RFCA Stakeholder Focus Group
December 12, 2001
Meeting Minutes

INTRODUCTION & ADMINISTRATIVE

A participants list for the December 12, 2001 Rocky Flats Cleanup Agreement (RFCA) Stakeholder Focus Group meeting is included in this report as Appendix A.

Reed Hodgin of AlphaTRAC, Inc., meeting facilitator, reviewed the purpose of the RFCA Focus Group and the meeting rules. Introductions were made.

AGENDA

Reed reviewed the agenda:

- Task 3 Peer Review and Wind Tunnel Technical Review – Update
- Timeline for Cleanup and its Affect on Focus Group Decisions
    - Overview of Scope and Schedule - Now Through 2006
    - FY2002 Environmental Remediation Scope
    - How RSAL and End State Discussions Must Fit Into the Broader Schedule
- Cleanup Funding Overview
    - Recap – Overall Closure Budget and Core Elements
    - Overall budget for Environmental Remediation Through Closure
- Cleanup Options That Have Been Identified
    - Options for Surface Remediation, Subsurface Remediation, Surface Water Protection, Stewardship
    - For Each Option: Baseline Assumptions and Funding Differences Between Options and Baseline

Task 3 Peer Review and Wind Tunnel Technical Review – Update

Wind Tunnel Peer Review

Reed informed the Focus Group that all three of the peer reviews were completed and have been sent to the Focus Group and the agencies. Reed asked the agencies about the status of the schedule. The Colorado Department of Health and Environment (CDPHE) responded with a two-week timeframe for completion.

Task 3 Report Peer Review

Reviewers have until the end of 12/2001 to complete their reviews of the Task 3 Report. AlphaTRAC has corresponded with each of the reviewers to assess the status. So far, all reviewers have all pertinent materials.

A Focus Group member asked how the comments were going to be handled. CDPHE responded by stating that each comment will be considered and resolved and as a result, the Task 3 Report will more than likely be modified.

Facilitator's Report on Focus Group – Interests and Path Forward

Reed presented *RFCA Stakeholder Focus Group* with an emphasis on a focused discussion involving:

> **"What are the options for cleaning up Rocky Flats within the available budget and how do these options serve the interests at the table?"**

From this perspective, the bounded discussion could be developed with an opportunity to identify less bounded (unbounded) options and to present information to support interests around the table.

Future meeting objectives could involve understanding the schedule and costs bounds associated with the options for the clean up discussion, as well as defining and understanding surface / subsurface tradeoff options, identifying needs for further discussion of surface / subsurface tradeoff options and to begin brainstorming additional options.

The syllabus for the next several meetings was proposed and included the following topics:

- Overview, schedule and choices
- Detailed discussion of surface contamination and options
- Subsurface contamination
- Surface water protection
- Stewardship
- Packages of options and draft conceptual agreement
- Conceptual agreement

Timeline for Cleanup and its Affect on Focus Group Decisions / Cleanup Funding Overview

Kaiser-Hill Ltd., described the framework for the discussion. The last Focus Group meeting resulted in an understanding that technical options needed to be described, funded and planned for. Also, there was a conceptual understanding that end state is dependent upon limited resources. To help with this, a funding profile was presented that discussed environmental restoration, and specifically the work upcoming in FY2002. Another document Kaiser-Hill prepared is the broader discussion of all of the site milestones and key targets chronologically to plant closure. This document can be made available by contacting Kaiser-Hill.

The overall budget for *decontamination/decommission, special nuclear material, support, waste* and *environmental restoration* is 3.9 billion dollars (3,963,000,000). The funding period is February 2000 through 2006.

Decontamination/decommission	$1.7 billion
Special nuclear material	$127 million
Support	$978 million
Waste	$590 million
Environmental restoration	$468 million

Details on the *environmental restoration* budget were presented. The budget is divided into seven keys areas:

1. Source removal - $114 million
2. Studies – $8.7 million
3. Waste Shipment Treatment & Disposal - $132 million
4. Characterization – $50.4 million
5. Monitoring & Long Term Stewardship - $36.3 million
6. Engineered Controls - $85.9 million
7. Planning & Documentation - $45.3 million

It was noted that the *environmental restoration* budget included the waste cost associated with environmental restoration.

The *studies* portion of the *environmental restoration* budget are being conducted now and include this Focus Group and its studies, actinide migration, water balance and the plant configuration studies.

A member of the Focus Group asked what the waste costs were based on. Kaiser-Hill stated that the waste cost was based on assumptions made on how much will be excavated, considering what type of waste it is, and then adding in the actual costs from the Rocky Flat's receiver sites. Specifically, the cost per yard, charged by the receiver sites, was added.

These costs represent baseline costs that are in the contract. It is likely that the most uncertain of the costs are the *environmental restoration* costs due to the number of assumptions being made.

In general terms, the *environmental restoration* costs, as all costs, have a regulatory basis. From there, individual decision documents are created that includes planning and documentation for fieldwork, health and safety plans and labor.

Next, the budget on *FY02 Field Work Schedule & Budgeted Cost* was presented. The chart represented the costs associated with fieldwork only for FY02 totaling $5,858 thousand. This budget is associated with the excavation source removal plan.

Given that RSALs are still being worked on, the plan is to begin with IHSS Group 100-4, Building 123 at a cost of $812 thousand in January 2002. Next is the IHSS Group 400-10, Building 664, where there is contaminated soil, at a cost of $1,147 thousand. Next is IHSS Group 800-4, Building 886 at a cost of $1,235 thousand

and then IHSS Group 800-6, which includes the Building 887 pad at $1,163 thousand. Then the 903 pad will be started in September of 2002. The current budget to begin the 903 pad is $1,500 thousand. The costs for the 903 pad will increase to around $1.5 million in the next fiscal year.

It was noted that these projects would probably not be affected by the surface RSAL. These activities are subsurface remediation activities.

From the budgetary standpoint, it is critical that discussions find direction and resolution. Resolution will help optimize risk reduction at Rocky Flats.

More information on projects can be found in the Historical Release Report.

Next, the Focus Group reviewed an options matrix, which captures the main points that have been discussed with the community to date, including:

- Surface remediation
- Subsurface remediation
- Water quality protection
- Stewardship

Each option included the baseline assumption and cost differences (plus or minus) compared to baseline.

Life cycle costs and offsite disposal costs could be compared to help examine priorities. Also, using risk as one factor for prioritization, with an emphasis on examining surface versus subsurface tradeoffs was discussed.

Another budgetary consideration is evaluating cost savings in the near term against life cycle costs relating to the various contamination pathways. Surface water quality standards and stewardship impacts are beyond the scope of this analysis for the next meeting

Cleanup Priorities – Group Identification of Options

For the next meeting, Reed instructed Focus Group members to develop surface cleanup options, with the objective of having the options clearly identified when January 2002's meeting adjourns.

Adjourn

The meeting adjourned at 6:00 p.m.

Information Needs

-Historical release report regarding UBC's for FY O2 remediation

-Summary (1 pager) on expected UBC for FY O2 work

-Summary of major closure projects/milestones

Key Points

-$469.8 million for ER in baseline

-4 UBC projects and start of 903 PAD in FY O2

-Substantial uncertainties in knowledge of UBC's

-Will have to learn as we go

Key Points

-Need to determine how to discuss tradeoffs in light of UBC/subsurface uncertainties

-903 PAD and L.P area are basically all of the SFC contaminates

Draft Matrix

-Cost estimates are rough

-Sharper estimates will be needed if appropriate

-Some discrepancy between current rough numbers and previous numbers

Draft Matrix – 2

-Assumption for MRS rough estimates
->Put MATL < 200pci/g in 371 basement

-Baseline assumption for subsurface contaminates is "typical"

Matrix – 3

-Subsurface option 1 is risk based

-Subsurface option 2 is risk-based with removal of some contaminates even though not triggered by risk

-100 Nci value in option 2 is arbitrary for discussion

-Option 2 is a place holder

Matrix – 4

Uncertainties for Sub Surface

-Source – significant uncertainties

-Pathway – still some significant uncertainties

-Receptor – better known (but not supported by All parties)

Matrix – 5

Other issues contributing
-Water balance
-Land Configuration

Confidence

-Conceptual pathway analysis for some contaminates

-Actinide Mi6 studies

-Preliminary water balance

-Ongoing monitoring results

Matrix – 6

-Preliminary sampling of UBCs

-Previous risk assessments

Issue: Life cycle cost
Issue: Stewardship cost
Issue: What happens if subsurface contaminates turs?
Issue: How to ensure that $savings go to remediation

-Design groupings for SS
-Pathway matrix

Risk Pathway
Activity Level

Priority Items

-Risk pathways

-Ecological impacts

-Contaminants

-Contamination level

-Depth
(See tool box check list for ideas)

-Institutional controls reg.

Information Needed

-Available characterization data

Conversations

-Risk approach
How to characterize for risk based approach

MRS

-Cost

-Availability of storage facility

-Reg barrier

Goals:
-Protection of surface water
-Protection of ground water
-Additional removal of subsurface contaminants
-Clean up of isolated how spots

-Each discussion – talk goals first for that area

Options for Strategies

-Clean up to 10 –5 risk for wildlife worker

-Clean up to 10 –5 risk for subsurface resident

-Clean up subsurface to 35pci and subsurface to 10 –5 and other needs

RFCA Stakeholder Focus Group
Attachment B

Title:	November 28, 2001 RFCA Focus Group Presentation: Interests and Path Forward
Date:	November 28, 2001
Authors:	Reed Hodgin
Phone Number:	(303) 428-5670
Email Address:	cbennett@alphatrac.com

RFCA Stakeholder Focus Group
Attachment C

Title:	RSALs Working Group Meeting Notes for November 29 and December 6, 2001
Date:	December 7, 2001
Authors:	Sandra MacLeod
Phone Number:	(303) 966-3367
Email Address:	sandra.macleod@rf.doe.gov

RFCA Stakeholder Focus Group
Attachment D

Title:	2nd Wind Tunnel Peer Review
Date:	December 7, 2001
Phone Number:	(303) 428-5670
Email Address:	cbennett@alphatrac.com

Site Critical Path - Baseline November FY02 Status

Data Date 26NOV01 Run Date 03DEC01 14:16 Sheet 1 of 1 C202	CPB CPB Status Progress Bar	CLOSURE PROJECT BASELINE STATUS Project Critical Path	KAISER • HILL COMPANY

Activity Description	
Set 09 CSV Pallet/Disposition P&E	24DEC01
Set 09 CSV Pallet/Disposition Ops/Prep/Readiness	25FEB02
Set 09 Dismantlement CSV Stor Container Pallets	28MAY03
Set 09 Disposal of Maintenance Pallets	25NOV03
Set 12 GB Deactivation Execution	02JUN04
Set 12 - (CWTS / Canyon Scrubber) Dismantlement	17OCT05
Set 52 - (Filter Plenum 243) Dismantlement	08FEB06
Area AE - (North Side - Basement) Dismantlement	15MAY06
Area AE - (North Side - Basement) Recon Charac	31MAY06
Area AE - (North Side - Basement) Decontamin	17JUL06
Area AE - (North Side - Basement) Final Survey	31JUL06
Area AQ - (B371/4 Structural) Demolition	06NOV06
Regrade Industrial Area	08DEC06
Revegetate Industrial Area	11JAN07
Site Closure Complete	11JAN07

KAISER-HILL COMPANY, LLC

WHITE PAPER

Potential Residential Use of Shallow Groundwater at RFETS

The feasibility of using shallow groundwater for residential water supply was evaluated as part of an overall risk assessment associated with future land use and redevelopment of RFETS. The evaluation included a drawdown analysis of site groundwater data to determine whether a hypothetical domestic well, completed in the unconsolidated surficial and upper weathered bedrock deposits at RFETS, could sustain well yields to support a family of four persons. The analysis was conducted using an analytical groundwater model that simulates drawdown in a pumping well. These simulations were performed independently on 140 existing monitoring wells that are completed in the Quaternary alluvium/colluvium and/or the upper Cretaceous sandstone in the Arapahoe and Laramie Formations. These wells had also been pump or slug tested for their hydraulic properties. Simulated drawdowns were compared to the actual measured saturated thickness at the monitoring wells to ascertain whether it was physically possible to lower water levels to a reasonable fraction of the existing saturated thickness.

Residential Water Requirements

Drawdown simulations for a hypothetical residential well were based on the premise that indoor water use for a family of four is 260 gallons per day. This value was obtained via oral communication from the Denver Water Department and was determined from a study conducted in 1997 by the American Water Works Association. The study concluded that the average daily per capita water useage in the Denver Metro area is 65 gallons. The value was calculated from a total per capita water useage of 176.88 gallons that includes both indoor and outdoor use and from an outdoor water useage of 118.88 gallons.

The discharge rate used in the model simulations was based on the average pumping rate of nine monitoring wells that were pump tested at RFETS and which were completed in the Quaternary surficial deposits and/or the upper Arapahoe and Laramie sandstone. Nine wells fit these criteria and were used to calculate the average pumping rate. Pumping rates for these wells varied significantly from 0.07 to 12.06 gallons per minute. Histograms of the pumping rates were generated as part of a descriptive statistical analysis to ascertain which distribution best fit the data and also to indicate if any outliers were present. Both the raw data and the natural log-transformed data were plotted. Histograms are presented in Attachment A. Although discharge rates from only nine wells were used in this analysis, the data appear to more closely fit a log normal distribution than a normal distribution. The histogram of the log-transformed data also indicated that the low value (0.07) was probably an outlier with respect to those wells that had pump tests performed. Thus, this value was excluded from further analysis.

Based on the log normal nature of the data, the geometric mean was used to estimate the mean of the pumping rates. The geometric mean of the pumping rates was calculated to be 2.03 gpm. To conservatively estimate pumping rates at the site, the lowest rate that statistically fell within the 95 percent confidence limit of the mean was used. This rate (1.83 gpm) was calculated using a one-sided lower confidence limit for a log normal distribution (Land, 1971 in Gilbert, 1987). The equation used to calculate this limit and the summary statistics for the pumping rates are presented in Attachment B.

Model Input Parameters

The length of time of pumping was calculated to be 2.4 hours which was the time required to pump 260 gallons per day at a rate of 1.83 gpm. The specific yield was assumed to be 0.20 and was based on information presented in the Hydrogeologic Characterization Report For the Rocky Flats Environmental Technology Site (1995) for the unconsolidated surficial deposits. The radial distance from the pumping well was assumed to 1.0 foot.

The hydraulic conductivity (K) was obtained from a database file of 140 wells that were previously pump or slug tested at the site. K values ranged from 4E-08 to 5E-02 cm/sec. Many of the wells that were field tested for K were analyzed using several different techniques. For example, wells that were slug tested were analyzed with Bouwer and Rice and Hvorslev methods. Wells that were pump tested were analyzed using Theis, Cooper/Jacob, Neumann, and Thiem techniques. K values from each of these analysis were averaged for each well.

Transmissivity (T) values for each well were calculated from the average hydraulic conductivity and from the average saturated thickness. The average saturated thickness was calculated from depth to water measurements that have been historically recorded during periodic monitoring events and from the total depth (TD) of casing data recorded during well construction. Water level measurements were obtained from the soil and water database file SWD and were average for the total record of measurement. TD data were obtained from a master database file and were joined in database query with the average water level depth to calculate the average saturated thickness for each of the 140 wells.

