FINAL REPORT

SELECTION OF RADIONUCLIDES FOR INCLUSION IN DOSE RECONSTRUCTIONS AT IDAHO NATIONAL ENGINEERING LABORATORY

Contract No. 200-2002-00367
Task Order 1, Subtask 4

A Report to the
Centers for Disease Control and Prevention
Atlanta, Georgia 30335

SC&A, Inc.
6858 Old Dominion Drive, Suite 301
McLean, Virginia 22101

SENES Oak Ridge, Inc.
102 Donner Drive
Oak Ridge, Tennessee 37830

Author:

David C. Kocher
SENES Oak Ridge, Inc.

July 2005

TABLE OF CONTENTS

LIST OF TABLES

1.0 INTRODUCTION

In a companion report (Kocher 2005), a method of screening to select radionuclides to be included in dose reconstructions for atmospheric releases from various facilities at the Idaho National Engineering Laboratory (INEL)[1] have been developed. Many radionuclides were released from the facilities of concern, but most would not have contributed significantly to doses received by the public. The purpose of screening is to select the radionuclides that could have been important for further analysis in a dose reconstruction.

In this report, the method of screening (Kocher 2005) is used to select radionuclides of primary concern in dose reconstructions for the following atmospheric releases at INEL:

- Releases from the Idaho Chemical Processing Plant (ICPP) during the years 1957-1959, when releases of radioactive iodine that resulted from radioactive lanthanum (RaLa) process operations were the highest, including releases that occurred following a criticality accident on October 16, 1959

- Releases that occurred during selected initial engine tests (IETs) that were conducted as part of the Aircraft Nuclear Propulsion (ANP) Program between February 1956 and March 1958

Section 2 of this report provides an overview of the screening methodology, which involves an assumption that a maximally exposed member of the public was a largely self-sufficient homesteader who resided at the closest populated location to either source of concern beyond the INEL site boundary. In Section 3, the methodology is used to select the radionuclides of concern in releases from the ICPP or the selected IETs in the ANP Program on the basis of estimated releases of radionuclides (source terms) in each case. Finally, Section 4 investigates whether consideration of other scenarios for exposure of the public at locations within the INEL site boundary, and thus closer to the sources, would result in the selection of additional radionuclides in a screening analysis.

[1]In this report, we refer to the site by its historical name at the time the releases of concern to this report occurred.

2.0 OVERVIEW OF SCREENING METHODOLOGY

A screening methodology developed to select radionuclides of concern in atmospheric releases at INEL must incorporate two basic elements (Kocher 2005):

(1) An assumed exposure scenario and assumptions about exposure pathways and model parameters in that scenario that are expected to result in overestimates of doses and risks actually experienced by the public as a result of releases of concern

(2) An assumption of a dose or risk sufficiently low that it generally would be considered negligible

If the dose or risk to a hypothetical member of the public calculated on the basis of an estimated release of a given radionuclide and the assumed exposure scenario, exposure pathways, and model parameters is less than the dose or risk that is assumed to be negligible (the screening criterion), that radionuclide is unimportant and can be excluded from further consideration in a dose reconstruction.

In the screening methodology (Kocher 2005), radionuclides are selected for further consideration on the basis of calculations of lifetime risks of cancer incidence. Cancer risks due to estimated releases of radionuclides are calculated as follows.

- An exposed member of the public is assumed to be a largely self-sufficient homesteader who resided at a populated location beyond the INEL site boundary that was closest to the ICPP or the site of the IETs in the ANP Program. The assumed locations of exposure are Atomic City, Idaho, in the case of the ICPP and Monteview, Idaho, in the case of the IETs. Both locations are approximately 19 km (12 miles) from the respective sources.

- Airborne concentrations of radionuclides at assumed receptor locations are calculated using a sector-averaged, straight-line Gaussian plume model of atmospheric transport, an assumption of ground-level releases, an average wind speed of 2 m/s, and an assumption that the plume is not depleted by deposition onto the ground surface. An assumption of Pasquill-Gifford stability category D, which represents neutral stability, is used to describe vertical dispersion of a plume during atmospheric transport, and the wind direction is assumed to be toward the receptor location 25% of the time during routine releases or 100% of the time during a short-term accidental release.

