup activities should proceed.

3.7. REENTRY DURING THE EARLY AND INTERMEDIATE PHASES

3.7.1. Assumptions and Definitions

The term reentry is used for emergency workers and members of the public going into radiologically contaminated areas temporarily under controlled conditions.

The incident response is divided into three activity planning phases. Early Phase begins with the incident and may last from hours to days. Intermediate Phase begins with control and characterization of the release; it may overlap early and late phase activity ~~and last from weeks to months.~~ , and is assumed to last for one year for purposes of dose projection only

Late Phase begins when recovery actions to reduce radiation in the environment begin and ends when all recovery actions are complete. The matrix below only addresses Early and Intermediate Phase activity.

3.7.2. Approach and Discussion

Interagency guidance informed this section, including—

- "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents" (EPA, 1992)[36].
- "Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident" (DOE 2009)[37].
- FRMAC Assessment Manual (Sandia National Lab, 2010)[38].

[36] PAGs Manual online at http://www.epa.gov/rpdweb00/rert/pags.html.

[37] The Operational Guidelines were developed by federal agencies and published in draft form by DOE in February 2009 with DOE reference number DOE/HS-0001; ANL/EVS/TM/09-1, on-line at http://ogcms.energy.gov/review.html.

[38] FRMAC Assessment Manual, Overview and Methods online at:

ED_001057_00010141

The Operational Guidelines include detailed numeric guidance, developed by a multi-agency working group as a follow-up to the RDD/IND Planning Guidance. That work focused specifically on response and recovery for an RDD event; however, that work can be expanded to include isotopes from a variety of incident types.

The Operational Guidelines are informative for this guidance, specifically the discussions about applicable dose-based limits, timeframes and pathways of exposure related to reentry tasks. Food and agriculture guides use FRMAC assessment methods as well as the Operational Guidelines for implementation. These tools allow derivation of decontamination thresholds for the early and intermediate stages of a response.

As part of the U.S. response to the Japanese Fukushima accident, scientists performed dose calculations to ensure that passengers and workers on train trips through contaminated areas do not exceed doses typically received from cosmic radiation during an international flight. DOE's Argonne National Laboratory scientists utilized the RESRAD-RDD tool and hand calculations to approximate the NPP radionuclides.

http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

ED_001057_00010141

ED_001057_00010141

3.8. REENTRY MATRIX FOLLOWING A RADIOLOGICAL INCIDENT OR ACCIDENT

PHASE	ACTIVITY	SUGGESTED LEVELS	CLEANUP ACTIONS
Early Phase ~~(first 4 days)~~	**Sheltering or Evacuation for the Public**	**Public**: 1,000-5,000 rem (10-50 mSv) projected over four days (See Ch. 2). A decision to evacuate weighs anticipated dose against feasibility of evacuating within a determined time frame, along with the risks associated with the evacuation itself.	It is too early for organized cleanup, due to chaos of the situation and higher priorities such as life-saving activities and clearly identifying shelter and evacuation zones. Any cleanup or decontamination information should focus on personal decontamination. It is doubtful any large-scale effort could change evacuation or shelter recommendations during this period (1st 4 days).
	Emergency Worker Protection	~~response worker~~ Emergency Worker: 5,000/10,000/25,000 rem (50/100/ 250 mSv) incurred over the response duration. The higher limits are based on task (e.g., protecting large populations or critical infrastructure or lifesaving). Responder doses will be tracked with dosimeters. Emergency workers have knowledge of the risks associated with radiation exposure, training to protect themselves and dosimeters to track their doses.	Once evacuation is completed, there are simple actions cities can implement themselves: rinsing roofs and streets, street sweeping. The objective of these efforts is to move the bulk amounts of contamination away from occupied areas or areas where reoccupation is a priority. These actions should be based on measured amounts of contamination and priority of the location. Workers may face high dose levels and will need health physics
Intermediate Phase ~~(first 30 days and up to a year)~~	**Relocation for the Public**	**Public**: 2,000 rem (20 mSv) projected first year, 500 rem (5 mSv) per year projected in subsequent years (See Ch. 3). In this phase, scientists run dose calculations with RESRAD RDD or Turbo FRMAC; the user can choose sensitive age groups, or enter lower guidelines, if desired. Additionally, local decision makers can adapt the guides with incident-specific considerations and implement variations as needed.	Early cleanup efforts should focus on the removable portion of the contamination: vacuuming, washing, vegetation removal. Vacuuming has the advantage of collecting removable contamination without water or surface impact, but is limited by equipment availability and can also expose the operators to high dose levels as the vacuums collect the contamination. Washing and rinsing are simple to implement, but only move the contamination to less-populated areas and may move contamination deeper into porous surfaces. For unpaved areas, vegetation removal can effectively reduce the amount of contamination present, but is labor intensive and can produce large amount of waste. Having addressed the removable part of the contamination, later efforts can focus on fixed contamination. Paved surface

Intermediate Phase ~~(first 30 days and up to a year)~~	**Reentry** **For Use of Critical Infrastructure** **Radiation Worker Protection**	**Public**: 2,000 rem (20 mSv) in first year (Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident, *Operational Guidelines Group C*). Dosimeters could be considered for the public. **Radiation Worker Protection**: (dose not to exceed) 5,000 rem (50 mSv) per year ((*Radiation Protection Guidance to Federal Agencies for Occupational Exposure*, EPA 1987). Radiation workers have knowledge of the risks associated with radiation exposure, training to protect themselves and dosimeters to track their doses. During an incident response, workers (police, waste handlers) needed in contaminated areas could be trained and given dosimeters. The guidance for Radiation Workers applies	removal is very effective, but requires specialized equipment and trained operators. Surface sealing is easier, but leaves the contamination in place, making it viable only in locations where the dose rates are low enough for occupation, or in low-occupancy areas. Repaving roads, lots and other paved surfaces is easy to implement, but can generate significant waste volumes. Unpaved areas can be further remediated by soil skimming (surface removal), deep plowing (turning the top foot or so of soil over) and appropriate chemical soil amendment methods like liming or chelating. As the Intermediate phase progresses, knowledge and experience increases and these methods can be re-applied, refined or customized for problem areas. Decisions about more difficult areas will benefit from professional judgment, additional analyses and application of more sophisticated technologies.
	Reentry For Use of Roads and Walkways	**Public**: 2,000 rem (20 mSv) first year, 500 rem (5 mSv) per year in subsequent years (*Operational Guidelines, Group E*). While the dose values here are similar to those for Use of Critical Infrastructure above, the derived concentrations measured as triggers are different because the exposure conditions are different.	
	Reentry For Access to the Relocation Zone	**Public**: 500 rem (5 mSv) over one year for temporary access with stay times dependent on reentry tasks and site-specific conditions (*Operational Guidelines, Group D*). 'Stay time' is a term of art used in the radiation safety field. Stay times are the amount of time a person may access the contaminated area. These times vary based upon site-specific factors or incident characteristics such as indoor or outdoor work, sensitive populations and level of radioactivity. Section 7.1 of the Operational Guidelines, "Worker Access to Businesses for Essential Actions," provides tables and graphs of stay times at various limiting concentrations (see Figure 7.5 and Table 7.8). For example, if the maximum surface street	

ED_001057_00010141

concentration of Cesium-137 is 3.00E+09 pCi/m2 (1.11E+08 Bq/m2), people limited to 500 rem (5 mSv) should be in the contaminated area less than four 8-hour days if staying outdoors.

This may apply to individuals retrieving belongings from homes or to workers providing security patrols, or even to people reopening businesses in the area. As contamination levels are reduced during cleanup, stay times can be extended and total doses reduced.

Operational Guidelines provide stay times and concentrations for several different sets of assumptions about the exposure. Residents retrieving possessions may spend most of their time indoors, where stay times are longer than they are for outdoors tasks. Stay time recommendations can be used to guide decisions about allowing entry into the contaminated area for a limited time and dose reduction techniques like wearing dust masks, cleaning shoes and car tires upon exit and using time wisely keep radiation exposure 'ALARA' below the Operational Guideline.

Table 7.8 Scenario D2-2 Operational Guidelines for 0.5 rem Annual Dose: Residents Access to Houses (Indoor Exposure)

	Surface Street Concentration (pCi/m^2)		
Radionuclide	1 Day	4 Days	12 Days
Am-241	7.51E+07	2.86E+07	1.59E+07
Cf-252	3.50E+08	1.32E+08	7.13E+07
Cm-244	1.27E+08	4.82E+07	2.68E+07
Co-60	2.72E+09	6.87E+08	2.33E+08
Cs-137	1.14E+10	2.94E+09	1.01E+09
Ir-192	9.93E+09	2.54E+09	8.92E+08
Po-210	1.17E+09	3.86E+08	1.74E+08
Pu-238	6.56E+07	2.50E+07	1.39E+07
Pu-239	6.01E+07	2.29E+07	1.27E+07
Ra-226	6.08E+08	2.10E+08	9.97E+07
Sr-90	2.48E+10	7.70E+09	3.18E+09

ED_001057_00010141

KEY POINTS IN CHAPTER 3 – INTERMEDIATE PHASE

- The principal protective actions for reducing exposure of the public to deposited radioactive materials are relocation, decontamination and time limits on exposure. The PAG for relocation is 2 rem (20 mSv) over the first year of exposure. After the first year, the PAG for relocation is 0.5 rem (5 mSv) per year.
- Boundaries of relocation areas should be established based on the relocation PAG and site-specific geographical features such as rivers, mountains or roadways.
- Exposure limits must be set for people who must enter the relocation area to perform vital services.
- Other protective actions, such as focused decontamination and time limits on exposure, are applied to people in areas where levels of deposited radioactivity are not high enough to warrant relocation.
- Protective action guidance for food is contained in FDA's "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies" (FDA 1998).
- EPA has established enforceable drinking water standards for radionuclides under the SDWA. EPA recommends that to the extent practicable, emergency measures for drinking water be based on the NPDWR for radionuclides. The Radionuclides Rule provides states with flexibility when responding to radiological events. Input on the appropriateness of, and possible values for, an intermediate phase emergency drinking water PAG is being sought during the public review of this Manual.
- To inform temporary reentry into relocation areas, use the Operational Guidelines (DOE 2009).

ED_001057_00010141

CHAPTER 4 – PLANNING GUIDANCE FOR THE LATE PHASE

4.1. CLEANUP PROCESS

This section describes the remediation cleanup process for the late phase of a nationally significant radiological incident, like a disaster at an NPP, an RDD or an IND. It should be noted that the extent and scope of contamination as a result of an NPP, RDD or IND incident may be at a much larger scale than a site or facility decommissioning or remedial cleanup. This process identifies the late phase remediation or cleanup process steps, including factors for decision makers to consider in determining final cleanup actions. For information on roles, responsibilities and authorities during emergency response and recovery please refer to the National Response Framework: http://www.fema.gov/national-response-framework and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008a, b).

4.1.1. Transitioning from Intermediate to Late Phase Cleanup

The late phase cleanup process begins sometime after the commencement of the intermediate phase and proceeds independently of intermediate phase protective action activities. The transition is characterized by a change in approach, from strategies predominantly driven by urgency, to strategies aimed at both reducing longer-term exposures and improving living conditions. The late phase involves the final cleanup of areas and property at which contamination directly attributable to the incident is present. It is in the late phase that final cleanup decisions are made and final recovery efforts following a radiological incident are implemented.

Unlike the early and intermediate phases of a radiological incident, decision makers will have more time and information during the late phase to allow for better data collection, stakeholder involvement and options analysis. There will be opportunities to involve key stakeholders in providing sound, cost-effective cleanup recommendations. Generally, emergency phase decisions will be made directly by elected public officials, or their designees, with limited stakeholder involvement due to the need to act within a short timeframe. Longer-term decisions should be made with stakeholder involvement and can also include incident-specific technical working groups to provide expert advice to decision makers on impacts, costs and alternatives. Community members will influence decisions such as if and when to allow people to return home to contaminated areas. There will be people living in contaminated areas, outside the evacuation and relocation zones, where efforts to reduce exposures will be ongoing.

Because of the extremely broad range of potential impacts that may occur from NPP incidents, RDDs and INDs (e.g., light contamination of one building to widespread destruction of a major metropolitan area), a process should be used to determine acceptable cleanup criteria based on the societal objectives for expected land uses and the options and approaches available. Implicit in these decisions is the ability to balance health protection with the desire of the community to resume normal life. Radiation protection considerations must be addressed in concert with health, environmental, economic, social, psychological, cultural, ethical, political, and other considerations. It is recognized that experience from existing programs, such as the U.S. EPA's Superfund program, the U.S. NRC's process for decommissioning and decontamination to terminate a nuclear facility license and other national recommendations may be useful in planning cleanup and recovery efforts.

Consistent with the "Framework for Environmental Health Risk Management," mandated by the 1990 Clean Air Act Amendments and published by the Commission on Risk Assessment and Risk Management in 1997, the late phase cleanup process consists of multiple steps, including 1) characterization and stabilization, 2) development of goals and strategies and 3) implementation and

ED_001057_00010141

reoccupancy. Stakeholder involvement should be integrated throughout the process. Characterization in this phase consists of delineation, in detail, of the nature and extent of contamination in areas impacted by the incident. Stabilization is intended to reduce the spread of contamination to clean areas, airborne inhalation hazards and the volume of radioactive waste generated. Establishment of cleanup goals and strategies should consider overall community health, along with a variety of factors described further below; they are based upon anticipated land use and a variety of selection criteria. Key to these steps is the involvement and acceptance of the impacted state and local community. These steps are discussed in more detail below.[39]

4.1.2. Characterization and Stabilization

The first step in the late phase remediation or cleanup process is characterization, or the comprehensive mapping and monitoring of the distribution and level of radioactive contamination. Characterization activities are necessary in the preparation for and verification of a successful remediation or cleanup effort. The late phase characterization work is designed to define, in detail, the nature and extent of the contamination and to provide information needed to develop and evaluate cleanup alternatives.

The characterization performed in support of the late phase will be much more detailed and comprehensive than the earlier characterization work to support PAG decisions made during the early and intermediate phases. It delineates the nature of any actual threat posed to human health or the environment and defines the extent of that threat.

Stabilization techniques are designed to immobilize radioactive contamination on soils, buildings, roads and equipment. This becomes paramount in a large-scale incident where the spread of contamination can occur from natural weathering effects to human and animal interactions with the environment. Stabilization reduces chronic low-level exposures to residual radiation, airborne hazards and volumes of secondary waste. These reductions can result in significant benefits to the long-term recovery in terms of time-to-normalcy and economic recovery.

4.1.3. Goals and Strategies

After late phase characterization and stabilization activities are accomplished, areas impacted by radioactive contamination are documented and defined to the best extent possible. At this point, decision makers must establish cleanup goals and strategies for moving forward. The development of goals and strategies marks the second step in the late phase remediation or final cleanup process. As part of an ongoing iterative process, cleanup goals are informed by the feasibility of cleanup strategies and specific cleanup strategies adjust as experience is gained. That is, risk management goals may be refined as decision makers and stakeholders gain appreciation for what is feasible, what the costs and benefits are and how the process of reducing exposures and risks can improve human and ecological health.

As actual levels for areas are determined, many factors come into play in decision making, such as balancing risk reduction with other factors, background levels of radioactivity and tolerance for voluntary versus involuntary risk. Determining these levels will require consideration of a number of factors—

- The types of contamination; the technical feasibility, cost, timeliness and effectiveness of decontamination measures; and the availability and cost of options for the disposal of wastes.
- The size and character of the areas that are contaminated; past and projected future uses for these areas; and the preservation or destruction of places of historical, national, or regional significance.
- Site-specific natural and anthropogenic background levels of radioactivity.
- Estimates of the impacts of both contamination and options for decontamination, on human health, communities, the economy, ecosystems and ecosystem services.

[39] This cleanup process does not rely on and does not affect any authority, including the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. 9601 et seq. and the National Contingency Plan (NCP), 40 CFR Part 300. This document expresses no view as to the availability of legal authority to implement this process in any particular situation.

ED_001057_00010141

- Public acceptability and intergenerational equity.

Community involvement and sentiment are vital to this process. The stress from both the incident itself as well as the longer term effects of separation from home will be important factors as overall community health is considered. In the United States, a range of one in a population of ten thousand (10^{-4}) to one in a population of one million (10^{-6}) excess cancer incidence outcomes is generally considered protective for both chemical and radioactive carcinogenic contaminant exposures. This range is the regulatory standard generally used in the context of EPA Superfund response actions. The NRC's decommissioning and decontamination process outcomes are usually in or near this range as well. A similar risk range may be an appropriate goal for radiological events that affect areas of comparable size. However, such risk ranges may not be practically achievable for major incidents that result in the contamination of very large areas.

Every incident response is unique in making decisions about cleanup goals and strategies for a particular event, decision makers must balance the desired level of exposure reduction with the extent of the measures that would be necessary to achieve it, in order to maximize overall human welfare.

While it may take many years to achieve final cleanup levels, a timely return to normalcy, including reoccupancy and a viable community, will require a cleanup process that is flexible, iterative and inclusive. Decisions must be made on a site-specific basis and should reflect the interim risks that are reasonable and acceptable to the affected community as active remediation, radioactive decay and natural weathering move the site toward long-term cleanup goals.

Cleanup strategies are adopted as decision makers and stakeholders gain an understanding of all relevant factors. Tradeoffs between alternatives should be considered and balanced so that the best options are chosen. Local acceptance will be a key component of a fully transparent approach to long-term remediation and cleanup. Factors to consider in determining cleanup actions include evaluating:

- areas impacted (e.g., size, location relative to population);
- actions already taken during the early and intermediate phases;
- the ability of a remedy to maintain reliable protection of overall human health and the environment over time;
- assessing the relative performance of treatment technologies on the toxicity, mobility or volume of contaminants;
- the success or effectiveness of the cleanup or remediation as the cleanup progresses (contaminant removal);
- the adverse impacts on human health and the environment that may be posed in the time it takes to implement the remedy and achieve the community-based remediation goals;
- the impacts of alternative levels of clean up on the local and regional economy (e.g., job loss due to closed businesses, job creation due to decontamination and waste handling operations) and on residents' sense of place (e.g., continued limited access to one's home and community until clean up levels have been reached); preservation or destruction of places of historical, national, or regional significance;
- the technical and administrative feasibility of the remedy, including the availability of materials and services needed to implement each component of the option in question;
- the cost of each alternative, including the estimated capital and operation and maintenance costs and net present value of capital and operation and maintenance costs;
- state concurrence with the remedy;

  community support for the remedy.

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This may be an iterative process. As experience is gained, adjustments may be required to achieve long-term goals.

4.1.4. Implementation and Reoccupancy

To implement cleanup actions in each community, measurable quantities associated with cleanup goals should be derived taking into account exposures from all potential pathways and through all environmental media (e.g., soil, ground water, surface water, sediment, air, animals or plants). These values typically are derived considering reasonably anticipated future land use, dietary habits and commerce patterns. If meeting acceptable levels based upon the reasonably anticipated post-incident land use is not practicable and cost-effective, decision-makers can look to more restrictive land uses through institutional and engineering controls. This approach is based on the belief that early community involvement focusing on desired post-incident uses of the property will result in expedited, cost-effective and publicly-supported cleanups. Overall community health, including stress factors from the initial event and separation from home or family is a necessary consideration.

In some situations, a site or area may reasonably be anticipated to support a range of uses, so cleanup goals may be different for different subareas of the impacted area. Although it may take years to achieve the final cleanup goals for all land uses, reoccupancy of the affected area will be possible when interim cleanup can reduce short-term exposures to acceptable levels during the time it takes to achieve the long-term goals. There may be institutional or engineering controls placed on some portions of the site to prevent excessive exposures until further active remediation, radioactive decay, or natural weathering allow the site to meet cleanup goals. An example of an institutional control might be a restriction on planting vegetable gardens to avoid ingesting radionuclides that may be taken up by the plant roots from the soil. An example of an engineering control to limit exposures might be adding a layer of pavement or cement over gamma emitting radionuclides that have become fixed in place by sorbing onto the street and sidewalks.

In complex cases such as the situation represented by a wide-area NPP, RDD or IND event, cleanup and reoccupancy are likely to occur subarea by subarea in order of priority and community assessments. Critical infrastructure is likely to have been restored to some level of functionality and further remediation of the infrastructure should be evaluated against the cleanup goal. A community-based and transparent development of priorities would follow, resulting in sequential actions, whereby areas (e.g., residential, commercial) would be remediated and reoccupied utilizing temporary cleanup levels that would be considered acceptable for an interim period of time prior to final cleanup goals being achieved. Land use may need to be changed in a subarea where it is not feasible with a combination of remediation, engineering and institutional controls to support the pre-incident land use in a manner that protects human health. In all cases, an appropriate population health monitoring program should be implemented proportionate to the potential or estimated health risk.

4.1.5. Stakeholder Involvement

Generally, early (or emergency) phase decisions will be made directly by elected public officials, or their designees, with limited stakeholder involvement due to the need to act within a short timeframe. With additional time and an increased understanding of the situation, there will be opportunities to involve key stakeholders in providing sound, cost-effective cleanup recommendations that are protective of human health and the environment.

Affected citizens should be involved in all phases of cleanup planning and long-term remediation of their communities. Early in the process, decision makers should bring together a broad group of stakeholders, e.g., residents, local business owners, local government officials and others interested in the processes that will be required to restore their communities. The credibility of a community group is a function of its inclusiveness. It must represent all stakeholder interests to ensure it is a voice for the entire community

ED_001057_00010141

rather than a few interested parties. Empowering individuals to assist in the process is important and effective. The affected local community will need to be involved until the site remediation activities are complete and possibly beyond that if institutional and engineering controls are placed on some subareas of the site.

4.1.6. Cleanup Process Implementation and Organization: An Example

This example, reprinted from the Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents (DHS 2008), describes a hypothetical organization to integrate federal cleanup support activities with state and local governments and the public. In particular, it addresses a scenario where the federal government is expected to be the primary funding entity for cleanup and recovery activities. For some radiological scenarios, states might take the primary leadership role in cleanup and contribute significant resources toward recovery of the site. This example does not address such a scenario, although states may choose to follow a similar process.

a) Cleanup Implementation

This approach describes how federal departments and agencies may coordinate during a response with state and local government counterparts and the public, consistent with the National Response Framework (NRF) (FEMA 2008a) and the National Disaster Recovery Framework (NDRF). The approach does not attempt to provide detailed descriptions of state and local roles and expertise. It is assumed those details will be provided in state and local level planning documents that address radiological/nuclear terrorism incidents.

During the intermediate phase, site cleanup planners should begin the process described below, under the direction of the on-site incident command or unified command (IC/UC) and in close coordination with federal, state and local officials. After early and intermediate phase activities have come to conclusion and only long-term cleanup activities are ongoing, the IC/UC structure may continue to support planning and decision-making for the long-term cleanup. The IC/UC may make personnel changes and structural adaptations to suit the needs of a lengthy, multifaceted and highly visible remediation process. For example, a less formal and structured command, more focused on technical analysis and stakeholder involvement, may be preferable for site extended site cleanup than what is required under emergency circumstances.

Radiological and nuclear incidents cover a broad range of potential scenarios and impacts. This example assumes that the incident is of sufficient size to trigger a state request for federal assistance and that the federal government is the primary funding agent for site cleanup. In particular, the process described for the late phase cleanup assumes an incident of relatively large size. For smaller incidents, all of the elements in this section may not be warranted. The process should be tailored to the circumstances of the particular incident. Decision makers should recognize that for some radiological/nuclear incidents, states will take the primary leadership role and contribute significant resources toward cleanup of the site. This section does not address such a scenario, but states may choose to use the process described here.

b) Cleanup Activities Overview

As described earlier in the document, radiological/nuclear emergency responses are often divided roughly into three phases: (1) the early phase, when the plume is active and field data are lacking or not reliable; (2) the intermediate phase, when the plume has passed and field data are available for assessment and analysis; and (3) the late phase, when long-term issues are addressed, such as cleanup of the site. For purposes of this example, the response to a radiological or nuclear incident is divided into two separate, but interrelated and overlapping, processes. The first is comprised of the early and intermediate phases of response, which consists of the immediate and near-term on-scene actions of state, local and federal ~~emergency responders~~ emergency workers under the IC/UC. On-scene actions include incident stabilization, lifesaving activities, dose reduction actions for members of the public and ~~emergency~~

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responders emergency workers, access control and security, emergency decontamination of persons and property, "hot spot" removal actions and resumption of basic infrastructure functions.

The second process pertains to environmental cleanup, which is initiated soon after the incident (during the intermediate phase) and continues into the late phase. The process starts with convening stakeholders and technical subject matter experts to begin identifying and evaluating options for the cleanup of the site. The environmental cleanup process overlaps the intermediate phase activities described above and should be coordinated with those activities. This process is interrelated with the ongoing intermediate phase activities and the intermediate phase protective actions may continue to apply through the late phase until cleanup is complete.

Cleanup planning and discussions should begin as soon as practicable after an incident to allow for selection of key stakeholders and subject matter experts, planning, analyses, contractual processes and cleanup activities. States may choose to pre-select stakeholders for major incident recovery coordination. These activities should proceed in parallel with ongoing intermediate phase activities and coordination between these activities should be maintained. Preliminary remediation activities during the intermediate phase—such as emergency removals, decontamination, resumption of basic infrastructure function and some return to normalcy in accordance with intermediate phase PAGs—should not be delayed for the final site remediation decisions.

A process for addressing environmental cleanup is presented below. This is a flexible process in which numerous factors are considered to achieve an end result that considers local needs and desires, health risks, costs, technical feasibility and other factors. The general process outlined below provides decision makers with input from both technical experts and stakeholder representatives and also provides an opportunity for public comment. The extent and complexity of the process for an actual incident should be tailored to the needs of the specific incident; for smaller incidents, the workgroups discussed below may not be necessary.

The goals of the process described below are: 1) transparency—the basis for cleanup decisions should be available to stakeholder representatives and to the public at large; 2) inclusiveness—representative stakeholders should be involved in decision-making activities; 3) effectiveness—technical subject matter experts should analyze remediation options, consider established dose and risk benchmarks and assess various technologies in order to assist in identifying a final solution that is optimal for the incident; and 4) shared accountability—the final decision to proceed will be made jointly by federal, state and local officials.

Under the NRF and NDRF, FEMA may issue mission assignments to the involved federal agencies, as appropriate, to participate in the overall recovery process. Additional funding may be provided to state/local governments to perform response or recovery activities through other mechanisms. The components of the process are as follows:

c) General Management Structure

Planning for the long-term cleanup should begin during the intermediate phase and at that time, a traditional National Incident Management System (NIMS) response structure should still be in place. However, NIMS was developed specifically for emergency management and may not be the most efficient response structure for long-term cleanup. If the cleanup will extend for years, the IC/UC may decide to transition at some point to a different long-term project management structure.

Under the NRF and NIMS, incidents are managed at the lowest possible jurisdictional level. In most cases, this will be at the level of the IC/UC. The IC/UC directs on-scene tactical operations. Responding local, state and federal agencies are represented in the IC/UC and Incident Command Post in accordance with NIMS principles regarding jurisdictional authorities, functional responsibilities and resources provided. For a wide-area radiological incident, multiple Incident Command Posts (ICPs) may be

ED_001057_00010141

established to manage the incident with an Area Command or Unified Area Command supporting the ICPs and prioritizing resources and activities among them. If the incident happens on a federal facility or involves federal materials, the representatives in the UC may change appropriately and the response will be conducted according to the applicable federal procedures.

Issues that cannot be resolved at the IC/UC or Unified Area Command level may be raised with the Joint Field Office (JFO) and JFO Unified Coordination Group for resolution. The JFO coordinates and prioritizes federal resources and when applicable, issues mission assignments to federal agencies under the Stafford Act. Issues that cannot be resolved at the JFO level may be raised to the DHS National Operations Center senior-level interagency management groups and the White House Homeland Security Council and National Security Council.

Day-to-day tactical management, planning and operations for the cleanup process will be managed at the IC/UC level, but for large-scale cleanups involving significant federal resources, it is expected that the JFO Unified Coordination Group and national level federal officials will review proposed cleanup plans and provide strategic and policy direction. The federal agency(s) with primary responsibility for site cleanup should be represented in the JFO Unified Coordination Group. The IC/UC will need to establish appropriate briefing venues as the cleanup process proceeds, including the affected mayor(s) and governor(s).

The discussion below assumes a traditional NIMS IC/UC structure; if the IC/UC transitions later to a different management structure for a longer-term cleanup, the IC/UC would need to determine the appropriate way to incorporate the workgroups described below into that structure.

This process will be managed by the IC/UC, who ultimately determines the structure and organization of the Incident Command Post, but the discussion below provides one recommended approach for managing the cleanup process within a NIMS ICS response structure. The Incident Command Post Planning Section has the lead for response planning activities, working in conjunction with other sections and would have the lead for development of the cleanup options analysis, working closely with the Operations Section. The NIMS describes the units that make up the Planning Section and allows for additional units to be added depending on site-specific needs. NIMS states that for incidents involving the need to coordinate and manage large amounts of environmental sampling and analytical data from multiple sources, an Environmental Unit may be established within the Planning Section to facilitate interagency environmental data management, monitoring, sampling, analysis, assessment and site cleanup and waste disposal planning. Radiological incidents would involve the collection of not only large amounts of radiological data, but also data related to other environmental and health and safety hazards and therefore would likely warrant the establishment of an Environmental Unit in the Planning Section. Planning for FRMAC radiological sampling and monitoring activities will be integrated into the Planning Section and coordinated with other Situation and Environmental Unit data management activities.

The IC/UC may assign the Environmental Unit the responsibility for coordinating the development of the cleanup options analysis. For large incidents requiring more complicated tradeoffs or the evaluation of cleanup goals with broad implications, the IC/UC may choose to establish a separate unit in the Planning Section (for example, a Cleanup Planning Unit) to coordinate the development of the cleanup options analysis. The IC/UC may then convene a technical working group and a stakeholder working group, managed by the Environmental or Cleanup Planning Unit, to analyze cleanup options and develop recommendations. The Environmental or Cleanup Planning Unit would coordinate working group processes and interactions and report the results of the cleanup options analysis and workgroup efforts to the IC/UC through the Planning Section Chief.

The development and completion of the cleanup options analysis is expected to be an iterative process and for large incidents, the cleanup will likely proceed in phases, most likely from the "outside in" toward the most contaminated areas. The extent of the analysis and process used to develop it would be tailored

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to the needs of the specific incident, but the following working groups may be convened by the IC/UC to assist decision makers in the cleanup options process, particularly for large or complex cleanups.

d) Technical Working Group

A technical working group should be convened as soon as practicable, ideally within days or weeks of the incident. The technical working group would be managed by the Planning Section Unit that is assigned responsibility for the cleanup options analysis. The technical working group may or may not be physically located at the ICP. The group may review data and documents, provide input electronically and meet with incident management officials. The group may also be asked to participate in meetings with the JFO Unified Coordination Group if needed.

Function: The technical working group provides multi-agency, multi-disciplinary expert input on the cleanup options analysis, including advice on technical issues, analysis of relevant regulatory requirements and guidelines, risk analyses and development of cleanup options. The technical working group would provide expert technical input to the IC/UC; it would not be a decision-making body.

Makeup: The technical working group should include selected federal, state, local and private sector subject matter experts in such fields as environmental fate and transport modeling, risk analysis, technical remediation options analysis, cost, risk and benefit analysis, health physics and radiation protection, construction remediation practices and relevant regulatory requirements. The exact selection and balance of subject matter experts is incident-specific. The Advisory Team for Environment, Food and Health is comprised of federal radiological experts in various fields that may warrant representation on the technical working group, therefore, the Team or some of its members may be incorporated into this group as appropriate.

e) Stakeholder Working Group

The stakeholder working group should be convened as soon as practicable, ideally within days or weeks of the incident. The stakeholder working group would be managed by the Planning Section Unit that is assigned responsibility for the cleanup options analysis. The IC/UC may direct the Public Information Officer (PIO) (who would coordinate with the Joint Information Center (JIC)) to work with the group, including establishing a process for the group to report out its recommendations. How and where the stakeholder working group would meet to review information and provide its input would need to be determined in conjunction with the group members. The stakeholder working group may also be asked to participate in meetings with the JFO Unified Coordination Group if needed.

Function: The function of the stakeholder working group is to provide input to the IC/UC concerning local needs and desires for site recovery, proposed cleanup options and other recommendations. The group should present local goals for the use of the site, prioritizing current and future potential land uses and functions, such as utilities and infrastructure, light industrial, downtown business and residential land uses. The stakeholder working group would not be a decision-making body.

Makeup: The stakeholder working group should include selected federal, state and local representatives, local non-governmental representatives as well as local and regional business stakeholders. The exact selection and balance of stakeholders is incident specific.

f) Activities: Cleanup Planning and Recommendations

The IC/UC directs the management of the cleanup options analysis through the Planning Section. Technical and stakeholder working groups assist in performing analyses and developing cleanup options and provide input to the IC/UC and may be asked to participate in meetings with the JFO Unified Coordination Group. The IC/UC reviews cleanup options analysis and selects a proposed approach for site cleanup in close coordination with federal, state and local officials. Again, depending on the incident size, it may be necessary to conduct the cleanup in phases. Thus, decisions on cleanup approaches may also be made in phases. As appropriate for the magnitude of the cleanup task, the IC/UC would brief

ED_001057_00010141

relevant federal, state and local government officials on proposed cleanup plans for approval. This may involve the office of the affected mayor and governor. At the federal level, it may involve the JFO Unified Coordination Group and higher-level officials.

g) Public Review of Decision

The IC/UC should work with the PIO and JIC to publish a summary of the process, the options analyzed and the recommendations for public comments. Public meetings should also be convened at appropriate times. Public comments should be considered and incorporated as appropriate. A reconvening of the stakeholder or technical working group may be useful for resolving particular issues.

h) Execution of Cleanup and Peer Review

Assuming a Presidential declaration of a major disaster or emergency, FEMA may issue mission assignments to the federal departments and agencies that have the capability to perform the required cleanup, remediation, or debris removal activities. Cleanup activities should commence as quickly as practicable and allow for incremental reoccupation of areas as cleanup proceeds. For significant decontamination efforts, the IC/UC may choose to employ a technical peer review advisory committee to conduct a review of the effectiveness of the cleanup. The technical peer review committee would evaluate pre- and post-decontamination sampling data, the decontamination plan and any other information key to assessing the effectiveness of the cleanup.

4.2. DISPOSAL OF LARGE VOLUMES OF RADIOLOGICAL WASTE

If a large scale radiological incident were to occur in the United States, the complexity of radiological waste disposal would depend on the magnitude of the release and the decisions related to site cleanup, both of which will determine the amount and types of waste requiring disposal. Primary responsibility for waste management decisions falls to state and local officials. If there is a limited radiological incident with relatively small waste volumes, existing licensed radioactive waste capacity is available and may be sufficient to address waste disposal. However, in a situation involving a more significant release and certainly in an event such as the 2011 incident at the Fukushima nuclear facility, the waste resulting from such an incident would likely overwhelm current disposal capacity. When waste volumes exceed existing capacity, options available for consideration include supplements to existing commercial licensed radioactive waste disposal facilities, such as a combination of hazardous waste landfills, solid waste landfills, DOE facilities and construction of one or more new disposal facilities. New disposal capacity could be located at the site where the radionuclide release originated, elsewhere within the contaminated area, or away from the affected area altogether.

This section provides a short introduction to the issue, a summary of the types of available disposal options, a more detailed discussion of each disposal option, including disposal capabilities and discussion of roles and responsibilities. Although not addressed explicitly in this section, the need to prepare for and conduct safe and environmentally protective storage of waste generated during remediation will also present a significant challenge, as illustrated by the challenges that Japan faced in the aftermath of the Fukushima accident. Many of the considerations for siting disposal facilities will also be applicable to storage sites.

Planners and decision-makers need to view the long-term remediation and recovery as a comprehensive process in which waste management and disposal needs are considered from the earliest stages. For example, the selected decontamination and remediation approach should involve consideration of a number of viable alternatives with regard to potential treatment and disposal options. The precise mix of treatment and disposal options employed would depend on the nature of the specific incident (e.g., location, waste volumes). The suitability of using any individual facility would depend on a number of factors, including but not limited to the toxicity, mobility and volume of radioactively-contaminated wastes (these would be evaluated as part of the characterization process), possible treatment technologies (e.g., volume reduction technologies at the incident location; thermal treatment; neutralization), cost-

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effectiveness and existing federal and state (and possibly local) legal requirements governing waste disposal.

4.2.1. Potential Waste Volumes and Existing Waste Disposal Options

As noted above, the complexity of radiological waste disposal decisions would depend on a number of factors, including the magnitude of the release and the decisions related to site cleanup. Consideration of these factors will determine the amount and types of waste requiring disposal. While disposal in a licensed low-level radioactive waste (LLRW) disposal facility may be the preferable first choice, there are a limited number of such facilities and not all states have access to all licensed commercial disposal facilities. If there is a limited radiological incident with relatively small waste volumes, existing capacity is available and may be sufficient to address waste disposal. However, waste resulting from a large scale incident would likely overwhelm current disposal capacity. For large waste volumes, supplements to existing commercial radioactive waste disposal facilities would need to be considered, such as a combination of hazardous waste landfills, solid waste landfills, DOE disposal facilities and potentially, the construction of a new disposal facility. Organizational and administrative issues related to federal and state government coordination and preparation are also important.

a) Waste Volume

Discussions of waste disposal options often involve comparisons of estimated waste generation and available disposal capacity. The amount of waste generated is related to the cleanup approach, as the selected approach to decontamination and remediation, as well as the long-term cleanup goals, can affect the volume of waste actually requiring disposal. The projected amounts of wastes for a large scale radiological incident may range from tens to hundreds of million cubic feet (or several million metric tons). Some of the waste may contain high radioactivity, especially at the incident's origin; however, most of the waste is expected to be only slightly contaminated, though in large quantities. The volume of contaminated soil in Japan resulting from the Fukushima incident is estimated to exceed one billion cubic feet.

As a point of comparison, roughly 28 million cubic feet of LLRW were disposed of at licensed commercial disposal facilities during the period 2002-2011. DOE disposed of approximately twice that volume in commercial facilities during the same period, in which it was involved in significant large-scale site cleanups.[40]Thus, over that ten-year period, an average annual volume of less than ten million cubic feet was disposed of in commercial facilities. Volumes from the non-governmental sector are not expected to increase significantly until the current fleet of NPPs is decommissioned. DOE generated additional waste volumes that were disposed of at DOE sites. For example, from 2000-2010, DOE disposed of approximately 20 million cubic feet of LLRW at the Nevada National Security Site (NNSS, formerly the Nevada Test Site). As it continues site cleanups, DOE projects generation of approximately 150 million cubic feet of LLRW for the period 2010-2015, most of which will be disposed at the site of origin or other designated DOE sites.

b) Capacity Issues

Managing the large volumes of waste resulting from a wide-scale radiological incident, such as with the Fukushima accident, would likely overwhelm existing capacity in the U.S. and thus require an overall strategy employing all available types of disposal facilities and integrating federal, state, local and private sector assets. For example, consider that:

- At the beginning of 2012, less than 100 million cubic feet of disposal capacity was licensed at commercial disposal facilities. An incident could consume all remaining licensed commercial LLRW disposal capacity, which would affect waste generators in the energy, industrial, research

[40] Information on disposal in commercial disposal facilities provided by the Manifest Information Management System (MIMS), operated by the DOE at http://mims.apps.em.doe.gov/.