Drawdown Calculations

Drawdown in each well was simulated in an Excel spreadsheet using the Theis equation. Due to the limitations of the Theis equation for low T values (<8.5 gallons per day per foot (gpd/ft)) which equates to a K value of <8 4E-05 cm/sec for 10 feet of saturated thickness, drawdowns in wells with this T value or less were assumed to exceed the TD of the well. At T values <8.5 gpd/ft, the corresponding well function value, W(u) becomes small enough to cause the drawdown value to decrease. This phenomenon is illustrated in Figure 3 which shows that as T values decrease, drawdown increases up to a point. It is at this inflection point, where T = 8.5 gpd/ft, that drawdown begins to decrease and the equation can no longer realistically predict drawdown in a well.

A reasonable amount of drawdown was assumed to be 1/3 of the available saturated thickness at each well. This value was considered reasonable in light of potential well losses attributable to well inefficiencies. Without compensating for these well losses, the Theis analysis would tend to underestimate actual drawdown values. Available drawdown is also reduced by the depth at which a pump is set and by inaccuracies in the theoretical equation due to the unconfined nature of the groundwater system. Relatively large drawdowns, with respect to a thin water-bearing zone, infer that flow is non horizontal, thus violating a primary assumption inherent in the Theis equation. Thus, 1/3 of the saturated thickness was considered as a physical limit to drawing down a water supply well. The results of the simulation indicated that 46 wells or 33 percent of the total 140 wells could sustain pumping and supply a residential family of four persons with water.

The spatial distribution of these 46 wells is shown in blue on the attached plate. The plate indicates that the wells are uniformly distributed over a wide area at RFETS and do not appear to be clustered in any one location. The wells used for this evaluation represent approximately 13 percent of the total number of wells installed at RFETS.

Attachment A

Figures

Figure 1
Histogram of Well Yields From Quaternary Surficial Deposits and Ka No. 1 Sandstone

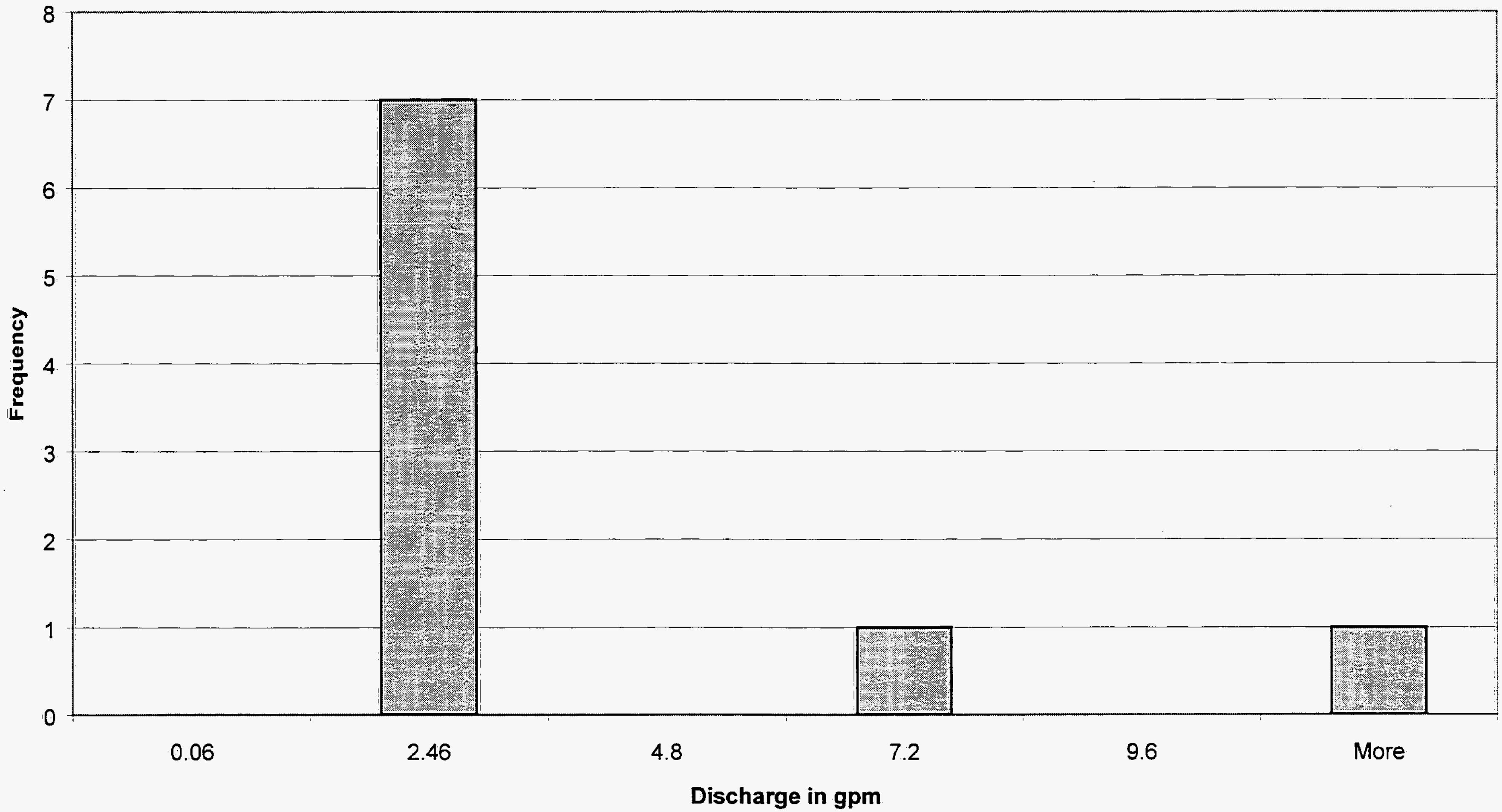


Figure 2
Histogram of Well Yields From Quaternary Surficial Deposits and Ka No. 1 Sandstone

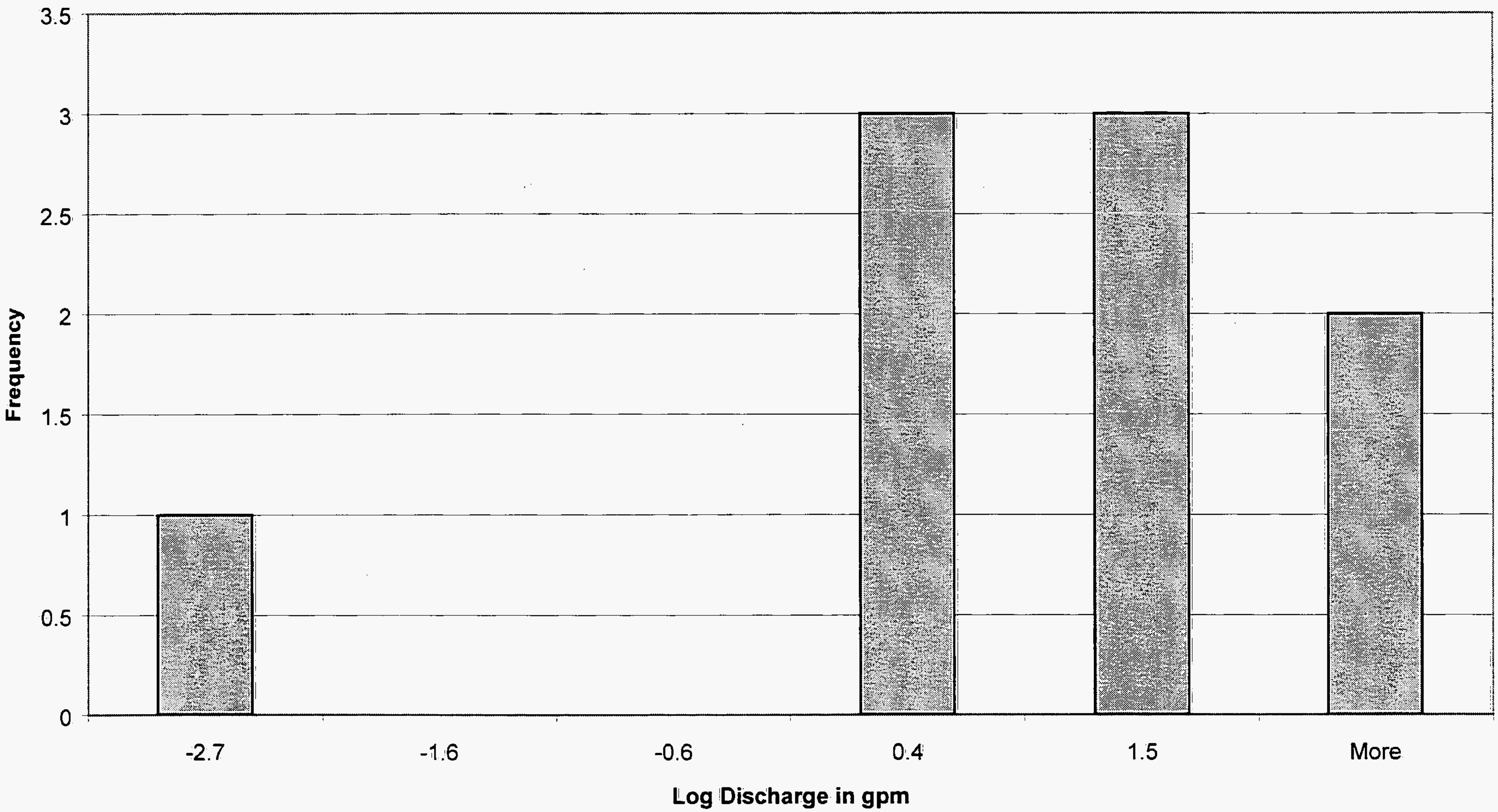
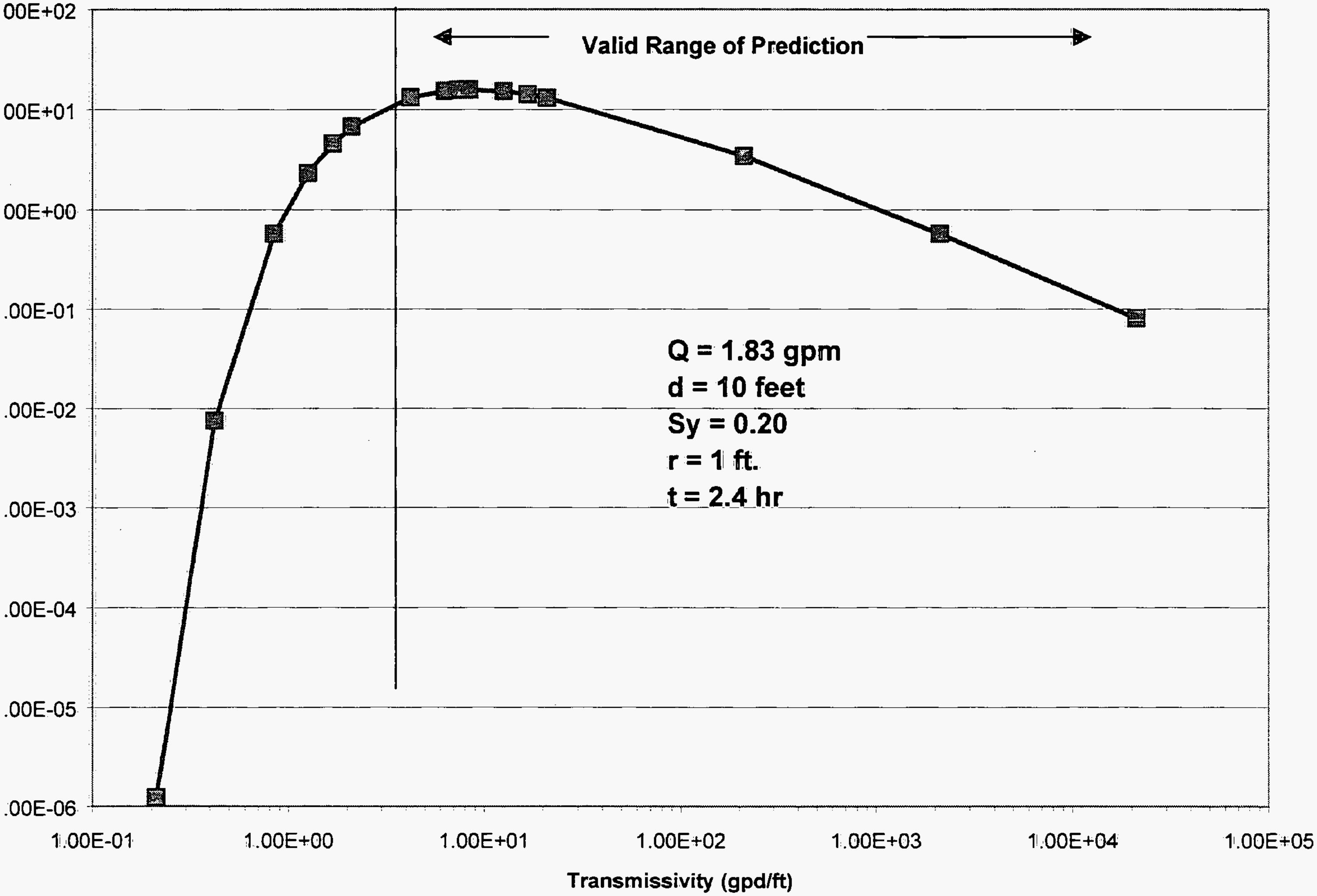


Figure 3
Drawdown Versus Transmissivity Using Theis Equation



Attachment B

One sided confidence limit for a log normal distribution is given by the following equation:

$$LL_{\alpha} = \exp(\bar{y} + 0.5S^2y + \frac{S_yH_{\alpha}}{\sqrt{n-1}})$$

where:

LL_{α} = Lower confidence limit
$\bar{y}$ = Mean
S^2y = Sample variance
Sy = Standard deviation
H_{α} = 1.633 (Statistic from Table A13 in Gilbert, 1987)
N = Number of samples = 8

References

Gilbert, R.O., 1987, Statistical Methods for Environmental Pollution Monitoring, Van Nostrand Reinhold, New York, New York

EG&G Rocky Flats, 1995, Hydrogeologic Characterization Report for the Rocky Flats Environmental Technology Site

RFCA Stakeholder Focus Group
Meeting Agenda

When: **December 12, 2001 3:30 - 6:30 p.m.**

Where: **Broomfield Municipal Hall, Bal Swan and Zang's Spur Rooms**

3:30-3:40 Ground Rules, Agenda Review, Objectives for this Meeting

3:40-3:50 Task 3 Peer Review and Wind Tunnel Technical Review - update

3:50-4:20 Timeline for Cleanup and its Affect on Focus Group Discussions
- Overview of scope and schedule – now through 2006
- FY-2002 Environmental Remediation scope
- How RSAL and Endstate discussions must fit into the broader schedule

4:20-4:50 Cleanup Funding Overview
- Recap – overall Closure budget and core elements
- Overall budget for Environmental Remediation through Closure

4:50-5:00 Break

5:00–6:10 Cleanup Options That Have Been Identified
- Options for surface remediation, subsurface remediation, surface water protection, stewardship
- For each option: baseline assumptions and funding differences between options and baseline

6:10–6:25 Path Forward for Focus Group Over Next Several Meetings

6:25–6:30 Review Meeting

6:30 Adjourn

Setting Cleanup Standards to Protect Future Generations:

The Scientific Basis of the Subsistence Farmer Scenario and Its Application to the Estimation of Radionuclide Soil Action Levels (RSALs) for Rocky Flats

by

Arjun Makhijani, Ph.D.
and
Sriram Gopal

A report prepared for the Rocky Mountain Peace and Justice Center, Boulder, Colorado

by the

Institute for Energy and Environmental Research

December 2001

Table of Contents

Acknowledgements

We would like to like to thank the reviewers of this report: Professor Thomas H. Pigford, professor emeritus at the University of California at Berkeley, Dr. John Till of the Risk Assessment Corporation, and Leroy Moore of the Rocky Mountain Peace and Justice Center. All of their comments and insights were extremely valuable, especially those of Professor Pigford who provided us with some of the references used in this report. We would also like to thank Dr. Bruce Napier of the Pacific Northwest National Laboratory and William E. Kennedy, Jr. of Dade Moeller & Associates for their help in finding some of the historical documentation that is referred to in this paper. We would also like to thank IEER Librarian, Lois Chalmers, for her extensive bibliographic research and fact checking. Of course, the authors of this report remain solely responsible for its contents, conclusions, recommendations, and any omissions or errors that might remain.