- Exposure pathways assumed in the scenario for exposure of a resident homesteader include external exposure to radionuclides in the atmospheric plume; inhalation of radionuclides in the plume; external exposure to radionuclides deposited on the ground surface; ingestion of radionuclides in locally produced vegetables, meat, and milk; and direct ingestion of radionuclides in surface soil. Assumptions about direct ingestion of contaminated soil are incorporated in the model of the vegetable pathway. The dose from each exposure pathway per unit concentration of a radionuclide in air at a receptor location is calculated using models and parameter values developed for purposes of

screening by the International Atomic Energy Agency (IAEA 2001). Calculated doses are effective doses as defined by the International Commission on Radiological Protection (ICRP 1991).

- The risk of cancer incidence per unit effective dose is assumed to be 0.1 $Sv^{!1}$.

The screening methodology thus gives a set of calculated lifetime risks of cancer incidence per unit release of radionuclides from a facility of concern.

The assumptions of ground-level releases, an average wind speed of 2 m/s, stability category D, and a frequency of the wind direction toward a receptor location of 25% or 100% used in the atmospheric transport model all should tend to result in overestimates of average airborne concentrations per unit release of radionuclides at the assumed locations of exposure beyond the INEL site boundary. Similarly, exposure times, consumption rates of contaminated foods, and parameters describing transfer of radionuclides in terrestrial food chains assumed by the IAEA (2001) are expected to result in overestimates of effective dose from each pathway per unit concentration of radionuclides in air at a receptor location. Finally, the assumed risk of cancer incidence per unit effective dose is expected to be somewhat above the average value in a normal population of all ages (EPA 1999). Thus, the screening methodology should give considerable overestimates of cancer risks to members of the public who resided near the INEL site boundary per unit activity of radionuclides released from the facilities of concern.

The screening criterion used in selecting radionuclides of concern is a lifetime risk of cancer incidence of $10^{!5}$. The assumed screening criterion lies within the range of lifetime cancer risks of about $10^{!4}$ to $10^{!6}$ that often are considered negligible. Given the assumption of a risk of cancer incidence per unit effective dose of 0.1 $Sv^{!1}$, the screening criterion corresponds to a total effective dose of 0.1 mSv (10 mrem).

3.0 SELECTION OF RADIONUCLIDES BY SCREENING

In this section, the screening methodology (Kocher 2005) summarized in Section 2 is used to select radionuclides of potential concern in releases from the Idaho Chemical Processing Plant (ICPP) or selected initial engine tests (IETs) in the Aircraft Nuclear Propulsion (ANP) Program. Lifetime risks of cancer incidence per unit activity of radionuclides released that were calculated using the screening methodology are combined with estimated releases of radionuclides in each case to yield estimated risks, and the estimated screening risks then are compared with the screening risk criterion of 10^{-5} to select the radionuclides of concern.

3.1 Releases from Idaho Chemical Processing Plant

Releases from the ICPP of primary concern in a dose reconstruction at INEL occurred during the years 1957-1959, when estimated releases of radionuclides, especially isotopes of iodine, due to RaLa process operations were the highest (DOE 1991). Although releases from the ICPP were estimated previously (DOE 1991), re-analyses of releases of important isotopes of iodine (I-131, I-132, and I-133) and other radionuclides attached to aerosols were performed as part of a dose reconstruction (Wichner et al. 2005a and 2005b). Those re-analyses include revisions of central estimates of releases and development of upper confidence limits based on considerations of uncertainties in the central estimates; upper confidence limits of the revised source terms are used in the screening analysis. Releases of H-3, less important isotopes of iodine, and isotopes of noble gases (Kr and Xe) were not re-evaluated by Wichner et al. (2005a and 2005b), and previous estimates (DOE 1991) are used in the screening analysis. Possible underestimates of the source terms for those radionuclides should be unimportant, because calculated risks are well below the screening criterion of 10^{-5} in all cases.