ED_001057_00010141

and medical sectors for whom the capacity was originally licensed. While there may be remaining property at the facilities that could be developed, there is no guarantee that additional capacity can be licensed or that states will allow all capacity to be consumed.

- Estimated waste volumes are comparable to projected generation from the entire DOE complex over the next several years, which include large-scale cleanups. While DOE is somewhat less constrained than non-DOE disposal sites in adding additional disposal capacity at its sites, displacement of projected DOE disposal with incident-related waste has the potential to interfere with ongoing cleanup activities, leading to extended on-site storage, slower cleanups and controversial efforts to expand disposal capacity at other DOE sites. Further, there is at present no mechanism to provide access to DOE disposal sites for disposal of incident-related waste.

4.2.2. Integrated Disposal Options

An effective response to a large-scale radiological incident will involve consideration of the entire range of potential disposal options. The precise mix of disposal options employed will depend on the nature of the specific incident (e.g., location, waste volumes). The process selected to plan and conduct the long-term decontamination and remediation should identify and make provisions for using the different available disposal options. In order to provide cleanup managers the use of all potential disposal capacity there are some issues that would need to be addressed, such as waste acceptance criteria for waste sites that have not been evaluated for radioactive material disposal. However, based on an understanding of the types of waste involved and the capabilities of existing disposal facilities, a generalized discussion of the attributes of the different disposal options, with qualifiers, can be developed and are discussed below.

- Licensed Commercial LLRW Disposal Facilities—
  - Can manage most anticipated waste types within license conditions.
  - Highest degree of public acceptance.
  - Significant bulk disposal volume possible.
  - Access restrictions may require special approval for waste from certain states.
  - Management of mixed radioactive and hazardous waste will need to ensure proper disposal and long-term groundwater monitoring.
- Solid and Hazardous Waste Landfills—
  - May offer local disposal option for expected large volumes with limited contamination.
  - May offer a disposal option at hazardous waste landfills for mixed wastes (mixtures of hazardous and radiological wastes); hazardous waste landfills have specified construction and engineering requirements.
  - Need to consider the location of the units in proximity to large or sensitive populations, sensitive eco-systems, and sole source aquifers.
  - May require design modifications to ensure that the waste can be managed protectively over time.
  - Difficulty in obtaining public acceptance, although some hazardous waste landfills have accepted waste with limited radionuclide content with state approval.
  - Requires additional demonstration of suitability to ensure protectiveness for radiological material (e.g., groundwater monitoring, additional engineering controls); many solid waste landfills have not been evaluated for disposal of radioactive material and may not be suitable for radiological material.
  - May require longer-term/special monitoring, as well as institutional control.
- DOE Disposal Sites—
  - Could potentially handle higher-activity waste if insufficient commercial access/capacity.
  - May be suitable for some problematic waste types (e.g., whole vehicles).

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- DOE disposal facilities generally accept only DOE-owned or DOE-generated waste. Disposal of non-DOE waste requires additional review and agreements involving the host state, consistent with DOE's authorities particularly where existing agreements limit DOE's waste disposal activities.

Each of these potential disposal alternatives is discussed in more detail below. There may also be some remaining wastes that might require special consideration based on factors such as level of contamination, waste form, lack of access or capacity or presence of other hazardous or toxic contaminants. These wastes could include those containing both hazardous and toxic constituents (e.g., mercury and PCBs), animal carcasses or contaminated vehicles (where dismantling the vehicle may represent a greater potential for dispersal of contaminants and exposure of workers).

a) Commercially Licensed LLRW Disposal Facilities

Given that the bulk of the waste resulting from the release of radionuclides from a nuclear facility or a deliberate action will contain radionuclides commonly contained in LLRW, licensed commercial disposal facilities would be the most appropriate and publicly acceptable option for disposal if the volumes of waste from the incident were relatively small. It would be anticipated that the waste would be mostly at the lower end of radionuclide concentrations. Thus, these facilities will be capable of handling all but the most problematic waste types, if the amounts were limited. At present, all commercial LLRW disposal facilities are licensed by states (through agreements with NRC, referred to as "Agreement States").

As described earlier, available capacity and access are significant concerns in relying on commercial LLRW disposal facilities. Further, even if a facility would be generally available to all waste generators and it is found that all but a small portion of the waste would meet that facility's disposal criteria, it is possible that there may be objections to accepting all waste from an incident outside the state, even if the facility's capacity was sufficient.

Access to other facilities generally unavailable to the state(s) affected by the incident might be feasible in an emergency situation under NRC regulations, but it should not be expected that large volumes of waste will be accepted under these provisions. There is also the possibility that the affected state could construct a disposal facility to provide additional capacity. Several states conducted extensive studies of their geology in anticipation of constructing disposal facilities and these studies may be of use in such situations.

b) Solid and hazardous waste landfills

Most states are authorized by the EPA under the Resource Conservation and Recovery Act (RCRA) to operate their own hazardous waste management programs in lieu of the federal Subtitle C program.[41] Management of nonhazardous solid wastes is governed by RCRA Subtitle D, which is administered largely by the states. Compared to the number of licensed LLRW disposal facilities in the U.S., there are a greater number of commercial landfills operating under Subtitle C and many more operating under Subtitle D of RCRA for disposal of hazardous and solid wastes, respectively. It would not be expected that all of these facilities (particularly those operating under Subtitle D) would be appropriate disposal options. However, some of the hazardous waste landfills have accepted some radioactive material for disposal and a few have received the necessary state approvals to do so on a routine basis. Historically, most of the radiological waste streams accepted by hazardous waste landfills contain naturally-occurring radionuclides not regulated by NRC, such as wastes from the oil and gas or other resource extraction industries, as well as water treatment residuals. However, both NRC and DOE, in coordination with state regulators and facility operators have approved disposal of radioactive waste in RCRA landfills on a case-by-case basis. Thus, there is reason to believe that one or more hazardous waste landfills could contribute to the disposal capacity for incident-related waste. The use of any particular RCRA facility for the disposal of radioactive contaminants or mixed contamination would require that the unit is well designed

[41] Alaska, Iowa, Puerto Rico, the Virgin Islands, American Samoa and the Trust Territories and Northern Marianas Islands do not have authorized RCRA programs

ED_001057_00010141

and managed appropriately. The uniform design and engineering requirements applicable to hazardous waste landfills would facilitate such an evaluation; by contrast, not all solid waste landfills are constructed to the same specifications. Further, the evaluation would include consideration of the waste characteristics, site characteristics, waste acceptance criteria and other facility attributes.

RCRA hazardous and solid waste landfills may also offer the advantage of disposal capacity suitable for large volumes of lightly-contaminated material (e.g., soil)[42]. In addition, these facilities are more likely to be located near the incident location, which can facilitate their use if deemed appropriate by federal, state and local officials. However, use of these facilities for disposal of radionuclides typically found in low-level radioactive waste, even if it contains very low concentrations of those radionuclides, may generate public concern if the facilities have not been previously approved for this type of disposal. Therefore, additional effort by state and local officials would be necessary to ensure the facility can manage the waste in a protective manner, including technical modification, if appropriate.

c) DOE Disposal Sites

DOE facilities could potentially be a disposal alternative that may be most appropriate for limited volumes of waste for which there is no other disposal outlet (such as high-activity waste, certain mixed wastes, or other problematic waste streams). Waste disposed at DOE sites must meet the waste acceptance criteria for those sites. DOE does not generally accept non-DOE-owned or generated waste for disposal at its sites. In addition, DOE has significant ongoing remediation at a number of sites that will generate large volumes of waste over the coming years. Diverting DOE disposal capacity to incident-related waste may interfere with those efforts. DOE has also utilized commercial low-level radioactive disposal, primarily for bulk waste streams from cleanups and this potential disposal alternative may also be affected by a wide-scale incident.

DOE's primary disposal site serving the DOE complex is the NNSS. DOE/NNSS continues to excavate additional disposal capacity as needed and estimates that significant additional capacity could be developed at NNSS.

DOE's other designated site for complex-wide disposal is Hanford, WA; however, DOE has an agreement with the State of Washington that it will not bring waste from other sites until certain remediation milestones have been met. Overall, DOE anticipates that most of its waste generated in the coming years will be disposed at the site of generation. Sites other than NNSS and Hanford are designated for disposal of waste generated at those sites, although exceptional situations may allow for disposal of waste generated off-site and development of some additional disposal capacity. Additional disposal capacity would likely be dependent upon agreement from the state in which the facility is located.

4.2.3. Planning and Coordination Among Federal and State Entities

A number of federal and state agencies may have important roles to play in making decisions on final disposal, depending on the extent of the waste. A framework for coordination with these various federal and state agencies should be an element of the process selected for long-term decontamination and remediation.

a) State Roles and Responsibilities

States must be intimately involved ahead of time in planning for a large-scale radiological incident and the resulting waste disposal.

- All existing commercial LLRW disposal facilities are licensed by Agreement States.

[42] EPA reports that about 132 million tons of municipal solid waste were landfilled in 2009, comparable to the rate over the past
two decades. The 2009 figure represents about 54% of total generation. "Municipal Solid Waste in the United States: 2009 Facts and Figures," EPA530-R-10-012, December 2010.

ED_001057_00010141

- Many, but not all, states have formed regional compacts (as authorized by Congress) to site and operate LLRW disposal facilities; compacts control access to these sites.
  - Although statutorily required[43] to provide disposal capacity for low-level waste generated within the compact boundaries (with certain exceptions), states are under no obligation to accept waste from outside their compacts. States that are not members of compacts do not have the statutory protection to prohibit disposal of out-of-compact waste.
  - All DOE disposal sites are located within states, many of which have agreements regarding the extent of long-term disposal or acceptance of off-site waste; States hosting DOE disposal sites should participate in planning for the potential disposal of incident-related off-site waste at DOE sites.
  - States regulate hazardous waste (when authorized by EPA) and solid waste landfills that may be used for disposal of waste with very low concentrations of radioactivity; in planning for disposal of incident-related waste, states should take into account any restrictions placed on the disposal of radionuclides in these facilities.
  - It is anticipated that on-site disposal at a location affected by the incident, where appropriate, will be one location of choice and that an affected state could approve construction of a new disposal facility for that purpose.

b) Federal Agencies

Depending on the circumstances, coordination with numerous federal agencies would be necessary. Of particular note:

- EPA is the coordinating agency for long-term remediation and cleanup, as designated by the National Response Framework (FEMA 2008a) and has federal authority for hazardous waste disposal;
- DOE is "owner" of federal sites that might be used for waste disposal;
- NRC is the federal authority for commercial LLRW disposal;
- USDA provides technical assistance for agricultural materials contaminated by the release, including animal carcasses.

4.2.4. Other Potential Options and Considerations

a) Potential Federal Actions to Increase Preparedness

- Develop criteria under which access to DOE disposal sites is acceptable and identify issues to be resolved.
- Facilitate agreements among regional LLRW compacts and states to address situations in which access to compact sites can be assured for all states.
- Identify geographically strategic federal sites that can be used for staging and interim storage of large waste volumes.
- Identify federal sites that can be characterized in advance for construction of disposal capacity for incident-related waste, should the need arise.
- Clarify federal authorities that can be used in exceptional circumstances for acquisition of property for use as disposal or long-term storage capacity and indemnification of private sector service providers.

[43] Pursuant to the Low-Level Radioactive Waste Policy Act of 1980 (LLRWPA) and the 1985 LLRWP Amendments Act of 1985.

ED_001057_00010141

- Assist state and local officials in planning for and making decisions to use local disposal options (solid and hazardous waste landfills) for waste that contains relatively low concentrations of radionuclides, including:
  - developing criteria for case-by-case alternate disposal evaluations, such as those employed by NRC, EPA and DOE for limited volumes of waste;
  - establishing generally applicable criteria for disposal of radionuclides in solid and hazardous waste landfills;
  - supporting federal research into behavior of radionuclides and decontamination residuals in solid and hazardous waste landfills;
  - providing technical assistance and streamlined regulatory review (e.g., permitting) for states to evaluate existing sites and identify new sites for incident-related waste disposal capacity; and,
  - developing and disseminating tools to support planning and decision-making regarding incident-related waste management.

b) Detailed Guidance

It may be appropriate for the federal government to develop detailed guidance to address factors such as waste acceptance criteria needed for waste disposal at RCRA disposal facilities, safety evaluation of existing disposal facilities, or siting, development and regulatory approval of new disposal facilities.

c) Adding Additional Disposal Capacity

Depending on the circumstances, it may be appropriate to create additional disposal capacity. This decision would most likely need to involve extensive discussion between the federal government and the affected state(s) where an incident occurred.

- On-site disposal. As a result of looking at the different choices, it may be advantageous to develop disposal capacity on-site (e.g., build a large disposal facility within the property boundaries where the facility causing the release is located), if the site is suitable.
- Off-site disposal. An additional option would be for a state or the federal government to build a disposal site on suitable public lands. The federal or state government could use the power of eminent domain to condemn property contaminated by a radiological incident and use it for waste disposal.

d) Site Selection Criteria

If it is determined that constructing a new disposal facility is the appropriate action, the proposed site(s) should be studied for suitability. Although the contemplated disposal actions would be taken in event of a national emergency, every effort should be made to ensure the protection of public health and the environment. Appropriate regulatory standards should be considered in developing a specific disposal plan. The disposal path and site suitability must take into account the radiological characteristics of the waste. As discussed above, some slightly radioactive materials are disposed in hazardous waste landfills if they are permitted for it. More radioactive materials are sent to sites licensed as LLRW disposal sites, though less contaminated materials are also sent to LLRW disposal sites. A small amount of waste from a radiological incident may have concentrated radioactivity, but most of the waste generated in a large scale radiological incident would likely be contaminated with low levels of radioactivity. The different radiological characteristics of the waste would have a bearing on the stringency of containment required of a waste disposal facility. All waste sites would need to have appropriate controls to protect public health and the environment for any level of radioactive contamination, but more highly radioactive materials would need more robust controls than slightly contaminated material.

e) Site Characteristics

The physical/geographic characteristics of the site and the availability of land will be important in determining the appropriateness of a potential disposal site. Sites with limited rainfall, high evapotranspiration, deep water tables and soil characteristics that limit migration of radionuclides have

ED_001057_00010141

been found to be best suited to disposal of radioactive waste, although waste management and engineering can be applied to improve performance at sites with less favorable characteristics (e.g., controls on the waste form or level of allowable radioactivity, addition of liners, cover requirements or through construction of concrete bunkers or vaults). Other characteristics, such as location in a high risk area (e.g., flood plain or seismic zone) or sensitive ecologic area, should also be considered. A disposal cell for 1 million cubic feet of waste will occupy 1 acre or more of surface area, assuming disposal to a depth of about 30 feet. Large-scale disposal operations may also require extensive surface facilities.

f) Other Important Considerations

Additional considerations can also be applied to make finer distinctions among potentially suitable sites. These criteria include:

- proximity to the incident – it may be useful to consider sites in different regions of the country to limit transportation demands;
- proximity to residential areas or commercial districts – the potential for disposal activities to affect nearby populations or commercial activities, whether located within the site boundaries or on adjacent property, should be considered;
- proximity to transportation – access to timely and direct transportation that can accommodate large shipments is desirable—
  - action to facilitate – construction of transportation infrastructure (e.g., direct rail lines);
- experience in waste disposal – waste disposal sites will have infrastructure, procedures and trained personnel that can make most efficient use of the site—
  - action to facilitate – development of infrastructure, training, construction of disposal cells and engineered containment (e.g., vaults or bunkers);
- level of existing contamination – areas that are unlikely to be remediated in the near future or unlikely to be released for public use may be more acceptable for disposal.

4.2.5. Potential Federal Actions to Develop New Disposal Capacity

In addition to criteria for siting new disposal facilities, the federal government has control of a large amount of land throughout the U.S. that could be repurposed, or could offer assistance to support state governments in developing new facilities.

a) DOE Sites

DOE has decades of experience in radioactive waste management. In considering the primary selection criteria described above, DOE sites in the western U.S. generally have more favorable characteristics and readily available property compared to those in the eastern U.S. However, DOE has successfully implemented disposal at the eastern sites, often with some engineering enhancements. DOE has several categories of sites for consideration, beginning with the most suitable—

- Active disposal or cleanup sites in the western U.S.
- Active disposal or cleanup sites in the eastern U.S.
- Closed sites with disposal areas.
- Closed uranium milling sites.
- Other long-term stewardship sites.

Considerations: Some DOE sites have agreements with states or other stakeholders regarding further disposal or cleanup activities. Current disposal sites have waste acceptance criteria by DOE policy or statute. Closed and long-term stewardship sites may not have large amounts of additional property

ED_001057_00010141

available for disposal.

b) DoD Installations

DoD maintains some installations with large land areas, primarily in the western U.S. Many of these sites have been contaminated through extensive training or other activities. DoD likely has more sites in the eastern U.S. than does DOE. Categories of sites that could be considered suitable include:

- bombing and firing ranges;
- chemical weapons demilitarization and storage sites;
- ammunition plants and arsenals;
- surplus properties (e.g., base realignment and closure (BRAC), formerly used defense site (FUDS)).

Considerations: Section 2692 of title 10, United States Code, "Storage, Treatment and Disposal of NonDefense Toxic and Hazardous Materials," generally provides that the Secretary of Defense may not permit the use of an installation of the DoD for the storage, treatment, or disposal of any material that is a toxic or hazardous material and that is not owned either by the DoD or by a member of the armed forces (or by a dependent of the member) assigned to or provided military housing on the installation. Radiological waste resulting from either a nuclear accident or a terrorist attack may fall under this prohibition. The Secretary of Defense may grant exceptions to this restriction when "essential to protect the health and safety of the public from imminent danger." A determination whether or not radiological waste meets the "imminent danger" threshold would be required.

Additionally, some DoD properties, including ranges in the western U.S., are on "withdrawn" lands, which are part of the public domain supervised by the Bureau of Land Management (BLM). Withdrawn land statutes permit DoD to use the property for specific military mission needs. The use of withdrawn lands to manage radiological waste would violate those statutes.

c) Other Federal Properties

Agencies such as the Department of Interior (DOI) or USDA own large properties that could be considered suitable for disposal, many of which are in the western U.S. These properties may be administered by discrete entities within the cabinet-level departments, such as the National Park Service (NPS), BLM, or Forest Service. Some properties may be in proximity to DOE or DoD lands.

Considerations: Properties may be designated for protection or public use (e.g., wilderness areas or preserves). Many properties are also in rugged terrain with difficult access or border tribal lands.

ED_001057_00010141

KEY POINTS IN CHAPTER 4 –LATE PHASE

- PAGs will not be used to guide restoration and recovery of areas impacted by a radiological incident; rather, planning activities should include developing a process to involve stakeholders in setting priorities and determining actions. Such a process should be flexible enough to adapt to a variety of situations.
- Planning considerations for worst case scenarios are provided. Smaller radiological incidents may be well addressed by existing emergency response and environmental cleanup programs at local, state, tribal and federal levels.
- Reoccupying households and businesses should be considered in balance with progress made in reducing radiation risks through decontamination, radioactive decay and managing contaminated waste.
- Exposure limits in a range of one in a population of ten thousand (10^{-4}) to one in a population of one million (10^{-6}) excess lifetime cancer incidence outcomes are generally considered protective, though this may not be achievable after a large radiological incident. In making decisions about cleanup goals and strategies for a particular event, decision makers must balance the desired level of exposure reduction with the extent of the measures that would be necessary to achieve it, in order to maximize overall human welfare.
- Incidents that create large volumes of waste from a wide-scale radiological incident would likely overwhelm existing radioactive waste disposal capacity in the U.S.
- Following a nuclear accident, the states bear primary responsibility to identify and provide waste management options, including disposal capacity; in the event of a terrorist attack, the federal government can offer a range of assistance to state governments to identify and implement waste management options.
- Safely managing and disposing of radioactive waste will require pre-planning at all levels of government and careful coordination with stakeholders at all stages of the decision-making process.

ED_001057_00010141

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ED_001057_00010141

APPENDIX B – GLOSSARY

Acute health effects: health problems caused by high radiation doses received in a short period of time. Examples of acute effects include erythema (reddening of skin), blistering, epilation (hair loss) and vomiting.

ALARA: acronym for "as low as is reasonably achievable" means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the activity is undertaken.

Alpha radiation: alpha radiation comes from the ejection of alpha particles from the nuclei of some unstable atoms. An alpha particle is identical to a helium nucleus and consists of two protons and two neutrons. Alpha particles are highly energetic, but can only travel a few centimeters in air. They have low penetrating power and can be stopped by a sheet of paper. Alpha particles generally cannot even penetrate the layer of dead cells on the skin, but can pose a health risk when inhaled or ingested.

Avoided dose: The radiation dose saved by implementing a protective action. (ICRP 1991b)

Beta radiation: beta radiation comes from the emission of beta particles during radioactive decay. Beta particles are highly energetic and fast-moving. They carry a positive or negative charge and can be stopped by a layer of clothing or few millimeters of a solid material. Beta particles can penetrate the skin and cause skin burns, but tissue damage is limited by their small size. Beta particles are most hazardous when inhaled or ingested.

Committed effective dose: The sum of the committed equivalent doses following intake (inhalation or ingestion) of a radionuclide to each organ multiplied by a tissue weighting factor.

Contamination: Radionuclides on surface or in the environment as a result of an accidental release.

Concentration: Radionuclide activity per unit of mass.

Chronic effects: Health problems caused by radiation doses delivered over a long period. Examples of chronic effects include cancer and genetic mutations.

Derived Intervention Level (DIL): Concentration derived from the intervention level of dose at which introduction of protective measures should be considered. (FDA 1998)

Derived Response Level (DRL): A level of radioactivity in an environmental medium that would be expected to produce a dose equal to its corresponding Protective Action Guide.

Dose: The amount of radiation exposure a person has received, calculated considering the effectiveness of the radiation type (alpha, beta, gamma), the timeframe of the exposure and the sensitivity of the person or individual organs.

Dose conversion factor (DCF): Any factor that is used to change an environmental measurement to dose in the units of concern.

ED_001057_00010141

Dose projection: A calculated future dose that an individual might receive; also the process of making these calculations.

Dose reduction factor: A factor by which a decontamination technique or protective action reduces the radiation dose to a person.

Dosimetry: The system for assessing radiation doses from external radiation exposures and from intakes of radionuclides using biokinetic models and dosimetric quantities developed by the ICRP and the International Commission on Radiation Units and Measurements (ICRU).

Effective dose: The sum of organ equivalent doses weighted by ICRP organ weighting factors.

Emergency Planning Zone: A designated zone around a commercial nuclear power plant for which radiological response plans must be maintained under Nuclear Regulatory Commission regulations.

Emergency Worker – Anyone with a role in responding to the incident whether a radiation worker or not, who should be protected from radiation exposure as describer in Section 2.5

Evacuation: The urgent removal of people from an area to avoid or reduce high-level, short-term exposure, from the plume or from deposited activity. Evacuation may be a preemptive action taken in response to a facility condition rather than an actual release.

Gamma radiation: Gamma radiation comes from the emission of high-energy, weightless, chargeless photons during radioactive decay. Gamma photons are pure electromagnetic energy and highly penetrating--several inches of lead or a few feet of concrete may be required to attenuate them. External exposure to gamma rays poses a health threat to the entire body. Inhalation and ingestion of gamma emitters also poses a health threat.

Graves' disease: An autoimmune disorder that leads to the over activity of the thyroid.

Groundshine: Gamma radiation emitted from radioactive materials deposited on the ground.

Half-life: The time required for the half the atoms of a given radioisotope to transform by radioactive decay.

Hashimoto's thyroiditis: An autoimmune disorder that leads to underactive thyroid with bouts of over activity.

Isodose-rate line: A contour line that is used to connect points of equal radiation dose rates.

Latency period, cancer: The time elapsed between radiation exposure and the onset of

cancer. **Microsievert:** One ten-thousandth of a rem. See Rem.

Millirem: One thousandth of a rem. See Rem.

Millisievert: One thousandth of a Sievert. See Sievert.

Noble gases: A group of elemental gases that are tasteless, odorless and that do not undergo chemical reactions under natural conditions. The noble gases consist of Helium, Neon, Argon, Krypton, Xenon and

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Radon

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Off-site: Areas outside the controlled border of a facility, such as a nuclear power plant. For an incident not involving a facility, this term may also be used to refer to areas impacted by contamination.

On-site: areas inside the controlled border of a facility, such as a nuclear power plant. For an incident not involving a facility, this term may refer to areas controlled during a response.

Potassium iodide: A salt of stable, nonradioactive iodine in medicine form. The administration of potassium iodine saturates the thyroid with non-radioactive iodine, so it does not absorb radioactive iodine released into the environment from a radiological incident.

Projected dose: The prediction of the dose that a population or individual could receive.

Protective actions: An activity conducted in response to an incident or potential incident to avoid or reduce radiation dose to members of the public.

Protective Action Guide (PAG): The projected dose to an individual, resulting from a radiological incident at which a specific protective action to reduce or avoid that dose is warranted.

Prophylactic: A treatment or medication designed to prevent exposure to radiation.

Rad (radiation absorbed dose): A basic unit of absorbed radiation dose. It is being replaced by the 'gray,' which is equivalent to 100 rad. One rad equals the dose delivered to an object of 100 ergs of energy, per gram of material.

Radioactive: Quality of a material that emits alpha particles, beta particles, gamma rays, or neutrons.

Radiological dispersion device (RDD): A device or mechanism that is intended to spread radioactive material from the detonation of conventional explosives or other means. An RDD is commonly known as a "dirty bomb."

Radiopharmaceutical: A radioactive chemical used for diagnosis, cure, treatment, or prevention of diseases.

Recovery: The process of reducing radiation exposure rates and concentrations of radioactive material in the environment to levels acceptable for unconditional occupancy or use.

Reentry: Workers or members of the public going into relocation or radiological contaminated areas on a temporary basis under controlled conditions.

Release: Uncontrolled distribution of radioactive material to the environment.

Relocation: The removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Not to be confused with *evacuation*.

Reoccupancy: The return of households and communities to relocation areas during the cleanup process, at radiation levels acceptable to the community.

ED_001057_00010141

Rem (roentgen equivalent man): The product of the absorbed dose in rads and a weighting factor which accounts for the effectiveness of the radiation to cause biological damage; a conventional unit for equivalent dose. One rem equals 0.01 Sv.

Release rate: The measure of the amount of radioactive dispersed per unit of time.

Return: Permanent resettlement in evacuation or relocation areas with no restrictions, based on acceptable environmental and public health conditions.

Sievert (Sv): International unit of equivalent dose.

Source term: The amount of a contaminant available in a scenario or actually released to the environment.

Total Effective Dose (TED): The sum of the effective dose (for external exposures) and the committed effective dose; also referred to in this Manual as whole body dose. See Section 2.4.

Yield-producing improvised nuclear device: A crude weapon fabricated from diverted fissile material that produces a nuclear explosion.

ED_001057_00010141

APPENDIX C – LIST OF ACRONYMS

AEA	Atomic Energy Act
ALARA	As Low as Reasonably Achievable
ANS	American Nuclear Society
BLM	Bureau of Land Management
BRAC	Base Realignment and Closure
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CWS	Community Water System
DCF	Dose Conversion Factor
DHS	Department of Homeland Security
DIL	Derived Intervention Levels
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOL	Department of Labor
DOT	Department of Transportation
DRL	Derived Response Level
EAL	Emergency Action Level
EPA	Environmental Protection Agency
EPZ	Emergency Planning Zone
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FRC	Federal Radiation Council
FRMAC	Federal Radiological Monitoring and Assessment Center
FRPCC	Federal Radiological Preparedness Coordination Committee
FUDS	Formerly Used Defense Site
HAZWOPER	Hazardous Waste Operations and Emergency Response
HHS	Department of Health and Human Services
HPS	Health Physics Society
IAEA	International Atomic Energy Agency
ICP	Incident Command Post

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ICRP	International Commission on Radiological Protection
ICRU	[WHAT DOES THIS STAND FOR]
IC/UC	Incident Command/Unified Command
IND	Improvised Nuclear Device

ED_001057_00010141

JFO	Joint Field Office
JIC	Joint Information Center
KI	Potassium Iodide
LLRW	~~Low-level radioactive waste~~ Lower-Level Radioactive Waste
LLRWPA	Low-Level Radioactive Waste Policy Act
MCL	Maximum Contaminant Level
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection and Measurements
NIMS	National Incident Management System
NNPP	Naval Nuclear Propulsion Program
NNSS	Nevada National Security Site
NPDWR	National Primary Drinking Water Regulations
NPP	Nuclear Power Plant
NPS	National Park Service
NRC	Nuclear Regulatory Commission
NRF	National Response Framework
NDRF	National Disaster Recovery Framework
NSS	National Security Staff
OSHA	Occupational Safety and Health Administration
PAG	Protective Action Guide
PIO	Public Information Officer
PPE	Personal Protective Equipment
RASCAL	Radiological Assessment System for Consequence Analysis
REMM	Radiation Emergency Medical Management
RCRA	Resource Conservation and Recovery Act
RDD	Radiological Dispersal Device
SDWA	Safe Drinking Water Act
SNL	Sandia National Laboratories
TED	Total Effective Dose
USDA	United States Department of Agriculture

ED_001057_00010141

10 GROUP G: FOOD CONSUMPTION

10.1 INTRODUCTION

Four subgroups of operational guidelines for food are presented here. These guidelines complement and supplement the DILs published by the FDA (FDA 1998). The first subgroup of guidelines is in terms of limiting concentration in food, which is similar to the FDA DILs, but includes additional radionuclides and utilizes updated dose conversion factors. The other three subgroups of operational guidelines are expressed as limiting concentrations in surface soil. They were developed by considering consumption of crops (vegetables, fruits, and grains) and animal products (meat and milk) that are linked to contaminated soils through uptake pathways. The ingestion of crops and animal products from affected areas would not result in radiation doses that exceed the corresponding PAGs, if their concentrations or the soil concentrations in which they grow are below the Group G operational guidelines.

The first subgroup of operational guidelines was derived by using a methodology consistent with the one used by the FDA for developing the DILs for foods after a nuclear accident (FDA 1998). It considers potential radiation exposure from food ingestion and is based on a food PAG of either 5,000 mrem/yr committed equivalent dose to an individual organ or tissue, or 500 mrem/yr committed effective dose (CED), whichever is more limiting. Age-dependent food ingestion rates and ICRP 72 (ICRP 1996) dose conversion factors were used in the derivation. The final operational guidelines were expressed in terms of food concentrations and were the most conservative values among the different age groups considered. To differentiate from the published FDA DILs, the derived food concentration values that use the FDA methodology are called planning values (PVs). These PVs are used as Group G, Subgroup 1, operational guidelines. These PVs could be used as an alternative to FDA DILs in the early phase of response after an RDD event.

In deriving the Group G, Subgroups 2 and 3, operational guidelines, the PVs for Subgroup 1 were applied for comparison with calculated concentrations in crops harvested or animal products produced after an RDD event. The operational guidelines of Subgroup 2 were developed by considering crops or fodder that had been growing during the event and became contaminated as a result of a passing contamination plume from the event. The methodology developed by FRMAC (Rhodes et al. 2003) was used to relate the plant/fodder concentration to

the deposited concentration on the ground surface. The operational guidelines are the concentrations in surface soil that would result in plant/milk concentrations equivalent to the PVs of Subgroup 1. Subgroup 2 soil operational guidelines supplement the PVs and are also intended for use in the early phase of response when measured concentrations of crops or animal products are not readily available.

Subgroup 3 soil operational guidelines consider crops planted after an RDD event that are intended for use in the intermediate phase of response after the event. Deposited soil and air concentrations, which were caused by resuspension from soil, were adjusted for weathering and radiological decay during the plant growing period. The RESRAD methodology (Yu et al. 2001) that accounts for foliar deposition and root uptake was used to calculate plant-to-soil concentration ratios, which were then used to back-calculate the soil operational guidelines.

Subgroup 4 soil operational guidelines also were developed by using the RESRAD methodology, except that they are based on a PAG of 500 mrem/yr (CED) rather than the PVs. To obtain the average concentrations in crops and animal products that are consumed over a year, the deposited soil and air concentrations were corrected for weathering and radiological decay over a 1-year period. The ingestion dose-to-source ratios were calculated and then were used to back-calculate the soil operational guidelines. The Subgroup 4 operational guidelines are dose (CED) based rather than PV based. They can be used for estimating the potential radiation doses that correspond to the Subgroup 3 soil operational guidelines. The Subgroup 4 operational guidelines are intended for use in the intermediate-to-late phase of response after an RDD event.

For Subgroups 2 to 4 operational guidelines, different types of plants (fodder, leafy vegetable, and grain and nonleafy vegetable) that link to the production of different types of food (meat, milk, and vegetables) were modeled. The most limiting food-to-soil concentration ratio (for Subgroups 2 and 3) or the sum of dose-to-source ratios (for Subgroup 4) was used to determine the final soil guideline.

It is important to note that Group G soil operational guidelines (Subgroups 2, 3, and 4) were developed by considering radiation exposure only through the food ingestion pathway. They can be used to determine whether ingestion of agricultural products (plant foods, meat, and milk) that are exposed to the contamination plume during an RDD event (Subgroup 2) or that will be cultivated and produced after an RDD event (Subgroups 3 and 4) would result in unacceptable human health risks. Because radiation exposure that would result from cultivating crops or raising livestock was not considered, Group G soil operational guidelines should not be

used to replace Group B operational guidelines for evacuation/sheltering or Group C operational guidelines for relocation. They can, however, be used in conjunction with the Group B or Group C operational guidelines to determine whether restriction on food ingestion or agricultural activities should be imposed on a contaminated area where residents are allowed to stay after an RDD event.

Comparisons of operational guidelines for the four subgroups in terms of their applications and derivations are presented in Appendix 10.A.

10.2 SUBGROUP 1 FOOD OPERATIONAL GUIDELINES FOR THE EARLY PHASE

For Subgroup 1, the derived food concentration PVs are used as operational guidelines. The derivation of PVs was based on the methodology used by the FDA for developing the DILs after a nuclear accident (FDA 1998). The PVs are not the same as the DILs, because updated dose conversion factors were used.

The FDA DIL for a specific radionuclide was calculated by using Equations 10.1–10.3:

$$DIL = \frac{PAG}{f \times FI \times DC} \tag{10.1}$$

$$FI = Annual\,Intake\,Rate \times IPC \tag{10.2}$$

$$IPC = \min\left[1 \;\; or \;\; -\frac{Ln(0.01)}{\lambda}\right] \tag{10.3}$$

where:

DIL = derived intervention levels (Bq/kg);

DC = dose coefficient, the radiation dose received per unit of radioactivity ingested (mSv/Bq);

f = fraction of the food ingested assumed to be contaminated;

IPC = ingestion period correction (yr);

λ = radionuclide decay constant (yr^{-1});

FI = food intake (kg); and

PAG = protective action guide for food ingestion (mSv).

Two PAGs were used in the calculation: 500 mrem (5 mSv) for CEDE, and 5 rem (50 mSv) for committed dose equivalent to an individual tissue or organ. The FDA DILs were calculated for nine radionuclides (I-131, Cs-134, Cs-137, Ru-103, Ru-106, Sr-90, Pu-238, Pu-239, and Am-241) and considered the receptors of six different age groups. In the calculation, age-dependent food ingestion rates and dose coefficients were used. The age groups considered were 3 months, 1 year, 5 years, 10 years, 15 years, and adult (>17 years).

The dose coefficients used by the FDA were from the International Commission on Radiation Protection (ICRP) Publication 56 (ICRP 1989). The food ingestion rates were based on the "entire diet" for each age group, which included tap water used for drinking. In deriving DILs, it was assumed that 30% of the food intake was contaminated (i.e., $f = 0.3$ in Equation 10.1). An exception was made for I-131 in the diets of the 3-month and 1-year age groups, for which the entire intake over a 60-day period was assumed to be contaminated. Table 10.1 provides the annual intake rates for the six age groups considered in deriving DILs. In the derivation of DILs, correction for radiological decay was not applied. However, the intake period was selected to be either 1 year or the time required for a radionuclide to decay to ~1% of its initial activity, whichever is smaller. As a result, for short-lived radionuclides, the intake period considered could be less than 1 year, and the yearly intake rate would be adjusted by the intake period correction factor (IPC in Equation 10.2). None of the radionuclides concerned for an RDD event in this report has a half-life short enough to require this correction. Appendix D in the FDA report (FDA 1998) describes in detail how DILs were calculated and lists the values of dose coefficients used. Among all the DILs that were calculated, combining different PAGs and age groups, the most limiting one was selected by FDA to be the recommended value for use after a nuclear accident.

TABLE 10.1 Dietary Intake Rates for Different Age Groups

Age Group	Annual Intake Rate (kg)
3-months	418
1-year	506
5-years	660
10-years	779
15-years	869
Adult	943

Later, the FDA calculated DILs for 15 more

radionuclides by using the same equations. Among all the radionuclides considered by the FDA (FDA 1998), six are among the RDD radionuclide list analyzed in this report. Table 10.2 lists the FDA DILs for those six radionuclides.

In deriving the DILs, the FDA followed the principles and general guidance provided by the ICRP Publication 40 (ICRP 1984). The ICRP has since updated its general concepts on intervention and has documented them in ICRP Publication 63 (ICRP 1991). The PVs for Subgroup 1 were calculated on the basis of the FDA methodology described previously, but with the updated concept (ICRP 1991) and revised dose coefficients obtained from ICRP Publication 72 (ICRP 1996). The dietary intake rates used for different age groups were the same as those listed in Table 10.1. Table 10.3 lists the dose coefficients from ICRP 72. Table 10.4 lists the calculated PVs for different age groups and different PAGs. The most restrictive value was selected to be the final operational guideline for Subgroup 1. The values are listed in Table 10.5, along with the corresponding age group and PAG. Measured radionuclide concentrations in crops or animal products produced from the affected area after an RDD event should be compared with the Subgroup 1 operational guidelines.