This report was prepared under contract with the Rocky Mountain Peace and Justice Center. The Rocky Mountain Peace and Justice Center was very helpful in pointing us to documents and keeping us current with ongoing developments regarding the standard setting process for cleanup at Rocky Flats.

This study required considerably more resources than were available to the Rocky Mountain Peace and Justice Center for it. Given the crucial national importance of the process of setting cleanup standards for sites contaminated by nuclear weapons production, we decided to use some of the funds we raise from foundations to complement locally available resources. As a result, funds for this study were also partly drawn from grants to IEER from the John Merck Fund, Stewart R. Mott Charitable Trust, Poughshares Fund, Public Welfare Foundation, Rockefeller Financial Services, Town Creek Foundation, and Turner Foundation. General support to IEER's nuclear work is provided by the Colombe Foundation, HKH Foundation, New-Land Foundation, and Rockefeller Financial Services for general support funding, part of which was used for this report. We deeply appreciate their generous support.

Arjun Makhijani, Ph.D.
Sriram Gopal
December, 2001.

Summary and Recommendations

Contamination of vast areas of land and huge amounts of water with dangerous long-lived radioactive and non-radioactive pollutants has posed a difficult problem for the generations of people who have created them. How can we ensure the health of future generations, of land and water resources, and of ecosystems thousands of years into the future?

The scientific tools at hand are relatively rudimentary, of recent vintage, and rife with uncertainties. The costs of cleanup of contaminated areas as well as their management, notably at the sites where processing of large amounts of nuclear materials has been done, are estimated to run into the hundreds of billions of dollars in the United States alone. Ensuring the effectiveness of public expenditures in ways that are compatible with health and environmental protection for thousands of years is a daunting task.

The nature of the problem requires the utmost care in the selection of the scientific tools that will be used to assess the health of future generations both in order to ensure a sound result and to promote effective expenditures. We have reviewed various approaches to protecting the health of people from radiation both in the present as well as in the long-term from the point of view of scientific defensibility. The scientific merits of any approach must take into account the historical experience that institutional memory about contamination is prone to fade in decades even in circumstances where very dangerous materials like chemical weapons have been handled and dumped. Laws can and do change, as do norms. Assessment of the risks of particular materials and of combinations of materials has evolved. Over the decades, the trend in official studies and evaluations has been to see radioactivity as more dangerous per unit of exposure than initially believed. In general, standards for environmental protection have become more stringent and support for such protection has increased.

Standard setting processes must take these fundamental considerations into account. A failure to do so is to risk the long-term health of both people and the environment.

Principal finding

Our principal finding is that the "subsistence farmer scenario," which assumes that people will live on the land and eat locally grown food, is a scientifically sound basis on which to base cleanup standards in general and regulations for residual radioactivity in the soil in particular. This finding is independent of any interim uses for which specific sites, such as the plutonium-contaminated Rocky Flats site near Denver, may be designated. *It is not appropriate to assume that site control, institutional memory, and legal land use restrictions will prevail for hundreds of years, to say nothing of thousands of years. There is little factual basis for such assumptions and much evidence that they are unwarranted.*

Choosing residual soil action levels based on the assumption that a wildlife refuge designation will endure for generations could result in residual radioactivity levels as high as several hundred picocuries of plutonium per gram of soil. This would be an unprecedented backward step in the history of the cleanup program.

Principal recommendation

Our principal recommendation for the Rocky Flats site is that, even if the site is designated as a wildlife refuge, the standard for residual radioactivity in the soil should be set assuming that at some time in the future the site will be used by a resident farmer or rancher.

One can derive a range of residual radioactivity levels for plutonium (and associated americium-241) based on the subsistence farmer approach, depending on details about groundwater use and future evolution of regulations in relation to groundwater. Current safe drinking water rules of the EPA for plutonium, americium, and other transuranic radionuclides have been set based on four-decade-old data, ignoring more recent data and calculation methods. They are also at variance with the State of Colorado limits for plutonium content of surface water, which are 100 times more stringent than current federal safe drinking water provisions for transuranic radionuclides. Drinking water rules for transuranics that are compatible with the Colorado rule for surface water or with the federal rule for most beta emitters would result in stringent residual soil levels toward the lower end of the range we recommend to be considered.

IEER recommends that residual soil action levels between 1 and 10 picocuries per gram be considered as the basis for the cleanup program at Rocky Flats, whether or not the site is designated as a wildlife refuge. This range is consistent with the approach we recommend. Soil action levels deriving from scenarios related to designation of the site as a wildlife refuge should be rejected.

There is official precedent for choosing a residual soil action level in this range. The preliminary recommendation for a remediation goal for industrial use of the Department of Energy's Lawrence Livermore National Laboratory site is 10 picocuries of residual plutonium per gram of soil. For a residential use scenario, the goal would be 2.5 picocuries per gram.

Other findings

1. The concept of the hypothetical maximally exposed individual has been the basis for protecting the general population from radiation released by nuclear facilities.

The hypothetical maximally exposed individual is a person at the site boundary who would receive the highest dose from a facility's operations. This is a hypothetical person in that it does not necessarily correspond to any actual person. The basis is that if the exposure of this hypothetical person is less than the maximum allowable then the rest of the population is also protected. Unlike radiation workers, the general population does not have radiation measuring equipment or monitoring, and this necessitates a conservative and more statistical approach to radiation protection that will ensure the health of the population to a high degree. An extension of this idea in time provides a part of the scientific basis for a subsistence farmer approach to protecting future generations.

2. The concept of the subsistence farmer scenario has evolved as the long-term equivalent of the hypothetical maximally exposed individual in situations where contamination or waste disposal activities may put future generations at risk.

Many radionuclides as well as other pollutants are very long-lived. Their fate in the environment over such long periods is very difficult to estimate with a high degree of precision. Long-term uncertainties are great on many fronts. Lifestyles, diet, population settlement patterns, land-use regulations, climate, environmental protection standards, future assessments of the risk of pollution or contamination, and future utility of specific resources are among the important factors that contribute to these uncertainties. The choice of a framework for cleanup cannot resolve these uncertainties as to what will happen, but it can address them in a manner as to make the cleanup standards relatively robust to changes that might occur.

The subsistence farmer scenario provides a reasonable, scientifically and historically defensible framework that is robust to a large variety of future uncertainties. Local use of land and water for farming and consumption is well founded. It is conservative in that there are few assumptions about future lifestyles that will result in much greater exposures. The remaining uncertainties are then in the parameters chosen for modeling future doses, such as those related to climate and hydrology and those related to mobility of contaminants through the environment. These can be addressed with reasonable conservatism in the subsistence farmer framework.

3. The wildlife refuge scenario does not provide an adequate basis for long-term public health protection.

The designation of a site such as Rocky Flats as a wildlife refuge does not address the many fundamental issues raised by the uncertainties as regards changing land-use, changing laws, lack of institutional memory, that are among the issues that are at the heart of the use of the subsistence farmer scenario as the method of choice for long-term population protection. The phasing of cleanup and issues related to keeping people out of a contaminated site should not be confused with the central concerns that give subsistence farmer scenario a robust character as the sound scientific choice for setting cleanup standards.

4. It is not clear that the integrity of wildlife will be protected over the long-term even if the designation of the site as a refuge can be sustained indefinitely.

Emerging understanding of genome-ecosystem interactions have led to the postulation of a genetic "uncertainty principle" according to which induced genetic changes that do not produce observable deleterious effects in individuals of a species may nonetheless be harmful to the entire species over the long-term. Understanding of genome-ecosystem interactions at the molecular level is still rudimentary at best. Radiation is one of the causes of genetic mutation. Some random mutations are harmful. It is therefore not at all clear that a designation of a contaminated site as a wildlife refuge will be protective of the integrity of species over the long-term even if it there is no observable harm to individual wildlife specimens in the short-term.

Other recommendations

1. **The designation of Rocky Flats as a wildlife refuge should not serve as a precedent for other sites or for reducing cleanup expenditures at other major DOE nuclear weapons sites.**

2. **The Department of Energy should adopt the subsistence farmer scenario as the basis for the cleanup program throughout its nuclear weapons complex.**

There is a considerable amount of literature supporting the idea of wildlife refuges at the major DOE weapons sites. The use of this designation as a way of avoiding cleanup expenditures would not be protective of future generations. While it is not desirable to release contaminated areas to the public, and site restrictions of various types may be adopted to achieve this goal in the short-term, that should not become the basis for avoiding the use of the subsistence farmer scenario as the basis for cleanup goals and standards.

1. Introduction

Historically, radiation standards were set in the context of worker protection, such as medical X-ray workers, radium-dial painters, and Manhattan Project personnel. These were situations where, in principle, the dose could be measured, via film badges for instance, or inferred, from urine data, for instance. There were no separate standards for public health protection. It was not until 1959, that the ICRP and NCRP recommended a maximum exposure limit of one-tenth of the occupational level of 5 rem per year for non-worker individuals (so the individual dose would be 0.5 rem per year) and one-thirtieth of the occupational level as an average for the entire population (0.17 rem per year).[1]

The extension of radiation protection to non-worker offsite populations created the problem of measuring dose because it was generally not practical to extend the same kind of measurement protocols to off-site populations as to workers. As discussed later in this document, this led to the idea of the hypothetical maximally exposed individual. The assumption was that if the dose to such an hypothetical individual were kept below a specified limit, then one would be sure that the rest of the population would have a lower dose and hence be protected relative to whatever standard was established for maximum allowable exposure. Of course, all of this is supposed to occur in the general context that the activity that imposes the risk upon people has some beneficial purpose, in order to guard against gratuitous imposition of risk (see below).

The protection of offsite populations from operations of nuclear facilities is complex enough, but the problem of protecting people far into the future from residual contamination of soil and water is far more complicated and difficult. A number of factors enter into the picture. For instance we know the diets of people who live near the facilities today. What about people far into the future? History is no help, other than to tell us that diets and preferences change.

When considering current operations, we know where the facilities are located and the approximate distribution of the pollutants. Even so, getting data that is precise enough for accurate dose determination for compliance can be a costly and difficult business.

When considering doses to populations far into the future, we do not know how the waste and residual activity will have migrated. We do not know what new activities might take place on the site. We do not know the population levels or distribution. We do not know what resources, other than water and food will be regarded as precious by society. We do not know how weather patterns will change or whether major geophysical disruptions will occur. Conditions that exist today will not endure indefinitely. Long-term waste management and long-term stewardship arising from residual radioactivity levels present some of the most conceptually difficult challenges for health protection. For instance, a few hundred years ago it would have been essentially impossible to predict that Las Vegas, Nevada, would become a bustling metropolitan area. Similarly, a hundred years ago the Midwest was being settled by then Europeans anxious to get a lot of land for farming. It would have been difficult to foresee the depopulation that is occurring in the Dakotas, for instance, outside of American Indian

[1] Mazuzan and Walker, 1984, pg. 259; Walker, 2000, pp. 25-26. See also IEER, 2000 for a summary of worker dose regulations.

reservations, or that many parts of the Midwest now fit the nineteenth century definition of wilderness areas because their population density is below one person per square mile.

Some basic concepts have been put forth in radiation protection to meet the challenge of protection of populations far into the future. The International Commission on Radiological Protection describes three basic concepts:

a) the justification of a practice,
b) the optimization of a practice so as to minimize exposure, and
c) the development of dose limits.[2]

The first item, justification, means that no activity, including disposal, involving radioactive materials will be undertaken unless its benefits to society outweigh any potential detriments. Optimization is the process by which exposures to individuals and entire populations should be as low as reasonably achievable. Finally, dose and risk limits should be developed before the activity takes place so that no individual is faced with unacceptable risks resulting from the use of radioactive materials.

Two methods have been suggested to meet the goals of radiation protection implicit in these concepts.[3] One is the concept of limiting population dose or risk from any facility or activity and the other is to limit individual dose or risk. For estimating the dose to populations in the vicinity of the contaminated area of a disposal site, this approach requires a large number of assumptions about future population distribution patterns and overall resources use. It is difficult to justify specific assumptions about future lifestyles in general and even more difficult to predict demographics thousands of years into the future. The examples of the difficulty of prediction that we have already cited can be easily multiplied. However, there are some areas where population dose estimates are possible and desirable. For instance, releases of carbon-14 to the atmosphere in the form of carbon dioxide has radiobiological effects in terms of dose that are have been established, since carbon dioxide becomes part of the food chain. While uncertainties will remain as to transport of carbon-14 in the atmosphere, the uptake of carbon-14 by plants, and the exact diets in the future, there is no question that the basic food constituents, such as carbohydrates, proteins, etc. will remain in the diet. All of them are affected by the presence of carbon-14 in the atmosphere.

Such an approach cannot be used with ease or accuracy to estimate future local doses. For instance, in attempting to estimate population doses and cancer fatalities as a result of the operation of a high-level waste repository, the EPA calculated future doses based on world average statistics on food and water consumption, water flow, and a future population of ten billion people that consumes water and food at a rate that is three times greater than that of the present population. Using these averages and assumptions, EPA estimates the fraction of world river flow that is used for drinking and growing food, the retention of radionuclides in soil as a result of irrigation with contaminated water, and the uptake of these radionuclides into plants and animals.[4]

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[2] ICRP, 1977, pp. 3, 28.
[3] See for instance NAS, 1983, Chapter 8
[4] Pigford, 1981; NAS, 1983, p.221.

This approach was criticized by the National Academy of Science (NAS) Waste Isolation Systems Panel, in its *Study of the Isolation System for the Geologic Disposal of Radioactive Waste* (1983). A part of the problem with the EPA approach was that it did not couple protection of local individuals who might be living in the area of the geologic repository with the global aim of keeping cancers to below 1,000 over a period of 10,000 years. Adopting such a global goal without sublimits may have permitted local doses to be huge. This was the central theme of the criticism of the repository standard proposed by the EPA in the early 1980s:

> "Because of the problems of making any meaningful estimates of numbers, locations, and eating habits of future populations, because of the many uncertainties in EPA's derivation of release limits to achieve its objective of population risk, because of the lack of justification of the EPA 10,000 year time limit for consideration of future releases of radionuclides to the environment, and because the population-dose-based release limits can allow individual radiation exposures greater than what we consider to be reasonable, we do not adopt population dose or activity release limits as an overall performance criterion for our study."[5]

The subsistence farmer scenario evolved over a period of time as a model by which the goals of radiological protection could be met in the context of long term waste management and disposal for local populations without recourse to assumptions about local lifestyles over very long time periods. If a future subsistence farmer, who used the local water supply and ate only locally grown food, were to be protected by radiation regulations, then all other people would have a risk of cancer lower than that of the subsistence farmer– and most people's risks would be much lower. The subsistence farmer concept has historically been coupled with defining a set of individuals called the "critical group" to which we now turn.