In the screening methodology (Kocher 2005), separate sets of screening factors (i.e., calculated cancer risks per unit activity of radionuclides released) were developed for routine releases from the ICPP during the years 1957-1959 and releases that occurred following a criticality accident on October 16, 1959. The only difference between the two sets of screening factors is that the wind direction was assumed to be toward the receptor location 100% of the time during the accident, in contrast to 25% of the time during routine releases. Thus, for a given radionuclide, the screening factor that applies to the criticality accident was assumed to be a factor of four higher than the screening factor during routine operations.

In this report, however, releases that occurred following the criticality accident are combined with releases during routine operations, and a single source term that represents all releases from the ICPP during the years 1957-1959 is used. This approach is justified on the grounds that, first, releases following the criticality accident were much less than releases during routine operations (DOE 1991; Wichner et al. 2005a and 2005b) and, second, releases following the criticality accident occurred over a period of several days (Wichner et al. 2005a), during which time shifts in wind direction almost certainly occurred. Thus, releases following the criticality accident are of the same kind as releases during routine operations and can be treated in the same way.

Application of the screening methodology to upper confidence limits of estimated releases from the ICPP during the years 1957-1959 gives the results in Table 3-1. A radionuclide is listed only if the calculated risk is 10% of the screening criterion or greater. When the calculated risk equals or exceeds the screening criterion of 10^{-5}, it is given in bold face to identify a radionuclide of primary concern.

As emphasized elsewhere (Kocher 2005), calculated screening risks in Table 3-1 are not intended to provide estimates of risk to any member of the public who resided at locations beyond the INEL site boundary during the years 1957-1959, because the calculated risks are based on upper confidence limits of estimated releases and the assumed models of atmospheric transport, exposure, and risk should result in considerable overestimates of risks per unit release of radionuclides. Calculated screening risks also should not be used to rank radionuclides released from the ICPP in order of importance (Kocher 2005), especially when the risks do not differ by large factors, because upper confidence limits of estimated releases and the models of atmospheric transport and exposure probably do not incorporate the same degree of overestimation for all radionuclides.

Nonetheless, the results of the screening analysis in Table 3-1 indicate that if a member of the public consumed substantial quantities of fresh milk produced near the INEL site boundary during the period of concern, it is almost certain that doses and risks from exposure to I-131 were more important than doses and risks from exposure to all other radionuclides. This conclusion is indicated by the much higher screening risk for I-131 compared with other radionuclides and the primary importance of the milk pathway for I-131 (IAEA 2001). It also should be noted that if a member of the public did not consume milk, vegetables, or meat that was produced near the INEL site boundary, doses and risks from all radionuclides combined due to external exposure and inhalation almost certainly were low, i.e., a small fraction of the unavoidable doses and risks from natural background radiation.

Table 3-1 Cancer Risks from Releases from the Idaho Chemical Processing Plant During 1957-1959 Calculated Using Screening Methodology and Comparisons With Assumed Screening Criterion