10.3 SUBGROUP 2 SOIL OPERATIONAL GUIDELINES FOR THE EARLY PHASE

Subgroup 2 soil operational guidelines were intended for use in the early phase of response after an RDD event. For this purpose, they consider the crops that have been growing during the event. As for the animal products, they consider those from livestock that fed on fodders grown in the field during the event. Because the crops or fodders are already growing during the event, the main contamination mechanism would be the uptake of radionuclides that

TABLE 10.2 FDA DILs with Corresponding PAG and Age Group for RDD Radionuclides

Radionuclide	DIL (Bq/kg)	Limiting Age Group	PAG (mSv)
Am-241	2	3-month	50
Cm-244	2	3-month	50
Cs-137	1,400	Adult	5
Pu-238	2	3-month	50
Pu-239	2	3-month	50
Sr-90	160	15-year	50

TABLE 10.3 Dose Coefficients (mSv/Bq)a from ICRP Publication 72 Used in Deriving the PVs for Food Operational Guidelines for the Early Phase (Subgroup 1)

Radionuclide	3-month	1-year	5-year	10-year	15-year	Adult
Am-241(BS)b	8.30E-02	8.30E-03	7.40E-03	7.30E-03	8.00E-03	9.00E-03
Am-241	3.70E-03	3.70E-04	2.70E-04	2.20E-04	2.00E-04	2.00E-04
Cf-252(BS)	0.11	9.90E-03	6.90E-03	4.00E-03	2.90E-03	2.90E-03
Cf-252	5.00E-03	5.10E-04	3.20E-04	1.90E-04	1.00E-04	9.00E-05
Cm-244(BS)	5.90E-02	5.80E-03	4.50E-03	3.90E-03	4.20E-03	4.90E-03
Cm-244	2.90E-03	2.90E-04	1.90E-04	1.40E-04	1.20E-04	1.20E-04
Co-60(LLI)b	9.9E-5(L)b	6.30E-05	3.70E-05	2.40E-05	1.5E-5(L)b	1.20E-05
Co-60	5.40E-05	2.70E-05	1.70E-05	1.10E-05	7.90E-06	3.40E-06
Cs-137(LLI)	4.90E-05	3.10E-05	1.90E-05	1.60E-05	1.60E-05	1.70E-05
Cs-137	2.10E-05	1.20E-05	9.60E-06	1.00E-05	1.30E-05	1.30E-05
Ir-192 (LLI)	1.40E-04	8.90E-05	4.60E-05	2.80E-05	1.60E-05	1.30E-05
Ir-192	1.30E-05	8.70E-06	4.60E-06	2.80E-06	1.70E-06	1.40E-06
Po-210 (Spleen)	2.20E-01	7.60E-02	4.10E-02	2.50E-02	1.60E-02	1.3E-02(K)b
Po-210	2.60E-02	8.80E-03	4.40E-03	2.60E-03	1.60E-03	1.20E-03
Pu-238(BS)	6.80E-02	6.90E-03	6.20E-03	5.90E-03	6.30E-03	7.40E-03
Pu-238	4.00E-03	4.00E-04	3.10E-04	2.40E-04	2.20E-04	2.30E-04
Pu-239(BS)	7.40E-02	7.60E-03	7.00E-03	6.80E-03	7.20E-03	8.20E-03
Pu-239	4.20E-03	4.20E-04	3.30E-04	2.70E-04	2.40E-04	2.50E-04
Ra-226(BS)	1.60E-01	2.90E-02	2.30E-02	3.90E-02	9.40E-02	1.20E-02
Ra-226	4.70E-03	9.60E-04	6.20E-04	8.00E-04	1.50E-03	2.80E-04
Sr-90(BS)	2.30E-03	7.30E-04	6.30E-04	1.00E-03	1.80E-03	4.10E-04
Sr-90	2.30E-04	7.30E-05	4.70E-05	6.00E-05	8.00E-05	2.80E-05

a The first listed value for each radionuclide is the most restrictive committed equivalent dose to an individual organ or tissue, $h_T(\tau)$. The second listed value for each radionuclide is the committed effective dose, $e(\tau)$. (τ is the time period over which the dose is calculated; that is, 50 years for adults and $(70-t_0)$ for children, where t_0 is the age considered for the age group.)

b BS = bone surface; LLI = lower large intestine; L = liver; K = kidney.

TABLE 10.4 PVsa (Bq/kg) for Different Age Groups and PAGs

Radionuclide	PAGs (mSv/yr)	3-month	1-year	5-year	10-year	15-year	Adult
Am-241(BS)[b]	50	4.8E+00	4.0E+01	3.4E+01	2.9E+01	2.4E+01	2.0E+01
Am-241	5	1.1E+01	8.9E+01	9.4E+01	9.7E+01	9.6E+01	8.8E+01
Cf-252(BS)	50	3.6E+00	3.3E+01	3.7E+01	5.3E+01	6.6E+01	6.1E+01
Cf-252	5	8.0E+00	6.5E+01	7.9E+01	1.1E+02	1.9E+02	2.0E+02
Cm-244(BS)	50	6.8E+00	5.7E+01	5.6E+01	5.5E+01	4.6E+01	3.6E+01
Cm-244	5	1.4E+01	1.1E+02	1.3E+02	1.5E+02	1.6E+02	1.5E+02
Co-60(LLI)[b]	50	4.0E+03	5.2E+03	6.8E+03	8.9E+03	1.3E+04	1.5E+04
Co-60	5	7.4E+02	1.2E+03	1.5E+03	1.9E+03	2.4E+03	5.2E+03
Cs-137(LLI)	50	8.1E+03	1.1E+04	1.3E+04	1.3E+04	1.2E+04	1.0E+04
Cs-137	5	1.9E+03	2.7E+03	2.6E+03	2.1E+03	1.5E+03	1.4E+03
Ir-192 (LLI)	50	2.8E+03	3.7E+03	5.5E+03	7.6E+03	1.2E+04	1.4E+04
Ir-192	5	3.1E+03	3.8E+03	5.5E+03	7.6E+03	1.1E+04	1.3E+04
Po-210 (Spleen)	50	1.8E+00	4.3E+00	6.2E+00	8.6E+00	1.2E+01	1.4E+01
Po-210	5	1.5E+00	3.7E+00	5.7E+00	8.2E+00	1.2E+01	1.5E+01
Pu-238(BS)	50	5.9E+00	4.8E+01	4.1E+01	3.6E+01	3.0E+01	2.4E+01
Pu-238	5	1.0E+01	8.2E+01	8.1E+01	8.9E+01	8.7E+01	7.7E+01
Pu-239(BS)	50	5.4E+00	4.3E+01	3.6E+01	3.1E+01	2.7E+01	2.2E+01
Pu-239	5	9.5E+00	7.8E+01	7.7E+01	7.9E+01	8.0E+01	7.1E+01
Ra-226(BS)	50	2.5E+00	1.1E+01	1.1E+01	5.5E+00	2.0E+00	1.5E+01
Ra-226	5	8.5E+00	3.4E+01	4.1E+01	2.7E+01	1.3E+01	6.3E+01
Sr-90(BS)	50	1.7E+02	4.5E+02	4.0E+02	2.1E+02	1.1E+02	4.3E+02
Sr-90	5	1.7E+02	4.5E+02	5.4E+02	3.6E+02	2.4E+02	6.3E+02

a The PVs are based on a PAG of either 50 mSv/yr committed equivalent dose to an individual organ or tissue (first listed value) or 5 mSv/yr committed effective dose (the second listed value).

b BS = bone surface; LLI = lower large intestine.

TABLE 10.5 Final Food Operational Guidelines (or PVs) for the Early Phase (Subgroup 1)

Radionuclide	Operational Guideline (PVs)		Age Group	PAG (mSv)
	Bq/kg	pCi/kg		
Am-241	4.8E+00	1.30E+02	3-month	50
Cf-252	3.6E+00	9.72E+01	3-month	50
Cm-244	6.8E+00	1.84E+02	3-month	50
Co-60	7.4E+02	2.00E+04	3-month	5
Cs-137	1.4E+03	3.78E+04	Adult	5
Ir-192	2.8E+03	7.56E+04	3-month	50
Po-210	1.5E+00	4.05E+01	3-month	5
Pu-238	5.9E+00	1.59E+02	3-month	50
Pu-239	5.4E+00	1.46E+02	3-month	50
Ra-226	2.0E+00	5.40E+01	15 year	50
Sr-90	1.1E+02	2.97E+03	15 year	50

were directly deposited on foliage from a contamination plume that passed the agriculture field. The potential contamination mechanism caused by root uptake of radionuclides deposited on surface soil would be much less because (1) it takes time for radionuclides to infiltrate to deeper soil, and the plants would be harvested or consumed before that occurs; and (2) the radionuclide concentration in the root zone would be greatly diluted by the bulk volume of soil. Although the root uptake mechanism would not contribute significantly to plant contamination during the plume phase, it was included in the modeling for completeness.

For the early phase of response (Subgroup 2), modeling of plant concentration was performed by using the FRMAC methodology (Rhodes et al. 2003). The crops considered for human consumption were leafy vegetables that were assumed to have a growing period of 0.2 year and a productivity of 2 kg/m2. Both are RESRAD default values (Yu et al. 2001). The radionuclide concentrations that were intercepted and retained on the foliage of crops during the plume phase were assumed to be 20% of those deposited on surface soil. This 20% value is the default used by FRMAC (Rhodes et al. 2003). The animal product considered for human consumption was milk. Contamination of meat products was not considered because it was not included in the FRMAC methodology. The growing period of fodder grazed by milk cows was assumed to be 0.08 year and the productivity to be 0.7 kg/m2. Both are RESRAD default values (Yu et al. 2001). The radionuclide concentrations directly deposited on the fodder were 50% of those deposited on surface soil, which was the default value used by FRMAC (Rhodes et al.

2003), and all fodder consumed by milk cows was assumed contaminated. The root uptake transfer factors and food-to-milk transfer factors used in the modeling were the default values used by FRMAC (Rhodes et al. 2003), and these are listed in Table 10.6. Note that the plant/soil transfer factors for root uptake used by FRMAC are taken from the RESRAD database (Yu et al. 2001).

Table 10.7 lists the calculated food-to-soil concentration ratios and soil operational guidelines corresponding to the PVs listed in Table 10.5. The calculated milk concentration was converted from pCi/L to pCi/kg by using an assumed milk density of 1 kg/L. For the plant concentration, washing or rinsing vegetables to remove radionuclides deposited on leaves was not considered. For each radionuclide, two operational guidelines were calculated on the basis of crop and milk consumption. The more conservative value from these two (the smaller one) was selected for use in the early response phase after an RDD event. For all radionuclides except Cs-137, the final operational guidelines were derived on the basis of leafy vegetable consumption. For Cs-137, the final operational guideline was derived on the basis of milk consumption because of the large fodder-to-milk transfer factor (0.0079 d/L) for Cs.

TABLE 10.6 Transfer Factors Used by the FRMAC and RESRAD Methodologies

	FRMAC Methodology		RESRAD Methodology		
Radionuclide	Plant/Soil Transfer Factor for Root Uptake	Milk Transfer Factor (d/L)	Plant/Soil Transfer Factor for Root Uptake	Meat Transfer Factor (d/kg)	Milk Transfer Factor (d/L)
Am-241	1.0E-03	1.5E-06	1.0E-03	5.0E-05	2.0E-06
Cf-252	1.0E-03	2.0E-06	1.0E-03	6.0E-05	7.5E-07
Cm-244	1.0E-03	2.0E-06	1.0E-03	2.0E-05	2.0E-06
Co-60	8.0E-02	2.0E-03	8.0E-02	2.0E-02	2.0E-03
Cs-137	4.0E-02	7.9E-03	4.0E-02	3.0E-02	8.0E-03
Ir-192	3.0E-02	2.0E-06	3.0E-02	2.0E-03	2.0E-06
Po-210	1.0E-03	3.4E-04	1.0E-03	5.0E-03	3.4E-04
Pu-238	1.0E-03	1.1E-06	1.0E-03	1.0E-04	1.0E-06
Pu-239	1.0E-03	1.1E-06	1.0E-03	1.0E-04	1.0E-06
Ra-226	4.0E-02	1.3E-03	4.0E-02	1.0E-03	1.0E-03
Sr-90	3.0E-01	2.8E-03	3.0E-01	8.0E-03	2.0E-03

TABLE 10.7 Subgroup 2 Soil Operational Guidelines for the Early Phase of Response after an RDD Incident

	Food/Soil Concentration Ratio [(pCi/kg)/(pCi/m2)]		Operational Guideline for Individual Food Category (pCi/m2)		Final Soil Operational Guideline (pCi/m2)
Radionuclide	Vegetable	Milk	Vegetable	Milk	
Am-241	1.00E-01	5.36E-05	1.30E+03	2.42E+06	1.30E+03
Cf-252	9.99E-02	7.13E-05	9.73E+02	1.36E+06	9.73E+02
Cm-244	1.00E-01	7.14E-05	1.84E+03	2.57E+06	1.84E+03
Co-60	1.00E-01	7.14E-02	2.00E+05	2.80E+05	2.00E+05
Cs-137	1.00E-01	2.82E-01	3.78E+05	1.34E+05	1.34E+05
Ir-192	9.91E-02	7.01E-05	7.63E+05	1.08E+09	7.63E+05
Po-210	9.95E-02	1.20E-02	4.07E+02	3.37E+03	4.07E+02
Pu-238	1.00E-01	3.93E-05	1.59E+03	4.06E+06	1.59E+03
Pu-239	1.00E-01	3.93E-05	1.46E+03	3.71E+06	1.46E+03
Ra-226	1.00E-01	4.64E-02	5.40E+02	1.16E+03	5.40E+02
Sr-90	1.00E-01	1.00E-01	2.97E+04	2.97E+04	2.97E+04

10.4 SUBGROUP 3 SOIL OPERATIONAL GUIDELINES FOR THE INTERMEDIATE PHASE

Subgroup 3 operational guidelines were intended for use in the intermediate phase of response after an RDD event. They consider crops or fodders that grow after the passage of the contamination plume. Plants become contaminated as a result of foliage deposition of airborne radionuclides that originate from the ground surface through resuspension. In addition to foliage deposition, radionuclides that infiltrate from the ground surface to deeper soils could also be taken up by root systems and transferred to plant tissues. Modeling of plant concentrations was performed by using the RESRAD methodology (Yu et al. 2001), because the consideration of direct plume deposition by the FRMAC methodology does not apply to the plants grown after the plume phase.

Two types of crops were modeled: (1) leafy vegetables and (2) grain and nonleafy vegetables. For animal products, meat and milk produced by livestock feeding on fodders grown after the plume phase were considered. The Subgroup 3 soil operational guidelines were derived in terms of the concentrations of radionuclide deposited surface soil that would result in the production of crops or animal products with contamination levels equivalent to the PVs (i.e., Subgroup 1 operational guidelines). In the modeling, average soil and air concentrations

over the growing periods of vegetables and fodders were used to calculate the respective plant concentrations. The use of average plant concentrations accounts for the decrease with time due to radiological decay and weathering. The methodology for calculating the average soil and air concentrations is consistent with that used in the operational guidelines for Groups B–E, which is described in Chapter 2.

The other assumptions used in the modeling include the following:

1. The growing period for leafy vegetables is 0.25 year, 0.17 year for grain and nonleafy vegetables, and 0.08 year for fodder.

2. The ingestion rate of fodder by meat cows is 68 kg/d and 55 kg/d by milk cows.

3. The ingestion rate of soil by meat and milk cows is 0.5 kg/d.

4. The storage times for grain and nonleafy vegetables, leafy vegetables, meat, and milk are 14, 1, 20, and 1 day, respectively.

5. The depth of soil mixing layer is the plow depth of 0.15 m.

6. The depth of roots is the same as the plow depth, 0.15 m.

7. The soil density is 1.5 g/cm3.

The root uptake transfer factors and fodder-to-meat and -milk transfer factors are listed in Table 10.6. Except for the depth of roots, all parameter values used in the modeling are RESRAD default values. The depth of roots is taken from FRMAC (Rhodes et al. 2003).

Table 10.8 lists the Subgroup 3 soil operational guidelines for different food categories. The food category that resulted in the minimum soil concentration was selected to be the final soil guideline value. For most of the radionuclides, except for Co-60, Cs-137, and Po-210, the final guidelines were determined by consumption of leafy vegetables. For Co-60, Cs-137, and Po-210, the final guidelines were determined by consumption of meat products.

TABLE 10.8 Subgroup 3 Soil Operational Guidelines for the Intermediate Phase of Response after an RDD Incident

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Radionuclide	Food/Soil Concentration Ratio [(pCi/kg)/(pCi/m2)]				Soil Operational Guideline for Individual Food Category (pCi/m2)				Final Soil Operational Guideline (pCi/m2)
	Nonleafy Vegetable	Leafy Vegetable	Meat	Milk	Nonleafy Vegetable	Leafy Vegetable	Meat	Milk	
Am-241	8.84E-06	2.00E-05	2.70E-07	9.59E-09	1.47E+07	6.49E+06	4.79E+08	1.35E+10	6.49E+06
Cf-252	8.62E-06	1.96E-05	3.18E-07	3.57E-09	1.13E+07	4.95E+06	3.06E+08	2.72E+10	4.95E+06
Cm-244	8.81E-06	1.99E-05	1.08E-07	9.58E-09	2.08E+07	9.21E+06	1.70E+09	1.92E+10	9.21E+06
Co-60	3.48E-04	3.56E-04	5.75E-04	4.76E-05	5.74E+07	5.61E+07	3.48E+07	4.20E+08	3.48E+07
Cs-137	1.79E-04	1.88E-04	5.12E-04	1.14E-04	2.12E+08	2.01E+08	7.39E+07	3.32E+08	7.39E+07
Ir-192	9.10E-05	1.00E-04	2.09E-05	2.08E-08	8.31E+08	7.53E+08	3.62E+09	3.63E+12	7.53E+08
Po-210	7.44E-06	1.79E-05	2.33E-05	1.54E-06	5.44E+06	2.26E+06	1.74E+06	2.63E+07	1.74E+06
Pu-238	8.83E-06	2.00E-05	5.41E-07	4.80E-09	1.80E+07	7.98E+06	2.95E+08	3.32E+10	7.98E+06
Pu-239	8.84E-06	2.00E-05	5.41E-07	4.80E-09	1.65E+07	7.30E+06	2.69E+08	3.04E+10	7.30E+06
Ra-226	1.79E-04	1.89E-04	1.71E-05	1.42E-05	3.02E+05	2.86E+05	3.16E+06	3.79E+06	2.86E+05
Sr-90	1.31E-03	1.31E-03	7.58E-04	1.54E-04	2.27E+06	2.27E+06	3.92E+06	1.92E+07	2.27E+06

10.5 SUBGROUP 4 SOIL OPERATIONAL GUIDELINES FOR THE INTERMEDIATE-TO-LATE PHASE

Subgroup 4 soil operational guidelines were developed on the basis of a PAG of 500 mrem/yr, rather than the PVs of Subgroup 1. They can be used for estimating the potential radiation doses that correspond to the Subgroup 3 soil operational guidelines and are intended for use during the intermediate-to-late phases of response after an RDD event. Like Subgroup 3 operational guidelines, they consider crops or fodders that grow in a contaminated area after an RDD event. The methodology used to calculate the concentrations in crops and fodder was consistent with that used in Subgroup 3, except that the soil and air concentrations were corrected for weathering and radiological decay for a 1-year period. This was done to calculate the average concentrations in food products that were assumed to be produced continuously throughout a year for consumption. The total radioactivity ingested within a year was calculated by multiplying the average concentrations in food products by the annual consumption rate of the products. The annual

ingestion of radioactivity was then converted to annual dose with the use of dose conversion factors.

An average adult was considered as the general receptor and was assumed to ingest 160 kg/yr of grain and nonleafy vegetables, 14 kg/yr of leafy vegetables, 92 L/yr of milk, and 63 kg/yr of meat. Among all food ingested, 30% was assumed to be contaminated, which was also the assumption used by the FDA when deriving the DILs. These consumption rates are consistent with RESRAD default values. Dose conversion factors were obtained from ICRP 72 (ICRP 1996). The derived soil operational guidelines for different food categories for Subgroup 4 are listed in Table 10.9. They are the surface soil concentrations that would produce contaminated crops and animal products through uptake pathways that, after consumption, individually would result in a radiation dose of 500 mrem/yr (CED).

The final soil operational guidelines were obtained by considering consumption of all the different types of food are produced from the same contaminated area. In reality, because of the limitation in size or location of the contaminated area, the agricultural activities may be limited to produce only a certain type, or types, of food. In that case, the final soil operational guidelines can be increased to reflect the real situations. The last column of Table 10.9 shows the soil operational guidelines that pertain to consumption of only leafy and nonleafy vegetables.

BLE 10.9 Subgroup 4 Soil Operational Guidelines for the Intermediate-to-Late Phase of Response after an RDD Incident

	Annual Dose/Soil Concentration Ratio ([mrem/yr)/(pCi/m2])				Soil Operational Guidelines for Individual Food Category (pCi/m2)				Final Soil Operational Guideline (all foods combined) (pCi/m2)	Soil Operation Guideline (lea and nonleafy vegetables combined) (pCi/
ionuclides	Nonleafy Vegetable	Leafy Vegetable	Meat	Milk	Nonleafy Vegetable	Leafy Vegetable	Meat	Milk		
-241	1.78E-07	2.74E-08	1.85E-09	1.03E-10	2.80E+09	1.82E+10	2.71E+11	4.86E+12	2.41E+09	2.43E+09
252	7.15E-08	1.15E-08	8.80E-10	1.55E-11	6.99E+09	4.37E+10	5.68E+11	3.23E+13	5.96E+09	6.03E+09
244	1.79E-07	1.63E-08	4.35E-10	6.07E-11	2.79E+09	3.07E+10	1.15E+12	8.23E+12	2.55E+09	2.56E+09
60	1.82E-07	1.62E-08	1.08E-07	1.30E-08	2.75E+09	3.09E+10	4.65E+09	3.83E+10	1.57E+09	2.52E+09
137	3.69E-07	3.31E-08	3.58E-07	1.17E-07	1.35E+09	1.51E+10	1.39E+09	4.27E+09	5.70E+08	1.24E+09
92	7.98E-09	8.49E-10	5.37E-10	7.88E-13	6.26E+10	5.89E+11	9.31E+11	6.35E+14	5.34E+10	5.66E+10
210	5.42E-07	1.09E-07	5.22E-07	5.36E-08	9.22E+08	4.58E+09	9.58E+08	9.32E+09	4.07E+08	7.67E+08
238	2.04E-07	3.15E-08	4.23E-09	5.90E-11	2.45E+09	1.59E+10	1.18E+11	8.47E+12	2.08E+09	2.12E+09
239	2.23E-07	3.43E-08	4.62E-09	6.44E-11	2.24E+09	1.46E+10	1.08E+11	7.77E+12	1.91E+09	1.94E+09
226	8.05E-06	7.21E-07	2.61E-07	3.19E-07	6.21E+07	6.93E+08	1.92E+09	1.57E+09	5.35E+07	5.70E+07
0	6.50E-06	5.71E-07	1.43E-06	4.25E-07	7.69E+07	8.75E+08	3.49E+08	1.18E+09	5.60E+07	7.07E+07

10.6 REFERENCES

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APPENDIX 10.A:

COMPARISON OF OPERATIONAL GUIDELINES FOR GROUP G

APPENDIX 10.A:

COMPARISON OF OPERATIONAL GUIDELINES FOR GROUP G

Comparisons of operational guidelines among the four subgroups are presented in this appendix. Table 10.A.1 compares the intended applications and the methodology used in the guideline derivation. Table 10.A.2 compares the parameter values used in the derivation.

TABLE 10.A.1 Comparison of Intended Uses and Derivation of Operational Guidelines for Subgroups 1–4

Parameters	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Expression form	In terms of limiting concentrations in food (pCi/kg)	In terms of limiting concentrations in surface soil (pCi/m2)	In terms of limiting concentrations in surface soil (pCi/m2)	In terms of limiting concentrations in surface soil (pCi/m2)
PAG	5,000 mrem/yr committed equivalent dose to an individual organ or 500 mrem/yr CED	Not required – use PVs (operational guidelines for Subgroup 1) as target food concentrations	Not required – use PVs (operational guidelines for Subgroup 1) as target food concentrations	500 mrem/yr CED
Intended uses	For placing embargo and consumption restriction on plant food or animal products that are exposed during an RDD event	For placing embargo and consumption restriction on plant food or animal products that are exposed during an RDD event	For placing land use restriction for agricultural activities after an RDD event	For (1) evaluating potential radiation doses corresponding to Subgroup 3 operational guidelines, and (2) placing land use restriction for agricultural activities after an RDD event
When to apply	In the early phase of response	In the early phase of response	In the intermediate phase of response	In the intermediate-to-late phase of response
How to apply	Compare with measured concentrations taken from food that was exposed during an RDD event	Compare with measured concentrations taken from surface soil in which plant foods/fodder were growing during an RDD event	Compare with measured concentrations taken from surface soil in the contaminated area	Compare with measured concentrations taken from surface soil in the contaminated area
Methodology	Based on FDA methodology for deriving DILs, but with updated dose coefficients	Used FRMAC methodology to relate concentrations in plant food/milk to the deposited surface soil concentration during the plume phase	Used RESRAD model to relate concentrations in plant food/meat/milk to the residual surface soil concentration; soil and air concentrations were corrected for weathering and radiological decay during the growing period	Used RESRAD model to relate the potential annual ingestion dose to the residual surface soil concentration, through the calculation of average concentrations in plant food/meat/milk; soil and air concentrations were corrected for weathering and radiological decay for 1-year period
Specific consideration/ comments	Different age groups and the respective dose coefficients	Foliar deposition results from a passing plume	Foliar deposition results from airborne contaminants that originate from ground surface due to resuspension	Same as Subgroup 3

TABLE 10.A.2 Comparison of Parameter Values Used in the Derivation of Operational Guidelines for Subgroups 1–4

Parameters	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Contaminated food types	All food types, including water	Leafy vegetables and milk	Grain and nonleafy vegetables, leafy vegetables, meat, and milk	Grain and nonleafy vegetables, leafy vegetables, meat, and milk
Contaminated soil	NR[a]	Mixing depth – 15 cm; soil density – 1.5 g/cm3	Same as Subgroup 2	Same as Subgroup 2
Dietary intake of human	Age-dependent: 3-month – 418 kg; 1-yr – 506 kg; 5-yr – 660 kg; 10-yr – 779 kg; 15-yr – 869 kg; adult – 943 kg.	NR	NR	Adult – 160 kg/yr of grain and nonleafy vegetables; 14 kg/yr of leafy vegetables; 93 L/yr of milk; and 63 kg/yr of meat
Dietary intake of livestock	NR	Milk cow – 50 kg/d fodder	Meat cows – 68 kg/d fodder and 0.5 kg/d soil; milk cows – 55 kg/d fodder and 0.5 kg/d soil	Meat cows – 68 kg/d fodder and 0.5 kg/d soil; milk cows – 55 kg/d fodder and 0.5 kg/d soil
Contaminated fraction of human food	0.3	NR	NR	0.3
Contaminated fraction of animal fodder	NR	1	1	1
Food growing period	NR	Leafy vegetables – 0.25 yr; fodder – 0.08 yr	Grain and nonleafy vegetables – 0.17 yr; leafy vegetables – 0.25 yr; fodder – 0.08 yr	Same as Subgroup 3
Crop productivity	NR	Leafy vegetables – 2 kg/m2; fodder – 0.7 kg/m2	Grain and nonleafy vegetables – 0.7 kg/m2; leafy vegetables – 1.5 kg/m2; fodder – 1.1 kg/m2	Same as Subgroup 3
Storage time	NR	Leafy vegetables – 1 d; fodder – 0 d; and milk – 2 d	Grain and nonleafy vegetables – 14 d; leafy vegetables – 1 d; fodder – 0 d; meat – 20 d; milk – 1 d	Same as Subgroup 3

TABLE 10.A.2 (Cont.)

Parameters	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Transfer factors	NR	Root uptake transfer factors and milk transfer factors are listed in Table 10.6	Root uptake transfer factors and meat and milk transfer factors are listed in Table 10.6; root uptake transfer factors are the same as Subgroup 2; milk transfer factors are slightly different from Subgroup 2	Same as Subgroup 3
Deposition velocity	NR	NR	0.001 m/s	0.001 m/s
Weathering removal constant	NR	NR	20 yr^{-1} for plants	20 yr^{-1} for plants
Foliage to food transfer factor	NR	1	Nonleafy – 0.1; leafy – 1; fodder – 1	Nonleafy – 0.1; leafy – 1; fodder – 1
Fraction of the initially retained deposition at harvest	NR	1	1	1
Fraction of deposition initially retained	NR	0.2 for crops, 0.5 for fodder	0.25	0.25

[a] NR indicates the information is not required.

Radiological Emergency Response - Quick Reference Guide 2
Accident Types

Source Document – *FRMAC Assessment Manual, Volume 2, Pre-Assessed Default Scenarios*, February 2010 (SAND2010-2575P)

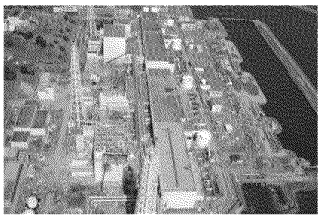
Primary purposes of the *Pre-Assessed Default Scenarios* Volume are to provide the user with:

- A sound scientific basis in technical and assessment processes, plus conversion values that have been agreed upon ahead of time. This assures that the correct values will be used and the results will be consistent among users from shift to shift.
- One document, for quick and easy use, that contains technical values and assessment processes expected to be used during a radiological response. However, reference documents will be available at the FRMAC for special assessments that are not included in the manual.

Users should verify they have the most recent version of the manual by visiting:

http://www.nv.energy.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx

Nuclear Power Plant Accident



Major Concerns: During plume passage, the primary concern is the thyroid dose due to inhalation of I-131. Following plume passage, the major source of dose is from external exposure from radioactive deposits. Principal nuclides expected to deliver the major portion of the radiation dose are primarily beta and gamma emitters:

- Plume Phase: Kr-88, Xe-133, Xe-135; I-131, I-132, I-133, I-135; Te-131m, Te-132, Sb-129
- First Year: I-131, Te-132; Cs-134, Cs-136, Cs-137; Ru-103, Ru-106; Ba-140, La-140; Nb-95, Zr-95; Ce-141, Ce-144; Pu-238 (alpha emitter), Pu-241 (beta emitter)

Major accidents at nuclear power plants have the potential to release large amounts of radioactivity to the environment.

- Total inventory of radioactivity in a 1000 MW_e reactor that has been operating for one year is approximately 1.5×10^{10} Ci.
- Inventory consists of:
  - Fuel – few hundred Ci
  - Fission products such as I-131 and Cs-137 – majority of inventory
    - Gaseous form such as Kr and Xe
    - Highly volatile form such as I
    - Particulate form such as Cs
  - Activation products such as Co-60 and Mn-54
  - Radionuclides formed from neutron capture reactions such as Pu-239.

Control maintained through containment features:

- Fuel pellet ceramic matrix
- Fuel cladding
- Reactor vessel
- Containment building

Aged Fission Product Accident

Major Concerns: External exposure to deposition and possible contamination of the skin are the major concern. Inhalation of material (plume or resuspension) is not likely to be a major dose pathway. Greatest challenge will be determination of the radionuclide mix which may change due to chemical reactions in the environment.

Most likely involve nuclear reactor wastes or fuel reprocessing materials. Severity will depend on the quantity and age of the material plus the mechanism by which it is released. Principal nuclides which are expected to deliver the major portion of the radiation dose are:

- Sr-90 (beta emitter)
- Cs-137 (beta and gamma emitter)
- Pu-239 (alpha emitter)
- Am-241 (alpha emitter)

Accidents posing greatest risk of release involve

- Process explosions
- Fires
- Widespread loss of containment due to an external event (earthquake, terrorist attack, airplane crash)

Nuclear Fuel Accident

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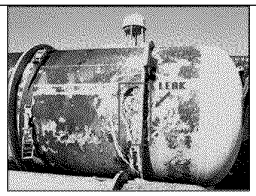
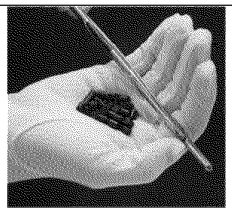


Cylinder Leak

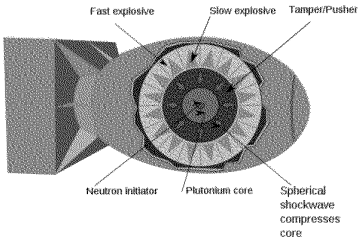


Major Concerns: For releases of UF_6, doses are dominated by inhalation pathway during plume phase. Doses due to resuspension will be small.

Strictly limited to unirradiated uranium fuel. Two types of accidents assessed:

- Dispersal of a large uranium inventory as a solid (e.g., metal, ceramic, powder)
  - Fires and explosions of a solid form of uranium cannot lead to serious dose, exposure, or contamination
- Release of uranium as uranium hexafluoride (UF_6)
  - Chemical toxicity effects may dominate the radiological consequences and must be considered
  - Inhalation dose is near negligible for uranium that has recently been chemically separated, but significant for uranium old enough to come to equilibrium with the progeny. Enrichment has little effect on the consequences.

Nuclear Weapon Accident (without Nuclear Yield)

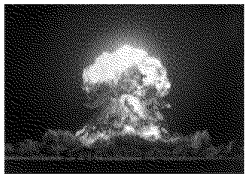


Major Concerns: Plutonium is primarily an alpha emitter that presents an internal radiation hazard from inhalation and ingestion.

Two accidents without nuclear yield:

- The nuclear weapon carrier (aircraft or vehicle) sustains an accident resulting in a fire or explosion, but the weapon survives essentially intact, without having detonated the high explosives or undergone a nuclear yield.
- The high explosives detonate with resulting dispersal of radioactive material into the environment, but there is no nuclear yield. Primary radiological hazard:
  - Plutonium – Pu-239 (alpha emitter) is expected to deliver the major portion of the radiation dose
  - Uranium – toxicological hazard (ingestion or inhalation can result in a type of heavy metal poisoning with possible renal damage)
  - H-3 (beta emitter)

Nuclear Yield Accident – NOTE: Section still under development – February 2010 version



Major Concerns: Criticality incidents have little potential for off-site consequences. However, can be lethal to those in near proximity with the most serious hazard from the large burst of prompt gamma and neutron radiation due to fission.

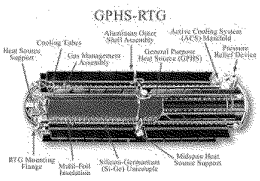
Nuclear detonation has two regions of effects:

1. A near-field region where the blast and thermal effects greatly exceed the radiological effects. The radiation levels will greatly exceed decision and turn-back levels. Mortal injuries will be unavoidable.
2. A far-field region which extends far downwind where only radiological hazards exist. Fallout may be delayed sufficiently to shelter or evacuate. Contamination of crops and animals in excess of FDA PAGs is likely to occur over a vast area.

Two accidents types:

- A nuclear criticality event – possible for lower enrichment levels given sufficient mass. Primary product is radiation arising from:
  - Prompt gamma and neutron radiation from the fission process
  - Gamma and beta radiation from the decay of fissions products created by the criticality
  - Radiation from surrounding materials that were activated by neutrons
- Detonation of a nuclear weapon with significant nuclear yield results in blast pressure, thermal radiation, direct (nuclear radiation), and radioactive fallout. FRMAC deals with:
  - Direct nuclear radiation – prompt gamma and neutron radiation from the fission process and residual radiation resulting from the decay of fission and activation products – considered a local (within a few kilometers) hazard
  - Radioactive fallout – beta and gamma radiation resulting from the decay of fission products that were condensed onto particles of inert material (dirt and dust) and vaporized in the detonation – has potential to present a hazard for much greater distances
- Ground level detonations produce a much greater amount of fallout than those that occur at higher altitudes

Radioisotopic Thermoelectric Generator Accident



Major Concerns: Inhalation is the principal radiological hazard. Since Pu-238 has a high specific activity, the radioactivity of a single microscopic particle in a measurement may be large compared to the decision level. So, monitoring effectiveness may not be a matter of detection sensitivity, but the challenge of finding and capturing a particle.

Nuclear power sources used in spacecraft consist of radioisotopic thermoelectric generators (RTGs) and radioisotope heater units (RHUs). These power sources use Pu-238 (alpha emitter) dioxide in a ceramic form. They are designed to contain their fuel under most accident conditions.

Several types of accidents may occur:

- First stage accident at launch
- Orbital decay resulting in re-entry to the earth's atmosphere
- Re-entry at higher than orbital velocities during a fly-by maneuver for deep space missions

Inadvertent re-entry is most severe environment and could lead to:

- Intact or damaged modules
- Intact graphite impact shells
- Fuel released at high altitude in both particulate and vapor form

Radiological Dispersal Device Accident

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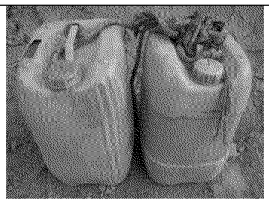 **Major Concerns:** Possible consequences depend on the type and quantity of radioactive material, the dispersal method, the location of the device, urban canyon effects, and local meteorological conditions. The effect may range from a small, localized area to a large, wide-spread area.	A Radiological Dispersal Device (RDD) is a device that is designed to spread radioactive material with the intent to cause panic and economic impact, and to contaminate and render large urban areas unusable. Materials most likely to be used are large industrial and medical sources including (but not limited to): ▪ Cs-137 (beta and gamma emitter) ▪ Co-60 (beta and gamma emitter) ▪ Am-241 (alpha emitter) ▪ Ir-192 (beta and gamma emitter) The explosive device also presents an immediate threat to human life, health, and property. Other hazards include fire, smoke, shock, shrapnel, industrial chemicals, and other chemical or biological agents.

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Radiological Emergency Response - Quick Reference Guide 3
2013 Draft PAG Manual Overview

Background: The 2013 Draft PAG Manual, Protective Action Guides and Planning Guidance for Radiological Incidents, was issued in March 2013 as a draft for interim use and comment. The manual was developed to assist public officials in planning for emergency response to radiological incidents. It provides radiological protection criteria for application to all incidents that would require consideration of protective actions, with the exception of nuclear war. The manual provides recommended numerical protective actions guides (PAGs) for the principal protective actions available to public officials during a radiological incident. **A PAG is defined as the projected dose to an individual resulting from a radiological incident at which a specific protective action to reduce or avoid that dose is warranted.**

The PAGs have not numerically changed from those provided in the 1992 PAG Manual (EPA 400-R-92-001, May 1992). However, EPA recommends that the dosimetry for all the PAGs be updated using the International Commission of Radiological Protection (ICRP) Publication 60 series. The PAGs may be implemented using calculated, measurable values such as those contained in the Federal Radiological Monitoring and Assessment Center (FRMAC) Assessment Manuals or through using other incident-specific dose assessment methodologies.

This Quick Reference Guide (QRG) provides an overview of the 2013 Draft PAG Manual.

Source Document: The 2013 PAG Manual, Protective Action Guides and Planning Guidance for Radiological Incidents. The document is broken into four chapters and three appendices. At the end of each chapter is a list of key points in that chapter.

Chapter	Title
	Limits on Scope
1	Overview
2	Early Phase Protective Action Guides
3	Intermediate Phase Protective Action Guides
4	Guidance for the Late Phase
Appendix	**Title**
A	References
B	Glossary
C	List of Acronyms

In addition to providing PAGs for determining protective actions for the public, the manual includes guidance for

- Determining the most appropriate protective action for each time phase (see Sections 2.3 and 3.3);
- Determining the sequence of events for doing dose projections (see Sections 2.4 and 3.4);
- Controlling exposure and dose to emergency workers and recovery workers (see Sections 2.5, 2.6, 3.4, and 3.8); and
- Controlling surface contamination (see Sections 2.7 and 3.8).