2. The concept of the critical group and the maximally exposed individual

The concepts of the critical group and maximally exposed individual originated from discussions regarding the disposal of high-level radioactive waste. According to T.H. Pigford, who has long been involved in discussions involving radioactive waste, projects for long-term disposal of high-level radioactive waste have been planned with the following ethical goals in mind:

A. Future people, of distant times, should be given the same health protection afforded to people living near nuclear facilities today.
B. Present generations should be responsible for safely disposing of the radioactive waste that we have created.
C. Future generations should not have to take conscious action to protect themselves from the radioactivity that we have created.
D. Disposal systems should provide long-term security against weapons proliferation.[6]

[5] NAS, 1983, pp. 230-231.
[6] Pigford, 1999.

The principal basis for radiation protection until recently has been to set limits on the maximum allowable exposures to individuals from man-made sources. For example, the overall individual dose limit for the general population from all man-made sources of radiation (other than medical) is 100 millirem per year. The limit for exposure due to emissions from specific facilities is generally in the range of 5 to 25 millirem per year.

Both the individual and population dose concepts are incorporated into current standards codified in federal regulations 40 CFR 191, which apply to all high-level waste repositories except Yucca Mountain.

The "maximally exposed individual" is a hypothetical construct, corresponding to a set of "reasonable" assumptions about human needs and activities. People who may be unusually sensitive to radiation or who have unusual habits are not used for standard setting. For example, a British inquiry omitted people who subsisted mainly on clams from its definition of the affected population because this diet was considered unusual.[7]

For the purposes of calculating radiation dose, a small, homogeneous group of individuals is used to define a "critical group." The concept goes back to at least 1977.[8] The International Commission on Radiological Protection (ICRP) defines the critical group in the following manner:

> "When an actual group cannot be defined, *a hypothetical group or representative individual* should be considered who, due to location and time, would receive the greatest dose. The habits and characteristics of the group should be based upon *present knowledge* using *cautious*, but *reasonable* assumptions. For example, the critical group could be the group of people who might live in an area near a repository and whose water would be obtained from a nearby groundwater aquifer. Because the actual doses in the entire population will constitute a distribution for which the critical group represents the extreme, this procedure is intended to ensure *that no individual doses are unacceptably high*."[9] (emphasis added)

Since an actual group can never be defined far into the future, it is generally necessary to define such a critical group in order to consider issues related to protection of local populations who may live in the area at that time. Since the critical group must be both small and homogenous, the concept essentially extends the idea of a maximally exposed individual, that is used for current operations, to people far into the future.

A description of the critical group is included in ICRP 26. This provides an explicit link between the critical group and the maximally exposed individual:

> "It is often possible to identify population groups with characteristics causing them to be exposed at a higher level than the rest of the exposed population from

[7] NAS, 1995, p. 171.
[8] ICRP, 1977, p. 17.
[9] ICRP, 1985, p. 9.

a given practice. The exposure of these groups, known as *critical groups*, can then be used as a measure of the upper limit of the *individual doses* resulting from the proposed practice. When several practices may contribute significantly to the exposure of the same exposed population, either simultaneously or successively, the definition of critical groups must take account of these separate contributions."[10] (emphasis added)

ICRP also recommends that critical groups be small so that they are homogenous with the upper limit to size usually being "up to a few tens of persons." They could be as small as only one person.[11]

> "In an extreme case it may be convenient to define the critical group in terms of a *single hypothetical individual*, for example when dealing with conditions well in the future which cannot be characterized in detail." (emphasis added)

In this specific instance, the congruence of the critical group with a hypothetical maximally exposed individual is complete.

Institutions in countries other than the United States have also adopted the ICRP recommendations on the critical group concept. The United Kingdom's National Radiological Protection Board (NRPB) says:

> "...it is appropriate to use hypothetical critical groups. For the purposes of solid waste disposal assessments, these are assumed to exist, at any given time in the future, at the place where the relevant environmental concentrations are highest, and to have habits such that their exposure is representative of the highest exposures which might reasonably be expected."[12]

The device of a small critical group is used to represent the maximally exposed individual for regulatory purposes. In practice, the maximally exposed individual should be in the critical group. Once the exposure scenario for the maximally exposed individual is selected, then it is possible to derive secondary standards for limiting concentrations of radionuclides in air, water, and soil. These secondary standards, if adhered to, would result in compliance with the primary dose standard.

The concept of the maximally exposed individual has existed for quite some time, although over time the terminology has changed. The roots of this concept can be traced back in part to the 1958 version of the Atomic Energy Commission's *AEC Manual* chapter 0524, where it was expressed in very rudimentary form, without the use of that expression.[13] It was in this document that the AEC discussed the idea that limiting doses near sites from its operations would be expected to produce lower average individual doses in the general population. This

[10] ICRP, 1977, p. 38-39.
[11] ICRP, 1984, p. 15.
[12] NRPB, 1992, p. 12.
[13] AEC, 1958, paragraph 12.

document was updated and renamed in 1963.[14] These documents first established radiation protection standards for populations located in uncontrolled areas outside of and around nuclear sites. To limit offsite doses, the maximum allowable concentrations of radionuclides were specified at the site boundary. This concept was also implicit in other regulations that were put into effect in the late 1960s and 1970s. *Regulatory Guides* 1.3 and 1.4 do not use the term maximally exposed individual, but their assumptions for calculating potential doses after a loss-of-coolant accident are designed to assess the maximum theoretical dose an individual could receive.[15, 16] *Regulatory Guide* (revision 1) 1.109 of 1977 explicitly uses the term "maximum exposed individual." In this document, dose estimates are given to assess the dose to the hypothetical "maximum exposed individual" in the absence of hard data.

Regulatory Guide 1.109 reads:

> "...the NRC staff has made use of the maximum exposed individual approach."
>
> "Maximum [exposed] individuals are characterized as 'maximum' with regard to food consumption, occupancy, and other usage of the region in the vicinity of the plant site and as such represent individuals with habits representing reasonable deviations from the average for the population in general." [17]

It is inherent in these definitions that these individuals' doses would be higher, possibly far higher, than those of the general population. The basic concept of this hypothetical construct clearly pre-dated these documents. For example, the Hanford environmental and evaluation staff would sum exposures from various sources "in a manner which tends to maximize the total dose."[18] This is essentially calculating the exposure that the maximally exposed individual would receive. One can use documents such as this and the ones mentioned above to create a rough lineage of the model in regulatory literature.

The concept of the maximally exposed individual, which is at the heart of current radiation protection regulations for present populations, goes back to about the early 1960s and has come into general use. For example, it is used in the implementation of the Clean Air Act. A hypothetical person living at the site boundary for 24 hours a day and 365 days a year, without any building shielding factor is specified as the basis for compliance with the maximum allowable dose of 10 millirem per year. The reasoning is that if the hypothetical individual at the site boundary gets less than the maximum allowable dose, then every other person in the population would get less than that and therefore have a risk of cancer lower than that implicit in the standard.

But even a situation that seems straightforward – that of protecting offsite populations from radiation emitted by current operations – the actual problem is often more difficult than this scenario would make it appear. Implicit in such a scenario is the assumption that the location of

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[14] AEC, 1963.
[15] AEC, 1970a.
[16] AEC, 1970b.
[17] NRC, 1977, p. 1.109-1.
[18] General Electric, 1963, p. 6.

the maximally exposed individual does not change during the year. Yet, changes of operations, accidents, sudden releases during cleanup operations, etc. could result in higher doses at other locations. There are examples when someone walking by a facility that has low normal emissions but is having an accident or an abnormal operation might receive a greater dose than a hypothetical maximally exposed individual whose location might be elsewhere based on routine operations. Hence, in order to determine who is really at risk requires a detailed knowledge not only of routine operations but also of extraordinary occurrences, possible accidents, and unanticipated events.[19]

If protecting people to pre-specified levels is difficult for the present generation, matters are far more complex and uncertain for future ones. The concept of the critical group, which is an extension of the concept of the maximally exposed individual, was created as a minimal, essential tool to assist in what might otherwise become an arbitrary exercise in wishful thinking.

3. Description of the subsistence farmer scenario

How should the critical group be defined? What are the criteria that must be used? Here also the basic thrust of historical practice has been to take a conservative, but reasonable approach that corresponds to the idea of the maximally exposed individual. We seek to define such a group at a time when we cannot know whether there may be radiation doses from other sources. Lack of knowledge in this regard has always meant that the maximum dose limit be kept well below the allowable exposure from man-made sources.

When the main route of exposure over long time periods is uncertain, it is the general practice to use the subsistence farmer scenario for calculating risk, or the level of permissible exposure. This approach assumes that a person would unknowingly use contaminated water for drinking and farming and would grow all their own food. Further, it assumes that such exposure would last a lifetime, and not just a few years. The people in the critical group spend most of their time on the contaminated site. In addition, it assumes that the diets as well as food and water intake of future populations will be similar to those of today. People are considered protected if their lifetime exposure is less than an assigned limit. The reasoning is that in such a case all other people would be protected since their doses would be lower than that of the hypothetical subsistence farmer.

The assumption that the risk of illness to all individuals within a population will be below that of the hypothetical subsistence farmer is not a prediction, of course. It is an estimate that, with some unknown, but small likelihood, may turn out to be wrong. The subsistence farmer scenario is a conservative, stringent, and practically bounding approach to calculating future regulatory dose limits. However, it should be recognized that, in general, it excludes the most extreme doses that it is possible to calculate. For instance, it is common to exclude extreme diets consisting only of the most contaminated foods. While such diets cannot be ruled out, they may reasonably be considered as improbable, unless there is some evidence to the contrary. The subsistence farmer scenario is akin to and based on the maximally exposed individual concept that we have discussed above, but for the purpose of long-term calculations.

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[19] Makhijani and Franke, 2000, pp. 4-5

One concept within the subsistence farmer scenario is the notion that radionuclides, once in the environment, can move up the food chain. This food chain concept was incorporated into regulations in Table 2 of 10 CFR 20, a regulation of the Atomic Energy Commission. This table, which still exists today in updated form, deals with the possible exposure of people who may live near a licensed nuclear facility and was initially a regulation of the Atomic Energy Commission, the predecessor to the Department of Energy, and still exists today (in updated form). It codifies the permissible concentration of various radionuclides in air and water based upon the allowable quantity of each radionuclide in the body. In preparing this table the AEC assumed that the individual continuously breathes contaminated air and only drinks contaminated water. The subsistence farmer scenario is one step beyond this one in that food is grown using the contaminated water. The one exception in 10 CFR 20 is the maximum permissible concentration for iodine-131. This regulation takes into account airborne radioiodine being deposited onto the ground and taken up by grass which cows then eat. The iodine is then concentrated in cow's milk and consumed by an infant.[20]

Much of the development of the subsistence farmer scenario was done by Bruce Napier and William Kennedy at the Hanford Pacific Northwest Laboratory in the 1980s. The early version of this model was known as the "backyard farmer" scenario.[21] In their analysis of allowable residual contamination levels (ARCL) at Hanford, they assumed that restricted use of the site for 100 years, controlled use for another 300, and unrestricted use of the facilities afterward. All of their assumptions are based on the ingestion characteristics of the " standard Hanford maximally-exposed individual," a construct that fits the description of the average adult male.[22] For unrestricted use, they assumed that an individual would have "free access to any remaining facilities or radionuclides on the site."[23]

> "...for the far-term scenario, it may be assumed that people will eventually move onto the waste site. This is not intended to imply that future populations are unintelligent or technologically inferior, but only that records of the waste sites are forgotten or ignored."[24]

This individual is "assumed to raise a large fraction of his own fruits and vegetables for personal consumption."[25] Calculations were carried out to determine doses at ten kilometers from the site, one kilometer from the site, and on-site. It was assumed that the individual would live downwind and downstream from the site. Because doses were found to be much smaller offsite than on, the onsite exposure scenarios were deemed the most critical.[26]

By the late 1980s, this model had been refined even further into three different scenarios.[27] These are the resource-recycle scenario, the residential/home-garden scenario, and the

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[20] Pigford, 2001.
[21] Napier, 2001.
[22] Napier, 1982, p. 34; Kennedy and Napier, 1985, p.155.
[23] Kennedy and Napier, 1985, pg.155.
[24] Kennedy, Napier, and Soldat, 1983, p. 106.
[25] Napier, 1982, p. 34.
[26] Kennedy, Napier, and Soldat, 1983 p. 106.
[27] Napier, *et al.*, 1988. p. 2.3-2.7.

agriculture scenario. The resource-recycle scenario bases its assumptions on an individual who recycles materials that were salvaged at a destroyed facility after institutional controls are lost.

The home-garden scenario is based on an individual who resides on-site and operates a home garden for 50 years. This person constructs a basement where the greatest contamination associated with a facility would occur. It is assumed that this person spends twelve hours per day outside where s/he is exposed to radiation from the soil and can inhale resuspended contamination from the soil surface. Also, twenty-five percent of the individual's fruit and vegetable intake is assumed to come from a backyard garden that is located on contaminated soil.

The agricultural scenario, a slight variation of the home-garden scenario, was designed to assess exposure resulting from eating agricultural products whose roots come into contact with buried radioactive materials.[28] In common with the home-garden scenario, Napier, *et al.* assume that only twenty-five percent of the diet would be from food grown on-site. While the home-garden model is only designed for one person, the agriculture system assumes that a family of four would get twenty-five percent of its total fruit and vegetable supply from the land. As a result, it is assumed that the land would be 0.1 to 1 hectare in size. It is assumed that 50 square meters would be used for above ground vegetables, 200 square meters would be used for root vegetables and grains, and slightly more than 200 square meters would be used for fruit trees. Homegrown animal products are not included in this scenario because it is assumed that one hectare of land would not be enough to grow animals as well as crops.

These scenarios were eventually adopted as official protocol for the Hanford site.[29] This is apparent in DOE's 1987 *Final Environmental Impact Statement: Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes*. In appendix R, a description is given of a "full garden scenario" that is very similar to the agricultural scenario described above, the only difference being that it assumes a small two hectare farm instead of the smaller ones described above.[30] While none of the scenarios described here is exactly like the subsistence farmer model, the DOE's official analysis has been along the lines of a subsistence-farmer-like model for quite sometime.