Protective action guidance for food and drinking water are summarized in Section 3.5 – food PAGs are found in FDA's "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies" (1998). A specific PAG for drinking water is not given; however, guidance for minimizing the impact of radioactivity in water is provided.

Section 3.8 (starting on page 47 of the manual) is a "Reentry Matrix Following a Radiological Incident or Accident." It provides a handy summary of the cleanup actions for each activity and suggested level for the Early and Intermediate time phases.

Chapter 4 describes the remediation cleanup process for the late phase including factors for decision makers to consider in determining final cleanup actions.

Incident Phases, Exposure Pathways, and Protective Actions:
Emergency planners divide response to radiological incidents into three phases of activity. These phases cannot be represented by precise periods of time and may even overlap. It is helpful to view them in terms of activities, rather than time spans.

- Early Phase – The beginning of a radiological incident when immediate decisions for effective use of protective actions are required and must be based primarily on the status of the radiological incident and the prognosis for worsening conditions.
- Intermediate Phase – The period beginning after the source and releases have been brought under control and reliable environmental measurements are available for use as a basis for decisions on protective actions and extending until these additional protective actions are no longer needed.
- Late Phase – The period beginning when recovery actions designed to reduce radiation levels in the environment to acceptable levels are commenced and ending when all recovery actions have been completed.

The table on the next page summarizes the incident phases, protective action guides, and protective actions is given below (it can be found on page 7 of the Manual – hyperlinks in the table do not work from this QRG).

QRG-5 provides a graphical representation of the incident phases, exposure pathways, and protective actions.

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Table 1-1. Planning Guidance and Protective Action Guides for Radiological Incidents

Phase	Protective Action Recommendation	Protective Action Guide or Planning Guide
Early (Chapter 2)	Sheltering-in-place or evacuation of the public[a]	1 to 5 rem (10 mSv to 50 mSv) projected dose/4 days[b]
	Administration of prophylactic drugs KI[c]	5 rem (50 mSv) projected child thyroid dose[d] from radioactive iodine
	Limit emergency worker exposure	5 rem (50 mSv)/year (or greater under exceptional circumstances)[e]
Intermediate (Chapter 3)	Relocation of the public	2 rem (20 mSv) projected dose first year[b] Subsequent years, 0.5 rem (5 mSv)/year projected dose
	Food interdiction[f]	0.5 rem (5 mSv)/year projected dose, or 5 rem (50 mSv)/year to any individual organ or tissue, whichever is limiting
	Limit emergency worker exposure	5 rem (50 mSv)/year[b]
	Reentry	Operational Guidelines[g] (Stay times and concentrations) for specific activities (see Section 3.7)
Late (Chapter 4)	Cleanup	Brief description of planning process
	Waste Disposal	Brief description of planning process

[a] Should begin at 1 rem (10 mSv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering may begin at lower levels if advantageous.

[b] Projected dose- the sum of the effective dose from external radiation exposure (i.e., groundshine and cloudshine) and the committed effective dose from inhaled radioactive material.

[c] Provides thyroid protection from internal exposure to radioactive iodines only. For other information on radiological prophylactics and treatment, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm063807.htm http://www.bt.cdc.gov/radiation and www.orau.gov/reacts

[d] Thyroid equivalent dose. For more information, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm072265.htm.

[e] When radiation control options are not available, or, due to the magnitude of the incident, are not sufficient, doses to emergency workers above 5 rem (50 mSv) may be unavoidable and are generally approved by competent authority. For further discussion see Chapter 2, Section 2.6.

[f] For more information on food and animal feeds guidance, the complete FDA guidance may be found at http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM094513.pdf

[g] For extensive technical and practical implementation information please see "Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident" (DOE 2009)

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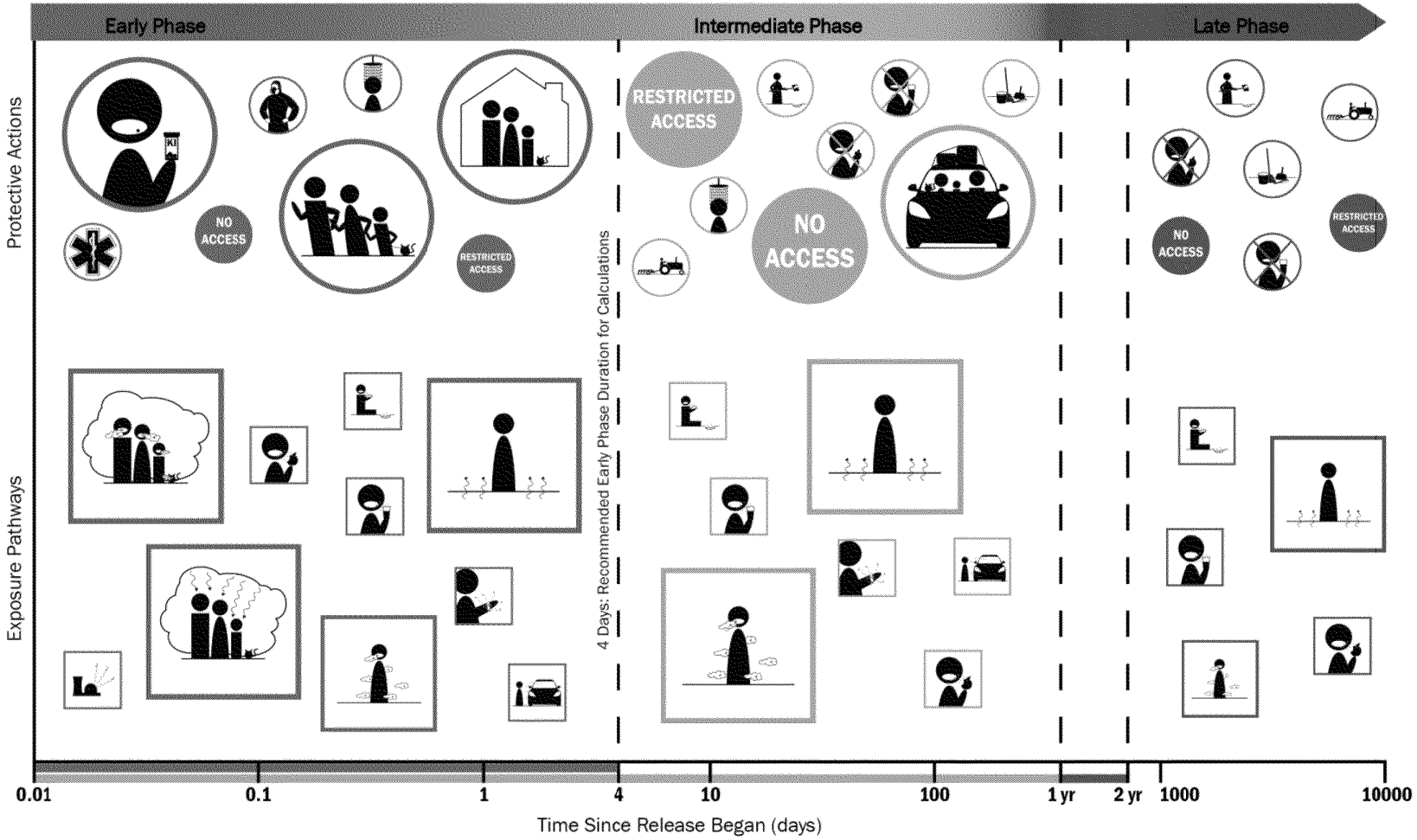
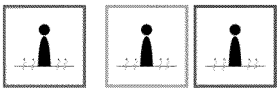
Radiological Emergency Response - Quick Reference Guide 5
Incident Phases, Exposure Pathways, and Protective Actions

Background and Source Document: The 2013 Draft PAG Manual, Protective Action Guides and Planning Guidance for Radiological Incidents, was issued in March 2013 as a draft for interim use and comment. The manual includes a description of the radiological incident phases and applicability of protective actions in Section 1.4. More specific information on exposure pathways and protective actions are given in Chapters 2, 3, and 4.

This Quick Reference Guide (QRG) was developed to visually represent the information provided in the Manual on Incident Phases, Exposure Pathways, and Protective Actions.



ICON	DESCRIPTION
Incident Phases:	
Early Phase	Early Phase – The Early Phase is the beginning of a radiological incident when immediate decisions for effective use of protective actions are required and must, therefore, be based primarily on the status of the radiological incident and the prognosis for worsening conditions. This phase may last from hours to days. EPA assumes a 4-day Early Phase (96 hours) for calculation of the integrated projected dose during that time for comparison to the Early Phase Protective Action Guide (PAG) (this integration is indicated by the solid red line at the bottom of the picture). Exposure pathways that may be encountered during the early phase are noted in red squares with the most common pathways indicated by larger icons. Protective actions for the early phase are noted in red circles with the most commonly used actions indicated by larger icons.
Intermediate Phase	Intermediate Phase – The Intermediate Phase is the period beginning after the source and releases have been brought under control (has not necessarily stopped but is no longer growing) and reliable environmental measurements are available for use as a basis for decisions on protective actions and extending until these additional protective actions are no longer needed. This phase may overlap the early phase and late phase and may last from weeks to months. EPA integrates projected doses in one year increments to compare to the Intermediate Phase PAGs (this integration is indicated by the solid yellow line for the 1st year integrated dose and the solid green line for the 2nd year integrated dose). Exposure pathways that may be encountered during the intermediate phase are noted in yellow squares with the most common pathways indicated by larger icons. Protective actions for the intermediate phase are noted in yellow circles with the most commonly used actions indicated by larger icons.
Late Phase	Late Phase – The Late Phase is the period beginning when recovery actions designed to reduce radiation levels in the environment to acceptable levels are commenced and ending when all recovery actions have been completed. This phase may extend from months to years. A PAG level, or dose to avoid, is not appropriate for long-term cleanup. Exposure pathways that may be encountered during the intermediate phase are noted in blue squares. Actions that may be taken during the late (recovery) phase are noted in blue circles; during the late phase, these actions are recovery actions and are not referred to as "protective actions."
Exposure Pathways:	
	Direct Plume Exposure – One of the expected principle sources of exposure during the Early Phase, direct plume exposure is that exposure from the contents of a plume of radioactive material. The contents will depend on the source of radiation involved and the conditions of the incident. Many radioactive materials emit gamma radiations that can exposure people in the vicinity of a passing plume.
	Plume Inhalation – Inhalation of the radioactive material contained in the plume is also one of the expected principle source of exposure during the Early Phase. Inhaled radioactive particulates, depending on their solubility in body fluids, may remain in the lungs or move via the bloodstream to other organs, prior to elimination from the body. Some radionuclides become concentrated in a single body organ, with only small amounts going to other organs.
	Direct Ground Exposure – External exposure to the radioactive material deposited on the ground from a passing plume is a pathway of concern during all incident phases. Deposited materials can continue to emit beta and gamma radiation as "groundshine" after the plume has passed causing continued exposure to skin and internal body organs.
	Inhalation of Resuspended Material – Inhalation of ground-deposited radionuclides that are resuspended into a breathing zone may be a pathway of concern during all incident phases; and, may be especially important for alpha-emitting radionuclides.
	Direct Exposure from the Facility – Under most circumstances, direct exposure from a fixed facility will only be a concern during the Early Phase of an incident. This may be an exposure pathway even if no release of radioactive material has occurred.
	Ingestion of Contaminated Food – Ingestion of contaminated food may be a pathway of concern during all incident phases, but will be of most concern during the Intermediate and Late Phases because of the longer intake times. FDA has issued information on food and animal feeds protective action guidance.
	Ingestion of Contaminated Water – As with ingestion of contaminated food, ingestion of contaminated water may be a pathway of concern during all incident phases, but will be of most concern during the Intermediate and Late Phases.
	Ingestion of Contaminated Soil – Ingestion of contaminated soil may be a pathway of concern during all incident phases, but will be of most concern during the Intermediate and Late Phases. It is not likely to be a controlling exposure pathway under any circumstances, but it was considered during PAG development.

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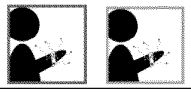
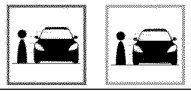
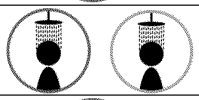
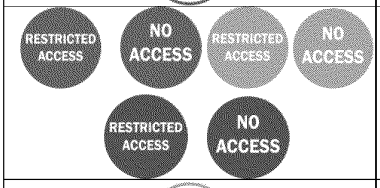
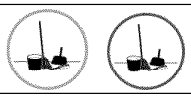
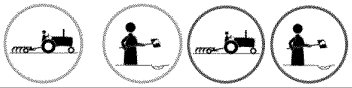
	Direct Exposure from Contaminated Skin or Clothing – Contaminated skin or clothing may be a source of exposure during any of the incident phases with the highest doses expected during the Early and Intermediate Phases.
	Direct Exposure from Contaminated Vehicles or Other Surfaces – Contaminated vehicles or other surfaces may be a source of exposure during any of the incident phases with the highest doses expected during the Early and Intermediate Phases.
Protective Actions:	
	Evacuation – Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure, from the plume or from deposited activity. Evacuation may be a preemptive action taken in response to a facility condition rather than an actual release. Evacuation is a principle protective action during the Early Phase.
	Sheltering-in-Place – Sheltering-in-place is a protective action that includes going indoors, listening to Emergency Alert System messages, closing all windows and doors, closing exterior vents, and turning off heating and air conditioning equipment using outside air. It is designed to avoid inhalation of gases or particulates in an atmospheric plume and to minimize external radiation exposures. Sheltering-in-place is a principle protective action during the Early Phase. It should be preferred to evacuation whenever it provides equal or greater protection. Sheltering-in-place followed by informed evacuation may be most protective.
	Ingestion (Use) of Radio-protective Drugs (such as Potassium Iodide, KI) – The use of KI or other prophylactic drugs is a supplementary protective action. KI is only effective for blocking or partially blocking the uptake of radioiodines by the thyroid through inhalation of radioiodines. It is most protective if taken prior to exposure. Its use may require approval of state medical officials (or in accordance with established emergency plans).
	Use of Personal Protective Equipment (such as Respirators or Protective Clothing) – Personal Protective Equipment (PPE) use by emergency workers and recovery workers will minimize the exposure those workers may receive from inhalation of radioactive material or exposure to contamination.
	Decontamination of People – The decontamination of people that have radioactive contamination on their skin or clothing will minimize the dose received. Normally, contamination will be most common during the Early and Intermediate Phases.
	Medical Care – Medical care may be necessary of people who have been exposed to high levels of radiation or who have been contaminated and cannot be decontaminated using normal means. Normally, this will only be necessary for exposure or contamination received during the Early Phase.
	Restricting or Banning Access – During all incident phases, restricting or completed banning access to contaminated areas may be necessary to minimize the dose received by the general population or emergency/recovery workers. Restricting access does not mean a total ban to an area; but, rather, includes access, on a limited basis, to specific individuals for specific purposes.
	Relocation – Relocation is the removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. It is the primary protective action used during the Intermediate Phase.
	Restricting or Banning Ingestion of Contaminated Food and/or Water – To limit the internal dose received from ingestion of contaminated food and/or water, locally produced food or local sources of water may be restricted or banned for use. FDA has issued guidance on the protective actions for food and animal feeds. These actions are normally taken during the Intermediate and Late Phases.
	Decontamination of Areas – To reduce the amount of contamination in an area, cleaning of surfaces may be done. These actions are normally taken during the Intermediate and Late Phases.
	Plowing or Removing Soil – to reduce the amount of contamination in soil, the soil may be plowed (to fix the contamination in a lower level of the soil) or the soil may be removed. These actions are normally taken during the Intermediate and Late Phases.

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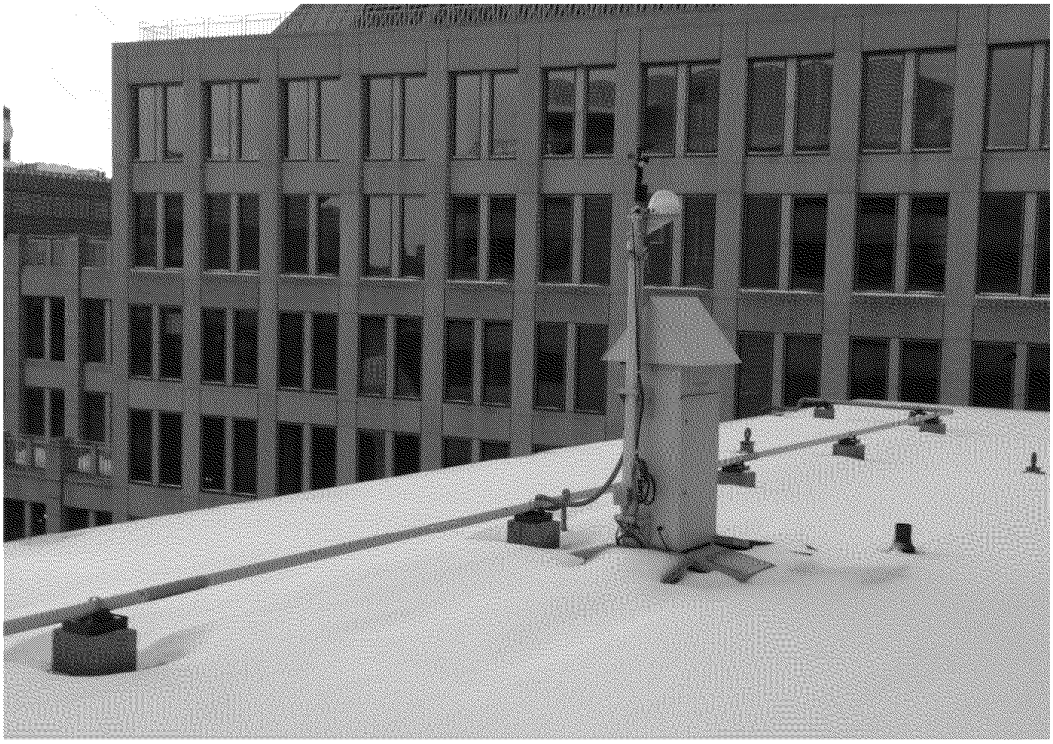
RPD's Items for the ORIA Weekly



OAR's RadNet Station to Move to the Ronald Reagan Building: After 8 years of service at 1310 L St, RadNet Station 302 will soon take up new residence on the roof of the Ronald Reagan Building. Known simply as the DC monitor, it is part of the Agency's network of 132 particulate air sampling stations nationwide. What makes these monitors so special is the combination of on-board radiation detectors and telecommunications systems that transmit hourly reports to EPA's National Analytical Radiation Environmental Laboratory (NAREL) in Montgomery, Alabama. These reports contain near-real time measurements of the buildup of radioactivity on the filter during collection, as well as other information about the status of the monitor. NAREL staff constantly review the data from all fixed monitors and, in the event of an incident, are able to detect, identify and quantify radionuclides in concentrations far below EPA's Protective Action Guides. Biweekly air filters are collected and counted by station operators, and then sent to NAREL for additional analyses. During the Fukushima incident in 2011, EPA's RadNet monitors helped inform the public and decision makers on the levels of radioactivity in air, food, and water in the United States from the releases occurring at the damaged nuclear reactors in Japan.

Participants in the monitor relocation are: Daniel Askren, NAREL; Alan Perrin, Lowell Ralston, Kathryn Snead, and Glenna Herrenbruck from ORIA's Radiation Protection Division; Neil Stewart and Mike Perry from OARM-FMSD; Becky Higgins from OAR-OPMO; and staff from the General Services Administration.

RPD Staff to Participate in Health Physics Society Meeting: From July 13-17, RPD staff will be attending the 59th annual meeting of the Health Physics Society (HPS) in Baltimore, Maryland. HPS is an organization for radiation protection professionals in the U.S., and several RPD staff are active members. This year's meeting features a highlighted lunchtime debate on Monday between RPD's Dr. Jerry Puskin and retired Washington State University Professor Antone Brooks on the topic, "Is there a dose of radiation that Is not dangerous?," with Jerry arguing the position that there is no completely safe dose. Sara DeCair will give a presentation on the 2013 Revision of the Protective Action Guides Manual on Tuesday. Mike Boyd is the Chair of the HPS International Collaboration Committee (ICC), which will meet in Baltimore on Tuesday, and has taken the lead in planning an all-day ICC special technical session on the topic "Recovery from Large Scale Nuclear Contamination - What Have We Learned?" Mike will also give a presentation on how nuclear power plant accident recovery has changed between the accidents at Three Mile Island and Fukushima. Reid Rosnick will give a lecture during the Wednesday afternoon special NESHAPS session, during which he will introduce the CAP88 version 4 code for evaluating compliance with radionuclide NESHAPS. Other RPD staff attending the HPS meeting include Phil Egidi, Jennifer Mosser, and David Pawel.

** RECOMMENDATION **

GUIDANCE ON PUBLIC RELOCATION, RE-ENTRY AND RETURN TO RADIOLOGICAL CONTAMINATION AREAS

DEFINITIONS

Reentry: Workers or members of the public going into relocation or radiological contaminated areas on a temporary basis under controlled conditions.

Relocation: The removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Not to be confused with evacuation.

Reoccupancy: The return of households and communities to relocation areas during the cleanup process, at radiation levels acceptable to the community.

Return: Permanent resettlement in evacuation or relocation areas with no restrictions, based on acceptable environmental and public health conditions.

RECOMMENDATIONS FOR RELOCATION, RE-ENTRY AND RETURN

- Relocation of the public is recommended for areas that exceed:
  - 2 rem (20 mSv) projected for the first year, and
  - 0.5 rem (5 mSv) per year projected in subsequent years.
- Re-entry of the public, if necessary should be performed with a dose level not to exceed 0.5 rem (5 mSv) over one year for temporary access within the relocation area, with stay times dependent on reentry tasks and site-specific conditions.
- Return of the public to relocation areas is not currently being restricted by the State of Indiana, but the following risks of return should be noted:
  - The lifetime risk of fatal cancer without radiation exposure is 24% (approximately 1 in 4).
  - Adults residing in areas that exceed the following dose levels for the first year have an excess lifetime risk of fatal cancer due to radiation exposure as follows:
    - 0.1 rem (1 mSv) for a year provides an excess risk of 0.005% (1 in 20,000)
    - 0.5 rem (5 mSv) for a year provides an excess risk of 0.025% (1 in 4,000)
    - 2 rem (20 mSv) for a year provides an excess risk of 0.1% (1 in 1000)
    - 5 rem (50 mSv) for a year provides an excess risk of 0.25% (1 in 400)
    - 10 rem (100 mSv) for a year provides an excess risk of 0.5% (1 in 200)
    - 50 rem (500 mSv) for a year provides an excess risk of 2.5% (1 in 40)
  - Infants, children, and other sensitive populations will exhibit a higher excess cancer risk than adults.
  - Federal Radiation Protection Guidance, adopted in 1987, recommends that dose to occupationally exposed pregnant women be controlled to keep the fetal dose below 0.5 rem over the entire term of pregnancy, and that no dose be delivered at more than the uniform monthly rate that would satisfy this limit (i.e., approximately 50-60 mrem/month).
  - The U.S. Nuclear Regulatory Commission enforces the following dose limits at their licensed facilities:
    - 5 rem (50 mSv) is the annual limit for occupational exposure;
    - 0.5 rem (5 mSv) is the limit to an embryo/fetus during the entire pregnancy, due to the occupational exposure of a declared pregnant woman;
    - 0.5 rem (5 mSv) is the annual occupational dose limit for minors; and
    - 0.1 rem (1 mSv) is the annual limit for individual members of the public from a

EXERCISE

licensed operation.

- The International Commission on Radiological Protection (ICRP, Publication 103, 2007) recommended limit for fetal dose (Declared pregnant occupational workers) is 0.1 rem (1 mSv).

RELOCATION

A relocation area is one determined not to be safe for prolonged occupation by the public, based on the post-emergency (intermediate phase) Protective Action Guidelines (PAGs), where a recommendation has been made that the public be relocated. Temporary access to relocation areas that exceed these levels should be permitted under the supervision, or with the permission of, radiation protection personnel. Relocation is not expected to be enforced by the State of Ohio and local governments at this time.

REOCCUPANCY

Reoccupancy of the relocation area is not recommended at this time, but reoccupancy is not expected to be enforced by the State of Ohio and local governments at this time.

ALTERNATIVES TO RELOCATION

Persons who are not relocated, in addition to dose reduction provided by partial occupancy in homes and other structures, can reduce their dose by the application of various techniques. Dose reduction efforts can range from the simple processes of scrubbing and/or flushing surfaces, soaking or plowing of soil, removal and disposal of small spots of soil found to be highly contaminated (e.g., from settlement of water), and spending more time than usual in lower exposure rate areas (e.g., indoors), to the difficult and time consuming processes of removal, disposal, and replacement of contaminated surfaces. It is anticipated that simple processes would be most appropriate to reduce exposure rates for persons living in contaminated areas outside the restricted zone. Many of these can be carried out by the residents with support from officials for monitoring, guidance on appropriate actions, and disposal. The more difficult processes will usually be appropriate for recovery of areas from which the population is relocated.

EXERCISE

Decontamination experiments involving radioactive fallout from nuclear weapons tests have shown reduction factors for simple decontamination methods in the vicinity of 0.1 (i.e., exposure rate reduced to 10 percent of original values). Other experiments using firehoses to flush asphalt and concrete surfaces contaminated with radioactive material of the type that might be deposited from reactor accidents, show decontamination factors for radionuclides chemically similar to cesium that are in the range of 0.5 to 0.95, depending on the delay time after deposition before flushing is applied. The average dose reduction factor for gamma radiation from combinations of simple decontamination methods is estimated to be at least 0.7. Consideration should then be given for the dose reduction offered by structural shielding of homes and other structures in the relocation zone.

RE-ENTRY

After the relocation zone is established, persons may need to reenter for a variety of reasons, including *a personal decision to return*, recovery activities, retrieval of property, security patrol, operation of vital services, and, in some cases, care and feeding of farm and other animals. It may be possible to quickly decontaminate access ways to vital institutions and businesses in certain areas so that they can be re-occupied by adults either for a permanent or semi-permanent return to homes and other living facilities (e.g., institutions such as nursing homes, and hospitals), or for employment. Clearance of these areas for such occupancy may require dose reduction to comply with occupational exposure limits. Dose projections for individuals should take into account the maximum expected duration of exposure. Persons working in areas inside the relocation zone should operate under the controlled conditions normally established for occupational exposure.

STAY TIME

'Stay time' is a term of art used in the radiation safety field. Stay times are the amount of time a person may access the contaminated area. These times vary based upon site-specific factors or incident characteristics such as indoor or outdoor work, sensitive populations and level of radioactivity. For example, a person in a 50 mR/hr area is limited to 500 mrem (5 mSv, 0.5 cGy) should be in the area less than 10 hours.

Generally, this may apply to individuals retrieving belongings from homes or to workers providing security patrols, or even to people reopening businesses in the area. It is important to note that as contamination levels are reduced during cleanup, stay times can be extended and total doses reduced. Residents retrieving possessions may spend most of their time indoors, where stay times are longer than they may be for outdoors tasks. Stay time recommendations can be used to guide decisions about allowing entry into the contaminated area for a limited time and dose reduction techniques like wearing dust masks, cleaning shoes and car tires upon exit and using time wisely keep radiation exposure "as low as reasonably achievable" (ALARA).

EXERCISE

STAY TIME TABLES FOR REENTRY

STAY TIME TABLE			
Total Dose Limit (mR)	Area Dose rate (mR/hr)	Stay Time (hours)	Stay Time (minutes)
500	5000	0.10	6
500	1000	0.50	30
500	500	1.00	60
500	100	5.00	300
500	50	10.00	600
500	10	50.00	3000
500	5	100.00	6000
500	1	500.00	30000

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STAY TIME TABLE (cGy/hr)			
Total Dose Limit (cGy)	Area Dose rate (cGy/hr)	Stay Time (hours)	Stay Time (minutes)
0.5	5	0.10	6
0.5	1	0.50	30
0.5	0.5	1.00	60
0.5	0.1	5.00	300
0.5	0.05	10.00	600
0.5	0.01	50.00	3000
0.5	0.005	100.00	6000
0.5	0.001	500.00	30000

EXERCISE

EXERCISE EXERCISE EXERCISE

Health Physics Pergamon Press 1958. Vol. 1. pp. 255–267. Printed in Northern Ireland

RADIATION EXPOSURES FROM NUCLEAR TESTS AT THE NEVADA TEST SITE

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Division of Biology and Medicine, U.S. Atomic Energy Commission, Washington, D.C.

(*Received* 29 *May* 1958)

Abstract—The purpose of this article is to summarize some of the pertinent data on radiation exposures around the Nevada Test Site as a result of nuclear tests. The data are categorized into:

(I) External γ-radiation.
(II) Activity concentrations in air.
(III) Activity concentrations in water.

Under each of these areas there is considered:

(A) The methods used to estimate the radiation exposure.
(B) The relevant data collected.
(C) Evaluation of the data.

The maximum external exposure has been up to 7–8 r for the fifteen persons involved. In terms of relative large populations the average exposure for the 1,000,000 persons living nearest the Test Site has been at the rate of about $\frac{1}{2}$ r/30 years. The highest concentration of fallout activity in the air has been about 1.3 μc/m^3 averaged over the 30 hr that the activity was present in significant quantities. The highest concentration of fallout activity in a potential drinking water supply has been about 1.4×10^{-4} μc/ml extrapolated to $D + 3$ days. Some evaluation is given for these data in the article.

I. EXTERNAL GAMMA RADIATION

A. *Methods of estimating*

The method used to compute the "estimated" γ-dose in communities around the Nevada Test Site is described in the first reference.[1] These calculations involve the parameters of radiological decay, weathering of the activity and shielding afforded personnel by normal structures. None of these, especially the latter two, will be identical for all cases.

The decay of activity of mixed fission products is generally assumed to follow the relationship of $(\text{time})^{-1.2}$. This is intended to apply to disintegrations of atoms. In estimating the reduction in time of γ-dose rates above a fallout field, there should be considered the changing numbers and energy spectra of γ-photons released per disintegration (as well as any effects of weathering). This estimation has been attempted.[2,3] These analyses indicate that when computing total doses which accrue from a fallout of fission products occurring within a few hours after detonation, the integration of the $(\text{time})^{-1.2}$ curve gives a fair approximation since most of the dose is accumulated during the early periods.

The effects of weathering (winds and rains) upon dose rates obviously will vary depending upon the time of occurrence and the degree of movement of the fallout material. In those localities where only one or a few measurements are made in time, a generalized rule for the effects of weathering must be assumed. For these cases, it has been assumed by us that the γ-dose rates at 3 ft above the ground will decrease according to $(\text{time})^{-1.2}$ for the first week after a detonation, $(\text{time})^{-1.3}$ for the second week and $(\text{time})^{-1.4}$ thereafter.

The protection afforded personnel by normal structures will also vary according to the type of structures and time spent within them. As a result of measurements taken within homes around the Nevada Test Site it was estimated that the attenuation might be about a factor of two. Assuming about half of the

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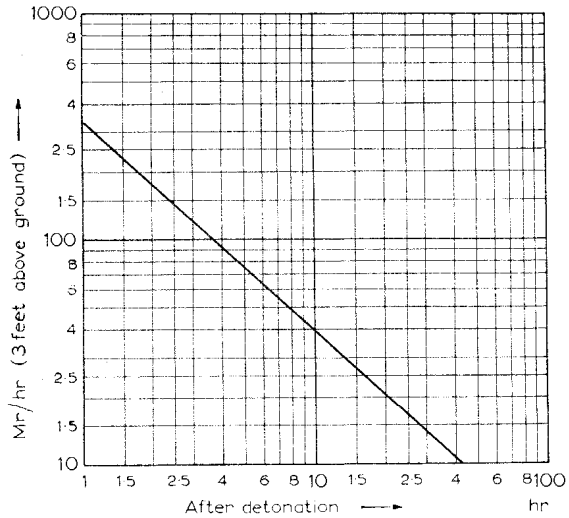

FIG. 1. Approximate γ-dose rates vs. time after detonation to produce 1 r estimated dose.

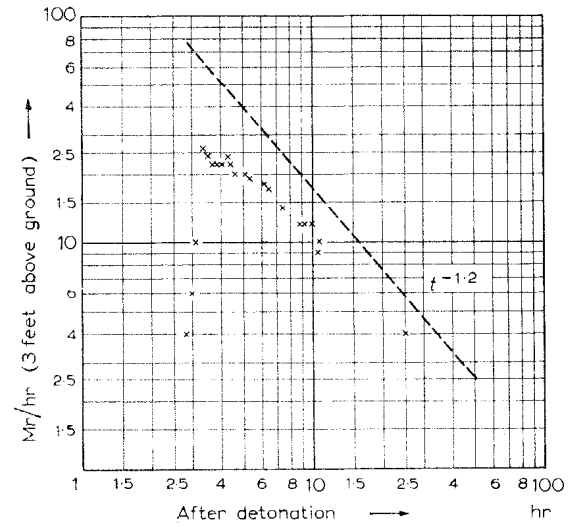

FIG. 2. γ-Dose rates at St. George, Utah (17 March 1953).

time is spent indoors, this means a 25 per cent reduction per day of the out-of-doors dose.

These assumed effects of radiological decay, weathering and shielding are combined into the preparation of Fig. 1.

Fallout of radioactive debris does not occur instantaneously. Fig. 2 shows the effects of the combination of fallout occurring in time, together with the concurrent radiological decay, at St. George, Utah on 17 March 1953. In estimating doses to communities around the Nevada Test Site, based only on monitoring data obtained after the peak has occurred, it has been assumed that all of the fallout occurred near the time of initial appearance. In this respect these "estimated" doses tend to overestimate the actual dose.

In any given community usually there will be an initial variation of dose rates owing to a somewhat uneven distribution of fallout. The higher values are used in computing the "estimated" dose.

B. *The data on external γ-exposures*

Table 1 summarizes the "estimated" doses to communities around the Nevada Test Site based on the above methods, as well as data obtained from the use of film badges and automatically recording instruments.[4]

The large mass of data collected over the past 7 years is currently being cross-checked and re-evaluated by a committee headed by Dr. A. VAY SHELTON of the University of California Radiation Laboratory. The analyses are still too preliminary to report results at this time.

C. *Evaluation of the external γ-exposures*

In June 1956 the National Academy of Sciences stated ". . . that individual persons receive not more than a total accumulated dose to the reproductive cells of 50 r up to age 30 years—and not more than 50 r additional up to age 40 . . . " and " . . . that for the present it be accepted as a uniform national standard that X-ray installations (medical and non-medical), power installations, disposal of radioactive wastes, experimental installations, testing of weapons and all other humanly controlled sources of radiations be so restricted that members of our general population shall not receive from such sources an average of more than 10 r, in addition to background, of ionizing radiation as a total accumulated dose to the reproductive cells from conception to age 30."[5]

On 8 January 1957 the National Committee on Radiation Protection recommended "The maximum permissible dose to the gonads for

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Table 1

Community	Approximate population	External γ-radiation (r) Operation Plumbbob	Cumulative for all nuclear tests
Arizona			
Beaver Dam Lodge			
Between Littlefield, Arizona and Utah Line, on Highway 91	6	0.21	2.21
Littlefield	44	0.25	0.25*
Mt. Trumbull	30	0†	0.16
Short Creek	90	0	1.60
Wolf Hole	10	0	1.30
California			
Quincy	1330	0.10	0.10
Nevada			
A and B Mine			
(South of M and M Mine)	4	0.10	0.10
Acoma			
(23 miles SE of Caliente)	16	0	3.00
Alamo	250	0.02	1.32
Apex	15	0	0.10
Ash Springs	5	0.01	0.61
Austin	520	0.14	0.19
Baker	60	0.10	0.90
Barclay (22 miles SE of Caliente)	38	0	2.00
Bardoli Ranch			
8 miles E of Nyala	4	0.28	0.28
Basalt	5	0.17	0.17
Belew Ranch			
Located at old Adaven Post Office	550	0.10	0.15
Beatty	3	0.30	0.30
Belmont	6	0.70	0.70
Buckhorn Ranch	12	0.04	0.94
Bunkerville	250	0	4.30
Butler Ranch			
30 miles S of Alamo	1	3.22	3.22
Caliente	970	0	0.70
Carp			
On UP, RR, 25 miles S of Caliente	Variable to 25	0.20	3.80
Charleston Lodge	60	0	0.15
Clarke's Station			
32 miles E of Tonopah on Highway no. 6	Variable 0–5	0	0.80
Coaldale	25	0.45	0.45
Crestline	22	0	0.70
Crystal	5	0	4.00
Crystal Springs	5	0.08	1.08

* Indicates relatively little fallout prior to Operation Plumbbob.
† Zero means no substantial fallout.

Table 1—(continued)

Community	Approximate population	External γ-radiation (r) Operation Plumbbob	Cumulative for all nuclear tests
Nevada (continued)			
Currant	75	0.27	0.77
Dodge Construction Co.	175	2.2	2.20
Dry Lake	20	0	1.00
Duckwater	50	0.02	0.82
East Ely	1000	0	0.60
Eden Creek Ranch 22½ miles NW of Highway 25 and 64 miles SW of Crystal Springs	0	0	0.70
El Dorado	3	0.36	0.36
Elgin	Variable, 30 avg.	0.03	3.53
Ely	3558	0.43	1.03
Eureka	500	0.4	0.60
Fallini Ranch	15	0.78	1.58
Fallon	2400	0.13	0.13
Fernley	418	0.1	0.10
Gault	0	2.86	2.86
Geyser Ranch	5	0.37	0.37
Glendale	50 avg.	0.08	0.78
Goldfield	220	0.52	0.52
Gold Point	10	0.17	0.17
Groom Mine	0	0.02	2.02
Hawthorne	1861	0.12	0.12
Hiko	55	0.05	1.05
Hoya	8	1.40	2.80
Indian Springs	250	0.09	0.14
Kimberly	120	0.05	0.55
Las Vegas	47,000	0	0.20
Lida	25	0.19	0.19
Lincoln Mine	250–500	1.25	5.25
Lockes	4	0.32	1.62
Logandale	300	0.03	0.43
Lund	250	0.28	0.36
Manhattan	42	0.14	0.14
M and M Mine (8 miles W of Warm Springs (on Highway 6) and 8 miles N of Highway 6)	2	2.34	2.34
Mesquite	590	0.08	1.88
McGill	2300	0.05	0.45
Millett (Ranch only—on Highway 8A, 33 miles S of Highway 50)	5	0.32	0.32
Mina	450	0.13	0.13
Moapa area	175	0.07	0.87
Montgomery Pass	3	0.15	0.15

Table 1—(*continued*)

Community	Approximate population	External γ-radiation (r) Operation Plumbbob	Cumulative for all nuclear tests
Nevada (*continued*)			
North Las Vegas	13,000	0	0.20
Nyala (Between Warm Springs and Adaven (H.N. Sharp Ranch))	6	0.17	1.87
Overton	725	0.01	0.36
Pahrump	89	0	0.20
Panaca	500	0.03	0.68
Parmans Ranch (10 miles S of Belmont)	7	0.78	0.78
Pioche	1392	0.03	0.73
Preston	60	0.31	1.01
Rattlesnake Maintenance Station	4	0.24	0.24
Reed	0	0	4.00
Reveille Mills (About 10 miles SE of Warm Springs (Highway 6))	4	3.40	3.40
Riverside Cabins	15	0	7–8
Round Mountain	200	0.17	0.22
Rox	13	0.21	3.21
Ruby Hill Mine	50	0.40	0.40
Ruth	1244	0	0.50
Schurz	100	0.13	0.13
Sharps (Adaven)	25	0	1.20
Shoshone	250	0	0.70
Silver Peak	7	0.38	0.38
Stone Cabin Ranch 23 miles E of Tonapah and 6 miles N of Highway 6	8	0.42	0.42
Stonehouse Ranch 5 miles N of Belmont on Nev. no. 82	4	0.27	1.27
South Paw Mine 5 miles N of Mt. Irish	3	0.41	0.41
Sunnyside	26	0.27	1.47
Tonapah	1375	0.62	0.62
Uhaldi Ranch About 1 mile S of Old Adaven P.O. location	5	0.29	0.29
Ursine	25	0	0.60
Walch Pine Creek Ranch	4	0.21	0.21
Warm Springs on Highway 6	55	0.25	0.75
Warm Springs Ranch 4 miles NW of Moapa and SW of Highway 93	58	0.04	1.04

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Table 1—(continued)

Community	Approximate population	External γ-radiation (r) operation Plumbbob	Cumulative for all nuclear tests
Utah			
Alton	154	0.02	0.82
Anderson Junction	17	0.40	1.60
Bear Valley Junction (Orton Junction)	15	0	0.40
Beaver	1685	0	0.25
Beryl Junction	8	0.03	1.03
Cedar City	6106	0.12	0.52
Central	49	0.30	0.30
Enterprise	800	0.05	0.75
Garrison	125	0.10	0.80
Glendale	275	0.06	1.26
Gunlock	127	0.24	2.24
Hamilton Fort	26	0.12	0.72
Harrisburg Junction	5	0.11	0.11
Hurricane	1375	0.08	4.28
Ivins	75	0.50	0.50
Kanab	1900	0	1.60
Kanarraville	263	0.47	1.67
Leeds	100	0.54	3.54
Long Valley	10	0.01	0.81
Lund	75	0	0.50
Milford	1673	0	0.10
Minersville	593	0	0.20
Modena	100	0.02	0.52
Mt. Carmel	125	0.02	0.87
New Castle	115	0.04	0.64
New Harmony	126	0.04	1.24
Orderville	371	0.05	1.55
Panguitch	1501	0.36	0.56
Paragonah	404	0.01	0.41
Parowan	1455	0.01	0.41
Pintura	50	0.62	1.82
Rockville	125	0.07	3.07
St. George	5000	0.50	3.50
Santa Clara	319	0.46	3.96
Shivwits	95	0.54	3.34
Springdale	209	0.05	2.65
Toquerville	219	0.17	2.17
Veyo	100	0.65	2.65
Virgin	135	0.08	1.58
Washington	435	0.13	3.13
Zane	25	0	0.30

ED_001057_00010124

the population of the United States as a whole from all sources of radiation, including medical and other manmade sources, and background, shall not exceed 14 million rems per million of population over the period from conception up to age 30, and one-third that amount in each decade thereafter. Averaging should be done for the population group in which cross breeding may be expected." Also, "while at the moment it is not feasible to determine the average exposure for the population with any reasonable accuracy, the adoption of some figure is necessary for planning purposes. For the immediate future, it may be assumed that the total integrated RBE dose received by all radiation workers will be small in comparison with the integrated RBE dose of the whole population. Furthermore, persons outside of controlled areas, but exposed to radiation from a controlled area, constitute only a small portion of the whole population. Therefore, if this small portion is assumed to receive yearly an average per capita dose of 0.5 rem, the total dose to the whole population from manmade radiations is not likely to exceed 10 million rems per million of population up to age 30. (This assumes a dose of 4 million rems per million of population over this age period from background radiation.)"[6]

Whereas, it may be possible to control the small incremental accumulation of an individual's radiation exposure during normal activities within an atomic energy installation, by the very nature of fallout phenomena one community may receive a relatively high exposure from a single fallout. Thus the Atomic Energy Commission has adopted for populations off-site, as an operational guide a maximum of 3.9 r per test series at the Nevada Test Site. Of course, extensive efforts are made to reduce the fallout to a minimum.[7]

The exposures to relatively small numbers of persons (in the context used here) are reported in Table 1. For larger populations, it was estimated that the one million persons living nearest to the Nevada Test Site have received an average per capita exposure of about 0.1 r for the first 6 years of testing at the Nevada Test Site. This is at a rate of about a $\frac{1}{2}$ r/30 years.[8] Operation Plumbbob (1957) contributed only a small increment to the average per capita exposure for these one million persons, and since this value now encompasses 7 years of testing, the rate of about $\frac{1}{2}$ r/30 years remains essentially unchanged.

II. ACTIVITY CONCENTRATIONS IN AIR

A. *Method of estimating radiation exposure from this source*

(1) "Infinity" doses to the lungs. *Assumptions:*

(a) The rate of inhalation is 20 m^3/24 hr,* (0·83 m^3/hr).

(b) The percentage of initial retention of particles (and activity) is 25 per cent.

(c) All of the air-borne activity is associated with particles in the respirable range.†

(d) The mass of the lungs is 1000 g and is uniformly irradiated.‡

(e) Mean energy of the β-particles = 0·4 MeV. (The relative dose from γ-emission may be roughly 10 per cent of the β-dose. Since this is less than the uncertainties in other estimations described below, it will not be considered here.)

(f) The dose rate decreases according to the relationship of $(\text{time})^{-1.2}$.

Step 1. Calculate the dose rate for 1.0 $\mu c/m^3$ per hr.

(a) For each 1 $\mu c/m^3$ activity present in the air per hour, (0.83) (0.25) = 0.21 μc of activity are initially retained.

(b) The initial dose rate to the lungs will be:

$$\frac{(0.21)(\mu c)(1.3 \times 10^8)(\text{d/hr per } \mu c)\ (0.4)(\text{MeV}) \times (1.6 \times 10^{-6})\ (\text{ergs/MeV})}{100\ (\text{ergs/g per rad})(1000)\ (\text{g})}$$

$$\cong 1.7 \times 10^{-4}\ \text{rads/hr}$$

* There will be higher volumes of intake during working hours than at other times. When such times are known, the assumption usually made is that 10 m^3 are inhaled during 8 hr of work and 10 m^3 inhaled for the remainder of the day.

† Generally, the cascade impactor data have shown 80–90+ per cent of the activity associated with particles 5 μ or less in size. However, it is quite possible that the high volume air samplers upon which most of the data are based, collect larger size particles which would tend to overemphasize the estimated lung dose.

‡ These may tend to underestimate the dose.

Step 2. Calculate the "infinity" dose to the lungs.

(a) $D_\infty = 5A_t t$

A_t = dose rate at time of deposition t after detonation (hr)

t = time after detonation that deposition occurs.

D_∞ = infinity dose (rads)

(b) $D_\infty = (5)(1.74 \times 10^{-4})(t)$ rads

$= (0.85)(t)$ mrads (per 1.0 $\mu c/m^3$ per hr)

[Based on 20 m^3/24 hr]

or $D_\infty = (1.28)(t)$(per 1.0 $\mu c/m^3$ per hr)

[Based on 10 m^3/8 hr]

$D_\infty = (0.64)(t)$(per 1.0 $\mu c/m^3$ per hr)

[Based on 10 m^3/16 hr]

(2) Doses to the thyroid. The method of estimating doses to the thyroid from inhalation of fallout material containing radioactive isotopes of iodine is described in the ninth reference.[9]

B. *The data on concentrations in air*

Ranger (spring 1951).[10] The highest average concentration of fallout activity measured off-site was about 1.7×10^{-5} $\mu c/m^3$ for the $2\frac{3}{4}$ hr the samplers were in operation at Charleston Peak, Nevada. Of course other areas not monitored, may have shown greater concentrations but since all five detonations during Operation Ranger were air bursts, it is unlikely that very high values were present off-site.

Buster-Jangle (autumn 1951).[11] The highest measured concentration of fallout debris in air was at Ely, Nevada, amounting to 0.202 $\mu c/m^3$ averaged over 24 hr. All other measurements were in order of magnitude lower.

Teapot (spring 1955).[14] "... The highest concentration of radioactivity in the air following any one detonation was at Ely, Nevada. This amounted to about $\frac{8}{100}$ $\mu c/m^3$ averaged over the 28 hr that the material was present in significant quantities ...."

Plumbbob (spring–summer 1957).[15] The measurements of concentrations of fallout material activities in the air during Operation Plumbbob and calculations of radiation exposures to the lungs show that the highest total accumulated dose (recorded at Eureka, Nevada, with a population of about 500) was less than that to be expected from breathing air containing normal amounts of naturally radioactive materials, for a period of about 2 weeks.

Tumbler-Snapper (spring 1952).[12]

Detonation	Locality	24 hr average concentration ($\mu c/m^3$)
7 May 1952	Ogden, Utah	0.020
25 May 1952	Price, Utah	0.001
1 June 1952	Elko, Nevada	0.024
5 June 1952	Elko, Nevada	0.014

Upshot-Knothole (spring 1953)[13]

Locality	24 hr average concentration ($\mu c/m^3$)
St. George, Utah	1.29
Lincoln Mine, Nevada	4.0×10^{-1}
Mesquite, Nevada	1.7×10^{-1}
Groom Mine, Nevada	3.4×10^{-2}
Pioche, Nevada	2.0×10^{-2}
Nellis AF Base, Nevada	1.7×10^{-2}
Ely, Nevada	1.6×10^{-2}
Las Vegas, Nevada	1.0×10^{-2}

C. *Evaluation of activity concentrations in air*

The method of estimating doses to the lungs suggested above clearly shows that in addition to the specific air concentration, the age of the fallout material is an important factor. A single value for a 24 hr concentration gives some perspective as to the potential dose but a more quantitative evaluation requires further

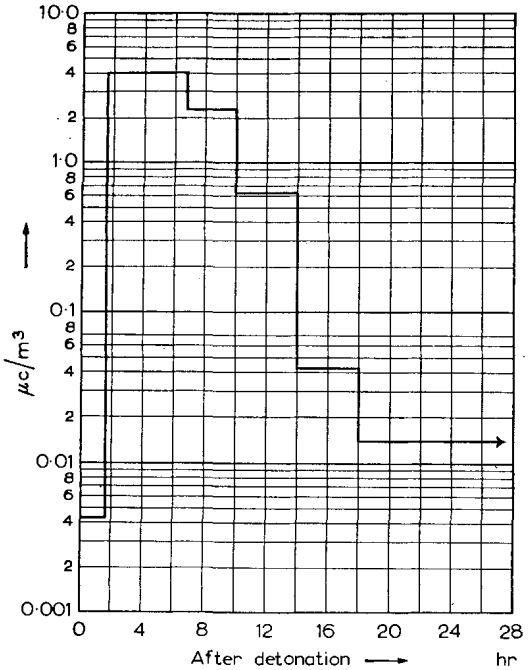

FIG. 3. Approximate concentrations of fallout activity in the air at St. George, Utah (19–20 May 1953).

analysis of the data. This is done below for the activity in the air at St. George, Utah on 19–20 May, 1953 which resulted in the highest estimated lung dose from any single event or in fact, from all fallouts in any given community.

Fig. 3 shows the approximate air concentrations at St. George, Utah 19–20 May, 1953 and a summary of the calculations based on these data are given below:

The above estimates are based on infinity doses. The actual dose will be less than this but the exact value is difficult to estimate. It is probable that some 40 per cent of the material (and activity) will be cleared from the lungs with a half-time of about 1 day. The remainder may have a half-time of removal of about 180 days.[16] Fallout that occurs 1 hr after a detonation will expend about 50 per cent of the potential infinity dose during the first day, while fallout that occurs 10 hr after a detonation requires about 15 days to deliver one-half of the infinity dose. The uncertainties in these and other estimates and assumptions do not justify attempting an exact calculation of actual radiation lung dose. However, it seems reasonable to assume the actual dose is less than the infinity dose and more than one-half of the maximum value.

The biological significance of doses to the lungs may be appraised by comparison with lung doses produced by natural occurring radioactive materials in the air (radon and thoron and their daughter products). These dose estimates vary owing to different assumptions as to natural air concentrations, percentages of activity initially retained in the lungs, rate of elimination, weight and volume of the lung tissue irradiated and the relative biological effectiveness of the α-particles. Some estimates made in this country are 2·6–26 mrems,[17] 70 mrems,[18] 50–100[19] and 100 mrems[20] per week. Based on breathing continuously radon and radon daughter products at a radon level of 1×10^{-11} c/l. (*not* assumed to be a normal concentration in air), HOLADAY

Air concentrations ($\mu c/m^3$)	Midpoint of sampling period (hours after detonation)	Duration of sampling	Infinity lung dose (mrems)
4.0	4.5	5	115*
2.3	8.5	3	75*
0.62	12.0	4	19†
0.43	16.0	4	18†
0.014	24.0	12	2.6†

* Based on 10 m³/8 hr.
† Based on 10 m³/16 hr.

et al.[21] have estimated an average dose from 190 to 43 mrems/week to the lung and from 2160 to 720 mrems/week to the bronchi depending upon the assumptions used. HULTQUIST[22] estimates values from 0·016 mrem/week for the lower limit within a ventilated wood structure to 4000 mrems/week as an upper limit within a lightweight concrete structure with alum shale in Sweden.

In evaluating doses to the lungs from inhalation of fallout, we have been using a comparative value of roughly 50 mrems/week from natural activity. Thus, the lung dose calculated above for fallout at St. George, Utah may be equivalent to that for a greater time period than we originally estimated. ". . . The estimated radiation dose to the lungs resulting from this activity was about the same as would be expected from breathing air containing normal amounts of radioactive substances for a period of less than a month."[23]

The doses to the thyroid from the same fallout at St. George were estimated to be about 0.3 rep according to the ninth reference.[9] These original calculations were based on an average inhalation of 0.83 m^3/hr. If the same rates of respiration are assumed as for estimating lung doses above, the value would be about 0.4 rep. Many thousands of rep doses are delivered to the thyroid during treatment of disorders of this gland without observable detrimental effects.[24, 25] There is some evidence that as little as 200 reps to the infant thyroid may produce carcinoma in a few percent so exposed.[26,27]

III. ACTIVITY CONCENTRATIONS IN WATER

A. *Methods of estimating internal doses*

The method of estimating doses to the gastrointestinal tract, thyroid and bones resulting from ingestion of water containing radioactive fallout are contained in the twenty-eighth reference.[28] An additional consideration for estimating doses to the bones is given below. *Assumptions:*

(1) The gross fission product activity is 5×10^{-3} μc/ml on $D + 3$ days.

(2) The daily intake is 2200 ml (probably an overestimation).

(3) This is the sole supply of water for 70 years.

Step 1. Compute the total dose to an organ from a daily intake of constant volume or mass but with the activity intake decreasing according to radiological decay of the isotope.

(a) The dose (ignoring for the time any biological decay) to the organ from any day's intake is:

$$D_1 = R_0 \int_0^T \exp(-\lambda_r \tau) d\tau - R_0 \int_0^\tau \exp(-\lambda_r \tau)\, d\tau$$

where

D_1 = dose from any day's intake
R_0 = initial daily dose rate
λ_r = radiological decay
T = number of days intake
τ = time in days (variable)

$$D_1 = \frac{R_0}{\lambda_r}(\exp(-\lambda_r \tau) - \exp(-\lambda_r T))$$

(b) The total dose (ignoring biological decay) to the organ is:

$$D_T = \frac{R_0}{\lambda_r} \int_0^T (\exp(-\lambda_r \tau) - \exp(-\lambda_r T)) d\tau$$

$$D_T = \frac{R_0}{(\lambda_r)^2}[1 - \exp(-\lambda_r T) - \lambda_r T \exp(-\lambda_r T)$$

(c) The dose to the organ considering biological decay is:

$$D_T = \left[\frac{\lambda_r}{\lambda_r + \lambda_b}\right] \frac{R_0}{(\lambda_r)^2} \times [1 - \exp(-\lambda_r T) - \lambda_r T \exp(-\lambda_r T)]$$

$$D_T = \frac{R_0}{(\lambda_r)(\lambda_r + \lambda_b)} \times [1 - \exp(-\lambda_r T) - \lambda_r T \exp(-\lambda_r T)]$$

Step 2. Compute initial daily dose rate (R_0).

$(5 \times 10^{-3})(2200) = 11$ μc gross fission product intake on $D + 3$

$(11)(5.8 \times 10^{-5}) = 6{\cdot}37 \times 10^{-4}$ μc of Sr^{90} intake on $D + 3$*

* Under the assumptions used here, the strontium-90 content accounts for almost all of the total dose. Percentages of strontium-90 are based on references 29 and 30.

$(6.37 \times 10^{-4})(0.25) = 1.59 \times 10^{-4}$ μc of Sr^{90} deposited in the bones†

$$\frac{(1.59 \times 10^{-4})(\mu c)(3.2 \times 10^{9})(\text{d/day per } \mu c) \times (1.0)(\text{MeV})(1.6 \times 10^{-6})(\text{ergs/MeV})}{100(\text{ergs/g per rad})(7 \times 10^{3})(\text{g})} = 1.16 \times 10^{-6} \text{ rads/day}$$

Step 3. Compute the total dose for 70 years (D_T).

$$D_T = \frac{R_0}{(\lambda_r)(\lambda_r + \lambda_b)} \times [1 - \exp(-\lambda_r T) - \lambda_r T \exp(-\lambda_r T)]$$

where

$R_0 = 1.16 \times 10^{-6}$ rad/day
$\lambda_r = 6.86 \times 10^{-5}$ day^{-1}
$\lambda_b = 1.78 \times 10^{-4}$ day^{-1}
$T = 25{,}550$ days

$$D_T = \frac{1.16 \times 10^{-6}}{(6.86 \times 10^{-5})(2.47 \times 10^{-4})} \times [1 - \exp\{-(6.86 \times 10^{-5})(25{,}550)\} - (6.86 \times 10^{-5})(25{,}550 \exp\{-(6.68 \times 10^{-5}) \times (25{,}550)\}] \cong 35.8 \text{ rads}$$

B. *The data on concentrations in water*

Ranger (spring 1951).[31] No water samples were taken during Operation Ranger. However, the fact that all five detonations were air bursts, and appreciable fallout outside the Test Site was not observed, leads one to estimate that any possible water contamination was quite small.

Tumbler-Snapper (spring 1952).[33]

Date	Analysis (μc/ml at 3 days after detonation)
1 May 1952 Crystal Springs Pond	0.5×10^{-8}
1 May 1952 Pahranagat Lake	1.0×10^{-8}
2 May 1952 Caliente (drinking water)	0.28×10^{-8}
2 May 1952 Creek North of Caliente	1.1×10^{-8}

Upshot-Knothole (spring 1953).[34]

Locality	Concentration (μc/ml) extrapolated to 3 days after detonation)
Virgin River Irrigation Canal, Nevada	8.7×10^{-5}
Irrigation Ditch, 56 miles north of Pioche, Nevada	4.5×10^{-5}
Lower Pahranagat Lake, Nevada	3.2×10^{-6}
Virgin River at Mesquite, Nevada	2.6×10^{-6}
Bunkerville, Nevada (tap water)	1.2×10^{-6}
Crystal Springs, Nevada (tap water)	1.1×10^{-6}

Teapot (spring 1955).[35]

Locality	Concentration (μc/ml extrapolated to 3 days after detonation)
Upper Pahranagat Lake, Nevada	1.4×10^{-4}
Waterhole near State (Nevada) Highway 25	9.2×10^{-5}
Meadow Valley (Nevada) Wash	3.3×10^{-5}

Buster-Jangle (autumn 1951).[32] Six samples from Lake Meade showed negative results.

Plumbbob (spring–summer 1957).[36] "It was difficult to extrapolate precisely all of the measurements taken of activity in the water to 3 days after the detonation during Operation Plumbbob. This was because after the second shot of the series it was possible that the measured activity represented fallout from more than one

† It is recognized that the amount of strontium-90 absorbed into the body is strongly a function of the calcium content of the food and water supply. These estimates are intended only to give perspective to the problem, not to be precisely quantitative.

explosion. The data do show that even the highest activity observed in a drinking water supply (Fallini Ranch, Nevada–population about 15) probably was less than one-hundredth of the operational guide...."

C. *Evaluation of activity concentrations in water*

The highest activity measured in any potential drinking water supply was at Upper Pahranagat Lake, Nevada during the 1955 test series amounting to 1.4×10^{-4} μc/ml extrapolated to 3 days after the detonation. (The Atomic Energy Commission has adopted as an operational guide a maximum of 5×10^{-3} μc/ml of gross fission products, extrapolated to $D + 3$ days). If this water from Upper Pahranagat Lake had been stored and used as a sole supply for 70 years the total internal doses would be estimated as follows:

Bones	~1.0 rad
Lower large intestine (with less doses to other parts of the G.I. tract according to reference 28)	~0.25 rad
Thyroid	~0.25 rad

One statement that summarizes some of the information on the effects of radiation doses to the bones has been given. "... visible changes in the skeleton have been reported only after hundreds of rep were accumulated and tumors only after 1500 or more."[37] Another statement that summarizes some of the information on short-term effects of doses to the gastrointestinal tract states: "... though the gastrointestinal tract is one of the sensitive systems to ionizing radiation, it also has a most remarkable regenerative and reparative capacity. It takes doses of well over 1000 r to damage the gut permanently in most mammals studied, and it is capable of rapid dramatic recovery of anatomical and functional integrity with doses in the lethal range."[38]

Some evaluation of radiation doses to the thyroid has been given above.

Acknowledgments—Many of the monitoring data reported here have been collected by the Off-Site Radiological Safety group of the Test Organization. This group has been operated since 1955 by the U.S. Public Health Service, in cooperation with the U.S. Atomic Energy Commission, under the leadership of Mr. Oliver Placak, (USPHS). Additional data originally collected by Mr. Kermit Larson of the University of California at Los Angeles for research purposes, have been very useful as documentary evidence.

During the spring and autumn 1951 test series the off-site monitoring activities were conducted by the H-Division of the Los Alamos Scientific Laboratory, and in the spring of 1952 and spring of 1953 by military personnel augmented by representatives from the U.S. Public Health Service and the Los Alamos Scientific Laboratory. During the test series in the autumn 1951, spring and autumn 1952, and spring 1953, the Health and Safety Laboratory of the New York Operations Office, AEC, operated mobile teams out to 300 miles from the Nevada Test Site, as well as a network of automatic γ-recording stations. The recording stations also were operated by them during the series in the spring 1955.

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THE POSTATTACK WATER-CONTAMINATION PROBLEM*

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Abstract—Because of an increasing interest in civil defense, together with an increased knowledge of the potential hazards due to fallout from nuclear weapons, more attention has been focussed on obtaining information on postattack problems.

The problems of concern are (1) the estimation of the probable level of contamination to be expected in the public water supply; and, to a lesser extent, (2) the role of contaminated water as a source of internal radiation hazard at early times. Unless the water supply is entirely from ground water sources, the water may become contaminated and be a potential radiological health hazard. This paper discusses contaminating conditions, fallout levels, internal-dose criteria, the early radioiodine ingestion problem, and the effectiveness of various water decontamination processes.

Dose calculations indicate that the problem of a fallout-contaminated water supply will not be severe in most cases. Radioiodine concentration by the thyroid and the resultant exposure is more serious the first 100 days after attack than the dose to the bone. However, the radiation exposures are such that they and the water supply hazard cannot be ignored. The effectiveness of various water decontamination processes is discussed.

In the event of a nuclear attack, one of the problems that will arise is contamination of public water supplies. Therefore, it was deemed necessary to investigate methods of water decontamination and to evaluate the effectiveness of existing water treatment equipment and methods. Meanwhile, other studies were conducted on fallout which are applicable to the water-contamination problem, and both are the subject of this paper.

Studies by Clark *et al.*[1] and Hawkins,[2] have resulted in predictions of the possible fallout radiation intensities under various levels of nuclear attack. From these one can estimate the amount of fallout beyond the zones of destruction. If then the water contamination hazard is related to the expected fallout in the neighborhood of the reservoir where the water is stored, one can calculate the probable contamination to be expected. It has been found that there is a probable upper limit to the fallout radiation intensities under any credible attack. The maximum probable contamination to be expected for any given water supply can be stated, and plans made accordingly.

As a result of drinking a fixed quantity of water each day from a reservoir contaminated with fallout, calculations were made of the dose rates to be expected in various organs of the body. These results are expressed in terms of the maximum dose delivered over any 90-day period, and apply to "standard" conditions: fallout material settling into a 1-ft deep reservoir where it is rapidly dissolved and thoroughly mixed, in an amount per unit area such that it would have produced a radiation field of 1 r/hr at 1 hr after explosion, 3 ft above a dry infinite plane. The ½ gal/day ingestion rate is based upon the Office of Civil Defense's estimated consumption.

These parameters can be readily adjusted to other average reservoir depths simply by dividing them by the depth. The hazard will also depend on how much of the radioactive material is dissolved, how it is distributed vertically in the water, and where the intake pipe is located in the reservoir. Very little data is available on the solubility of close-in fallout material. Assuming

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100 per cent solubility* and mixing, this assumption should yield the maximum hazard, and can be modified later on to take into account new knowledge about solubility. Similarly, by assuming homogeneous mixing, one need not be involved with the pattern of flow in reservoirs.

The principal limit on the postattack ingestion level is set by the dose delivered to the lower large intestine by β-emitters in the gross fission product activity, and the long-term irradiation of blood-forming organs by bone-seeking isotopes is considerably less important. But, both these effects are less important than the effects of the accompanying external γ-dose.

The activities present in the fallout material are assumed to be proportional to the fission products obtained by the thermal neutron fission of U^{235}, together with equal amounts of U^{238} and U^{239}.

The fission product activity in fallout from a weapon detonation may differ from the computed distribution because the radioisotopes which are gases or have volatile precursors that will not condense on the fallout particles but will remain at high altitude. LOWE *et al.*[3], among others, suggested such "fractionation" to explain the deficiencies of certain nuclides observed in close-in fallout. This phenomenon is not understood well enough to make reliable predictions, so it has been assumed, for simplicity, that fractionation does not take place.

It is assumed that fallout is rapidly dissolved and homogeneously mixed in the reservoir. Also, that any water entering the reservoir comes in at the same concentration level as the water already there, so that the principal change with time arises from physical decay.

A small amount of experimental evidence available indicates that up to half of the gross activity in a sample of fallout from a ground burst may dissolve in water. But it is not known whether this is a function of the type of soil on which the weapon was exploded, or to what degree some fission products dissolve more completely than others. LINDSTEN *et al.*[4] report some data on solution rates. It is safe to assume that if the fallout particles dissolve during their trip from the surface to the bottom of the reservoir, then the activity distribution will be fairly uniform. If they dissolve very slowly, the bottom layers will be more active than the surface layers. In this case the depth of intake of the reservoir may be important. These factors are not known, therefore, homogeneous mixing was assumed.

The results have been expressed as the instantaneous dose rates for the important radioisotopes, as shown in Fig. 1, plotted against time after attack. The results are given in rem† per week.

The total dose received by the bone is delivered chiefly by long-lived isotopes in group II, while the doses to the thyroid and gut are the result of radionuclides having half-lives up to 8 days. This suggests that it might be advantageous to delay the start of ingestion for a week or more after the attack. However, calculations show that such delays, to be useful, must be about a month. Fig. 2 shows this result in quantitative terms, indicating the reduction in the 90-day dose (received under standard conditions) as a function of a delay in the start of ingestion.

The dose delivered to the thyroid glands may be reduced by taking sufficient inert iodine to saturate the thyroid before drinking contaminated water. Such a procedure may reduce uptake of radioiodine from 75 to 90 per cent of the amount expected under normal conditions. A small amount (about $\frac{1}{2}$ g) of potassium iodide (KI) taken prior to ingestion should be sufficient. Then the limiting factor in the ingestion of contaminated water will be the dose delivered to the lower large intestine.

Assuming that no time restriction is imposed on water consumption, one can calculate the maximum fallout field which can be tolerated around a reservoir, for any given maximum dose to the organs. For example, drinking $\frac{1}{2}$ gal/day from a 10-ft deep reservoir in a fallout field of 20 r/hr at 1 hr after the detonation would result in an intestinal dose equal to a 90-day dose of 6 rems. If this field were increased to 100 r/hr at 1 hr after detonation, the intestinal dose would be about 30 rems in 90 days. These fallout levels are on the low side of the range of intensities to be expected from an all-out attack. Of

* Solubility as used herein refers to the radioactive material alone, and not the inert fallout.

† rem = roentgen equivalent man (or mammal) = RBE × rad. We assumed the RBE = 1.0.

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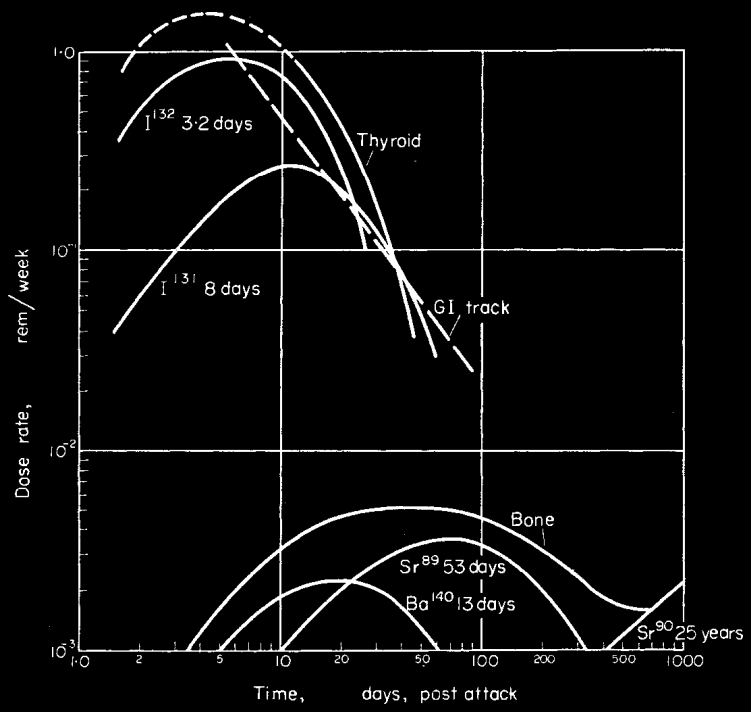

FIG. 1. Instantaneous dose rate from ingesting $\frac{1}{2}$ gal/day of contaminated water from a source, 1 ft deep in a field 1 r/hr at $H + 1$.

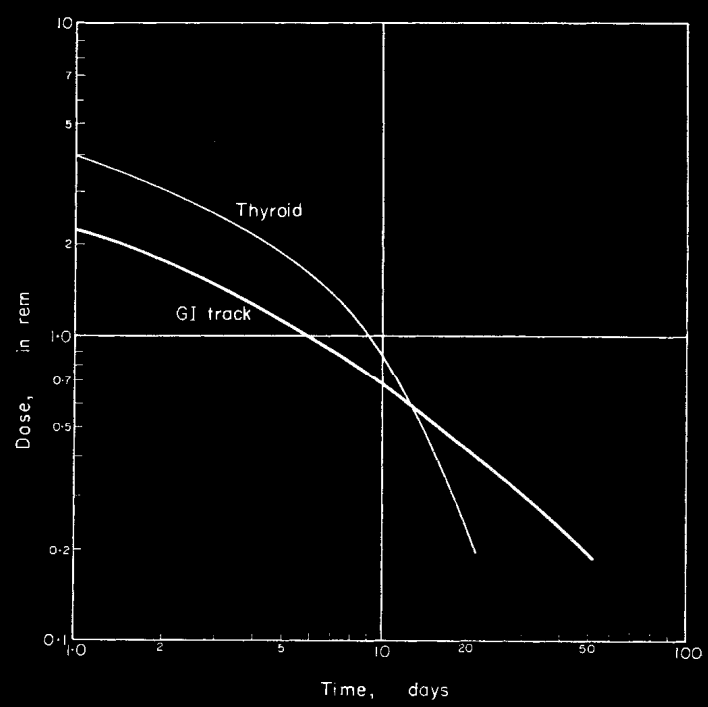

FIG. 2. 90-day dose rates as a function of starting time postattack; assuming ingestion of $\frac{1}{2}$ gal/day from a source 1 ft deep, in a fallout field of 1 r/hr at $H + 1$.

significance here is DUNNING's[5] conclusion that several hundred rems to the lower large intestine may be in the range of onset of radiation sickness.

However, one must realize that even though contaminated water is not expected to cause a great many cases of radiation sickness, the ingested activity in many areas may exceed 10 times the maximum allowable peacetime level (3 rems/90 days) and, in a few areas, 100 plus times this level.

The effectiveness of various radioactive water decontamination processes is difficult to predict with accuracy because of the uncertainty of the physical and chemical characteristics of the fallout material. For guidance, the range of effectiveness of the various treatment processes in removing the fallout is indicated in Fig. 3. The data was derived from various experiments conducted on a laboratory and pilot-plant scale as well as actual experience with treatment equipment on fallout from nuclear weapons tests. The information should serve as a guide for postattack recovery estimate.

The conventional water treatment processes investigated to determine their efficiency for the removal of radioactive materials included coagulation, sedimentation, filtration, lime-soda ash softening, and ion exchange.

Filtration. Except for removal by simple straining or simple sorption by biological life contained on top of the filter, sand filters have not been effective for the removal of radioactive materials. Their major function is to remove the radioactivity previously incorporated in floc particles.

Clay slurry. Considerable work has been reported on the use of natural clays and soil materials for the removal of specific radioisotopes from water and waste solutions. Although this method is feasible, large volumes of clay must be handled both initially and finally as a mass of contaminated material for disposal. If combined with chemical coagulation, still larger volumes of contaminated sludge must be handled. Providing no health hazard will result from the release of these materials, his method has its greatest potential use where geological and

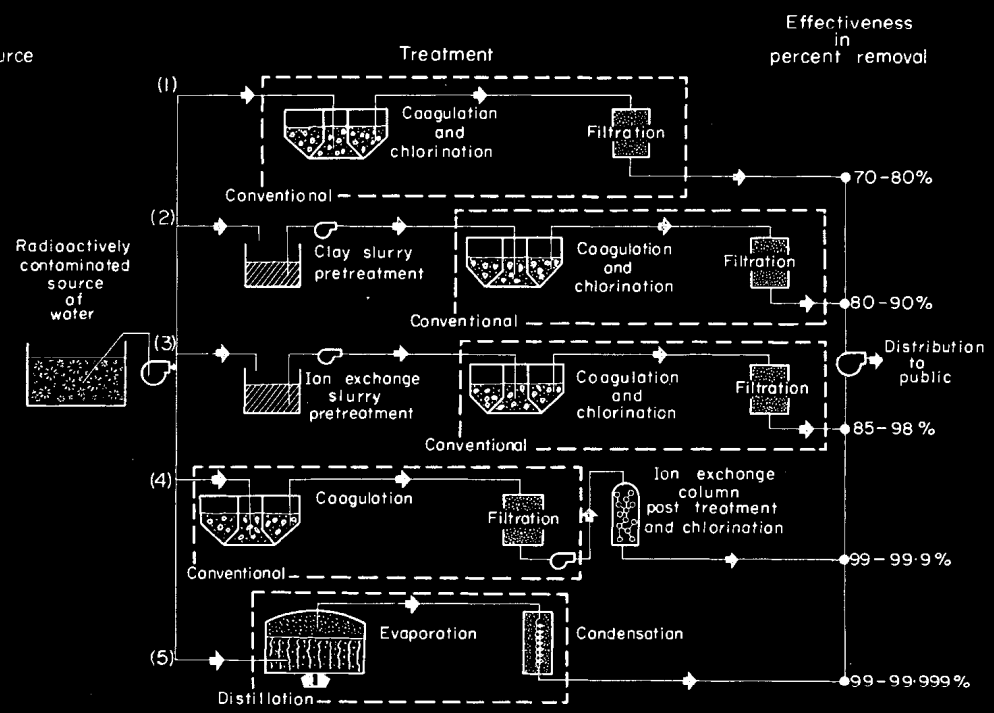

FIG. 3. Radioactive water decontamination processes.

hydrological conditions are such as to permit use of the ground for disposal. Incorporation of a polyelectrolyte as a coagulant aid would be of great help in this area.

Ion exchange. Ion exchange resin used as a slurry in a pre-treatment has been shown to be effective in removing over 98 per cent of the dissolved radioactive contamination. The ion exchange process is also used in softening municipal water supplies. Removal of radioactive materials by this process, usually a post-treatment, is feasible; and for most effective removal, mixed resins in series is recommended. Results with various types of exchange materials are very high. Following ion exchange, it may be necessary to adjust the pH of the effluent water. Home water softeners have been found to be very effective water decontamination devices, yielding about 98 per cent removal of radioactive material.

Distillation. Although not a generally accepted municipal water treatment method, distillation is included in this discussion as it is the most effective process presently available for concentrating radioactive materials. High decontamination factors are possible, but the cost is too great for normal use; however, under emergency conditions, distillation may prove feasible.

These are only some of the aspects of the postnuclear attack water contamination problem. Other areas of interest have been considered and are available in the open literature. However, there are still phases that remain to be developed as part of our civil defense planning.

Acknowledgements—The authors wish to thank Dr. E. T. Clarke and Mr. M. B. Hawkins for their valuable contributions on this general subject.

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INTERNAL DOSE FOLLOWING A MAJOR NUCLEAR WAR

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Abstract—**The PATHWAY model results were used, in conjunction with a hypothetical major nuclear attack on the U.S., to arrive at the ratio of internal to external dose for humans from early (48 h) fallout. Considered were the four nuclides (^{137}Cs, ^{89}Sr, ^{90}Sr, ^{131}I) that account for most of the reconstructed whole-body committed equivalent dose from internal radiation in people who lived downwind of the Nevada Test Site during atmospheric tests. Effects of climate perturbations (the "nuclear winter" effect) on food crops were considered. These could increase internal dose estimates, depending on the severity of the climate perturbations. Internal and external doses to humans for 10 locations within the U.S. have been calculated, with varying local conditions and varying assumption about their shelters. The estimated 50-y internal dose commitment ranged from 0.0–0.17 Sv, the 48-h external dose from 0.15–4.6 Sv. The resultant ratios of internal to external committed dose received in the first months (until food transport was restored) varied from less than 0.01 to about 0.2. In all cases examined, the total dose from early fallout was found to be dominated by the external dose.**

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Key words: fallout; dose, internal; nuclear war; weapons

INTRODUCTION

THE RELATIONSHIP between external and internal doses from exposure to nuclear radiation has become better defined during the past several years. During atmospheric testing of nuclear explosives in the 1950s and early 1960s, little was known of the relative magnitude of the internal dose to people from ingestion of foods contaminated by radioactivity. In the late 1960s and the 1970s, models were developed to estimate the contribution of internal dose to total dose. These early models were designed primarily for application to long-term releases, such as from nuclear power plants. In the 1980s, advanced dynamic models for terrestrial food paths have appeared. With proper input, these models can be used to reconstruct internal doses to people affected by radiation from past atmospheric nuclear tests. The same models are suitable for estimating in persons the internal doses that might result from multiple explosions, over a relatively short time, produced by a large-scale nuclear war.