As another example, the Yucca Mountain Project has, in the past, based estimated future doses on subsistence farmers using computer modeling in the biosphere scenario.[31] The U.S. Nuclear Regulatory Commission (NRC) has also performed calculations to assess the risk of exposure to future populations due to geologic disposal at Yucca Mountain. In its calculations, the NRC has used a hypothetical self-sufficient farm family of three who obtain all of their water from a contaminated well. This same water is used to grow the family's crops, and their meat and milk is obtained from farm animals raised on vegetation that is irrigated by it.[32] The NRC also did not restrict the location of the critical group to currently populated areas, but it is assumed to live at the boundary of the controlled area.[33] This is consistent with ICRP 43 recommendations for

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[28] Napier, *et al.*, 1988, pp. 2.6 to 2.8.
[29] Napier, 2001.
[30] DOE, 1987, Appendices F (vol. 2) and R (vol. 3)
[31] EPA, 2000. The biosphere scenario is an exposure calculation that translates concentrations of radionuclides in environmental media to estimates of dose and risk to future populations, pp. 8-49 to 8-52.
[32] NRC, 1995, pp. 7-8, 7-10; Napier, *et al.*, 1988
[33] NRC, 1995, p. 7-10.

calculating doses from major sources because the recommendations do not specify occupancy parameters. They only state that the chosen parameters be "appropriate."[34]

Other projects that have used the subsistence farmer scenario or variants thereof include the Waste Isolation Pilot Plant (WIPP) and Sandia National Laboratories.[35] The WIPP project was formed to dispose of transuranic waste in bedded salt, while Sandia ran an evaluation of spent fuel in a tuff repository. The Hanford repository program uses the subsistence farmer approach to calculate exposure when the locations and other traits of exposed individuals are unknown. So, a strong precedent has been set for the use of the subsistence farmer scenario when the location and lifestyles of the exposed population are unknown. Finally, in regulatory terms, the EPA in establishing Superfund regulations has used the subsistence farmer scenario.[36]

4. International use of the subsistence farmer approach

There is a considerable international consensus about the subsistence farmer approach, which has been used in Britain, Sweden, Finland, and other countries.[37] In Switzerland, the critical group is defined as a self-sustaining agricultural community that obtains no food and water from outside sources and is located in the area of highest potential concentration.[38] This concept includes estimates of doses from the food chain (i.e. through crops, cow's milk, etc.)[39]

The British National Radiological Protection Board (NRPB) uses similar language to define the critical group. They state the critical group (they replace the term critical group with "reference community") should be defined as "'typical' subsistence farmers, i.e., perhaps a few families who produce a range of food to feed themselves."[40]

The Finnish government defines their critical group as a:

> "...small self-sustaining community in the vicinity of the disposal site. They are assumed to be exposed e.g. through abstracting water from a shallow well for drinking water or for irrigation of plants, or through catching fish from a small lake."[41]

The International Atomic Energy Agency writes that:

> "...there may also be benefits to be gained from choosing one particular biosphere/critical group combination as an international benchmark. This should

[34] ICRP, 1984, p. 15
[35] Sandia, 1995, Chapter 14; Pigford, 2001.
[36] Federal Register, 1998. See also EPA, 1989. Superfund regulations do not address very long periods of time and are oriented to allowing re-use of sites. They are therefore different in intent than regulations specifically created for long-term health protection. Superfund exceptions from the subsistence farmer approach allowing for industrial "brownfields" use do not address long-term health impacts or site use issues, which is the subject of the present report.
[37] NRPB, 1992, p.14; Charles and Smith, 1991, pp. 6 to 8; Ruokola, 1998, p.40.
[38] Switzerland, 1985; NAS, 1995, p. 164.
[39] Switzerland, 1985, chapter 12.
[40] NRPB, 1992, p. 14.
[41] Ruokola, 1998, p. 40.

be selected in such a way that the calculated doses and risks would be representative of the highest likely to be received in the future. An example of one such possibility, a northern temperate inland biosphere with a hypothetical reference critical group of subsistence farmers ..."[42]

Norway used several different scenarios, all of which have some similarities to the subsistence farmer scenario to estimate dose calculations for areas around their proposed site for low and medium level waste at Himalden. Calculations were done for five scenarios that included the four critical groups of:

1. Smallholder farming community located close to the facility by a stream.
2. Smallholder farming community located by a river downstream of the facility.
3. Hunter-gatherers consuming wild game from the area around a lake near the facility.
4. Fishermen consuming fish caught in that same lake.[43]

The Finnish example shows clearly that there is some flexibility in determining what specific scenario should be used depending on local custom and diet. But in all cases, the scenarios are constructed with the idea that a plausible maximum dose should be estimated based on a model akin to the subsistence farmer. The fisherman and hunter-gatherer models are really local variants of the subsistence farmer model and the Arctic climate makes such scenarios plausible. Similarly, the Risk Assessment Corporation used a subsistence rancher scenario as a reasonable local variant of the subsistence farmer scenario in assessing Rocky Flats radionuclide soil action levels (RSALs).[44] These are the residual levels of radionuclides that would remain in the soil after it has been declared cleaned up by the DOE.

One reason for the international acceptance of the subsistence farmer scenario is that it complies with the recommendations made by the International Commission on Radiological Protection for exposure, risk estimation procedure, and definition of the critical group. ICRP 46 and 43 both recommend calculating the average dose from a repository to a homogeneous group that is expected to receive the highest dose equivalent.

ICRP 43 reads:

"It is clearly stated by the Commission ... that the dose-equivalent limits are intended to apply to the mean dose equivalent in a reasonably homogeneous group. In an extreme case it may be convenient to define the critical group in terms of a single hypothetical individual, for example when dealing with conditions well in the future which cannot be characterized in detail."

ICRP 46 reads:

"Because the actual doses in the entire population will constitute a distribution for which the critical group represents the extreme, this procedure is intended to ensure that no individual doses are unacceptably high." [45]

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[42] IAEA, 1999, p. 7
[43] Sörlie, 1998, p.61.
[44] RAC, 2000, pp. 25 to 27.
[45] ICRP, 1984 p. 3,4,15; ICRP, 1985 p. 9.

The subsistence farmer scenario used by other countries where a small community is defined as the critical group meets these criteria. However, it is also valid for institutions to use a single subsistence farmer as their critical group because ICRP recommendations state that "it may be convenient to define the critical group in terms of a single hypothetical individual, for example when dealing with conditions well in the future."[46] The term "well in the future" is especially applicable in cases such as Rocky Flats or waste repositories because of the long time-frame at issue.

The subsistence farmer also meets several other criteria that have been recommended by ICRP. First, the diet, habits, and dose response of the farmer "should be based on present knowledge using cautious, but reasonable, assumptions."[47] It is both cautious and reasonable to assume that such a subsistence lifestyle could be viable in the future. It is neither cautious nor reasonable to assume that institutional restraints preventing use of the property as farmland will be effective for thousands of years. Historical examples ranging from house construction on dumps containing radioactive materials and chemical munitions within the space of decades provide ample reason to base future long-term health protection on an approach that does not assume prolonged institutional memory or controls. The subsistence farmer scenario provides such an approach and is therefore supported by both scientific and historical considerations.

Finally, the subsistence farmer represents the upper bound of exposure and the extreme of the actual doses in the entire population. ICRP 46 states that "the critical group represents the extreme" and "is intended to ensure that no individual doses are extremely high."[48] It has already been argued that the subsistence farmer meets the definition of a critical group. But, the language here shows that it is acceptable to protect this hypothetical individual in order to ensure that no other individual doses are unacceptably high.

One argument against this model is that it is too stringent for proposed geologic disposal sites such as Yucca Mountain or nuclear facilities such as Rocky Flats. However, this argument against the subsistence farmer scenario is weak and may be mathematically unsound (see discussion below). Because the behavior of future people is unknown, using a bounding approach, an approach that maximizes the number of people that would be protected, will limit the number of arbitrary assumptions that can be made to change estimated doses and possibly put future generations at risk. Also, in relation to Yucca Mountain, it has been shown that the repository design adopted by the DOE would in future time exceed established performance limits. This does not mean that the subsistence farmer scenario is too stringent but rather that the repository design is weak. Rather than adopting less stringent regulations, the DOE should improve its designs in order to avoid unacceptably high doses.

5. Reasonableness of the subsistence farmer scenario on occupational grounds

Today the term subsistence farmer often connotes a poor person scratching out a meager living from the soil. But this is not the assumption in radiation protection regulations. They assume

[46] ICRP, 1984 p. 15.
[47] ICRP, 1985 p. 9.
[48] ICRP, 1985 p. 9.

that a subsistence farmer will eat a good diet, which will be locally grown with local water supply. It is not at all fanciful to consider a future where people might choose to grow most of their own food and, thanks to advanced technology, be able to do so very efficiently and in a sustainable way. Such individuals may even be able to devote most of their time to other pursuits and might be economically well off even by today's U.S. standards. Yet they would fit the radiological description of a subsistence farmer scenario. The term "subsistence farmer" is a rather unfortunate one in that it usually connotes a poor person. A "self-sufficient" farmer might be more appropriate to describe the hypothetical person created by radiation protection regulations.

It is not at all implausible that there may be significant numbers of people in the future who would choose to be self-sufficient farmers or something close to it, even in the context of rapid urbanization of populations. In fact, the adoption of lifestyles closer to the land is a trend that has emerged in reaction to the increasing distance from the production and reproduction of our own existence that characterizes modern lifestyles. It is not necessary for a majority or even a substantial minority to adopt a self-sufficient farmer lifestyle for it to be germane to future health protection. It should only be a *plausible* lifestyle for some people based on what we know of society today. Indeed, it is quite possible to imagine economic, social, and technological arrangements under which a large proportion of the population of the future would grow most of their own food or obtain it very locally.

Some recent trends point in the direction of preference for local food and reinforce the arguments for adopting the subsistence farmer scenario. There has been a boom in the demand for organic food and the large numbers of people who are willing to work long hours, days, and years as organic farmers to meet that demand. The markets for such very local products now amount to billions of dollars per year in the United States alone. This means that the numbers of people who may consume the kind of diet assumed in the subsistence farmer scenario could be far larger than a small local community living on contaminated land. While this larger population would not have direct gamma radiation doses from contaminated land, and may not have the same drinking water doses as the subsistence farmer, they may have a similar dietary dose. There are many circumstances in which the dietary component dominates the dose. Such considerations mean that the dose calculated for some of the people who are not part of the critical group may not be significantly lower than that of the subsistence farmer. This is another important reason for using the subsistence farmer scenario as the basis for a clean up standard. It is important therefore to not only use the subsistence farmer scenario as the basis for protecting future populations, but to set a stringent standard limiting risk to protect against the possibility of large population doses due to lifestyle changes that are foreseeable based on many people's preferences today.

In addition to being a reasonable scenario in general, it is also important to underscore the point that this is reasonable for the Rocky Flats site. Because the Denver-Boulder corridor is one of the fastest growing areas in the country, there is a great deal of pressure to develop open spaces. There are farms, businesses, and homes located just up to the boundary of the site. The reasons given for declaring Rocky Flats a wildlife refuge include preserving open space and limiting the costs of cleanup.[49]

[49] Udall and Allard, 2001.

However, declaring the site a refuge and limiting short-term expenditures should not be confused with long-term public health protection and clean up standards for the site. If a law can create a wildlife refuge out of a plutonium contaminated site in a few months time, a reversal of such a decision can also be made. The pressures of development makes such a reversal plausible, if not likely. Further, preserving open space is not at variance with the adoption of a subsistence farmer scenario. Indeed, such a scenario would not only be more protective of human health, it would also be more conducive for the same reasons in protecting the integrity of any wildlife on the site, should the area be designated as a refuge. The idea that leaving a place highly contaminated by human occupation standards would preserve the space for wildlife, such as the endangered Prebles Jumping Mouse, begs the question of what such contamination could do to the long term health of the wildlife that is sought to be preserved. Finally, protection of the health of future generations should not be based on the budgetary convenience of the moment but on sound scientific arguments that take the context of clean up decisions into account. In other words, a soil standard should be set according to stringent public health standards that are independent of current and short-term designations of site use since the basic concept of a standard should be long-term public health protection.

6. Relation of the subsistence farmer scenario to Radionuclide Soil Action Levels (RSALs) at Rocky Flats

Health risks to people living near a site that has been decommissioned may arise from a number of different sources, such as:

- Direct gamma radiation from residual radionuclides, and in some cases also neutron and beta radiation
- drinking contaminated water
- eating food grown using contaminated water for irrigation
- eating contaminated soil or ingesting it during periods when the air is dusty or via food
- breathing air containing contaminated soil that has re-suspended due to high winds
- breathing contaminants entering the air during fires
- exposure *in utero* via the mother's diet

These sources of risk are not static or independent. One of the most important sources of the evaluation of total risk and the distribution of doses via specific pathways is the residual contamination in the soil. For instance, the contamination in the soil acts as a reservoir for potential contamination of water that would be used for drinking or irrigation. As another example, the amount of radioactivity that is present in the air during periods of heavy wind, such as those that occur commonly at Rocky Flats, depends directly on the residual soil contamination, as does uptake of radioactivity by plants. Both of course, depend on other factors as well.

These points were illustrated by the Risk Assessment Corporation (RAC) in their analysis of RSALs at Rocky Flats. Their conclusions were that the most important exposure pathway at Rocky Flats was the inhalation of contaminated soil that had been resuspended by gusts of wind.[50] In addition, their recommended RSAL of 35 pCi/g does not assume a 100% probability of a large grass fire that would enhance the resuspension of contaminated soil. If this were the case, the RSAL would be even lower than 35 pCi/g.[51] This analysis also admits shortcomings in its investigation into the groundwater exposure pathway.[52]

Because of the crucial connection of residual soil contamination to a number of dose pathways, the residual concentration of long-lived radionuclides in the soil is a parameter of central importance in assessing the efficacy of clean up in protecting future populations. A number of radionuclides, such as tritium and strontium-90 are known to migrate rapidly through the soil. It had been the conviction of the DOE and its contractors for several decades that plutonium would not migrate rapidly through the soil. However, evidence has been accumulating for over two decades that, under a variety of conditions, the ion-exchange property of the soil that would bind plutonium and greatly retard its migration is overwhelmed by countervailing phenomena: migration of plutonium in colloidal form, the mobilization of plutonium by natural organic materials in the soil and spilled or dumped solvents, and complexing of plutonium with compounds present in the soil.[53]

For instance, experience at Oak Ridge has shown that organic materials in the soil can mobilize plutonium by forming complexes with it causing rapid movement through the soil and into groundwater. The rate of plutonium migration under such conditions was estimated in an Oak Ridge National Laboratory report to be 100 to 1,000 times faster "than predicted from batch adsorption studies in the literature."[54]

Assumptions in the early years that insoluble forms of plutonium would remain that way in the environment for long periods of time or remain bound by ion exchange in the soil for hundreds of thousands of years are being shown to be contrary to actual experience under a variety of circumstances. One fundamental reason is that the chemistry of plutonium is extremely complex. According to a Los Alamos scientific evaluation of the properties of plutonium, "[n]o other element displays such a complex chemistry."[55]

Specifically, the Los Alamos paper describes, among other things, the behavior of plutonium in oxidation state IV, which is the oxidation state of plutonium dioxide. This is the most insoluble form of plutonium and it is also the form that has been found at Rocky Flats Pad 903.[56] But insolubility does not guarantee that plutonium will remain relatively immobile, an assumption that has been made in evaluations of Rocky Flats.
Insoluble plutonium can be mobilized and can move rapidly through the vadose zone into groundwater in colloidal form. This has been found not only at the Nevada Test Site as noted

[50] RAC, 2000, p. 25.
[51] RAC, 2000, pp. 30-32.
[52] RAC, 2000, p. 34.
[53] For instance Kersting *et al.*, 1999, p. 58 and p. 59 have shown that plutonium has migrated in colloidal form at the Nevada Test Site from one of the test locations at a rate orders of magnitude faster than ion-exchange and other solute-solid interactions would lead one to expect. See below.
[54] ORNL, 1996, p. 4-20. See also Fioravanti and Makhijani, 1997, pp. 121-124, for a discussion.
[55] Clark, 2000, p. 364.
[56] RAC, 1999b, p. 9.

above, but has been noted to be a specific property of plutonium in the IV valence state found at Rocky Flats. According to the Los Alamos study:

> "In oxidation state IV, plutonium strongly hydrolyzes (reacts with water), often to form light green "sols," or colloidal solids that behave much like a solution. These intrinsic colloids eventually age, and the solubility decreases over time. These intrinsic colloids can also attach themselves to natural mineral colloids that have important consequences for the migration of plutonium in the natural environment."[57]

A growing body of careful research shows that the migration of plutonium in the environment is dependent not only on the oxidation state of plutonium but on the environmental conditions in which that oxidation state is present. A changing environment will change the potential for plutonium mobility. .