In this study, the PATHWAY model (Whicker and Kirchner 1987) results were used in conjunction with a reasonably postulated hypothetical nuclear attack on the U.S. to arrive at calculations of internal dose estimates from local fallout. Because of the many variables involved in calculating an individual dose, and the inherent uncertainties associated with the many possible nuclear war scenarios, a "user's manual" approach is taken.‡ Estimates are presented with a synopsis of the calculational aids that enable readers to use their own nuclear war scenarios, fallout patterns, assumptions about the impact on radionuclide pathways from global climatic changes brought on by large fires following a major nuclear war, the viability of the transportation system for food delivery, the quality and quantity of water and foods available locally, the required caloric intakes of the survivors, and several other factors.

By utilizing the above input for one particular attack scenario—a major strategic nuclear attack on the U.S.—the internal and external doses have been calculated for 10 locations within the U.S. These 10 case studies have variable external doses, shelter factors, availability of foods from nearby supply centers, other foods available within walking or bicycling distances, and other variables. The estimated 50-y internal dose commitment ranged from 0.0–0.17 Sv, the 48-h external dose from 0.15–4.6 Sv. Calculations show that for this attack, the ratios of internal to external whole-body dose vary from less than 0.01 to about 0.2. Seven of the case studies have ratios less than 0.02. The higher ratios result from the effects of a large shelter factor (reducing the external dose) combined with consumption of contaminated foraged food for long periods (increasing the internal dose). A qualitative discussion leads to the conclusion that the effects of climate per-

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‡ This paper is a condensed version of an earlier report (Peterson et al. 1988). The reader is referred to that for a more detailed description of this work. Detailed worksheets that guide the reader through each step of the calculations are given there.

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turbations on food crops would increase internal dose estimates, depending on the nature and severity of the climate perturbations.

These results indicate that the average American family that survives a large-scale nuclear war, using their own home or workplace as a refuge, would receive from local fallout a total internal dose from ingestion that is less than 2% of the total body external dose. Those who stayed where shelter-protection factors and foraged food consumption were large could receive internal doses of from 2% to about 20% of the external dose, but the total dose would be smaller because of the larger protection factors. The ratio of internal to external dose from global fallout, not considered here, would be higher than for local fallout. Total doses from global fallout would, in general, be considerably smaller than those for local fallout (Shapiro et al. 1986; Knox and Shapiro 1986).

PATHWAYS

Following single or multiple nuclear explosions, persons downwind of the resultant radioactive fallout can be exposed to both external and internal doses from the radiation primarily generated by the fission part of the weapon. While fallout is occurring, the external dose is caused partly by radioactive particles passing overhead ("cloud shine") and the immersion dose received as the particles move past the person. However, the major contributor to the external dose, particularly in the long term, is from the deposition of radioactive particles on the surface because the potential exposure time is much longer.

Internal dose is caused by inhalation and ingestion of radioactivity. The inhalation dose occurs when falling or resuspended particles are breathed into the lungs, where they can remain or be transferred to other organs. Doses from ingestion occur after the radioactive particles have deposited on vegetation, the ground, or on a water surface.

Dose from consumption of contaminated water is a straightforward pathway; the dose is a function of the level and decay rate of radioactivity in the water and the quantity and rate of consumption. For edible crops, the path is more complex and involves a multitude of factors, such as the season of the year, the structure of the plants and their growth rate, the rate at which specific nuclides pass through the leaves or roots, the effects of resuspension and rainsplash, the type of soil, weathering of nuclides (from plants to soil), percolation and leaching of the radioactivity in the soil, nuclide uptake by roots, and the time of year when the crops are harvested. Doses via the livestock pathway depend on such variables as the type of animal, the percentages of fresh and stored feeds, the quantity of nuclides in these feeds, the amount of soil ingested by the animal and the animal's ingestion, absorption and excretion rates of nuclides, and the food-supply-distribution system.

Since the 1950s, extensive studies have been made on the magnitude of the external dose to humans from fallout following nuclear explosions, including simulated attacks on the U.S. Some recent examples of such research appear in the TTAPS (Turco et al. 1983), OTA (Office of Technology Assessment 1979), and SCOPE (Pittock et al. 1986) studies. Quantitative estimates of external doses to humans in the aftermath of a nuclear war require selection of a fallout pattern, a population distribution, and choices of the extent of sheltering and evacuation of people (Knox and Shapiro 1986; Shapiro et al. 1986).

The literature on internal dose estimation from local fallout in a nuclear war situation is far less abundant than that for external dose. Past studies usually have been confined to atmospheric tests. There have been extensive studies on inhabitants of the Marshall Islands who were exposed to fallout from the atmospheric tests conducted there in the 1950s (Lessard et al. 1984; Robison and Conrado 1991). Dietary intake of ^{137}Cs was the major dose contributor for the years after initial contamination. Whicker and Kirchner (1987) refer to studies indicating that "...doses to most organs from external radiation from fallout on the ground tend to be of the same order to roughly tenfold higher than internal doses via ingestion." Rotblat[§] estimates that internal dose is (a) roughly 20% of the external dose from local fallout, (b) about equivalent for intermediate fallout, and (c) somewhat greater than external dose from long-term fallout. Our results are consistent with these earlier estimates.

Part of the reason that more research has not been devoted to internal dose estimates that might result from a nuclear war is that—in addition to fallout, population dynamics, and sheltering—one has to consider the complexities of estimating the survivors' diets. This requires assumptions about the quantities of food and uncontaminated water that families have on hand at the onset of the war. Then, when stored supplies are exhausted, estimates must be made of (a) the external dose families would receive while foraging for food and water from government distribution centers or supermarkets (these two sources, if available, would most likely be uncontaminated), farmers, and open fields; and (b) how much internal dose the families would receive from ingesting foraged foods and water. In areas that initially received heavy fallout, foods grown in the contaminated soil could give substantial doses for months or years later. Also, if smoke and soot from fires started by nuclear bursts caused climatic perturbations ("nuclear winter"), the effect on the quantity of foodstuffs and their internal dose potential could be substantial.

In the detailed version of our report (Peterson et al. 1988), an outline is given of a "user's manual" approach to enable readers to estimate internal doses based on their own assumptions about fallout patterns,

[§] Personal communication (1984), J. Rotblat, University of London, London, England.

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shelter factors, the amount of water and the types and quantities of stored food, and the foods and water available from local sources. In this report, a range of internal dose estimates and summaries of the internal and external doses received from fallout following a hypothetical nuclear war are given for fictitious families in 10 locations in the U.S.

In the next sections of this paper, the following will be identified:

- radionuclides that would contribute the most to internal dose,
- the most significant food pathways,
- organs affected most by these nuclides, and
- relative effects on internal dose of potential climatic perturbations caused by nuclear war.

SELECTION OF PRINCIPAL RADIONUCLIDES

A nuclear explosion creates over 200 radionuclides, which have wide ranges of yields, half-lives, and physical, chemical, and biological properties. Only a small number of these are significant sources for internal dose to humans via ingestion.

The most important radionuclides for internal dose were selected from a study of dose reconstructions of 24 persons who lived near, but in various directions from, the Nevada Test Site (NTS) during periods of atmospheric nuclear weapons testing in the 1950s (Ng[‖] and Ng et al. 1990). Each person had consumed foods that were exposed to fallout from two to eight (median, five) atmospheric tests. Their organ and whole-body doses were reconstructed from (a) records of exposure rates measured in their communities after each atmospheric nuclear test, (b) surface deposition as calculated by Hicks from measured external exposure rates (Hicks 1982), (c) the integrated intakes of radionuclides [estimated by the PATHWAY model (Whicker and Kirchner 1987)], and (d) committed dose factors. During the 1950s, there was an awareness of the potential internal dose hazard to the civilian population from the NTS atmospheric tests. Nevertheless, it was believed the internal doses would be inconsequential. Hence, few mitigating actions were taken, and the downwind residents generally continued to consume the same foods as at other times.

As part of the assessment of these 24 people, doses to 11 internal organs, including the whole body, were estimated for 20 radionuclides. For this paper, radionuclides contributing to the whole-body equivalent doses were given the most attention. Initially, the 10 nuclides that gave the largest internal whole-body equivalent dose were selected. These 10 accounted for ~90% of the total internal dose from all 20 nuclides. Some of these 10 more significant, dose-contributing nuclides did not appear within the 10 highest for all of the people.

[‖] Personal communication (1988), Y. Ng, Lawrence Livermore National Laboratory, Livermore, CA.

When the number of most significant nuclides was reduced to four, total dose averaged 73%, and all four of the selected nuclides appeared at or near the top of the list for all 24 subjects. This study focuses on these four nuclides, which are, in relative order of importance for the NTS study, ^{137}Cs, ^{90}Sr (together accounting for about 50% of whole-body internal dose), ^{131}I, and ^{89}Sr. The range of total whole-body dose from these four nuclides combined varied from 54% to 83% of the 20-nuclide total, representing, principally, variations in diet.

INTERNAL DOSE PATHWAYS

The two primary pathways for internal dose are inhalation and ingestion. Ng et al. (1990) determined that inhalation is usually a minor contributor to internal dose when compared to ingestion. Levanon and Pernick (1988) examined the inhalation hazard from a ground burst and concluded that for the conditions they assumed, inhalation was not a significant contributor to dose largely because inhalation is only significant during cloud passage or when local fallout is occurring. Following that, resuspension in the air of surface deposition, which occurs at unpredictable times and is generally of low magnitude, is the only natural mechanism capable of producing inhalation doses. Therefore, ingestion of the four selected nuclides in contaminated water and food, which could occur for years after a single deposition event, is the only internal pathway considered here. The principal ingestion pathways are given in a later section.

CALCULATION OF INGESTION DOSE-CONVERSION FACTORS

An ingestion dose-conversion factor (DCF) is defined as the committed equivalent dose to an organ of an individual of a specific age, via a particular pathway, that would result from a unit deposition of radioactivity. DCF units are given in Gy per MBq m^{-2}. Because the fallout radiation dealt with here predominantly consists of gamma rays and high-energy betas, the absorbed dose and the equivalent dose are the same. Hence, units in sievert are used interchangeably with units in gray. In all cases, what was actually calculated was equivalent dose. Multiplication of a DCF by a surface-deposition value provides a dose estimate to an individual for the organ to which the DCF applies. Implicit in the DCF values are assumptions about the types, quantities, and contamination of food and water that would be consumed by humans and the committed dose per unit intake of the radionuclides.

Several models have been developed for calculating DCFs, which include HERMES (Fletcher and Dotson 1971) and a later version of HERMES, such as FOOD (Baker et al. 1976). The major problem of using these models for internal dose calculations following a nu-

clear war is that the models were designed for estimating routine annual doses from nuclear power facilities and are not applicable to relatively short, multiple releases. Two of the recent models that do not have this restriction are PATHWAY (Whicker and Kirchner 1987) and RADFOOD (Koch and Tadmor 1986).

PATHWAY was selected as the model of choice, not only because it is a dynamic model for terrestrial food paths, but also because it is applicable to deposition over a period of hours to days, involving a single or multiple release of radioactivity. Depending on the radionuclide, the dose estimates for a short release differ from those for continuous releases. Koch and Tadmor (1986) state that "...the steady-state (equilibrium) approach [used by annual dose models] is not suitable for the description of acute radioactivity releases, following nuclear power plant accidents or nuclear explosions. These are characterized by transient peaks of radioactivity along the food chain and thus changes occurring with time are of particular importance."

PATHWAY is a computerized food chain-transport model that enables one to calculate the time-integrated human ingestion intake after a single deposition from the atmosphere to the surface. Concentrations of radionuclides in soil, vegetation, animal tissues, and animal products are estimated by solving a system of linear-coupled differential equations. The model accounts for interception by plant surfaces, weathering, absorption, plant growth, uptake, harvest, senescence, soil resuspension, percolation, leaching, tillage, radioactive decay, livestock ingestion and excretion, and other processes. Additional features of PATHWAY are human dietary intake, seasonal changes in the biomass of vegetation, animal diets, and plowing and harvest times.

The model is site-specific to a region but can use agricultural data bases for any climatic regime. As part of the program to reconstruct doses from the atmospheric tests in the U.S. (Ng et al. 1990), the PATHWAY authors used agricultural data for the area within several hundred kilometers of the Nevada Test Site. The crops were assumed to be irrigated and livestock assumed to graze on irrigated pastures or stored feed. Stored feeds in the Western United States are usually protected by physical barriers and would be relatively uncontaminated by fallout. In addition, the percentage of locally grown food types is an integral part of the model as applied to the Western U.S.

The DCFs used here were obtained in the atmospheric test dose reconstruction using the assumption that the fallout levels of interest were sufficiently low so that the normal food pathways downwind were not changed by any mitigating actions. Of course, this would not be expected in a nuclear war situation. Application of the model to a post-nuclear-war episode assumes that families initially would use prewar food sources stored at home. In nearly all cases, this food would have little or no radioactive contamination. It is also assumed that, after stored food was depleted, survivors would leave their refuge and forage for food that might be available locally (at farms, fields, or food-distribution centers). Most of this food would probably be contaminated by fallout. By utilizing the PATHWAY DCFs that were calculated assuming no time delay before ingestion, the internal doses calculated here would represent an upper bound because varying time delays are assumed in our scenario before contaminated food is ingested. This strengthens our conclusion that the total body committed equivalent dose from early fallout is dominated by the external dose.

Franz and Kearny (1979) examined the serious and complicated problem of nutritional adequacy in a prolonged food crisis. The study by Haaland (1977) indicates that sufficient grain stocks and transport can be available after the attack to ensure survival of the remaining American population.

Specific foods that are modeled in PATHWAY include milk, beef, poultry, leafy and non-leafy vegetables, and grain. Root uptake by crops is not considered in evaluating ingestion dose because it "...contributes little to the human dose under the circumstances to which PATHWAY applies..." (Whicker and Kirchner 1987).

The food dietary intake model that is used in the published version of PATHWAY does not include sufficient data for either lamb or hog meat; it is suggested that the DCFs for beef be used for these foods. Aquatic biota are also not included because, except for some local situations, fish are not available in the U.S. as abundant, major food sources. Rupp (1980) estimates that the average daily adult intake of saltwater fish in the U.S. is 12% of daily beef consumption; for freshwater fish, the ratio drops to <2%.

Dose from ^{239}Pu ingestion has not been included because of minimal biological transport and because relatively little is released, resulting in small surface concentrations (Bair and Thompson 1974). Its dose via ingestion is usually negligible compared to the nuclides that have been selected. Plutonium was included in the NTS studies (Whicker and Kirchner 1987; Ng et al. 1990) and the Marshall Island studies (Lessard et al. 1984; Robison and Conrado 1991); it was a very small contributor to the total body committed equivalent dose in all of the studies.

In using the PATHWAY model, the DCFs in Gy per Bq m^{-2} (or rad per Ci m^{-2}) (see Fig. 1) are calculated from

$$\mathrm{DCF} = \mathrm{TIC} \times \mathrm{DT} \times \mathrm{DF}, \qquad (1)$$

where TIC is the time-integrated concentration in food per unit fallout deposition (Bq d kg^{-1} per Bq m^{-2}) from the PATHWAY model; DT is the average U.S. dietary consumption (kg d^{-1}), from Rupp (1980); and DF is the dose factor (Gy Bq^{-1}) obtained from Ng.[¶] TIC depends on the ingestion path, nuclide, time of year,

[¶] Personal communication (1988), Y. Ng, Lawrence Livermore National Laboratory, Livermore, CA.

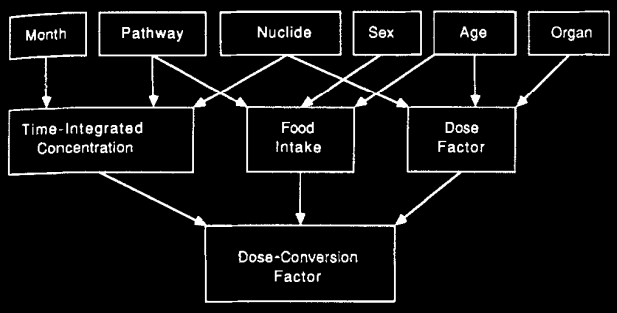

Fig. 1. Relationship between variables that contribute to a dose-conversion factor in the PATHWAY model.

and ingestion pathway; DT is a function of age and gender and represents an average food consumption for the U.S. (Whicker and Kirchner 1987); DF depends on nuclide, age, and body organ.

For the DCFs used in this study, a nuclear attack in July was assumed so as to assess the internal dose at the season when fresh food is most readily available and the impact of a nuclear-war-induced climatic change is believed to be the most severe on agriculture.* Two age categories were chosen: adult (18 y or older) and child (1 to 11 y). For adults, both genders were selected; the assumption in PATHWAY is that the adult female's daily food intake is about 80% of an adult male's. On average, most children under 12 y old consume about the same amount of food, regardless of gender. It is possible, with different dose factors, to calculate DCFs for infants (less than 1 y) and teenagers (12 to 17 y). However, in the interest of simplicity, it is assumed here that infants consume the same types and amounts as children; teenagers are assumed to consume the same quantities as adults.

As mentioned earlier, ^{89}Sr, ^{90}Sr, ^{131}I, and ^{137}Cs account for 73% of the reconstructed whole-body dose; these are the only radionuclides included in our calculations. The DCFs for a normal global climate (no "nuclear winter") are too voluminous to be presented here. They appear in the report by Peterson et al. (1988), which gives the dose (total body, bone surface, bone marrow) for the four nuclides, two age groups, and various food pathways (milk, beef, poultry, leafy vegetable, non-leafy vegetable, and grain).

DCFs were calculated using the PATHWAY model with an average U.S. diet, as estimated by Rupp (1980). The internal dose calculations reported here used estimates of dietary intake from local sources (instead of the Rupp diet) for several regions of the U.S. These estimates are based on U.S. Department of Agriculture county data bases of crops and livestock grown in the U.S. (National Agricultural Statistics Service 1987). The time-integrated doses have been calculated for people in 10 locations within the U.S. that are assumed to have varying diets and fallout severity.

* In the absence of food supplies from external sources, an attack during the winter could greatly magnify local food problems because fresh foods would not be available for most of the U.S.

CLIMATE CHANGES FROM A NUCLEAR WAR

Various researchers, using global climate computer models, have shown recently that the injection into the atmosphere of large amounts of smoke and soot produced by fires generated by a hypothetical major nuclear war could produce significant changes in the earth's climate (the "nuclear winter" effect; Ghan et al. 1988; Malone et al. 1986; Pittock et al. 1986; Thompson 1985; Turco et al. 1983). Despite many improvements in modeling efforts during the past several years, there remains considerable uncertainty in the climate projections, primarily because of the large uncertainties in the characteristics of the smoke injections assumed by the climate modelers (National Research Council 1985; Penner 1986). Smoke- and soot-induced changes in climate are a subject of some dispute and large uncertainties.

In this report, internal radiation dose in a climate perturbed by a nuclear war is estimated. Because of the large uncertainties in climate effects, a qualitative approach is taken as a first approach to this new area of research. Four categories of climate perturbation are considered: (1) none or slight change, (2) moderate, (3) severe, and (4) very severe. If the perturbation in a region is extremely severe (category 4), all livestock and cultivated plants are presumed to be dead or extremely contaminated, making the DCF values meaningless. This approach allows for a changing spectrum of calculated climate responses as the models and the input parameters continue to evolve.

To obtain qualitative estimates of the effects of the projected perturbed climate on internal dose calculations, the recent climate projections of Ghan et al. (1988) using the GRANTOUR model (Walton et al. 1988) are employed. The range of the climatic perturbations obtained in the Ghan et al. study (1988) are typical of many of those obtained by others in recent studies. The most relevant potential effects on climate are changes in surface air temperature, precipitation, and insolation. Each of these potentially has a major impact on internal radiation doses from ingested food.

Fig. 2a illustrates the temperature changes during the first 10 d following a nuclear war in July. For these model calculations, no areas of the U.S. show freezing temperatures, although near-freezing is shown in parts of the South-Central and Southeastern United States. By comparison, calculations by Malone et al. (1986) for days 5 to 10 (not shown) show most of the interior regions of the U.S. with temperature decreases of more than 15°C, and a few small regions of sub-freezing temperatures. Fig. 2b depicts the calculated percent changes in precipitation for the initial 10-d period. The greatest drought occurs in an arc extending from West-

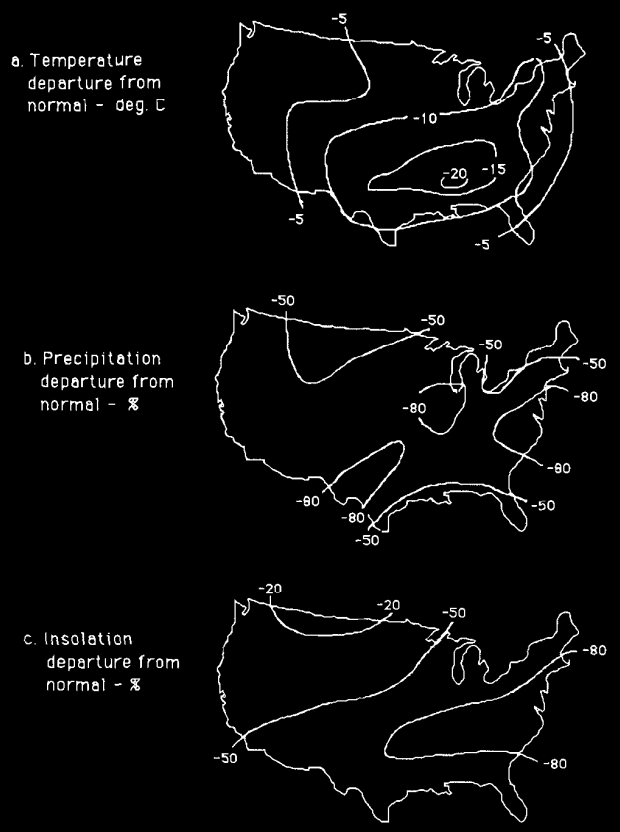

Fig. 2. Climatic changes expected after large fires ("nuclear winter") following a nuclear war in July. Charts, based on the work of Ghan (1988) and Walton (1988), are applicable to the first week following the war.

ern Texas to the Middle Atlantic states. Fig. 2c shows the percent changes in insolation at the surface for the same period. Minimum insolation** is seen over an area from Northern Texas to Massachusetts to Georgia.

EFFECTS OF A PERTURBED CLIMATE ON INTERNAL DOSES

The "nuclear winter" effect would be expected to increase the internal dose received by the surviving population over the doses that might be received in the absence of climate perturbations. This results from the assumption that crop output would be reduced by these perturbations.

In Table 2 of Peterson et al. (1988), the effects of reduced temperature, precipitation, and insolation on animal forage and cultivated crops for each food pathway were estimated. These provide a qualitative basis for adjusting the normal dose-conversion factors for the effects of an atmosphere altered by smoke and soot. The column in Table 2 labeled "Other Effects" indicates that food consumption would be reduced following a nuclear war. This assumption is made because, today, most food is transported by truck, rail, or aircraft. A nuclear war would most likely contaminate large agricultural areas, as well as disrupt large segments of the transportation industry, which would lead to food shortages, even with a reduction in the population due to fatalities caused by prompt effects and local fallout from nuclear weapons.

The average American adult consumes between 2000 to 2500 kcal d^{-1}. With an adequate supply of water, healthy humans can live initially for up to 30 d without solid food before irreversible health effects are encountered. This information comes from observations of people who have fasted for political or religious reasons and from persons who have been stranded with water, but with little or no food. About 1000 calories are required to keep adults and teenagers reasonably healthy, although at this intake level nearly all persons would lose weight.

Following a nuclear war, it is expected that the caloric intake would be less than under normal conditions. However, because of the stress expected in a postwar environment, it is reasonable to assume that survivors would consume more than a starvation diet, provided some foods were available. In America, most families would probably have at least a 1- to 2-wk supply of uncontaminated canned and other stored foods.[††] For these reasons, it is assumed that the daily human caloric intake would average about 75% of normal, or about 1700 kcal d^{-1} for an adult or teenage male, 1400 kcal for an adult or teenage female, and 1000 kcal for a male or female child. Hence, the ratio of postwar to prewar food energy intake (0.75) will be used as a multiplicative factor in estimating food-consumption rates following a nuclear war. Undoubtedly, not only the quantity but the mix of foods would be altered. Types of foods available to survivors would be strongly dependent on regional supplies. Most survivors would consume more specific food types, depending on what is locally available. The "user's manual" approach, given in detail in Peterson et al. (1988), allows the reader to use any postwar diet that they feel is appropriate.

Dose from fresh foods consumption in the second year following a nuclear war would be considerably less than the first year, partly due to the relative inefficiency of the uptake of radioactivity through root structure compared to ingestion from direct deposition on leafy structure; radioactive decay, runoff, percolation, and deep plowing of the soil also contribute.[‡‡] Furthermore, it is expected that the transportation system could be restored sufficiently within 3–6 mo to enable the delivery of foodstuffs from farms in areas that experienced relatively small radiation levels.

** Received solar radiation.

[††] This estimate is based on a literature survey and interviews with friends of the authors.

[‡‡] Calculations indicate that second-year climatic perturbations are considerably smaller than in the first year. We assume the effects on DCFs in the second year are negligible.

DOSE-CONVERSION FACTORS FOR A PERTURBED CLIMATE

Current climate computer models offer a wide range of potential climatic impacts of nuclear war. Perturbation values could range from unity to very large factors for the most severe climate changes. To estimate these factors, without adding several more climatic severity subclasses, the relative factors in the last column of Table 2 of Peterson et al. (1988) have been developed to estimate the perturbation factors for moderate and severe climatic effects. All dose-conversion factors (DCFs) are for food that is produced locally, and, unless stated otherwise, are for livestock and crops that remain unsheltered until consumption by humans.

FALLOUT PATTERN FOR A NUCLEAR ATTACK DURING SUMMER

Because this paper compares external and internal doses from a nuclear war, this section discusses the selection of deposition patterns for the four radionuclides chosen earlier. As a starting point, the 48-h integrated gross fission product external dose values of Harvey et al. (1987, 1992) have been used for a countervalue-counterforce attack scenario on the contiguous U.S. during the summer.

Using a target list based on the best available knowledge of the Soviet's nuclear arsenal, Harvey et al. (1987, 1992) postulated a major nuclear attack involving about 3000 Mt, comprised of about 4000 weapons; some 1900 Mt are assumed to be surface bursts. The study assumed that all weapons would be directed at (1) military bases, (2) military industrial facilities, and (3) the politico-economic base of the U.S. No weapons were assumed to be specifically aimed at urban centers. However, because many of the above targets are in or near cities, collateral effects on civilian populations would be very large. The attack-day meteorology was selected from one of the more frequent atmospheric flow patterns established by a 5-y typing scheme of daily 500 millibar (about 5.5 km) upper air charts (Harvey et al. 1987) for the contiguous U.S.

Sheltering protection factors (PF) used were taken from Lee.[§§] PF values ranged from 3–5 for single-story, woodframe houses; from 5–10 for multistory residences; 20–60 for basements in structures of a single story to a few stories; and 1000 or higher for deep basements of large buildings, subway stations, and tunnels located in metropolitan areas. Other protection factor profiles could be used. In general, using lower protection factors (for example, as in UNSCEAR 1982 or FEMA 1983) would increase the external dose and hence lower the ratio of internal to external dose.

Studies based on analyses of the blast and thermal effects of the nuclear weapons exploded over Hiroshima and Nagasaki and nuclear weapons testing at the Nevada Test Site in the 1950s have shown that thermal effects extend farther from ground zero than blast effects (Glasstone and Dolan 1977; Postol 1986). The thermal conflagration model used in the Harvey et al. study (1987) assumes: (a) a 100% fatality rate within a thermal fluence of 20 calories cm^{-2} or greater, (b) a 70% fatality rate for fluences between 10 and 20 calories cm^{-2}, and (c) no fatalities from thermal fluences less than 10 calories cm^{-2}.

The model used to predict the fallout from the hypothetical attack was KDFOC2 (Harvey and Serduke 1979). In this model, radioactivity is conserved, observed vertical wind profiles are used, and the geometry of a stabilized nuclear cloud is realistically emulated. The model successfully predicts many of the measured fallout patterns from atmospheric tests conducted at the Nevada Test Site and in the South Pacific. KDFOC2 tracks, in space and time, a large number of vertically stacked "altitude" disks. Each of these disks is segmented into many "particle-size" disks. All of the disks fall toward the surface under the influence of gravity, winds, and diffusion. For the nuclear war scenario, the model followed nearly 20 million disks.

Targets used in calculating the fallout pattern assumed nuclear strikes against (1) missile silos; (2) military facilities with surface forces, aircraft, industrial facilities, and submarine bases; (3) nuclear weapons production facilities; and (4) the politico-industrial base of the United States (including ports, petroleum refineries, electric power-generating plants, and selected political targets). It was estimated that 75% of all military and 80% of all politico-economic targets were destroyed to an extent that they were rendered useless for several months or longer.

All weapons were assumed to be of the fission–fusion–fission type with fission fractions of 50% (Harvey et al. 1987). The population data base was taken from the 1980 census (Bureau of Census Data 1980) and was divided into three parts: urban, suburban, and rural. The fallout pattern for the selected summer day is shown in Fig. 3. The contours, varying from 1 to 10 Sv (100 to 1000 rem), are for an unsheltered population and represent integrated external gamma doses from time of explosion to 48 h. The targeting scenario assumed air bursts on many targets that have been treated as surface bursts in some previously published fallout patterns. Almost all of the countervalue targets were assumed to be air bursts, which is why most of the Western U.S. in Fig. 3 is not covered by cigar-shaped fallout patterns over most of the major population centers. If sheltering or evacuation is not considered, the postulated attack causes 98 million deaths due to prompt effects and an additional 10 to 13 million fallout fatalities. If none of the population was evacuated, but most were sheltered, deaths from prompt effects would be virtually unchanged but the number of fallout deaths would drop to 0.7 million.

To obtain internal doses to the survivors of the above attack from the four selected radionuclides, it is necessary to have an estimate of their surface concentrations (in MBq m^{-2}). For this purpose, the integrated

[§§] Personal communication (1976), H. Lee, SRI International, 333 Ravenswood Ave., Menlo Park, CA.

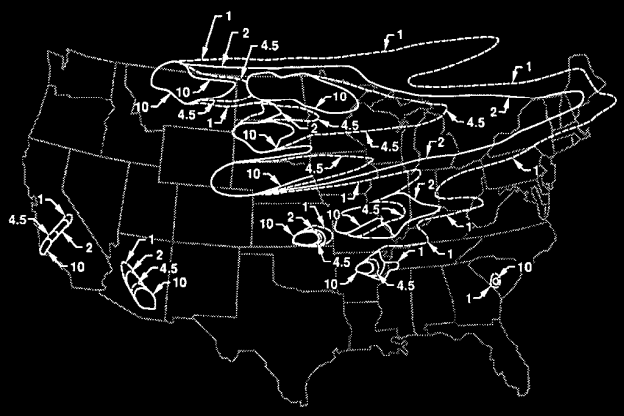

Fig. 3. Fallout pattern for a counterforce–countervalue attack on the U.S. during summer. Contours represent the 48-h dose in sieverts.

dose contours of Fig. 3 have been used to develop a procedure that approximates nuclide aerial densities to within about a factor of 2. The gross fission product dose contours are not convertible to exact nuclide aerial densities because each fallout disk for this calculation was time-integrated from its time of arrival (TOA) to 48 h; then all disks were summed. It was assumed that the unfractionated fission products followed a $t^{-1.2}$ time-decay dependence (Glasstone and Dolan 1977), a very good approximation for the period of interest (minutes to days).

To estimate the amount of specific nuclides reaching a specific point, a location-dependent "weighted" TOA for the area of interest was determined. Ten hours after detonation is a central value that was assigned as an overall TOA, which approximates—within a factor of 2—the dose on fallout disks that arrives from 3 to 21 h. Using this TOA and the chain yield of each nuclide from unmoderated neutron-induced fissions of ^{235}U (Crouch 1977), factors were produced that convert the gross fission product doses to surface depositions mostly within a factor of 2. These factors for the selected nuclides are shown in Table 1. Comparing these factors with those prescribed by Hicks (1984) gives agreement within the uncertainty estimates.

Another factor used in this study is an estimate of the depletion factor for radionuclide aerial density due to percolation into soil, from the time that it would be safe to leave the refuge for extended periods to 180 d. A rate constant of 0.02 d^{-1} has been used to estimate the depletion rate (Whicker and Kirchner 1987) and is assumed to be a reasonable approximation when applied to percolation through residential lawns and soils. To a lesser extent, it would be applicable to paved surfaces in cities and suburbs. There is some evidence that the depletion rate for paved surfaces would be less for removal of radionuclides by precipitation; however, the extent and efficacy of decontamination procedures after a nuclear war are unknown. For this reason, the same rate constant has been applied to paved surfaces and is considered a conservative approximation. Readers can use their own rate constant estimates by obtaining the original report (Peterson et al. 1988).

Table 1. Conversion factor of a 1-Sv time-integrated whole-body external equivalent dose (from H+10 to H+48 h) to a surface deposition for the four significant radionuclides. ^{235}U fission is assumed.

Nuclide	Factor (MBq m^{-2} per Sv)
^{89}Sr	18.00
^{90}Sr	0.11
^{131}I	66.00
^{137}Cs	0.12

INTERNAL DOSE ESTIMATION

Fig. 4 presents the steps needed to calculate internal and external dose following a nuclear war. The left side of the figure is used to estimate how long stored water and food would last and what internal dose would be received from these stored supplies. The right side shows the information required to calculate the internal dose from consumption of foraged water and food. Factors included in this assessment are:

- how long the transport of food and water would be disrupted,
- the shelter factor of the refuge,
- how long stored and foraged water and food would last,
- the radioactivity in stored and foraged water and food, and
- the total external and internal doses to an individual.

DESCRIPTION OF WORK SHEET AND AUXILIARY AIDS

The calculation of internal dose is accomplished using hand computers by making entries into a series of forms given in Peterson et al. (1988). The main form is labeled "Work Sheet." This calls on other sheets, tables, and figures at various places. These ancillary aids include (1) dose-conversion factors (DCF); (2) factors for enhancing the DCFs because of climatic changes due to smoke and soot; (3) energy values in kilojoules (kJ) and kilocalories (kcal) for many types of food, based on Deatherage (1975); (4) decay factors from an initial time to a final time for gross fission products and the four radionuclides determined to be the most significant contributors to internal dose; and (5) tables to determine radionuclide decay while in a refuge and while outside foraging for water and food.

Other aids used with "Work Sheet" are U.S. maps of external dose (in sieverts) following a 3000-Mt nuclear war and deposition on the surface (in MBq m^{-2}) of ^{89}Sr, ^{90}Sr, ^{131}I, and ^{137}Cs. Deposition maps were generated from the external dose figures using the meth-

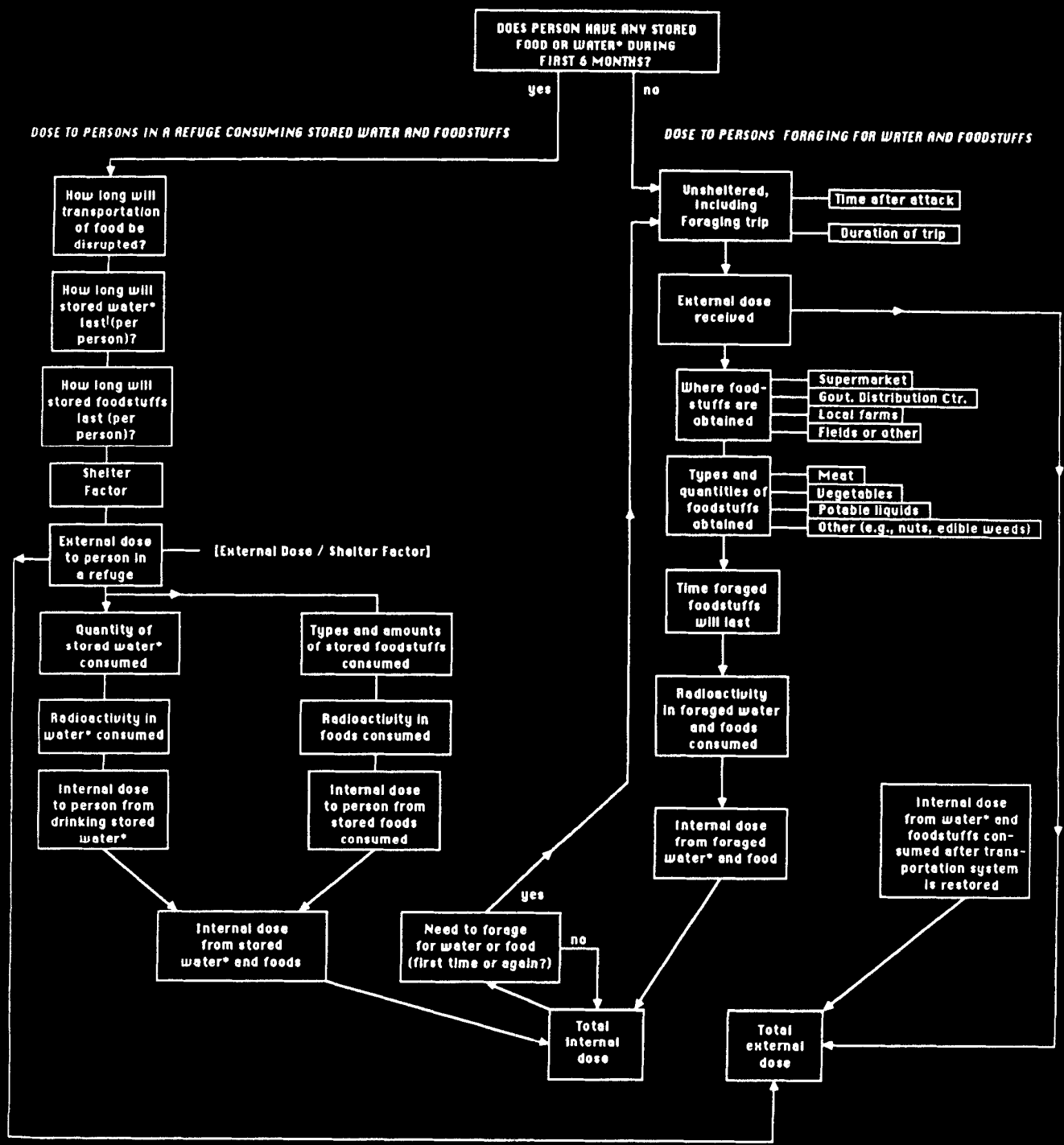

Fig. 4. Flow chart illustrating the parameters used to calculate internal and external doses following a large-scale nuclear war.

Table 2. Default values for Work Sheet variables used in estimating internal dose from a nuclear war.