Even if almost all the plutonium were to be in this insoluble form today, there is no guarantee that it will remain so in the future. Complexing with carbonate ions, for instance, can mobilize plutonium. Use of Rocky Flats as a wildlife preserve may considerably increase the amount of vegetable, animal, and related organic matter over the decades at Rocky Flats, creating new and unforeseen mechanisms for complexing and mobilization of plutonium. Natural organic matter has been known to mobilize plutonium at least one DOE site (Oak Ridge).[58] Hence if the site is first used as a wildlife refuge and then as a residential site, a ranch or a farm, the potential for harm may actually increase in comparison to a cleanup of the soil to a level corresponding to a subsistence rancher or farmer scenario.

Further evidence explaining the rapid migration of plutonium in groundwater is illustrated by the work of Haschke, Allen, and Morales.[59] Their experiments have shown that the water-catalyzed oxidation of plutonium dioxide (PuO_2) in air yields PuO_{2+x} in which plutonium is in its Pu(VI) valence state and therefore in a soluble form. The increase in solubility would increase mobility in groundwater. This might further explain the rapid migration of plutonium (1.3 km in 30 years) described by Kersting, *et al.*

The current contamination of groundwater at Rocky Flats with americium-241 and plutonium-239/240 is generally regarded as minimal. For instance, the reported maximum contamination levels in the fall of 2000 were 0.0354 and .0193 picocuries per liter respectively.[60] On an annual basis, these concentrations would result in doses of 1.7 and 0.9 millirem per year from drinking water alone, using EPA Federal Guidance Report 11 dose conversion factors.[61] These add up to 2.6 mrem per year, or more than half of the drinking water limit of 4 mrem per year set for beta emitters.[62] A two-fold increase would result in the drinking water dose exceeding 4 mrem per

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[57] Clark, 2000, p. 373.

[58] ORNL, 1996, pp. 4-20 and 4-21. See also discussion in Fioravanti and Makhijani, 1997, pp. 121-124.

[59] Haschke, Allen, and Morales, 2000.

[60] Kaiser-Hill, 2001, Appendix A, table on radionuclides.

[61] EPA, 1988, Table 2.2.

[62] The Safe Drinking Water standard (40 CFR 141) of 15 picocuries per liter for alpha emitting transuranics like plutonium-238, plutonium-239, or americium-241 does not follow a 4 mrem per year dose limit. For reasons that are unclear, it allows doses on the order of a hundred times higher than the 4 millirem annual limit to the critical

year. A six-fold increase in transuranic contamination would result in a drinking water dose exceeding the 15 mrem per year limit used by RAC for its calculations.

For a 500 pCi per gram of soil residual plutonium level, plus the associated americium-241 of about 55 pCi per gram of soil, RAC analysis estimated a water pathway dose of 88 mrem/year, mainly from drinking water.[63] For the 35 pCi/gram suggested as the plutonium RSAL by RAC, the dose would be about 6 mrem/year, which is in considerably excess of the safe drinking water limit for most beta emitters. (See footnote 62.) . The RSAL based on a 4 mrem per year dose limit to the bone surface corresponding to this calculation would be about 1.2 pCi/gram, or about 30 times lower than that recommended by the RAC team.. While this is not the current way that safe drinking water limits are defined, it is a reasonable to assume that limits for alpha emitters, which are today set according to dose estimation procedures that are 40 years old, will, in the future, be brought into line with the methods now used in all other regulations, or even more current methods.[64]

The RAC analysis used a low solubility assumption for plutonium and did not account for colloidal transport, which is the subject of ongoing investigations, which it cited. (Most of the RAC water dose is from the residual americium-241.) These calculations assume low plutonium mobility. RAC did recognize that plutonium may become more mobile than it assumed, but the complexity of the problem, the ongoing nature of the debate on plutonium migration, and the limited scope of the project that RAC undertook meant that a more sophisticated groundwater calculation was not done.[65] The RAC assumption about plutonium mobility was based on analyses of the present chemical form of plutonium in the 903-pad soil at Rocky Flats.[66] Corresponding to these assumptions, RAC concluded that plutonium would probably not reach groundwater within the calculation period of 1000 years and, hence, that plutonium would not be likely to contribute to the peak dose via the groundwater pathway. Only americium-241 would contribute to the groundwater dose.[67]

The assumption of low plutonium mobility cannot be supported for the long-term in the absence of a more detailed environmental analysis, as the RAC team recognized. The analysis above regarding the complexity of plutonium migration under real-world conditions in the natural environment indicates that the possibility that water pathway doses could be an order of magnitude or more greater in the long-term than estimated by RAC cannot be and should not be ruled out. Indeed, that possibility could be enhanced by the designation of Rocky Flats as a

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organ specified for most beta emitters. The RAC dose is a whole body effective dose equivalent. The individual organ dose to the critical organ, in this case the bone surface, would be about 20 times bigger.

[63] RAC, 1999b, p. 14. The dose is mainly from americium-241 associated with the plutonium contamination since a very low solubility was attributed to plutonium.

[64] Federal Guidance Report No. 13 of the EPA (EPA, 1999) incorporates more recent scientific methods. The methods are not directly comparable. On approximate basis, an RSAL based on these methods would be about 3 picocuries of plutonium per gram of soil.

[65] RAC, 1999b, pp. 14 to 16.

[66] RAC, 1999b, p. 9. Note that RAC used the dose conversion factors from ICRP 70, while the calculations relating to the clean water act done using Federal Guidance Report No. 11 (EPA, 1988) imply dose conversion factors from ICRP Publication 30 (ICRP, 1979, *etc.*). We have used the latter, older factors, since they are still the basis of US regulations. The qualitative conclusions are unaffected by the change, however.

[67] See RAC, 1999b, pp. 12 and 14, where the parameters of migration of plutonium and americium on which RAC based these tentative conclusions are discussed. See also RAC, 1999c, p. 27.

wildlife refuge. Yet no study to date has addressed the potential synergism between such a designation and the long-term water pathway dose.

This analysis of the water pathway dose indicates the crucial importance of using the subsistence farmer scenario as the basis for protection of future populations. It is unrealistic to assume that site control and specific current site uses will endure for long periods of time. The evolution of the contamination over time could result in far greater threats to future populations than if a thorough cleanup were carried out in the first place corresponding to a subsistence farmer scenario.

7. Erosion of the subsistence farmer scenario[68]

An official recommendation to do away with the subsistence farmer scenario as the basis for public health protection first appeared in the *Technical Bases for Yucca Mountain Standards*. This report was prepared by an *ad hoc* committee of the National Research Council, the research arm of the National Academy of Sciences (NAS). That National Research Council (NAS-NRC) committee on Yucca Mountain standards, chaired by Robert Fri of Resources for the Future, recommended that the concept of establishing secondary measurable standards limiting releases of radionuclides from a repository be abandoned. In fact, the NAS-NRC committee is explicit that it does not include the current goal of protecting groundwater as a resource in its recommendations. The report states that the EPA regulation for high-level waste disposal,

> "40 CFR 191 includes a provision to protect ground water from contamination with radioactive materials that is separate from the 40 CFR 191 individual-dose limits. These provisions have been added to 40 CFR 191 to bring it into conformity with the Safe Water Drinking Act, and have the goal of protecting ground water as a resource. We make no such recommendation, and have based our recommendations on those requirements necessary to limit risks to individuals."[69]

The NAS-NRC committee recommended instead that the risk to a critical group be limited. It also recommended that this group would be defined in a new way. Professor Thomas H. Pigford (Emeritus, Nuclear Engineering, University of California, Berkeley), who was a member of that committee, disagreed and wrote a dissent.

If the recommendation of the majority were to be followed, there would be no explicit limits to the contamination of groundwater as such. It would be legally permissible for water to become highly contaminated, depending largely on the way the critical group was selected. The consequent radiation doses to some of the people using contaminated water could be very high.

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[68] This section is an adaptation of a review of the 1995 NAS report by Arjun Makhijani entitled "Calculating Doses from Disposal of High-Level Radioactive Waste," *Science for Democratic Action*, vol. 4, no. 4, Fall 1995. It also draws on the dissent of Thomas H. Pigford from NAS, 1995 and his guest editorial entitled "The Yucca Mountain Standard: Proposals for Leniency," *Science for Democratic Action*, vol. 6, no. 1, May 1997.
[69] NAS, 1995, p. 121.

The possibility of very high radiation doses, far above allowable limits, from consumption and agricultural use of water contaminated by a high-level waste repository at Yucca Mountain is real. Since water is scarce in the area, there is only a relatively small volume available (compared to other repository locations) to dilute leaking radionuclides.[70] The 1983 NAS study estimated that peak doses could range from a low on the order of one rem (perhaps less) to about 1,000 rem per year depending on the assumptions about the behavior of the waste and water travel time.[71] Subsequent studies by INTERA (1993) and Sandia (1994) lowered estimated peak doses at 30 and 20 rem per year, respectively.[72]

The controversy surrounding the proposed Yucca Mountain standards is illustrated by the disagreement between the NAS committee and its lone dissenter, Professor Pigford, . The questions that are at the center of this disagreement include the following:

1. Could the NAS committee's recommendation of limiting risk to individuals be compatible with allowing high doses of radiation to maximally exposed individuals, and in particular to subsistence farmers?
2. Are the committee majority's recommendations in conformity with those of the ICRP?

Insight into these questions can be gained through the analysis of Appendix C of the NAS-NRC report. Here, the majority outlines its eight-step process of determining the exposure of the critical group. The fundamental difference between this protocol and those that preceded it is that it defines the exposure limit for the critical group based on calculated risk from exposure rather than calculated dose. That is, it is recommended by the majority of the panel that dose calculations be made on the basis of hypothesized probabilistic distribution of future populations.

1. *Identify the population which contains the people at risk of getting the highest doses.* The example adopted by the committee is a farming community in the Amorgosa Valley. However, the term "farming community" could include many occupations, not just subsistence farmers. It could be a large, inhomogeneous group, which would be incompatible with ICRP's recommendation for a critical group, or a small, homogeneous group. For instance, it may consist of farmers, casino operators, and defense workers or it may have farmers only. These farmers may or may not be subsistence farmers.[73]
2. *Quantify the demographic and geographical characteristics of the population so as to determine what areas in the region "have the potential for farming and groundwater use." If possible, limit the area for exposure analysis by excluding some areas, such as those not likely to be farmed or where groundwater might be too deep.* On this basis, the area and groundwater in the immediate vicinity of the Yucca Mountain repository could be excluded from the calculations.
3. *Identify the intersections of those areas that might be farmed and those beneath which radioactively contaminated water would be present at some time.*
4. *Model the release of radionuclides from the repository and take into account that the plume of contamination passes through various areas at different times, limiting exposure in this*

[70] NAS, 1995, pp. 27, 28.
[71] NAS, 1983, pp. 264, 278.
[72] Sandia, 1994; INTERA, 1993.
[73] NAS, 1995, page 145.

way. Model various possible ways in which the contaminated plume of groundwater might travel (these are called "plume realizations"). People living in such areas before the plume is directly under them will be "at no risk" during these periods.

5. *Calculate doses for a large variety of possible conditions and times, sampling from among the various plume realizations.* This step acknowledges, in contradiction to the one just above, that people "outside the area overlying the plume" could be exposed due to local export of water or food."
6. *Calculate the times at which the groundwater under various exposed populations would be most contaminated.*
7. *Divide the results of each plume realization into geographical subareas in which doses are to be arithmetically averaged. The population of each subarea should be large enough to "allow computation of a meaningful average dose." Then define a "critical subgroup" consisting of all subareas with average risks within a factor of ten of the "maximum average" subarea risk.* The term "meaningful average" is not defined. This requirement could, in some cases, conflict with the ICRP recommendation that the critical group be small.
8. *Average the average doses for the critical subgroups in Step 7 for each plume realization.* This final average of averages is defined by the committee majority to be the "technically appropriate representation for the critical group risk."

The report implies that this new method is consistent with the ICRP's recommendations for the selection of a critical group, except that the committee uses risk in place of dose. The committee's definition of the critical group is very similar to that of the ICRP.

> "The critical group for risk should be representative of those individuals in the population who, based on cautious, but reasonable, assumptions, have the highest risk resulting from repository releases. The group should be small enough to be relatively homogenous with respect to diet and other aspects of behavior that affect risks."[74]

This definition is close to that of the ICRP except that it does not explicitly define the term "small."

Professor Pigford's dissent is given in Appendix E of the 1995 NAS report and his central arguments are that the majority's opinion is not consistent with ICRP recommendations, the majority's methodology for calculating exposure is not valid, and the standards would be too arbitrary and lenient. He argues that the committee majority abandoned the subsistence farmer scenario that is the most sure and most conservative method for protecting all future populations. This scenario is in conformity with the recommendations of the ICRP and is also consistent with the regulatory procedures of other countries and agencies within the United States itself. In addition, the probabilistic critical group approach recommended by the majority is "demonstrably less stringent in protecting public health than the subsistence farmer approach."[75] The example of the farming community in the Amorgosa Valley would contain part-time farmers, but the "full-time subsistence farmer will not be found on that distribution." (emphasis

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[74] NAS, 1995, p. 53.
[75] NAS, 1995, p. 182.

in original)[76] Therefore, this recommendation would not be in conformity with ICRP recommendations. Pigford also argues that the method is subject to manipulation because it allows for the arbitrary choices of parameters such as population characteristics and sizes of subareas. Such choices could lower the calculated doses that would provide "an illusion of safety, but with a serious loss of credibility."[77]

A major argument against the probabilistic critical group method as developed in the 1995 NAS report is that it is not mathematically valid. Pigford's claim is that the procedures set forth in Appendix C of the NAS report do not result in a critical group that corresponds to a critical group as defined by the ICRP. This is because step 7 of the calculation process divides the region into subareas where there is no necessity for homogeneity within the subarea. This means that doses to individuals within the subarea can be very different and a few individuals with high doses could be averaged with a large number of individuals with low doses. This would result in a low average dose to the entire area. These same inconsistencies were noted by Professor Peter Bickel in a letter to Dr. Bruce Alberts, President of the National Academy of Sciences. Professor Bickel noted that the procedure recommended by the majority "could be made arbitrarily discrepant – five times could be turned into 5000 times and more."[78]

ICRP recommendations require that the individuals with the highest dose be part of the critical group. In the probabilistic method, the averaging process over a subarea could result in the highest exposed individuals being in a subarea that has a low average dose. This could result in their exclusion from the critical group defined in step 8 of Appendix C because there may be many subareas with a higher average dose but that do not include the individuals with the highest dose.

EPA stated in its Background Information Document for Yucca Mountain that it did not accept the approach outlined in Appendix C of the NAS report.[79] It instead decided to use a scenario more along the lines of the subsistence farmer scenario outlined in Appendix D of the report. However in the final standards for Yucca Mountain, a vicinity-average dose has been introduced, which has the effect of introducing leniency into the calculation. According to the EPA rule water under Federal lands is exempt from safe drinking water rules, creating an unprecedented loophole for similar future exemptions. This extends to about 18 kilometers from the repository location. Drinking water and other doses are to be calculated outside this perimeter. Considerable dilution can be expected over such a distance and this would reduce the calculated vicinity average dose.

Another reason to adopt the subsistence farmer scenario is that it has been shown that the uncertainties associated with the subsistence farmer dose decrease over time.[80] This introduced leniency coupled with the decrease in dose uncertainties may lead to doses that are unacceptably high.