Work Sheet item no.	Description	Default value
3	Food transport disrupted	1–3 mo
5a	Drinking water	1 L/person d^{-1}
5b	Washing and cooking water	0.5 L/person d^{-1}
7a	Minimum energy value of food	1700 kcal d^{-1} (male adult)
11a	Shelter factors[a]	
	Single-story buildings, wood-frame buildings, wall-bearing buildings, and forests	2–5
	Multistory structures that are steel or reinforced concrete framed	5–10
	Basement of multistory apartment building	20–60
	Underground shelters (1 m earth cover) and sub-basement of large urban building	100–1000

[a] Personal communication (1976), H. Lee, SRI International, 333 Ravenswood Ave., Menlo Park, CA.

odology described to prepare Table 1. Finally, other data sheets in conjunction with "Work Sheet" are used to (1) determine the energy value for each type (and the total) of stored or foraged food; (2) estimate the internal dose from consuming foraged water (and stored water if it is contaminated by fallout); and (3) estimate internal dose from consuming foraged foods.

To estimate the types of food obtained locally by foraging, U.S. Department of Agriculture (USDA) computer tapes were obtained that list the crops and livestock by year for nearly every county of the United States. These were used for the 10 locations where internal dose calculations have been made. U.S. counties typically do not report to the U.S. Department of Agriculture crop and livestock data from small farms. Therefore, in the listings of food available to foragers, the USDA data have been used as a guide; however, foods were entered occasionally that were not in the USDA data bases. The assumption is that such foods would be available in limited quantities from small farms.

Default values used in making internal dose estimates are given in Table 2. The user should feel free to employ his or her own values for the listed variables when making entries in the Work Sheet and the supplementary aids in Peterson et al. (1988).

RESULTS

Internal dose calculations for the 10 locations are presented in Table 3. It is not possible to predict exact scenarios for individuals after a nuclear attack; the approach used here was a representative sampling of 10 different situations around the U.S. where survivors of the attack would be expected. The 10 case studies considered included a variety of geographical locations, levels of local fallout, varying shelter factors (representing homes, apartment buildings, and large urban buildings), varying assumptions about food and water availability, differing impacts of climatic change, and a variety of other factors. For example, the assumptions for Memphis, TN included a shelter factor of 200 for the sub-basement of a large office building, water for 15 d, and no stored food. The assumptions for Washington, DC included a shelter factor of 2 for a single-family suburban home with basement and structural damage due to the attack, food for 32 d, and water for 26 d.

Values presented for internal dose are those resulting from the four most important radioisotopes considered. Because these four, on average, contributed 73% of the total from all the isotopes considered in the dose reconstruction of the Nevada atmospheric tests, one could make an approximate correction to the internal dose here for the other isotopes not considered by multiplying the doses in Table 5 by 1.4. We have not done so because this factor is more than compensated for by using the PATHWAY model DCFs that include uninterrupted ingestion from the time of fallout deposition. For the cases studied here, ingestion of contaminated foods begins after stored food is depleted—a significant time delay. The early days of fresh deposits on leafy vegetables contribute a significant portion of the dose commitment. Hence, the internal doses reported here are probably overestimates.

SUMMARY AND CONCLUSIONS

PATHWAY model results have been used in this study, in conjunction with a hypothetical nuclear attack on the U.S., to arrive at calculations of the ratio of internal to external dose estimates to humans from early fallout. The calculational methods, detailed as a "user's manual" in Peterson et al. (1988), enable individuals to use their own nuclear war scenario, fallout pattern, protection factor profile, assumptions about the climatic changes brought on by large fires following a nuclear attack, the viability of the transportation system for food delivery, the quality and quantity of water and food available locally, the required caloric intake of the survivors, and several other factors. The methodology used is amenable to programming on a computer, thereby providing a useful tool that could be

Table 3. Internal and external whole-body equivalent dose for 10 locations in the United States.

Location	Shelter factor	External dose (Sv)	Internal dose (Sv)	Total dose (Sv)	Ratio of internal to external dose
1. St. Louis, MO	7	3.7	0.066	3.8	0.02
2. Cincinnati, OH	4	0.87	0.0054	0.88	0.006
3. Buffalo, NY	3	1.9	0.010	1.9	0.005
4. International Falls, MN	2.5	2.6	0.0	2.6	0
5. Sidney, MT	5	5.6	0.17	5.8	0.03
6. Memphis, TN	200	0.15	0.033	0.18	0.2
7. Phoenix, AZ	2	2.3	0.033	2.3	0.01
8. Washington, DC	2	0.39	0.0033	0.39	0.008
9. Milwaukee, WI	100	0.28	0.027	0.31	0.1
10. Des Moines, IA	1.5	1.9	0.0013	1.9	0.0007

quickly applied to large releases of radioactivity (e.g., the 1986 Chernobyl disaster).

The four significant nuclides that account for nearly three-fourths of the reconstructed whole-body internal dose to people who lived within a few hundred kilometers of the Nevada Test Site have been identified as ^{89}Sr, ^{90}Sr, ^{131}I, and ^{137}Cs. Foods considered for internal dose estimates include milk, beef, leafy and non-leafy vegetables, poultry, and grain. Except for the ^{131}I dose to the thyroid, inhalation doses are insignificant compared to external doses. Only doses from early or local fallout have been considered because global fallout would cause relatively small doses (Knox and Shapiro 1986). Intermediate fallout, that part of global fallout that is initially placed into the troposphere and removed principally by rainout and washout within the first few weeks, would be significant only in areas of precipitation where meteorological clouds extend high into the troposphere. These areas are spotty and would be small in total area, especially under conditions of reduced precipitation that are expected from the climatic impact of smoke and soot.

Maps that estimate the reductions in temperature, precipitation, and insolation that would be likely after a large-scale nuclear war have been developed. A map of early fallout from an attack on the U.S., based on the work of Harvey et al. (1987), has been used.

A methodology for estimating doses from ingestion of water and food contaminated by radioactivity has been developed for the diets of survivors of a large-scale nuclear war. Studies have been made of the effects of a war on food distribution systems (Billheimer and Simpson 1978; Haaland 1977). While it is difficult to predict an exact scenario, it is assumed here that, after such a war, the food-transportation system would be disrupted for 1–3 mo. During this time, survivors of the first days after the attack would subsist on their own stored food and water for as long as possible. Then it is assumed that they would forage for local water and food obtained from sources such as local farmers, fields, and food distribution centers, until food transport is restored.

Internal and external doses for 10 locations within the U.S. have been calculated. The estimated 50-y internal dose commitment ranged from 0.0–0.17 Sv, and the 48-h external dose ranged from 0.15–5.6 Sv. Ratios of internal to external dose vary from less than 0.01 to about 0.2; seven of the case studies have ratios less than 0.02. The higher ratios result from the effects of a large shelter factor (reducing the external dose) and consumption of contaminated foraged food for long periods (increasing the internal dose). A qualitative discussion leads to the conclusion that the effects of climate perturbations on food crops would increase internal dose estimates, perhaps by factors of several depending on the nature and severity of the climate perturbations.

Of the four isotopes considered here, the principal contributor from ingestion to the total body equivalent dose in almost all of the 10 sites is ^{89}Sr, with ^{90}Sr close behind. Down by factors of several is ^{137}Cs, with the ^{131}I a distant fourth. This result for local fallout from weapons is consistent with those reported for the reconstructed doses downwind of the Nevada Test Site (Ng et al. 1990). This hierarchy differs from the global fallout situation where ^{137}Cs and ^{90}Sr dominate, and also differs from the Chernobyl reactor fallout situation where ^{137}Cs and ^{134}Cs dominate. Of course, if one is considering the dose to a specific internal organ, other isotopes may dominate (e.g., ^{131}I for the thyroid).

In conclusion, the average American family that survived a large-scale nuclear war, using its own home or workplace as a refuge, could receive a total internal dose from ingestion of the four most important radioisotopes that was less than 1% of the total external dose. Those who stayed where shelter protection factors and contaminated foraged food consumption rates were large could receive internal doses that are typically from 2% to ~20% of the external dose. Even with the considerable uncertainties in these dose estimates, the total dose from early fallout is dominated by the external dose in almost all cases of interest.

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EMERGENCY RADIATION MONITORING OF DRINKING WATER*

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Abstract—A simple method using standard radiation survey meters is given for monitoring drinking water against bomb fallout. The γ-field associated with a suitable volume of water is measured and compared with the fields expected from permitted concentrations of fission products of known age. The fields produced by these permitted concentrations have been tabulated, and the concentrations are themselves chosen consistent with U.S. and British recommendations.

The validity of the technique is examined from a number of points of view and has been checked by experimental studies. The method is generally applicable with minor limitations whether or not water treatment has been undertaken.

INTRODUCTION

SOME time ago a simple method was developed at Chalk River for emergency monitoring of drinking water against bomb fallout using standard radiation survey meters.[1] As the hazard considered appeared slight and as British and U.S.[2,3] reports giving other techniques appeared at the same time no widespread distribution of the information was attempted. With present concern about fallout from the larger weapons, our proposed method seems to have increased value. It is less dependent on specialized equipment and of more general application than other proposed methods. The following report includes further work carried out in development of this approach.

The basis of the method is the measurement of the γ-field associated with a suitable volume of water and comparison with fields from permitted concentrations of fission products of known age.

The primary hazard from fresh bomb fallout is taken to be due to Sr^{89} and Ba^{140} ($+La^{140}$). This view parallels the U.S. and U.K. assumptions made in deriving their recommended permissible levels[3,4]. The emergency permissible intake is set at the U. K. figure of 30 μc Sr^{89} plus 150 μc Ba^{140} ingested over a 10 day period. This is expected to lead to an irradiation of 5 r to the sensitive volumes of the bones. For fresh fission products the Sr^{90} hazard is considerably less than that due to Sr^{89} and Ba^{140}. The U.S. recommendation, although not entirely comparable in form, is similar.

Two other sources of hazard exist which might conceivably be comparable in effect. They are I^{131} and the general irradiation of gut. Arguments for disregarding I^{131} as a limiting toxin are given in both the U.S. and U.K. reports. It is held that any need to hold thyroid exposures to permissible levels for whole body irradiation is not borne out by medical experience. It has also been suggested that general irradiation of the G.I. tract might be significant in the case of recently formed fission products. However, assuming a minus 1.2 power law decay and meter readings no higher than given below for tolerance doses, the maximum integrated exposure of the G.I. tract would be about 12 tissue rads of β- and γ-radiation.

The key to the method lies in the inability

* This paper is a condensation of a Chalk River Report distributed as AECL 505.

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of natural processes or simple methods of treatment to separate the strontium and barium isotopes. That is, the proportions of Sr^{89}, Sr^{90}, Sr^{91} and Ba^{140} will be set largely by the elapsed time after formation. In addition the daughters of the above nuclides will usually be present in appropriate proportions unless unusual treatment methods have been carried out. Consequently, it is possible to estimate the concentration of toxic nuclides including pure beta emitters by measuring the γ-field from associated isotopes emitting γ-radiation.

In mixed fission products γ-radiation will be emitted by many nuclides in addition to the members of the alkaline earth family. It might be thought desirable to include the γ-radiation coming from these less dangerous nuclides in estimating the total flux from any given concentration of the toxic nuclides. Failure to include such contributions to the total flux will certainly result in an error in estimating the toxicity from the observed γ-field. However it can be shown this error will take the form of a moderate safety factor which should rarely exceed three. Further, by neglecting the contribution of nuclides which are not members of the alkaline earth family there is no need to be concerned as to whether any selective concentration of the Sr–Ba group has occurred.

The concentrations of the more toxic nuclides, Sr^{89} and Ba^{140} (plus La^{140}) are therefore estimated in terms of the radiation field from the γ-emitting isotopes Sr^{91}, Ba^{140} (plus La^{140}).

THEORY

The fallout fission products are presumed to be distributed throughout the water either in solution or suspension. In an extensive body of water in equilibrium if N is the number of quanta originating per ml per sec, then it is also the number stopping per ml/sec. This figure must also be given by the product of the flux and the absorption coefficient. At the interface between active water and inactive air the flux will be very nearly half that within the water.

$$F = N/2\mu_w \qquad (1)$$

where F is the flux in air in quanta per cm^2/sec and μ_w is the linear absorption coefficient for water.

The ionization produced in air by this flux is $F\mu_A E/w$ where μ_A is the linear absorption coefficient for air, E the energy per quantum and w the energy dissipated per ion formed.

A computed value for μ_A/μ_w combined with equation (1) gives:

$$\text{Radiation field} = 3.05 \times 10^{-8}\ NE \text{ mr/hr} \qquad (2)$$

Field from a large body of contaminated water

The activities of the various significant nuclides (relative to Sr^{89} as unity) are as in Table 1.[4]

For a 10-day consumption of 25 l, the permissible concentration is 1.2 μc Sr^{89} plus 6.0 μc of Ba^{140} per l. The corresponding concentrations of Sr^{91} (plus Y^{91}), Ba^{140} (plus La^{140}) found from Table 1 combined with γ-ray energies given in standard tables of disintegration energies are substituted in equation (2) to give the fields over a large body of contaminated water as in Table 2.

Table 1. Relative activity of significant nuclides

Nuclide	*Time after bomb burst*			
	12 hr	1 day	2 days	10 days
Sr^{89}	1	1	1	1
Sr^{90}	0.006	0.006	0.006	0.007
Sr^{91}	68	28	5	0
Ba^{140}	5.4	5.3	5.0	3.6
La^{140}	1.1	2.2	4.5	3.7
All fission products	1000	420	170	36

(The total γ-field for all fission products in equilibrium with permissible levels of Sr plus Ba at 1 day is about 200 mr/hr and for all the non-volatile fission products about 140 mr/hr.)

The permissible levels are set on the supposition that all the γ-radiation found arises from Sr and Ba and their immediate daughters introducing at the most, a safety factor of about three. If drastic segregation and enhancement of the most toxic components have occurred the standard of monitoring remains adequate. The

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Table 2. γ-Fields at the surface of a large body of water contaminated to the maximum permissible level for 10 day consumption

	Time after bomb burst			
	12 hr	1 day	2 days	10 days
γ-Field from Sr^{91} + Y^{91} (mr/hr)	98	40	7.2	0
γ-Field from Ba^{140}	2.6	2.4	2.3	1.7
γ-Field from La^{140}	3.4	6.6	13.3	11.2
Total γ-field Sr + Ba (mr/hr)	104	49	22.8	12.9

only necessary precaution is in connection with the presence of La^{140} which is the major contributor to the γ-field after 2 days. Some forms of water treatment might possibly remove La relative to its Ba precursor. Therefore, complete assurance as to water safety would require that in testing water more than 2 days after the bomb functioned, a day elapse between any drastic water treatment and final monitoring. However, it is doubted if any water treatments likely to occur in practice will separate Ba and La.

An additional advantage in using the monitoring levels set on the assumption that Sr (+Y) and Ba (+La) are the sole sources of γ-radiation lies in the fact that such levels do not raise any question of gastrointestinal damage from general irradiation. If the levels were raised appreciably a dose to the gut might be achieved which some authorities regard as objectionable.

The recommended technique is to hold a γ-indicating survey meter close to the surface of any large body of water. Meter readings are then compared with the values in the last row of Table 2 for the appropriate time after the bomb exploded.

With longer periods of consumption, the initial concentration need not be reduced proportionately since much of the Ba^{140} activity will have decayed prior to ingestion.

The γ-fields corresponding to the permissible concentration for 30 day ingestion are found to be one half those given above for 10 day ingestion.

Fields from limited volumes of water

The range of application of this technique is increased if it can be applied to typical water containers. The following water containers were studied: (a) 1 l. aluminum canteen; (b) 2 gal (Canadian) light steel can: 12 in. × 8½ in. × 5½ in.; (c) 4 gal (Canadian) heavy steel can: 15 in. × 13 in. × 6 in., "Jerry-can".

Fields to be expected for these and other vessels when filled with water contaminated to the maximum permissible level were calculated in the following way. The container was considered replaced by a cylindrical vessel with its section equal in area to the cross-section of the vessel perpendicular to its long axis. The γ-flux at the surface of such a cylinder of infinite extent was then calculated using a suitably modified form of equation (2):

$$\text{Radiation field} = 3.05 \times 10^{-8} \left[2 + 2r\mu_w - 2r^2\mu_w^2 \left\{ I_0(r\mu_w)K_0(r\mu_w) + I_1(r\mu_w)K_1(r\mu_w) + \frac{I_0(r\mu_w)K_1(r\mu_w)}{r\mu_w} \right\} \right] NE \text{ mr/hr} \quad (3)$$

where r is the radius of the cylinder, μ_w the absorption coefficient neglecting Compton scattering and K_0, K_1, I_0 and I_1 are the usual Bessel functions. The correction for the finite length of the container was considered in the following way. The field was found for an infinite rod lying along the axis of the cylinder loaded with radioactivity per unit length equal to that per unit length of the cylinder. The correction factor for a rod of finite length was calculated and this factor applied to the values given by equation (3). This approximation was considered reasonable since the end correction is not great and the rod and cylinder calculations give approximately the same fields if the radiation mean free path is greater than the radius of the cylinder. For larger tanks the correction

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is probably slightly overestimated but this will set an upper limit to the estimated concentration and provide a safety factor. Table 3 can then be calculated.

Table 3. γ-Radiation field from permissible levels of fresh fission products in drinking water (mr/hr)

(Fields are to be measured at the center of one surface and correspond to the ingestion of 30 μc Sr^{89} plus 150 μc Ba^{140} over a 10day period.)

Object	*Time after bomb burst*			
	12 hr	1 day	2 days	10 days
Large body of water	104	49	23	13
Tank truck (1000 gal.)	68	32	15	8.5
4 gal Jerry can	28	13	6	3.5
2 gal oil can	25	12	5.5	3.
Water bottle (1 l.)	13	6	3	1.5

Experimental verification

The validity of equation (2) was originally tested[1] with Na^{24} dispersed in a large tank of water.

The accuracy of the estimation of the fields from the smaller irregular bodies of water was now investigated using material more closely approximating the toxic fallout. A solution of 55μc/l. of Ba^{140} was used after reaching equilibrium with its La^{140} daughter. Measurements were also made with a solution of 11 μc Ba^{140} (plus La^{140})/l. The water containers tested were the 1 l. bottle and the 2 and 4 gal cans. γ-fields were measured using two types of survey meters, an ion-chamber type (Tracerlab–SU–1F) and a halogen geiger type (Atomic Energy of Canada 1922). The latter is designed to read directly in mr/hr. Each survey meter was placed in contact with the center of the broadest face of each vessel. Table 4 compares the measured fields with calculated values found as for Table 3.

Agreement is good except in the case of the 1 l. canteen. The low values for the measured fields in this case are obviously due to the fact that the size of the sensing element of the meter is large compared to the dimensions of the vessel and thereby fails to give a reliable measure of the γ-field at the vessel's surface. This is borne out by the observation that the AEP 1922 instrument with smaller chamber gives more nearly the calculated field.

Materials likely to be used in construction of tanks and water trucks were tested by insertion between the sample vessel and the meter: $\frac{1}{8}$ in. aluminum and $\frac{1}{8}$ in. and $\frac{1}{4}$ in. bakelite had no measurable effect. The plastic was considered equivalent to thermal lagging materials likely to be used in practice.

Practical application

The calculations and observations made in the previous sections can be applied very simply. The chief modification required is to round off some of the figures and generalize requirements. Table 5 is the basic table proposed.

The above table applies whether the water has been subject to treatment or not. The only exception would be for fallout more than 2 days

Table 4. γ-Field at the surface of containers

Vessel	Concentration of Ba^{140} (μc/l.)	Observed field		Calculated field (mr/hr)
		SUIF (mr/hr)	AEP 1922 (mr/r)	
4 gal can	55	40	40	44
	11	8	8	8.7
2 gal can	55	32	32	39
	11	6.5	—	7.8
1 l. can	55	8.5	13.5	20

ED_001057_00010127

Table 5. γ-Field measurements (mr/hr) *for maximum permissible water contamination*

This table applies to any fresh fallout contamination and is for 10 day consumption. Values should be halved for 30 day consumption.

Water body	*Time since bomb burst*			
	12 hr	1 day	2 days	10 days
Reservoir or lake, measured far from shore	100	50	25	12
Reservoir, pond, etc., measured at arms length from shore, close to surface and over water at least 2 ft. deep	50	25	12	6
Water tank, from 150 to 1000 gal measured in contact with center of one surface	50	25	12	6
Water can, from 2 to 4 gal	25	12	6	3

old and subject to unusual chemical treatment. To cover all possibilities in such a case it might be desirable to allow a day to elapse between treatment and final monitoring. Water that has been contaminated with old fission products cannot be monitored by this method and recourse would be necessary to full radiochemical analysis. If more than 2 weeks elapse between the contaminating incident and monitoring, radiochemical analysis is suggested. However, this is not expected to arise as a practical military or civil defense problem.

The monitoring of individual containers of capacity less than 2 gal is not recommended because of the large effects of chamber size on response. If necessary, however, the user could easily compare fields from small and larger containers holding samples from the same contaminated water supply. In this way, permissible fields could easily be determined for any small containers and meters available.

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ED_001057_00010129

The Relative Importance of Internal Dose: An Analysis of the Detonation of a 10-kT Improvised Nuclear Device using HPAC and FIIDOS

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Outline

- Background and Overview
- Initial Conditions and Parameters
- External Dose and Casualties
- Internal Doses
- Future Work
- Summary

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Motivation

- Various efforts are underway to assess the effects of a 10 kiloton improvised nuclear device in a tier 1 Urban Area Security Initiative (UASI) city
  - New York/New Jersey, National Capitol Region, Houston, Chicago, Los Angeles, and San Francisco/Bay Area
- The Institute of Medicine of the National Academies hosted two workshops during summer 2008 on the medical preparedness of these cities for such an attack
  - One theme was the level of preparedness to treat radiation illnesses, including the efficacy of medical countermeasures, and the medical capacity for decontamination of the affected population
  - Though internal dose was mentioned, it was not directly addressed in a quantitative manner for the particular scenario under consideration

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Motivation

- The threat of nuclear terrorism is real and possibly growing
  - The Commission on the Prevention of WMD Proliferation and Terrorism suggests that the US should expect a biological or nuclear attack by 2013
- Many government agencies are trying to come to grips with the impacts of such an attack
- One of the unique large-scale impacts of a nuclear detonation is the fallout
  - Fallout patterns will constrain rescue and emergency response
  - Fallout patterns will constrain evacuation
- One consideration that is often mentioned, but not directly addressed in a quantitative manner is the relative impact of internal dose compared to externally delivered dose

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Methodology

- Two modeling codes were used to analyze the relative impacts of internal and external dose
  - Hazard Prediction and Assessment Capability (HPAC)
    - Used to predict the fallout pattern
    - Analyze the external dose contribution
  - Fallout Inhalation and Ingestion Dose to Organs (FIIDOS)
    - Used to analyze the internal dose contribution

ED_001057_00010129

What is HPAC?

- Hazard Prediction and Assessment Capability
  - Predict the effects of hazardous material releases into the atmosphere and its impact on civilian and military populations
  - Integrates source terms, high-resolution weather forecasts and particulate transport analyses to model hazard areas produced by military or terrorist incidents and industrial accidents.
- Developed and released by the Defense Threat Reduction Agency (DTRA)
  - DoD Science and Technology community
  - Original Beta release in February 1995
  - HPAC 5.0 SP1 release this year

ED_001057_00010129

What is FIIDOS?

- Fallout Inhalation and Ingestion Dose to Organs
  - Developed for and used by the Nuclear Test Personnel Review Program (NTPR) to calculate the internal dose to participants in atmospheric nuclear testing and the occupation of Hiroshima and Nagasaki, Japan.
  - Core “subroutine” is a modified version of the Oak Ridge Isotope Generation and Depletion Code (ORIGEN), Version 2.1, with nuclear decay and gamma production data updated to ENDF/B-VI.
- Developed and maintained by Science Applications International Corporation (SAIC) for the NTPR program
  - Original version completed in 1985
  - FIIDOS2 created in 1995
  - Minor revisions were made in subsequent years

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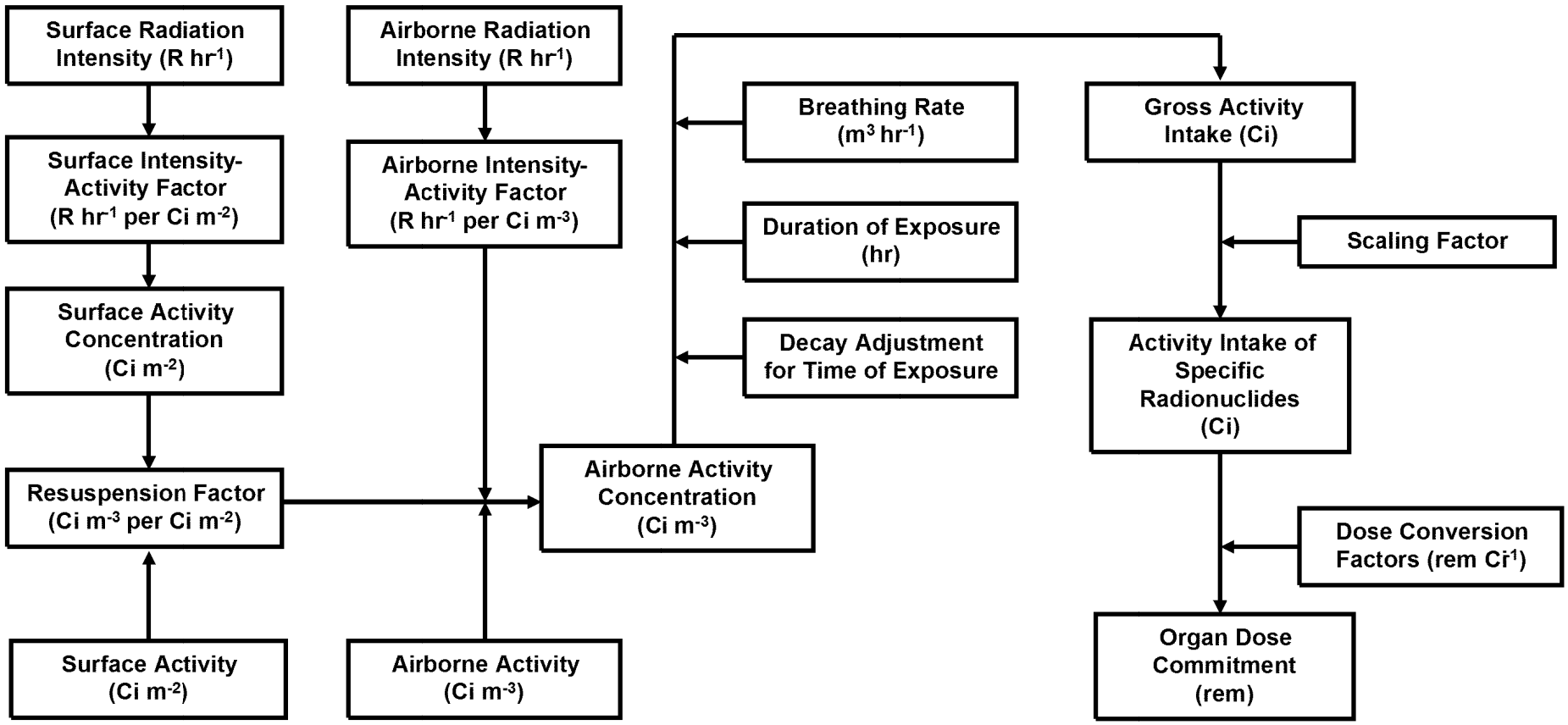
How Does FIIDOS Work?



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What is needed to run FIIDOS?

- FIIDOS estimates the internal committed dose relative to the external dose-rate due to ground shine
- External dose-rate parameters used as inputs for the FIIDOS runs can be generated using HPAC
  - Peak intensities (dose-rates)
  - Corresponding times at which those peaks occurred
- Fission yields, activation products and actinide concentrations are part of the FIIDOS input file
  - FIIDOS generates the total relative inventories of theradionuclides based on the ground shine dose-rate
- Other FIIDOS inputs include
  - Breathing rate
  - Resuspension factor
  - Time and duration of exposure

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FIIDOS' Inhalation Dose Coefficients Were Chosen to High-side Internal Doses

- FIIDOS' internal dose coefficients are taken from the ICRP-72 electronic database
  - Inhalation dose coefficients for the four available particle size distributions, with AMADs of 1, 3, 5, and 10 micrometers, were compared
  - The highest dose coefficient from the four particle size classes was selected and put into FIIDOS' dose coefficient table for each radionuclide
  - Metabolic characteristics of each radionuclide are based on the recommended absorption type for the particulate form
- Allows use of more nominal or scenario-specific assumptions for the other exposure parameters without sacrificing high-sidedness of results

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Sample Scenarios Were Run Using HPAC

- A 10-kT detonation was modeled at an arbitrary location in the center of the United States with several different wind patterns
- Though urban settings can be important for some incidents, the urban atmospheric transport models are not necessary for the purposes of this study
- DELFIC cloud rise model option was turned on, with 100 percent of the yield from U238tn fission (the default fissile fuel in HPAC)
- The output time interval was set as small as 30 seconds to resolve fallout patterns at short times after detonation

Released Material is Transported and Dispersed Downwind

- Transport model is the Second-order Closure, Integrated PUFF model (SCIPUFF)
- The numerical technique uses the Gaussian “puff” method
  - The time-dependent concentration field of released material is represented as a collection of three-dimensional puffs
- The turbulent diffusion parameterization is based on second-order turbulence closure theory
  - Provides a direct connection between atmospheric turbulence wind velocity statistics and the predicted dispersion rates of lofted materials

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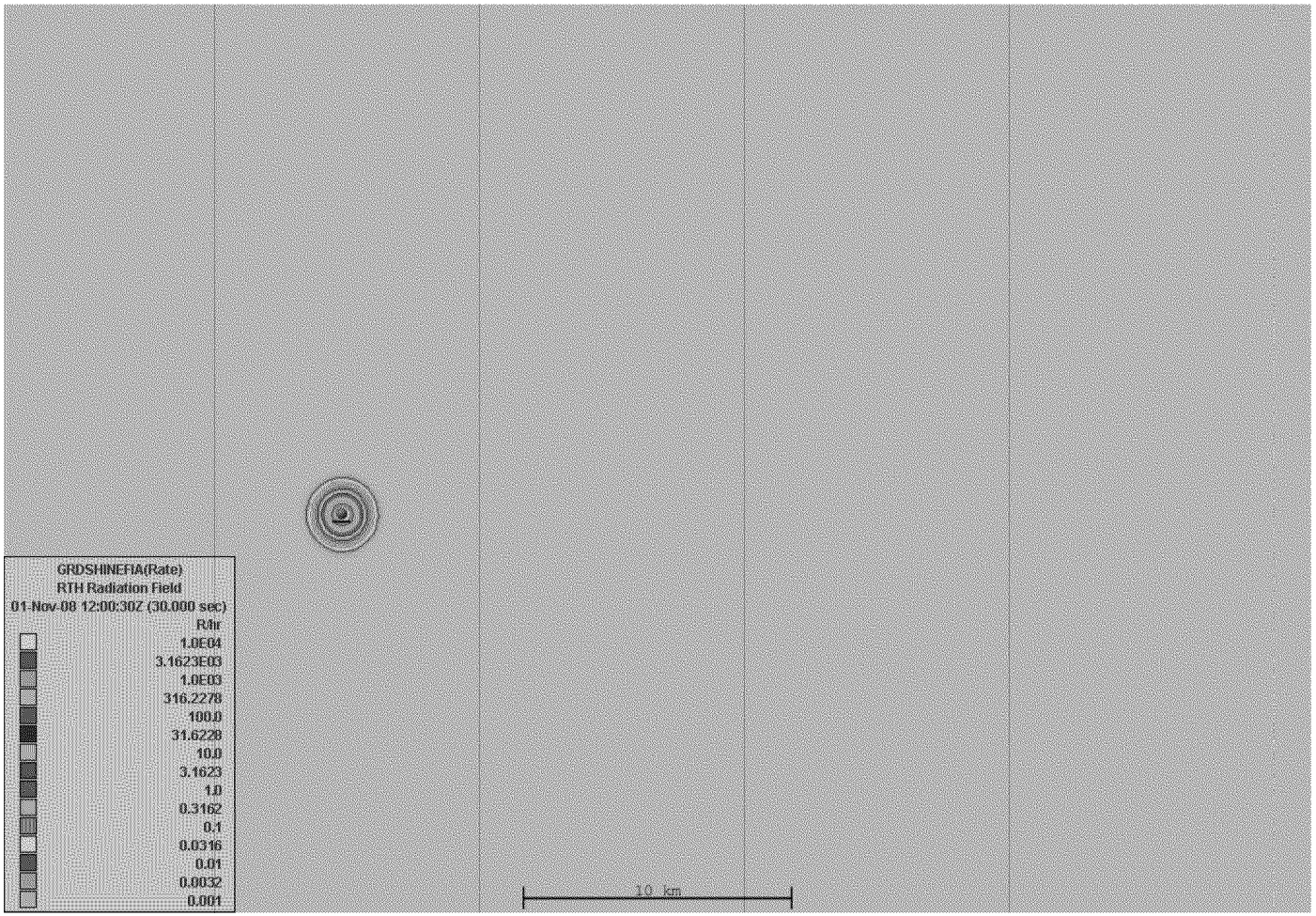
Sample HPAC Animation Showing Fallout from the Detonation



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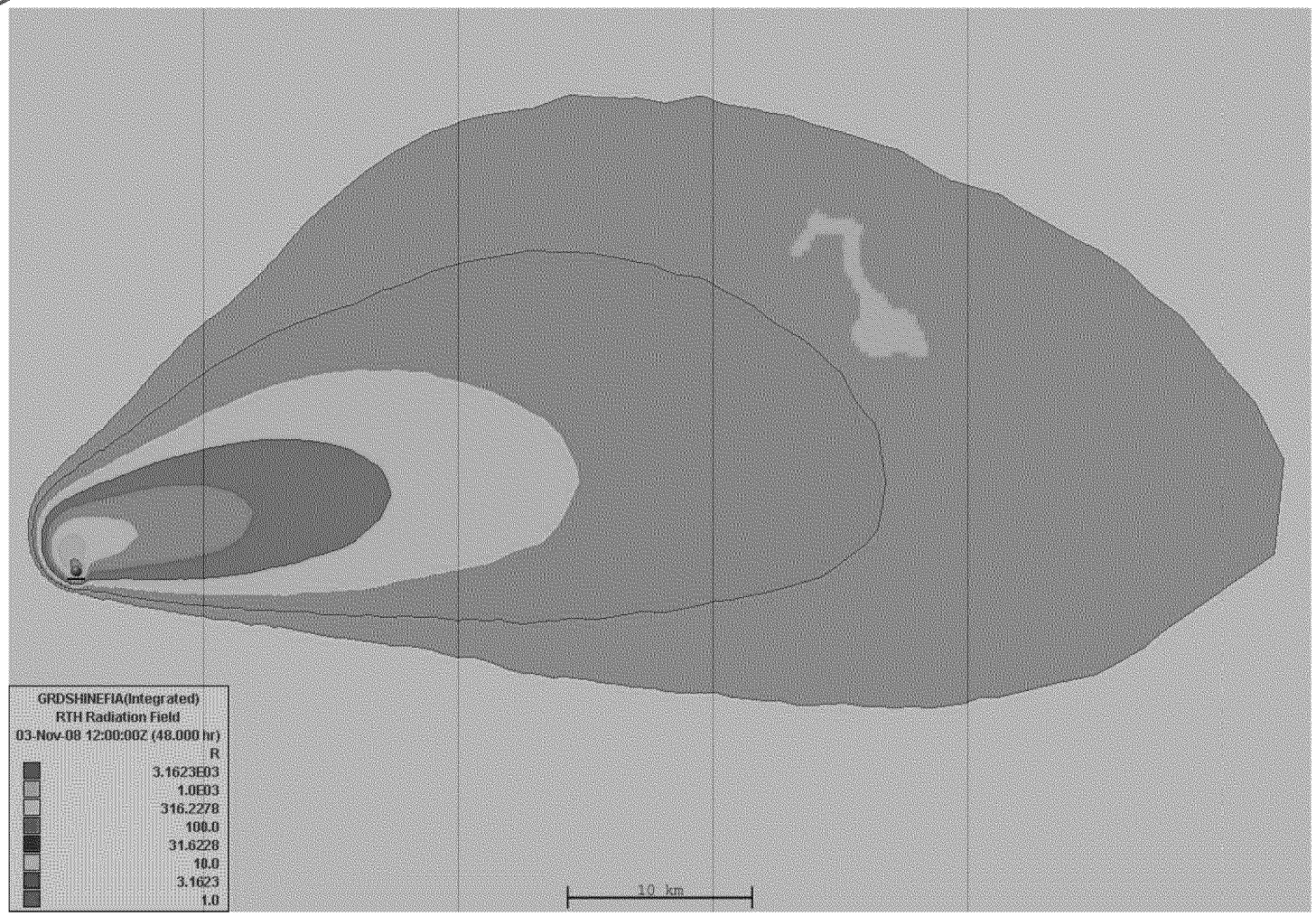
Sample HPAC 48-Hour Total Integrated Fallout Intensity



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Summary Results from Sample HPAC Run – Intensities, Fatalities, and Casualties

Peak Intensity	1000 R/hr	100 R/hr	10 R/hr
Distance Downwind (km)	1.3	2.7	9.8
Time of Peak Intensity (minutes)	9.0	35.5	92
Integrated Exposure to Peak Intensity (R)	66	24	5.0
Integrated Exposure to H+48 hours (R)	1900	480	100
Probability of Prompt Fatality/Casualty	52%/64%	0%/3%	0%/0%
Total Probability of Fatality/Casualty at H+48	>99%/>99%	17%/>99%	0%/16%

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Particle Size Distributions for Internal Dose Assessments are Not Easily Predicted

- Large particles will fall to the ground first, but some portion of smaller particles will always be mixed in
  - A distribution of particle sizes fall at any given location
  - Small and large particles start from different heights
- Shock of impact and mechanical disturbances after deposition may create smaller particles which are more easily resuspended and inhaled or ingested
- Factors such as height of burst, native soil particle size distribution and material composition play a role in determining the overall fallout particle size distribution

Solution: Perform internal dose analysis with FIIDOS, where dose coefficients were chosen assuming the worst case with regard to the particle size distribution

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Characteristics of the FIIDOS Internal Dose Calculations

- The specified external dose rates are converted to equivalent ground concentrations of radionuclides in Ci/m^2
- Descending fallout air concentrations of contaminants are calculated assuming the total ground concentrations fell from a height of 10,000 meters and were evenly distributed over that columnar volume
- Air concentrations from resuspended fallout are calculated using the calculated ground concentrations multiplied by a resuspension factor of 10^{-5} m^{-1}
- The breathing rate in all calculations is assumed to be 1.2 m^3/hr

FIIDOS Results for Simulation (Assuming 5% Fission Yield)

Internal Dose Category	Fissile Fuel	1000 R/hr	100 R/hr	10 R/hr
Descending Internal Dose – CEDE (rem)	U235ff	0.14	0.15	0.08
	U238ff	0.13	0.15	0.09
	U238tn	0.14	0.15	0.09
	Pu239ff	0.14	0.15	0.09
Resuspended Internal Dose – CEDE (rem) to H+48 hours	U235ff	0.83	0.29	0.09
	U238ff	0.89	0.33	0.10
	U238tn	1.1	0.39	0.12
	Pu239ff	1.1	0.35	0.11