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76 NAS, 1995, p. 168
77 NAS 1995, p. 179.
78 Bickel, 1996. Dr. Alberts in turn reiterated the NAS-NRC majority position. Alberts, 1996.
79 EPA, 2000, pp. 8-49 to 8-73.
80 Pigford, 1999.

A proposal similar to the NAS-NRC majority has been put forth by the Electric Power Research Institute (EPRI). This is the vicinity-average dose model.[81] However, in this case there is no averaging of averages. Rather, the model converts "the results from calculations for a maximally exposed individual into an estimate of risk to an *average* individual in a *local population group*."[82] This method establishes a standard by calculating an average dose to a future population in the general vicinity of a geologic repository and allowing that average dose to be as large or larger than current exposure limits.[83] This would undermine the concept of the reasonably maximally exposed individual in much the same way that the NAS-NRC panel's plan does. The average dose may meet standards but there still exists a possibility that a small subset of the population could be exposed to very high doses while the remainder is exposed to very small ones. This would violate some of the basic tenets of radiological protection. The EPRI scenario was incorporated into legislation put before Congress to assess the performance of the Yucca Mountain disposal site.[84] This legislation did not pass.

The lowering of protection standards has led to degradation in other regulatory fields as well. A perfect example of this is the Department of Energy's (DOE) refusal to adopt clear national cleanup standards. The DOE remediation program has been operating under rules that allow it to impose site specific standards without any national standard upon which to base them. A process by which the EPA was setting cleanup standards for nuclear weapons sites was ended by a brief letter from an Assistant Administrator of the EPA.[85] The plan, which had consumed a great deal of time and energy, was abandoned without any plans for its resumption. The 1996 EPA draft 40 CFR 196 of 15 and 85 mrem/year dose limit (the variation depends on the chosen use of the site) was used to calculate Rocky Flats RSALs in 1996. A 15 mrem limit was used by the Risk Assessments Corporation in its calculations.[86]

The lack of clear standards is also illustrated by comparing the cleanup levels DOE has used at various sites across the country, summarized in Table 1. For example, at the Livermore site in California, the industrial preliminary remediation goal is 10 pCi/g and the residential goal is 2.5 pCi/g of soil.[87] Meanwhile, at the Mound site in Ohio, the cleanup guideline value is 55 pCi/g.[88]

Table 2 shows various nuclear sites around the country and the exposure scenarios they have chosen to adopt. These scenarios are generally less stringent than the subsistence farmer model. Table 2 illustrates this variation as it shows the soil action levels of various contaminated sites and the resultant doses that were estimated using a variety of scenarios.[89] This data was compiled by RAC. While it is up to the community to decide what scenarios and uses for the site to be used in determining cleanup levels, it is important to state that the process should be based on the same target dose/risk. That is, cleanup levels may be different, but the risks to individuals

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[81] EPRI, 1994, p. 3-20 to 2-23.
[82] EPRI, 1994, p. 3-20. Italics were used in original text.
[83] Pigford, 1999.
[84] U.S. Congress, 1999; Pigford, 2001.
[85] EPA, 1996.
[86] RAC, 2000, pp. 3,5;DOE, 1996, p. 6-6.
[87] EPA, 1998; Berg, 2001.
[88] Mound, 2001.
[89] RAC, 1999a.

on site should be standardized. The table clearly shows that there is no clear mandate for clean up levels and that ratios given show the relationship between cleanup levels and the annual dose.

Table 1: Soil Cleanup Guideline Values at Lawrence Livermore National Lab (LLNL) and the Mound Site, Ohio

Source: EPA, 1998 and Mound, 2001

Site	Radionuclide	Location	Scenario	Guideline Value (pCi/g)
Mound	Pu-238	Onsite	Construction Worker	55
Mound	Pu-238	Offsite*	Recreational	75
LLNL	Pu-239/240	Onsite	Commercial	10
LLNL	Pu-239/240	Onsite	Residential	2.5

*The only offsite removal action that has taken place was the Miami-Erie Canal for which this was the agreed upon cleanup level.

8. The Radioactive Wildlife Refuge

In the early 1990s, the DOE embarked on a cooperative process with the EPA to develop national cleanup standards, but it reneged on this process and has, since the mid-1990s attempted to proceed on a site-by-site basis. This has led to a welter of proposals for cleanup using various scenarios, with the wildlife refuge having emerged as one of the favorites of the DOE and its contractors. Proponents of this method argue that because nuclear weapons sites have been off limits to the public for so long, they have become havens to endemic species that would otherwise have been at risk due to sprawl and human intervention (see for example, *From Waste To Wilderness)*.[90] They also argue that up until now, the DOE cleanup program has been very expensive, ineffective, inefficient, and the costs will only increase. On the other hand, declaring them wildlife refuges would exempt the DOE from major cleanup and would also serve to protect the natural ecosystems that have flourished. The Chernobyl Exclusion Zone has been described by a scientist, Ron Chesser, from the Savannah River Ecology Laboratory run by the University of Georgia for the DOE, as "a beautiful place with thriving wildlife communities. Without a Geiger counter you wouldn't know you were in a highly contaminated place."[91]

Five sites out of the more than 130 sites in the nuclear weapons complex are expected to account for the majority of cleanup costs. These sites are Oak Ridge in Tennessee, Hanford in Washington State, Savannah River Site in South Carolina bordering on Georgia, Rocky Flats in Colorado, and the Idaho National Engineering Laboratory. These same sites are now being proposed as wildlife refuges by proponents of this model.[92] Of these Rocky Flats is the only one located in the middle of a rapidly growing urban corridor. Congressional legislation is pending to designate Rocky Flats as a wildlife refuge.

[90] Nelson, 2001.
[91] Ron Chesser as quoted in Cookson, 2000.
[92] Nelson 2001.

Robert Nelson has argued for the wildlife refuge scenario for DOE sites based on the following four principles:[93]

A. Old DOE sites have a high ecological value in their current condition.
B. A wildlife refuge would minimize actual risk to off-site human populations by restricting access to the site, which would be done in case of its designation as a wildlife refuge. Indeed, he has cited "radiation danger" and site access restrictions as the basic reasons that wildlife is flourishing at several sites in the nuclear weapons complex as well as areas in other parts of the world.[94]
C. The technology for long-term cleanup to high levels is not available at present and it will require technological advances to accomplish such clean up.
D. Ecological values at DOE sites will be conserved by stewardship that would be implicit in a wildlife refuge and contribute in that way to protecting public health.

The second and fourth points are substantively the same. There is also a partial overlap of these points with the first one. The high bio-diversity at some DOE sites such as Savannah River and Hanford does not actually apply to Rocky Flats, which is a far smaller site and relatively homogenous ecologically. It is also already a part of the rapidly growing Denver–Boulder urban corridor, and therefore not a promising prospect as a long-term wildlife refuge. Further, the proposals for making contaminated sites into wildlife refuges have not taken into account the long-term evolutionary impacts on wildlife. For instance, synergisms of radioactive with non-radioactive contaminants have not been well studied even as they relate to human beings, much less wildlife.

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[93] Nelson, 2001, pp. 12-14.
[94] Nelson 2001, p. 11.

Table 2: Soil Action Levels (SAL), Resultant Doses, and Ratios for Comparison at Different Sites
Source: RAC, 1999a

		Soil Action Level (pCi/g)		Dose from SAL (mrem/year)		Dose to SAL ratio ([mrem/year]/[pCi/g])		SAL to Dose ratio ([pCi/g]/[mrem/year])	
Site	**Scenario**	Pu-239/240	Am-241	Pu-239/240	Am-241	Pu-239/240	Am-241	Pu-239/240	Am-241
Rocky Flats	Open Space	9906	1283	15	15	0.00	0.01	660.40	85.53
	Office Worker	1088	209	15	15	0.01	0.07	72.53	13.93
	Future Resident	252	38	15	15	0.06	0.39	16.80	2.53
	Future Resident	1429	215	85	85	0.06	0.40	16.81	2.53
Hanford	Rural Residential	34	31	15	15	0.44	0.48	2.27	2.07
	Industrial Worker	245	210	15	15	0.06	0.07	16.33	14.00
Nevada Test Site*	Rural Residential	162	13.2	10.7	1	0.07	0.08	15.14	13.20
	Rancher	162	13.2	42.6	3.56	0.26	0.27	3.80	3.71
	Farmer	162	13.2	20.1	1.84	0.12	0.14	8.06	7.17
	Child Rancher	162	13.2	16.7	1.61	0.10	0.12	9.70	8.20
	Industrial Worker	162	13.2	3.97	0.42	0.02	0.03	40.81	31.43
Johnson Atoll	Residential (inhalation)	17	N/A	20	N/A	1.18	N/A	0.85	N/A
Maralinga	Residential (inhalation)	280	N/A	500	N/A	1.79	N/A	0.56	N/A
Palomares	Residential (inhalation)	1230	N/A	100	N/A	0.08	N/A	12.30	N/A

*At Nevada Test Site the doses were calculated from assumed soil concentrations. They are not true SALs.

There is a more fundamental evolutionary argument against using highly contaminated sites as wildlife refuges. Proponents have argued that flora and fauna are thriving in radioactively contaminated environments. By leaving them contaminated, human beings will leave these contaminated areas to wildlife. Rather than the genetic abnormalities often attributed to radiation, Nelson cites radio-ecologist Ward Whicker's findings that wildlife is healthy and "absolutely thriving."[95]

Yet, it is well established that ionizing radiation is one of the causes of genetic mutation. It is also known that some of these mutations are deleterious. Even if we grant that all of the arguments about the health of individual wildlife specimens that have been observed are correct, one cannot therefore conclude that there is no danger to the genetic integrity of wildlife and hence to the ecosystem.

Diethard Tautz has argued, in the context of genetic engineering, that subtle genetic changes that do not result in readily observable effects upon individuals in a species may nonetheless have substantial and possibly devastating impacts upon the species in the long term. He has noted that "...genes or genetic functions that have only a very small effect on the fitness of an individual, but are nonetheless important for long-term fitness within a population," an adequate understanding may require "experiments that involve the whole population of the respective species."[96] This genetic "uncertainty principle" means that nearly the entire population would have to be changed to discover whether deleterious changes have occurred.

Understanding of gene-ecosystem interactions at the molecular level and their implications for evolution is an emerging science in which there are huge uncertainties.[97] Long-term considerations of the integrity of wildlife are simply not understood well enough to support the claims of wildlife refuge proponents that assigning contaminated areas to wildlife will be a boon to natural ecosystems and to life forms that are now endangered that society has decided to protect.

Further, the radiological pathways from animals to humans are being revealed as far more complex than is recognized in standard risk assessments. In recent years surprising problems regarding the spread of contamination have emerged. For instance, a garden in a private home near the Sellafield nuclear materials processing site in England was found to be contaminated with radioactive pigeon droppings to the point that the soil and the pigeons had to be declared a radioactive waste.[98]

The problem of non-availability of technology is at least in part a spurious one in regard to RSALs. There is no reason why highly contaminated soil cannot be removed and stored retrievably as radioactive waste. It is desirable to develop technologies to cleanup this soil in the long term to avoid the problem of shallow land burial, but soil removal and

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[95] Whicker as cited and quoted in Nelson 2001, p. 9. See also footnote 93.
[96] Tautz, 2000.
[97] Makhijani, 2001. Additional references can be found in this publication, which is on the web at http://www.ieer.org/pubs/e&g-toc.html.
[98] Greenpeace, 1998.

storage allows the contamination to remain concentrated which makes for easier long-term cleanup and also prevents the spread of radioactivity in the environment. Most importantly, soil removal and storage protects vulnerable populations from exposure by the various pathways that have been described in the RAC reports. While it is true that present technology will not return some portions of the site to near pristine conditions, there is no incentive for developing new technologies if standards are so loose that large amounts of residual contamination are left behind as a matter of routine, as would be the case with a wildlife refuge scenario.

The protection of public health by restricting site access can only be a temporary expedient, at best. It would be unreasonable to assume long-term site control or that site use will not be changed in the future due to loss of institutional control and institutional memory. A current example from Washington, D.C. is discussed in the next section. It shows that institutional memory may not endure even a few decades where military contamination is concerned even in the heart of the capital of the United States. Restricting site control can only be a temporary expedient for other purposes but cannot be justified on the grounds of public health protection over a period of decades, much less hundreds or even thousands of years. Therefore even if the Rocky Flats site is designated as a wildlife refuge at present, this is not an adequate basis on which to set RSALs. Stringent RSALs at the outset will not only ensure that public health is protected in the long-term, but also that resources will be set aside in order to ensure the protection of public health.

Finally, the DOE has done quite a bit to characterize the nature of the environmental problem in the weapons complex since the end of the Cold War. However, the actual process of cleanup has been limited by the fact that DOE has been unable to develop a coherent set of priorities. Much of the waste of money is not due to the difficulty of cleanup but the poor management that has plagued DOE projects. Poor institutional culture is at the core of the problem, as IEER has shown in a previous detailed study of the subject.[99] While even a well managed and coherent cleanup program would be expensive, one must look at these costs in context. The DOE estimate for partial environmental restoration, waste management and disposal is $227 billion over 75 years. Between 1940 and 1996, the United States spent 5.5 trillion dollars to construct and deploy nuclear weapons.[100] Cost internalization of environmental problems is an important principle that the government tries to impose when it creates regulations for private industry. Setting and meeting strict cleanup standards is a part of cost internalization for nuclear weapons. It is essential that the government set for itself the high standards it expects of the private sector. The costs of the cleanup program overall are estimated at about five percent of the total cost of nuclear weapons during the Cold War . This is hardly an excessive expense. Moreover, most of this expenditure is actually for materials management and safeguards, site security, and the like, which would have to be spent anyway. Actual cleanup costs are possibly on the order of a couple of percent of the total Cold War nuclear weapons expenditure even if it is done to exacting standards, if the money is well spent.

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[99] Fioravanti and Makhijani, 1997, page 3.
[100] Schwartz, ed., 1998, page 4.

9. Enforcement for the eons

Short-term considerations such as availability of funds or priorities such as plutonium stabilization (as is the case at Rocky Flats) cannot detract from the reality that long-term site control is unrealistic and should not be the basis for cleanup plans. A failure to set stringent standards can result in increased risks to an unknowing and unsuspecting public in the future. This would not be the case were public health protection under a reasonably strict criterion undertaken from the very beginning.

The problem of leaving sites with huge amounts of contamination has recently been dramatically illustrated in the capital of the United States in relation to abandoned chemical munitions in one of the most sought-after real estate locations in Washington, D.C. – the area near American University.

In 1986, the United States Army discovered that there were abandoned chemical munitions on the grounds of American University and parts of the environs of the campus, including some homes. The horribly confusing situation that has emerged in the course of just one century in a plush area of the capital of the country should, perhaps suffice to dispel any illusions regarding long-term site control, the vigilance of the authorities or even their use of common sense in informing people at risk. The following is based on an article in the Washington Post on July 25, 2001. There have been many news articles, official reports, and other documents around this problem in the past fifteen years.

The Army did not inform local authorities in 1986 when it found the problem. A pair of reports in 1995 by the Army, which had investigated its own conduct in 1986, came to the following confusing conclusions:

> "A report by the Army Audit Agency presented to the Army Corps of Engineers on June 6, 1995, concluded that the Army did not 'notify local authorities and third parties in accordance with laws and regulations in effect in 1986.'
>
> But the same agency's final review, dated July 27, 1995, found that 'the Army had no duty to notify local authorities or third parties in 1986, as the developer claimed.'"[101]

One of the serious problems arising from the Army's chemical dumping in the area has been high arsenic contamination of the soil, including the yards of many homes. In one such case, the high contamination was discovered in 1994 but officials covered up the discovery of the contamination, presumably for fear of the potential liabilities, even though it was high enough to designate the soil as hazardous waste. In the meantime the family that lived in the home used the garden, planted things. Children played in it. One of the people (the mother) got a brain tumor that was operated on, but there is now no

[101] Vogel, 2001.

way to tell whether it was caused by the arsenic. The family will live in fear that their children may develop diseases as a result of their exposure for the rest of their lives. This occurred despite the family's vigilance, since they did ask the authorities repeatedly whether they would face problems as a result of the contamination. The family was not informed of the contamination until 1999, when they demanded all the documentation. They were reassured by the government that all would be well, and no action was taken, despite the high levels of arsenic. In 2001, the family moved out of the house.

When the official purpose of an operation has been fulfilled and the funds have dried up, site control can be tenuous, and institutional memory even more so. The tendency to cover up even at possible cost to people's health is strong, and this is not the only case in which such tendencies can be seen. There are, after all, no designated funds to deal with it. It is an old operation whose benefit to the sponsoring institution has long since expired.

Besides the evolution of conditions on a site and of site use that may increase the risk to future generations, there is also possible evolution of the understanding of risk per unit of exposure. Historically, radiation protection standards have been set in terms of radiation dose. There is a consideration of cancer risk in the process of setting standards, but a limitation on the risk itself has not generally been used in the standard setting process. The reason, of course, is that one can measure dose, in principle, while risk is a more abstract concept, even though it is the one most directly linked to population protection.

The issues in regard to whether risk or dose should be the measure in setting residual soil action levels (RSALs) is a complex one. For instance, it is likely that the stream of money available for clean up would dry up once the site has been taken off the books of the party that owns it. This makes it quite different from worker protection in an operating factory, for instance. Moreover, it is impossible to actually measure dose to future populations. Therefore, if the goal is to protect generations a considerable time into the future, then it is prudent to revisit the issue of risk versus dose as the basis for setting RSALs (as well as other cleanup standards).

There are several aspects to considering risk versus dose issues:

A. In general, risks depend on the organ exposed, age at exposure, and, for some kinds of cancer, gender.
B. It is important to consider non-cancer risks, and a simple dose approach often is not conducive to such assessment.
C. There may be synergistic effects between exposure to non-radioactive hazardous materials and radioactivity.
D. The same dose may result in a different risk to different sections of the population, since it is likely that sensitivity to radiation is highly variable in populations, even if they are otherwise homogeneous by age, class, ethnicity and gender.
E. The scientific evaluation of the risk of radiation may change with time, as it has in the past.
F. The regulatory procedure by which standards are established may change.

A. Organ and population specific risks

A risk approach to soil action levels could deal with each one of the factors specified in item A above (organ, age, and gender), while a dose approach usually considers a single cancer risk factor when setting the dose limit. A risk approach to residual soil action means that the implications of the proposed RSALs for various cancers (organ specific doses) and for different populations would need to be examined. The RSAL would be set only after the doses assessed in these different ways have been evaluated and their implications for cancer risk have been calculated. Dose assessments are all scenario-dependent. In general, the subsistence farmer or rancher (i.e., consuming local food and water only) scenario is the appropriate one to consider in evaluating risks.

B. Non-cancer risks

There are a variety of non-cancer risks, some of which are radionuclide-dependent. The dose approach to regulation adds up all doses, internal as well as external, into a single effective dose equivalent and then applies a cancer risk factor. This approach does not give adequate weight to adverse outcomes, such as miscarriages due to intake of tritiated water or developmental risks to children and fetuses from other radionuclides, such as strontium-90, iodine-129, tritium, and cesium-137 which cross the placenta. While these particular radionuclides are not thought of as problems in the Rocky Flats environment, they have been present in the past. The main point here is that different radionuclides carry different risks.

A risk-based approach allows the differentiation of internal from external radiation and hence allows for better organ, gender, and age-specific evaluation of the consequences of cleanup rules. A recent study evaluating the risk of DNA aberrations in the children of Chernobyl liquidators found a surprising seven-fold increase compared to children of the same people born before the exposure of the parent.[102] This high mutation rate is at considerable variance with the Hiroshima/Nagasaki data. The latter data indicate a doubling of mutations at doses of 100 to 200 rad. These are considered high doses of radiation, when delivered in a short time, as, in fact, they were by the bombings. By contrast, Chernobyl liquidator doses have been estimated to be in the low-dose range -- 5 to 20 rad. No dose reconstruction was possible for the specific persons in the study. Still, the clear conclusion of the study is that low dose radiation, possibly an order of magnitude or more less than the Hiroshima/Nagasaki doses cited above, could cause the same mutation rate.

The Chernobyl study did not attempt to assign a cause of the high mutation rate, other than to identify it with radiation dose. It is plausible that at least some of the difference from the Hiroshima/Nagasaki data may be due to internal exposure of the liquidators. The doses received by Hiroshima/Nagasaki survivors were mainly external gamma and neutron doses. The main concern at Rocky Flats would be the internal exposure from

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[102] Weinberg, *et al.*, 2001.

alpha radiation. An internal dose of an alpha emitter would be more harmful than an external one.

The large uncertainties in the area of heritable mutations can be factored in better using a risk-based approach. A safety factor that corresponds to the uncertainty arising from the fact that exposures to future populations from plutonium in the Rocky Flats environment will largely be internal can be developed using Chernobyl liquidator data from the above study, for instance.

C. Synergistic effects

Rocky Flats, like many other DOE sites, has both radioactive and non-radioactive pollution. Little is known about synergistic risks of toxic chemicals and radionuclides, particularly when considerations of internal dose discussed briefly above are taken into account. Chemicals may compromise immune and/or endocrine systems in ways that may increase risks from radionuclide intake. The scientific consideration of such issues is in its initial stages, and it would be a surprise if there were no surprises as regards synergistic health risks. A risk-based approach would include an evaluation of what is known, the extent of the ignorance about synergistic effects and the implications of that analysis for choosing a safety factor that would allow risks to be kept below specified levels. An approach that relies only on cancer risk deriving from radiation dose alone *by its nature* excludes these important considerations.

D. Differential population sensitivity

The occurrence of cancer appears to be mediated by the immune system. The immense variation in allergic response among populations that are relatively homogeneous in other respects implies that there may be a large differential sensitivity to radiation between individuals. A risk-based or a dosimetric approach to RSALs could take this into account, were the differential sensitivity known. Alternatively a safety factor that would reduce allowable dose or risk may be selected. In any case, it is prudent to explicitly factor in some consideration of possible differential population sensitivity to radiation within homogeneous population groups.

It is difficult to select a safety factor at the present time since the factors that contribute to differential allergic response are only now beginning to be understood. Typically, these factors are genetic, developmental, and environmental, making the situation quite complex.

A safety factor that acknowledges this ignorance is especially important in regard to long-lived residual radioactivity. The long half-lives mean that a variety of people are likely to come into contact with the residual radioactivity over the ages. There is therefore a high likelihood that individuals who are among the most sensitive in the population will at some time be exposed.

E. Future changes in the average dose to cancer-risk relationship

The past half-century has seen increases in estimates of cancer risk per unit of dose based mainly on reassessments of Hiroshima and Nagasaki survivors. Future assessments of these data may or may not result in increases in risk, depending on such factors as whether the missing cohorts from the time immediately after the explosions are taken into account and how neutron doses are evaluated and interpreted.

There are a number of differences between the populations that would be exposed to residual radioactivity and Hiroshima/Nagasaki survivors. The recent study of the children of Chernobyl liquidators creates additional uncertainty about too heavy a reliance on Hiroshima/Nagasaki data, though these should of course be included in risk evaluations. Reductions in cancer risk estimates for future populations exposed to residual radioactivity based on reassessments of Hiroshima/Nagasaki data would be especially inappropriate at this time. For a variety of reasons, many of which are discussed above, the uncertainties in regard to risk per unit of exposure to future populations are much greater than those indicated by the analysis of Hiroshima/Nagasaki survivor data.

F. **Future changes in regulatory procedure especially with respect to water**

Besides changes in regulations arising from changes in risk assessment, regulations may be changed due to other factors. Regulations generally result from a variety of historical, institutional, scientific, and political considerations. They can therefore have glaring inconsistencies that may be corrected at some future time when the political conditions are appropriate. Take, for instance, safe drinking water regulations in relation to transuranic radionuclides. These regulations allow total contamination by these radionuclides of up to 15 pCi per liter. At the same time, the doses for most beta emitters are limited to 4 mrem per year. The allowable concentrations are not specified but must be derived from prevalent dose conversion factors. It turns out that if the currently applicable dose conversion factors are applied to transuranics, the drinking water doses resulting from 15 pCi per liter would be roughly a hundred times greater than the 4 mrem allowed for most beta emitters. Contamination of water to just a fraction of a picocurie of plutonium-239/240 is sufficient to yield a drinking water dose of 4 mrem per year. It is quite possible that the public might demand both consistency and water purity in the future, given that the public places a very high value on water purity.

The State of Colorado already has a state standard for plutonium in surface water of 0.15 pCi/L and at Rocky Flats the standard is enforced at the downstream boundary of the site where 30-day moving average is calculated from streams exiting the site. For two separate 30-day periods in 1997, averages for Walnut Creek exceeded the standard.[103] Moreover, as noted above, the Colorado standard is a reasonable one based on the 4 mrem annual drinking water dose limit that applies to most beta emitters. There is no rational reason for that same limit not to be extended to alpha emitters.

[103] RMRS, 1997, table 1.

The DOE has suggested changing the Colorado standard by changing the averaging period from one month to longer periods.[104] At the same time, a multi-year study concluded that cleanup to an RSAL of 10 pCi/g would not meet the 0.15 pCi/L water standard for the most contaminated areas downstream from the 903 Pad (the most contaminated part of the Rocky Flats facility).[105] This is one example of the uncertainty of regulatory issues.

Other changes may arise from the fact that there has been as yet no regulatory assessment, much less action, on possible synergisms between hormonally active compounds, like PCBs and dioxins, and radiation doses. Recent acceptance of the potential harm by hormonally active compounds for non-cancer end-points, such as developmental abnormalities, as well as advances in the biological effects of radiation at the cellular and sub-cellular level could lead to considerable changes in the regulatory system in the coming decade or two. It is not possible at this time to predict the magnitude of these changes, but some risk estimates may go up as these effects are considered for the simple reason that the present assumption is of zero synergisms in the absence of data and analysis.

10. Conclusions and Recommendations

There is sound scientific basis to use the subsistence farmer scenario, or its local equivalent such as the subsistence rancher scenario, as the basis for protection of future populations when long-lived contaminants are present on a site. Site use restrictions are, at best, a temporary expedient. If such restraints are assumed in the absence of a more stringent goal for clean up derived from the subsistence farmer scenario, the health and ecological damage that may result would likely be higher as would the cleanup costs if the site must be revisited. There is plenty of evidence that a revision of prior lax decisions is costly from every point of view – health, environment, fiscal, or public trust in the government.

Beyond the subsistence farmer scenario based on present day risk coefficients and understanding, a safety factor is also needed. The many uncertainties in estimating future risk and the many areas of science that have been relatively neglected that may result in increased risk estimates per unit of dose indicate the need for an substantial safety factor to obviate the necessity of revisiting cleanup due to changes in risk coefficients. The complexity of plutonium chemistry in the natural environment, notably in relation to possible water contamination, also points to the need for an adequate safety factor. These two safety factors combined would reduce the maximum RSAL at Rocky Flats that results from scenario calculations considerably. Such an approach can be justified because a new cleanup effort in the future that would be far more difficult and costly, and the temptation of government inaction or worse would be avoided.

The RAC team recommended an RSAL of about 35 picocuries per gram of plutonium, plus the associated TRUs in specified ratios. Though this RSAL is based on a reasonably

[104] Rampe, 2001.
[105] Kaiser-Hill, 2000, pp. E-3, E-4.

conservative subsistence rancher scenario, it reduces the estimated dose from a fire probabilistically. The RAC analysis leads to an RSAL of 10 picocuries per gram if the probability of a fire is taken as 1. As we have discussed, this analysis potentially underestimates doses by the groundwater pathway, if site conditions evolve to allow much faster plutonium migration than assumed in the RAC study. The plausibility of such rapid migration has been discussed in this report.

In light of the fact that these factors and others, discussed above, may increase risk from residual soil contamination at Rocky Flats, it would be highly advisable to set an RSAL below 10 picocuries per gram. This implies a safety factor of about 3 or more relative to the RAC recommended RSAL of 35 pictures per gram. How much larger this safety factor should be is a matter for public debate.

IEER's recommendations can be summarized as follows:

- The subsistence farmer or subsistence rancher scenario should be used as the basis for setting a residual soil action level at Rocky Flats.
- The subsistence farmer or rancher approach should be adopted even if the site is designated as a wildlife refuge, since it is not reasonable to assume that such a designation will endure for hundreds of years.
- Careful investigations of the effect of high residual contamination on wildlife should be undertaken, before the site is actually so designated. Investigations of the potential for such a site designation to enhance the mobility of plutonium into the accessible environment, including groundwater, should also be undertaken.
- RSALs between 1 and 10 picocuries per gram should be considered for Rocky Flats. This range is compatible with a subsistence farmer scenario. At the upper end of this range, the groundwater doses would be downplayed, but a safety factor of about 3 relative to the RAC model would be built in. Such a safety factor is desirable for a variety of reasons discussed in this report. If doses from groundwater are factored in, it would be reasonable to set an RSAL at the lower end of this range. Such an RSAL would also be compatible with the dose implications of the current state of Colorado surface water standard of 0.15 pCi/liter of plutonium, should it be extended to groundwater in the future.
- The steps towards the achievement of the ultimate RSAL, and the institutional arrangements in the interim, are beyond the scope of this report. But any cleanup plan should specify how a standard based on the subsistence farmer or rancher scenario would be achieved, and how any interim steps would relate to this goal.

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February 8, 2002

Dear Stakeholder:

The Rocky Flats Cleanup Agreement (RFCA) Stakeholder Focus Group will meet at the Broomfield Municipal Center at One DesCombes Drive on February 20, 2002 from 3:30 to 6:30 p.m.

The agenda for the February 20 meeting is enclosed (Attachment A). We will discuss the following topics:

The handouts from the February 6, 2002 RFCA Focus Group meeting are enclosed as Attachment B, and include:

- RSALs Task 3 and Windtunnel Review Comments,
- Summary of End State Options – Surface Contamination,
- RFETS End State Options, Holistic Summary
- Papers from LeRoy Moore, Rocky Mountain Peace & Justice Center: "Excess Cancers among Workers Exposed to Plutonium on the Job at Rocky Flats;" "Risk from Plutonium in the Environment at Rocky Flats;" From *Closing the Circle on the Splitting of the Atom* (Washington, DC: U.S. Department of energy, January, 1995) page 38: "The Evolution of Health Protection Standards for Nuclear Workers;" and from the *Health Physics The Radiation Safety Journal*, "Public Involvement in Science and Decision Making?" Submitted by Steve Tarlton.

Attachment C is the RFCA Focus Group meeting minutes of August 22, 2001.

The RSALs Working Group meeting notes for the February 7, 2002 meeting is Attachment D.

You may call either Christine or me if you have any questions, comments, or suggestions concerning the RFCA Stakeholder Focus Group or the upcoming meeting.

Sincerely,

C. Reed Hodgin, CCM
Facilitator / Process Manager