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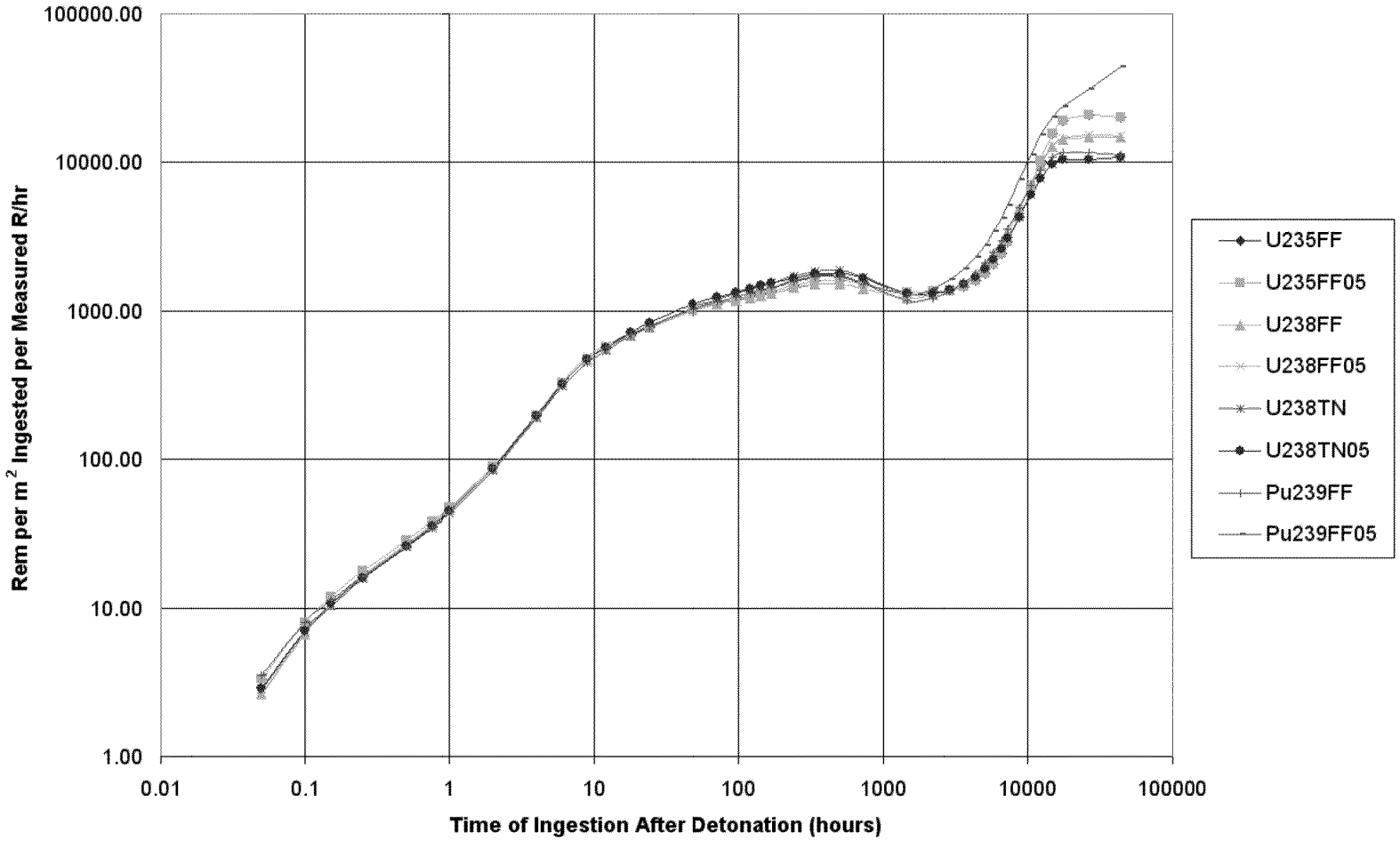
Ingestion Doses Must be Handled Differently

- Ingestion doses, unlike inhaled doses, are accrued only if and when contaminated material is consumed
  - A contaminated plate may be used hours or days after the deposition of fallout
  - Contaminated water will take time to work through the distribution system
- The selection of an appropriate unit reduces calculations to a series of linear corrections to dose factors in units of Rem per m^2 ingested per R/hr, where
  - Area indicates cross sectional area of consumed food or collection volume (for exposed water supplies)
  - Radiation intensity is measured at the point of collection and the time of consumption after the detonation
  - Corrections can be transfer factors, filtering efficiencies, capture percentages, or even could be correlated to a consumption rate and integrated over time

CEDE Coefficients for the Ingestion of Contaminants at Specific Times after Detonation



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A Practical Example

- Using the external dose results from the HPAC runs, the internal doses from ingesting fallout contaminated food can be calculated for each peak intensity location
- The CEDE coefficients for ingestion for the various fission types are not appreciably different, so an average value can be used
- The NTPR program typically assumes that a 9-inch diameter plate is left in the open during the period of fallout deposition
- For this example assume the exposed individual is inside their home
  - Assume the radioactive material enters the home through normal ventilation during the fallout period of about 10 minutes
  - Given the recommended home ventilation rate (0.35 exchange/hr*), the amount of contamination inside is about 1/17 the levels outside
  - The food is assumed to be consumed 1 hour after the peak intensity

* American Society of Heating, Refrigeration and Air Conditioning Engineers, Std 62-1999

FIIDOS Ingestion Results Assuming Consumption of a 9-inch Diameter Plate of Food after the Cessation of Fallout

Peak Intensity	Time of Peak Intensity (min)	50-Year CEDE (rem)
1000 R/hr	9	46
100 R/hr	35.5	13
10 R/hr	92	3

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Final Results of Internal Dose Analysis and Comparison using HPAC and FIIDOS

Dose Type	1000 R/hr	100 R/hr	10 R/hr
External (R) (to H+48)	1900	480	100
Descending Internal CEDE (rem)*	0.14	0.15	0.09
Resuspended Internal CEDE to H+48 (rem)*	1.1	0.39	0.12
Ingested Internal CEDE (rem)	46	13	3

* Worst case fission type assumed

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Future Work

- Activation products and fractionation effects are not currently included in HPAC
- FIIDOS does include capability to assess doses from activation products and can fractionate the inventories, but estimates are needed to quantify these effects
- Future version of HPAC may include capabilities needed to refine the internal dose assessment

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Summary

- HPAC is a well established tool that has gained widespread use, not only within the US DoD, National Guard, and NATO, but also with civilian universities and research institutes
- FIIDOS, in concert with HPAC, can be used to provide useful bounds to the potential range of internal doses
- As with all models, the results should not be taken as truth, but a reasonable prediction of a bounding dose given the input parameters
- Based on the scenarios provided, a “worst-case” total internal dose from the inhalation of fallout is 1.3 rem, which corresponds to the location where the peak fallout intensity is 1000 R/hr and the principle cause of fatality is from prompt effects
- Though ingestion doses cannot be quantified with any certainty, there is the potential for some additional internal doses to be accrued from the ingestion of fallout contamination

Radiological Emergency Response - Quick Reference Guide 6
1992 PAG Manual Overview

Background: The Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, EPA 400-R-92-001, is usually referred to as the "PAG Manual" or the "1992 PAG Manual." The manual was developed to assist public officials in planning for emergency response to radiological incidents. It provides radiological protection criteria for application to all incidents that would require consideration of protective actions, with the exception of nuclear war. The manual provides recommended numerical protective actions guides (PAGs) for the principal protective actions available to public officials during a radiological incident. **A PAG is defined as the projected dose to an individual resulting from a radiological incident at which a specific protective action to reduce or avoid that dose is warranted.**

This Quick Reference Guide (QRG) provides an overview of the 1992 PAG Manual.

Source Document: The Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, EPA 400-R-92-001, begins with a general discussion of the protective Action Guides (PAGs) and their use in planning for protective actions to safeguard public health. It then presents PAGs for specific exposure pathways and associated time periods. These PAGs apply to all types of nuclear incidents. This is followed by guidance for the implementation of PAGs (including the Dose Conversion Factors (DCFs) and how to calculate them). Finally, appendices provide definitions, background information on health risks, and other information supporting the choice of the numerical values of the PAGs. Chapter 1 provides an overview of the Manual; Appendix A is a Glossary; Appendix B provides information about the risks to health from radiation doses that may result from nuclear incidents.

Phase	PAG and Protective Action Chapter	Implementation Chapter	Supporting Information Appendix
Early (Emergency), Emergency Worker Dose Limits	2	5	C
Intermediate – Food & Water	3*	6*	D*
Intermediate – Deposited Material	4	7	E
Late	-	8 (reserved)	F (reserved)
*FDA issued revised guidance on food PAGs and protective actions in 1998 (63 FR 43402).			

Phase and Protective Action	PAG (projected dose)	Type of Dose	Pathway	Implementing DCF Table		
				Table No.	PAG Manual Page No.	PDF Version Page No.
Early – Evacuation (or sheltering)	1-5 rem	Total Effective Dose	Air submersion, plume inhalation, 4-day ground-shine from deposited mat'l	Table 5-1	5-9 – 5-14	61 – 66
	5-25 rem	Thyroid Committed Equivalent Dose	Plume inhalation	Table 5-2	5-15	67
	50 – 250 rem	Skin Committed Equivalent Dose	Skin contamination			
Administration of stable iodine (KI)	25 rem [a]	Thyroid Committed Equivalent Dose	Plume inhalation	Table 5-2	5-15	67
(Both Early Phase PAGs, Table 2-1, Page 2-6; PDF Version page 24)		External Effective Dose	Air submersion	Table 5-3	5-25 – 5-30	77 – 82
		Committed Effective Dose	Plume inhalation	Table 5-4 (includes repeat of Table 5-2)	5-31 – 5-36	83 – 88
	1-5 rem (if plume no longer present)	External Effective Dose	4-days of exposure to groundshine from deposited mat'l	Table 5-5	5-37 – 5-41	89 – 93
Intermediate – Food	0.5 rem Or 5 rem Whichever is limiting	Committed Effective Dose Or Committed Equivalent Dose (to a tissue or organ)	Ingestion of contaminated food	See FDA Guidance: Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies, August 13, 1998		
Intermediate – Deposited Material – Relocation (Table 4-1, Page 4-4, PDF Version page 50)	2 rem	Total Effective Dose for 1st year	Groundshine from deposited mat'l and inhalation from resuspended mat'l	Table 7-1 Table 7-2 Table 7-4	7-9 7-10 7-16	155 156 162
	0.5 rem	Total Effective Dose for any year after the 1st	Groundshine from deposited mat'l and inhalation from resuspended mat'l	Table 7-1 Table 7-2 Table 7-4	7-9 7-10 7-16	155 156 162
	5 rem	Total Effective Dose for 0-50 years	Groundshine from deposited mat'l and inhalation from resuspended mat'l	Table 7-1 Table 7-2	7-9 7-10	155 156
[a] Requires approval from State medical officials. FDA issued revised guidance in 2001 that is based on risk groups (66 FR 6404 6).						

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Guidance on Dose Limits for Workers Performing Emergency Services (taken from 1992 PAG Manual, Chapter 2, Table 2.2, Page 2-10, PDF Version page 28)				
Total Effective Dose (rem)*	**Lens of Eye (rem)**	**Other Organ, Thyroid, Skin (rem)**	**Activity**	**Condition**
5	15	50	All	
10	30	100	Protective valuable property	Lower dose not practicable
25	75	250	Lifesaving or protection of large populations	Lower dose not practicable
>25	>75	>250	Lifesaving or protection of large populations	Only on a voluntary basis by persons fully aware of the risks involved.
*Sum of external effective dose and committed effective dose to non-pregnant adults from exposure and intake during an emergency situation. These limits apply to all doses from an incident, except those received in unrestricted areas as members of the public during the Intermediate Phase of the incident.				

What Tables to use for the Early Phase

If you know this kind of concentration	Use this table in the 1992 PAG Manual, Chapter 5	To calculate this dose (for EACH radionuclide)	To compare to this PAG (for SUM of all radionuclides) 1992 PAG Manual - Chapter 2
Time-integrated air concentration (μCi-hr/cm^3) and the plume is present	Table 5-1 (rem per μCi-hr/cm^3)	Total Effective Dose from Air Submersion, Plume Inhalation, and Groundshine (from deposition time + 4 days after deposition)	1 - 5 rem Evacuation should normally be initiated at 1 rem. Shelter-in-place may be preferred when it provides protection equal to or greater than evacuation.
	Table 5-2 (rem per μCi-hr/cm^3)	Thyroid Committed Equivalent Dose from Plume Inhalation	5 - 25 rem - Evacuate ≥25 rem* - administration of stable iodine (Potassium Iodide, KI)
	Table 5-3 (rem per μCi-hr/cm^3)	External Effective Dose from Air Submersion	
	Table 5-4 (rem per μCi-hr/cm^3)	Committed Effective Dose from Plume Inhalation	
	Table 5-5 (rem per μCi-hr/cm^3)	External Effective Dose from Groundshine (from deposition time + 4 days after deposition)	
* 1992 PAG Manual endorsed the use of KI when the thyroid committed equivalent dose from radioiodine inhalation was ≥25 rem (at that time, it was the FDA guidance on the use of KI, 47 FR 28158, June 29, 1982). In 2001, FDA issued revised guidance that recommended KI use be based on risk group (66 FR 64046, December 11, 2001). See table below for new guidance.			

What Tables to Use for the Intermediate Phase

If you know this kind of concentration	Use this table in the 1992 PAG Manual Chapter 7	To calculate this dose (for EACH radionuclide)	To compare to this PAG (for SUM of all radionuclides) 1992 PAG Manual – Chapter 4
Ground Deposition Concentration (pCi/m^2)	Table 7-1 or Table 7-2 initial exposure rate at 1 m (mR per pCi/m^2)	Initial Exposure Rate at 1 meter above contaminated ground	
	Table 7-1 or Table 7-2 year one* (mrem per pCi/m^2)	Total effective dose for 1st year from groundshine and inhalation of resuspended material *	≥ 2000 mrem - relocate; <2000 mrem - apply simple dose reduction techniques
	Table 7-1 or Table 7-2 year two* (mrem per pCi/m^2)	Total effective dose for 2nd year from groundshine and inhalation of resuspended material *	≥ 500 mrem – mitigate or relocate
	Table 7-1 or Table 7-2 0-50 years* (mrem per pCi/m^2)	Total effective dose for 0-50 years from groundshine and inhalation of resuspended material *	≥ 5000 mrem – mitigate or relocate
* 1992 PAG Manual does not include inhalation dose from resuspended materials – it is generally considered to be a small part of the total integrated dose (especially for radionuclides expected from NPP accidents). Radioactive decay and weathering are included (Table 7-2 includes factors without weathering). To determine the total effective dose using the 1992 PAG Manual, an air sample should be taken and used with the conversion factor in Table 7-4 to determine the committed effective dose from inhalation of resuspended material.			
Air Concentration (at beginning of year one) (pCi/m^3)	Table 7-4 ** (mrem per pCi/m^3)	Committed effective dose from inhalation of resuspended material	
** This dose may be combined with the doses calculated from Table 7-1, year one or year two to determine the total integrated doses for those years.			

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Radiological Emergency Response - Quick Reference Guide 8
US Nuclear Power Plant (NPP) Types and Emergency Planning Information

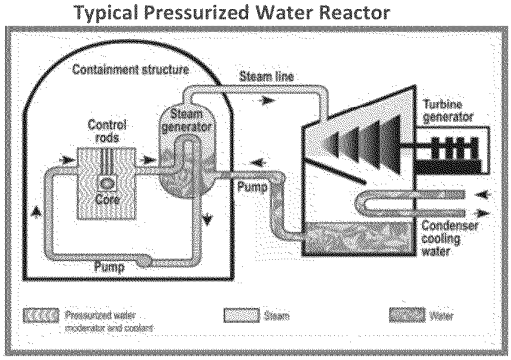
Background: In the United States, there are 104 licensed nuclear reactors. There are 69 Pressurized Water Reactors (PRWs) and 35 Boiling Water Reactors (BWRs).

Source Document: The following information is taken from the NRC.gov website, the World-Nuclear.org website, and previously generated EPA training material.

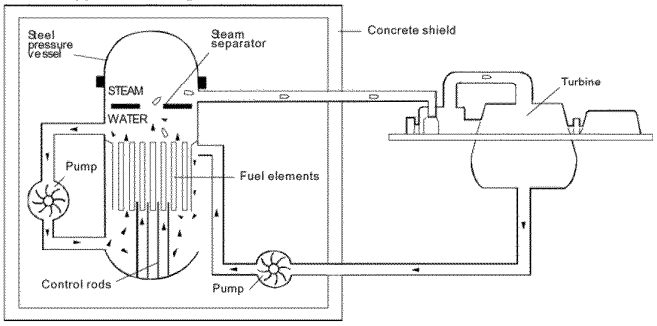
Pressurized Water Reactors

In a typical commercial pressurized light-water reactor (drawing on left) the core inside the reactor vessel creates heat; pressurized water in the primary coolant loop carries the heat to the steam generator; inside the steam generator, heat from the water is transferred to a separate system creating steam; and the steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity. The unused steam is exhausted in to the condenser where it condensed back into liquid water. The resulting water is pumped out of the condenser with a series of pumps, reheated and pumped back to the steam generators. The reactor's core contains fuel assemblies that are cooled by water circulated using electrically powered pumps. These pumps and other operating systems in the plant receive their power from the electrical grid. If offsite power is lost, emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need power. Pressurized-water reactors contain between 150-200 fuel assemblies.

Typical Pressurized Water Reactor



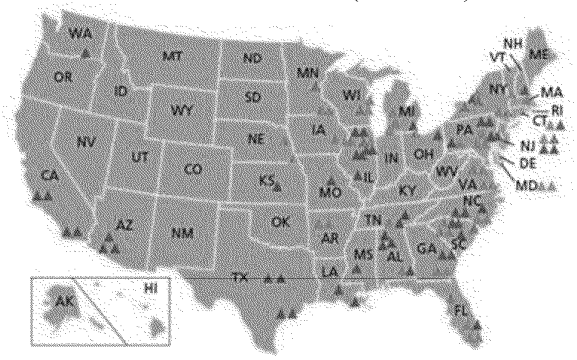
Typical Boiling Water Reactor



Boiling Water Reactors

In a typical commercial boiling-water reactor (drawing on right), the core inside the reactor vessel creates heat; a steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core, absorbing heat; the steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line; and the steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity. The unused steam is exhausted into the condenser where it is condensed back into liquid water. The resulting water is pumped out of the condenser with a series of pumps, reheated and pumped back to the reactor vessel. The reactor's core contains fuel assemblies that are cooled by water circulated using electrically powered pumps. These pumps and other operating systems in the plant receive their power from the electrical grid. If offsite power is lost emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need electric power. Boiling-water reactors contain between 370-800 fuel assemblies.

Location of US NPPs (as of 2010)



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Emergency Classification

An **Emergency Classification** is a set of plant conditions which indicate a level of risk to the public.

- **Notification of Unusual Event -** Under this category, events are in process or have occurred which **indicate** *potential degradation in the level of safety of the plant*. No release of radioactive material requiring offsite response or monitoring is expected unless further degradation occurs.
- **Alert -** If an alert is declared, events are in process or have occurred which involve an ***actual or potential substantial degradation in the level of safety of the plant***. Any releases of radioactive material from the plant are expected to be limited to a small fraction of the Environmental Protection Agency (EPA) protective action guides (PAGs).
- **Site Area Emergency -** A site area emergency involves events in process or which have occurred that result **in *actual or likely major failures of plant functions needed for protection of the public***. Any releases of radioactive material are not expected to exceed the EPA PAGs except near the site boundary.
- **General Emergency -** A general emergency involves ***actual or imminent substantial core damage or melting of reactor fuel with the potential for loss of containment integrity***. Radioactive releases during a general emergency can reasonably be expected to exceed the EPA PAGs for more than the immediate site area.

Emergency Planning Zones

To facilitate a preplanned strategy for protective actions during an emergency, there are two emergency planning zones (EPZs) around each nuclear power plant. The exact size and shape of each EPZ is a result of detailed planning which includes consideration of the specific conditions at each site, unique geographical features of the area, and demographic information. This preplanned strategy for an EPZ provides a substantial basis to support activity beyond the planning zone in the extremely unlikely event it would be needed.

Plume Exposure Pathway EPZ: The plume exposure pathway EPZ has **a *radius of about 10 miles*** from the reactor site. Predetermined protective action plans are in place for this EPZ and are designed to avoid or reduce dose from potential exposure of radioactive materials. These actions include sheltering, evacuation, and the use of potassium iodide where appropriate.

Ingestion Exposure Pathway EPZ: The ingestion exposure pathway EPZ has a ***radius of about 50 miles*** from the reactor site. Predetermined protective action plans are in place for this EPZ and are designed to avoid or reduce dose from potential ingestion of radioactive materials. These actions include a ban of contaminated food and water.

Protective Action Recommendations

Immediately upon becoming aware that an incident has occurred that may result in a radiation dose that exceeds EPA's Protective Action Guides (PAGs), responsible nuclear power plant personnel evaluate plant conditions and then make protective action recommendations (PARs) to the State and local government agencies on how to protect the population living and working in the area. Nuclear power plant personnel are required to report the PARs to the State or local government agencies (within 15 minutes). State and local agencies may independently assess the situation to ensure that the correct protective action decisions are made. Independent assessments performed during an accidental radiological release from a nuclear power plant ensure that the best possible action is taken. ***State and local officials make the final decision on what protective action is necessary to protect public health and safety***, and then relay these decisions to the public in a timely manner.

Protective Actions: Evacuation, Sheltering, and the Use of Potassium Iodide

Protective actions considered for a radiological emergency include evacuation, sheltering, and, as a supplement to these, the prophylactic use of potassium iodide (KI), as appropriate. Under most conditions, evacuation may be preferred to remove the public from further exposure to radioactive material. However, under some conditions, people may be instructed to take shelter in their homes, schools, or office buildings. Depending on the type of structure, sheltering can significantly reduce a person's dose compared to remaining outside. In certain situations, KI is used as a supplement to sheltering.

Evacuation does not always call for completely emptying the 10-mile zone around a nuclear power plant. In most cases, the release of radioactive material from a plant during a major incident would move with the wind, not in all directions surrounding the plant. The release would also expand and become less concentrated as it travels away from a plant. Therefore, ***evacuations should be mapped to anticipate the path of the release***. Generally as a minimum, in the event of a General Emergency, a two-mile ring around the plant is evacuated, along with people living in the 5-mile zone directly downwind and slightly on either side of the projected path of the release. This "keyhole" pattern helps account for potential wind shifts and fluctuations in the release path. Evacuation beyond 5 miles is assessed as the accident progresses. Also in response to a General Emergency, people living in the remainder of the 10-mile zone will most likely be advised to go indoors to monitor Emergency Alert System broadcasts.

Sheltering is a protective action that ***keeps people indoors***, such as at home, the office, school, or a shopping mall to reduce exposure to radioactive material. It may be appropriate to shelter when the release of radioactive material is known to be short-term or controlled by the nuclear power plant operator.

Another protective action in the 10-mile EPZ involves **KI**, a compound that helps prevent the thyroid from absorbing radioactive iodine, one of several radioactive materials that could be present in a release from a nuclear power plant accident. ***If taken within the appropriate time and at the appropriate dosage, KI blocks the radioactive iodine from being absorbed by the thyroid gland and reduces the risk of thyroid cancers and other diseases. KI does not protect against any other inhaled radioactive materials, nor will it offer protection from external exposure to radiation.*** The Food and Drug Administration (FDA) has determined that KI is a safe and effective drug when used for this purpose. However, there may be risks and potential side effects in using KI, including gastrointestinal disturbances, allergic reactions, and iodide goiter and hypothyroidism. Please consult a physician for questions on the potential side effects.

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Radiological Emergency Response - Quick Reference Guide 9
Radiation Units – Conventional and International System

Background: In the United States, conventional units (such as "rem" and "Curie") are normally used to express radiation concepts. However, most of the world uses the International System of Units (abbreviated SI from French: *Le Système international d'unités*). This QRG provides a brief explanation of the radiation concepts and units and the relation between the conventional and SI units.

Prefixes

Prefixes are added to unit names to produce multiple and sub-multiples of the original unit.

Multiplying Factor	SI Prefix	Scientific Notation	Exponential Notation
1 000 000 000 000 000 000 000 000	yotta (Y)	10^{24}	1E+24
1 000 000 000 000 000 000 000	zetta (Z)	10^{21}	1E+21
1 000 000 000 000 000 000	exa (E)	10^{18}	1E+18
1 000 000 000 000 000	peta (P)	10^{15}	1E+15
1 000 000 000 000	tera (T)	10^{12}	1E+12
1 000 000 000	giga (G)	10^{9}	1E+09
1 000 000	mega (M)	10^{6}	1E+06
1 000	kilo (k)	10^{3}	1E+03
0.001	milli (m)	10^{-3}	1E-03
0.000 001	micro (µ)	10^{-6}	1E-06
0.000 000 001	nano (n)	10^{-9}	1E-09
0.000 000 000 001	pico (p)	10^{-12}	1E-12
0.000 000 000 000 001	femto (f)	10^{-15}	1E-15
0.000 000 000 000 000 001	atto (a)	10^{-18}	1E-18
0.000 000 000 000 000 000 001	zepto (z)	10^{-21}	1E-21
0.000 000 000 000 000 000 000 001	yocto (y)	10^{-24}	1E-24

Radiation Concept: Activity

Activity is the rate of disintegration (transformation) or decay of radioactive material.

Conventional Unit	International System (SI) Unit
The ***curie*** is the common non-SI unit for activity. The symbol for the curie is ***Ci***. The ***Ci*** is defined as 3.7×10^{10} decays (or disintegrations) per second.	The SI unit for activity is the ***becquerel***. It is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. The symbol for the becquerel is ***Bq***. It is equivalent to inverse second (s^{-1}).
Commonly used units of activity	
1 Ci	3.7×10^{10} Bq = 37 GBq
27 mCi	1 GBq
1 mCi	3.7×10^{7} Bq = 37 MBq
27 µCi	1 MBq
1 µCi	3.7×10^{4} Bq = 37 kBq
27 nCi	1 kBq
1 nCi	3.7×10^{1} Bq = 37 Bq
27 pCi	1 Bq
1 pCi = 2.22 disintegrations/minute	3.7×10^{-2} Bq = 37 mBq
0.027 pCi	1 mBq

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Radiation Concept: Exposure

Exposure is a measure of the strength of a radiation field at some point in air. Exposure is only applicable to x-rays and gamma rays.

Conventional Unit	International System (SI) Unit
The ***roentgen*** is the common non-SI unit for exposure. The symbol for the roentgen is ***R***. The ***R*** is defined as 2.58×10^{-4} Coulomb/kilogram.	The SI unit for exposure is given as ***coulombs of electrical charge per kilogram of air (C/kg)*** and is not given a special single symbol.
Commonly used units of exposure	
3.9×10^{3} R	1 C/kg
3.9 R	1 mC/kg
1 R	2.58×10^{-4} C/kg
3.9 mR	1 µC/kg
1 mR	2.58×10^{-4} mC/kg = 0.258 µC/kg
3.9 µR	1 nC/kg
1 µR	2.58×10^{-4} µC/kg = 0.258 nC/kg

Radiation Concept: Absorbed Dose

Absorbed dose is the amount of energy that ionizing radiation imparts to a given mass of matter.

Conventional Unit	International System (SI) Unit
The ***rad*** is the common non-SI unit for absorbed dose. The ***rad*** is defined as 0.01 joule/kilogram.	The SI unit for absorbed dose is the ***gray***. The symbol for the gray is ***Gy***. One Gy is equal to an absorbed dose of 1 joule/kilogram.
Commonly used units of absorbed dose	
100 rad	1 Gy
1 rad	1 cGy
0.1 rad = 100 mrad	1 mGy
1 mrad	0.01 mGy = 10 µGy
0.1 mrad	1 µGy
1 µrad	0.01 µGy

Radiation Concept: Dose Equivalent

The dose equivalent relates the absorbed dose to the biological effect of that dose. The absorbed dose of a specific type of radiation is multiplied by a "quality factor" to arrive at the dose equivalent.

Conventional Unit	International System (SI) Unit
The ***rem*** is the common non-SI unit for dose equivalent.	The SI unit for dose equivalent is the ***sievert***. The symbol for the sievert is ***Sv***.
Commonly used units of dose equivalent	
100 rem	1 Sv
1 rem	1 cSv
0.1 rem = 100 mrem	1 mSv
1 mrem	0.01 mSv = 10 µSv
0.1 mrem	1 µSv
1 µrem	0.01 µSv

Other common equivalencies

Conventional Unit	International System (SI) Unit
1 µCi/kg = 1×10^{6} pCi/kg	37 kBq/kg
1 µCi/m^2 = 1×10^{6} pCi/m^2	37 kBq/m^2
1 Ci/m^3 1 µCi/cm^3 1×10^{6} pCi/cm^3	37 GBq/m^3
1 pCi/cm^3 = 1×10^{6} pCi/m^3	37 kBq/m^3
3.7×10^{12} rem/Ci 3.7×10^{9} mrem/µCi 3.7×10^{3} mrem/pCi 3.7×10^{6} µrem/pCi	1 Sv/Bq
1 (mrem/yr)/(µCi/m^2) 0.114 (rem/hr)/(Ci/m^2)	8.6 (aSv/s)/(Bq/m^2)

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Radiological Emergency Response - Quick Reference Guide 10
Emergency Worker Protection

Background: EPA established guidance on dose limits for workers performing emergency services in 1992 and reiterated the guidance in the 2013 Draft PAG Manual.

Source Document: The 2013 PAG Manual, Protective Action Guides and Planning Guidance for Radiological Incidents, was issued in March 2013 as a draft for interim use and comment. The manual is expected to be finalized in 2015. This QRG summarizes emergency worker protection for EPA personnel responding to radiological emergencies and includes **EPA specific administrative levels, turnback levels, and example stay times.** These EPA specific levels may not be appropriate for other response organizations.

With proper preparedness measures (training, personal protective equipment (PPE), etc.), **most radiological emergencies, even lifesaving operations, may be manageable within the 5 rem (50 mSv) occupational limit.** Even in emergency conditions, every reasonable effort should be made to control doses to levels that are as low as practicable. There are some emergency situations, however, for which higher exposure limits may be justified in order to prevent further loss of life and prevent the spread of massive destruction. Justification of any such exposure must include the presence of conditions that prevent the rotation of workers or other commonly-used dose reduction methods. It is essential that emergency workers have full knowledge of the associated risks prior to initiating emergency action and medical evaluation of emergency workers after such exposure.

The doses to workers performing emergency services are assumed to be "once-in-a-lifetime" doses; they are not added to occupational exposure accumulated under nonemergency conditions, and it is assumed that future radiological exposures would be substantially lower. Any radiation exposure of workers that is associated with an incident, but accrued during nonemergency operations, should be limited in accordance with relevant occupational limits for normal situations. The performance of emergency services should be limited to non-pregnant adults. Once the emergency phase is over (i.e., the source and releases have been brought under control and environmental measurements are available for use as a basis for decisions on protective actions), individuals who are permitted to reenter a restricted zone to work, or for other justified reasons, should have their dose limited in accordance with occupational limits.

Response Worker Guidelines
(2013 Draft PAG Manual, Chapter 2, Table 2-2)

Guideline	Activity	Condition
5 rem (50 mSv)	All occupational exposures	All reasonably achievable actions have been taken to minimize dose.
10 rem (100 mSv)[a]	Protective valuable property necessary for public welfare (e.g., a power plant)	Exceeding 5 rem (50 mSv) unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose.
25 rem (250 mSv)[b]	Lifesaving or protection of large populations	Exceeding 5 rem (50 mSv) unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose.

[a] For potential doses > 5 rem (50 mSv), medical monitoring programs should be considered.
[b] In the case of a very large incident, such as an IND, incident commanders may need to consider raising the property and lifesaving response worker guidelines to prevent further loss of life and massive spread of destruction.

Information about the health risks associated with acute doses of radiation

Acute Radiation Syndrome[a]
(2013 Draft PAG Manual, Chapter 2, Table 2-3)

Feature or Illness	Effects of Whole Body Absorbed Dose from external radiation or internal absorption, by dose range				
	0 – 100 rad (0 – 1 Gy)	100 – 200 rad (1 – 2 Gy)	200 – 600 rad (2 – 6 Gy)	600 – 800 rad (6 – 8 Gy)	> 800 rad (> 8 Gy)
Nausea, Vomiting	None	5 – 50%	50 – 100%	75 – 100%	90 – 100%
Time of Onset		3 – 6 hours	2 – 4 hours	1 – 2 hours	< 1 hour to minutes
Duration		< 24 hours	< 24 hours	< 48 hours	< 48 hours
Lymphocyte Count	Unaffected	Minimally decreased	< 1000 at 24 hours	< 500 at 24 hours	Decreases within hours
Central Nervous System Function	No impairment	No impairment	Cognitive impairment for 6 – 20 hours	Cognitive impairment for > 20 hours	Rapid incapacitation
Mortality	None	Minimal	Low with aggressive therapy	High	Very High: significant neurological symptoms indicate lethal dose

Source: Medical Management of Radiological Casualties, Second Edition, Armed Forces Radiobiology Research Institute. Bethesda, MD, April 2003.
[a] Percentage of people receiving whole-body doses within a few hours expected to experience acute health effects.

The 25 rem (250 mSv) lifesaving response worker guidelines provide assurance that exposures will not result in detrimental deterministic health effects (i.e., prompt or acute effects). However, it could increase the risk of stochastic (chronic) effects, such as the risk of cancer. The estimated risk of fatal cancer for workers exposure to 25 rem (250 mSv) is 1.5 percent (15 cases per 1000 exposed). Because of the latency period of cancer, younger workers face a larger risk of fatal cancer than older workers. For example, when exposed to 25 rem (25 mSv), 20 to 30-year-olds have a 9.1 per thousand risk of premature death, while 40 to 50-year-olds have a 5.3 per thousand risk of premature death. (Source: EPA 402-R-99-001, Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Federal Guidance Report No. 13, September 1999)

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EPA Specific Response Information

EPA Administrative Levels for Radiation Exposure During Non-Emergency Conditions (Safety, Health, and Environmental Management Program Guidelines – SHEMP Guideline 38, March 2006)		
Administrative Control Level (ACL)	**500 mrem/year**	The total effective dose [sum of the committed effective dose (from internal exposure) and the effective dose (from external exposure)] in any period of twelve (12) consecutive months. If a worker has reached the ACL, work assignments with a potential for additional radiation exposure should be restricted until the ACL is again satisfied.
Action Reference Level (ARL)	**50 mrem/quarter**	The effective dose from external exposure OR the committed effective dose from internal exposure during a calendar quarter. If a worker exceeds the ARL, a review of the circumstances relating to the radiation exposure should be undertaken by the RSO or designated SHEMP Official in collaboration with the worker, the worker's supervisor, the manager of the work area or site, and, if needed, a health physicist.
Exceeding either of these levels, even during emergency conditions, requires the concurrence of the senior EPA official onsite, the Incident Commander, the Health and Safety Officer, or the Radiation Safety Officer (RSO).		

EPA Responder Guidelines for Alpha and Beta Radionuclides	
Alpha Radionuclides Deposited on the Ground – Turnback Level	**Beta Radionuclides Deposited on the Ground – Turnback Level**
2000 dpm/100 cm^2 [≈ 400 cpm with Ludlum Model 2241-2 (or comparable) coupled with Alpha Probe Model 43-90]	10,000 dpm/100 cm^2 [≈ 400 cpm with Ludlum Model 2241-2 (or comparable) coupled with Pancake Probe Model 44-9]
Action: Leave the area until you have protective clothing and respiratory protection – evaluate actions against dose limits	Action: Leave the area until you have protective clothing and respiratory protection – evaluate actions against dose limits
Personnel protective equipment (tyvek suit, boots, and gloves) should be worn in the presence of ANY alpha or beta contamination above natural background.	
Appropriate respiratory protection should be worn in the presence of LOOSE alpha and beta contamination above natural background.	
Incidents involving airborne alpha or beta emitters require proper instrumentation as noted above.	
Informed safety decisions regarding subsequent site activities should be made based on air sample analysis and nuclide identification. These values assume a static measurement on the ground (or a flat surface at a distance of 1 cm. Alpha-only or beta-only instruments may respond erroneously in a high gamma rate field – BE AWARE!	

In December 2006, "Turnback Guidance for EPA Personnel Responding to Radiological Emergencies" was issued to supplement current radiation policies and guidance for EPA emergency responders. The guidance provided exposure rate (commonly called "turnback") levels at which EPA emergency responders should turn back and seek further guidance before proceeding. The rates were based on many assumptions, including: 1) the rates only apply to EPA responders doing work within the EPA mission and objectives; 2) the rates ONLY apply during emergencies and are not to be applied during normal operations or site work; and 3) emergency responders as well as managers will ensure responder exposures remain as low as reasonably achievable (ALARA).

EPA Emergency Responder Gamma Exposure Rate Turnback Exposure Rate Levels			
Time Phase (TP)	**Employee Type**	**Turnback Exposure Rate Level**	**Condition**
Early Phase (release ongoing)	OSCs, initial EPA responders	10 R/h	Voluntary, with supervisor review, for lifesaving or critical actions ONLY – evaluate anticipated doses against dose limits in Table 5 above.
Early Phase (release terminated)	OSCs, RERT-Forward, ERT and initial EPA responders		
Intermediate Phase (some data available)	OSCs, RERT-Forward, ERT	1.5 R/hr	Dose management imperative
Late Phase (clean-up)	Any EPA employee, RERT-Support and Home Teams	Site-specific according to site health and safety plan	EPA ARL (50 mrem/quarter) and ACL (500 mrem/year) apply
DOSE MANAGEMENT should begin at 1 mR/hr			

Early and Intermediate Phase EXAMPLE "Stay Times"			
Exposure Rate (R/hr)	**Up to 5 rem Total Effective Dose[a]**	**Up to 10 rem Total Effective Dose[a]**	**Up to 25 rem Total Effective Dose[a]**
0.1	50 hours	100 hours	250 hours
21	5 hours	10 hours	25 hours
5	1 hour	2 hours	5 hours
10	30 minutes	1 hour	2.5 hours
25	12 minutes	24 minutes	1 hour
50	6 minutes	12 minutes	30 minutes
100	3 minutes	6 minutes	15 minutes
[a] This table assumes that only the EXTERNAL dose is of concern – if airborne radioactive material is present, appropriate respiratory protection must be used. If the internal dose is of concern, these stay times must be modified to include the internal component.			
Stay times can be useful in instances where radiation levels are mostly homogeneous, to assess whether the mission can be accomplished quickly enough to avoid excessive radiation dose.			
Exposure rates and doses in the shaded areas exceed guidance levels and are to be used ONLY when critical actions or lifesaving are warranted.			

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