Nuclide	Activity released (Ci)*	Screening factor (risk per Ci)†	Screening risk‡	Ratio to screening criterion§
Sr-89	6.1×10^{2}	1.6×10^{-7}	1.0×10^{-4}	**10**
Sr-90	6.6	5.1×10^{-6}	3.3×10^{-5}	**3.3**
Y-91	7.2×10^{2}	1.0×10^{-7}	7.6×10^{-5}	**7.6**
Zr-95	7.5×10^{2}	6.0×10^{-8}	4.5×10^{-5}	**4.5**
Nb-95	5.0×10^{2}	2.1×10^{-8}	1.1×10^{-5}	**1.1**
Mo-99	2.7×10^{2}	3.9×10^{-9}	1.1×10^{-6}	0.11
Ru-103	4.3×10^{2}	4.2×10^{-8}	1.8×10^{-5}	**1.8**
Ru-106	1.2×10^{1}	7.2×10^{-7}	8.7×10^{-6}	0.87
Te-129m	1.1×10^{1}	3.3×10^{-7}	3.5×10^{-6}	0.35
Te-132	2.3×10^{2}	4.2×10^{-8}	9.5×10^{-6}	0.95
I-131	5.1×10^{3}	1.1×10^{-6}	5.7×10^{-3}	**570**
I-132	5.8×10^{4}	1.1×10^{-10}	6.5×10^{-6}	0.65
I-133	7.3×10^{2}	1.8×10^{-8}	1.3×10^{-5}	**1.3**
Cs-134	3.0	1.4×10^{-6}	4.3×10^{-6}	0.43
Cs-137	6.8	1.3×10^{-6}	9.2×10^{-6}	0.92
Ba-140	8.4×10^{2}	1.9×10^{-7}	1.6×10^{-4}	**16**
La-140	9.4×10^{2}	9.0×10^{-9}	8.5×10^{-6}	0.85
Ce-141	8.7×10^{2}	2.0×10^{-8}	1.8×10^{-5}	**1.8**
Ce-144	2.1×10^{2}	2.7×10^{-7}	5.6×10^{-5}	**5.6**
Pr-143	8.9×10^{2}	2.9×10^{-8}	2.6×10^{-5}	**2.6**
Pu-238	2.5	6.9×10^{-6}	1.7×10^{-5}	**1.7**
Others			$< 1.0 \times 10^{-6}$	< 0.1

* Source term for each radionuclide listed is based on re-analyses of releases from routine operations and criticality accident of October 16, 1959 (Wichner et al. 2005a and 2005b) and is intended to be an upper confidence limit. Radionuclide is listed only if calculated screening risk is 10% of assumed screening criterion of 10^{-5} or greater.

† Lifetime risks of cancer incidence per unit activity released calculated using screening methodology and obtained from Table 4-1 of Kocher (2005). Values may differ slightly from those given by Kocher (2005), due to differences in procedures used to round off products of different terms that comprise the screening factor.

‡ Product of estimated release and screening factor.

§ Assumed screening criterion is lifetime risk of cancer incidence of 10^{-5} (Kocher 2005). Calculated risks equal to or greater than screening criterion are indicated in bold face.

3.2 Releases from Selected Initial Engine Tests in Aircraft Nuclear Propulsion Program

The IETs in the ANP Program of primary concern in a dose reconstruction at INEL are designated as IETs #3, #4, and #10. These tests took place between February 1956 and March 1958, and they resulted in the highest estimated releases of radionuclides of all such tests (DOE 1991). Although releases from these IETs were estimated previously (DOE 1991), a re-analysis of each source term was performed as part of a dose reconstruction (Behling and Mauro 2005), with the intent to provide source terms that did not underestimate actual releases. The revised source terms are used in the screening analysis.

Application of the screening methodology to estimated releases from IETs #3, #4, and #10 combined gives the results in Table 3-2. Again, a radionuclide is listed only if the calculated risk is 10% of the screening criterion or greater, and a calculated risk that equals or exceeds the screening criterion of $10^{!5}$ is given in bold face to identify a radionuclide of concern.

As in the case of routine releases from the ICPP considered in the previous section, calculated screening risks in Table 3-2 are not intended to provide estimates of risk to any member of the public who resided at locations beyond the INEL site boundary during the period of the selected IETs, nor should the calculated risks be used to rank radionuclides released from the IETs in order of importance. Nonetheless, these results again indicate that I-131 was the most important radionuclide if a member of the public consumed fresh milk produced near the INEL site boundary.

Further discussions of the results of screening calculations, including comparisons of results in Tables 3-1 and 3-2, are given in the following section.

Table 3-2 Cancer risks from releases from initial engine tests #3, #4, and #10 in Aircraft Nuclear Propulsion Program between February 1956 and March 1958 calculated using screening methodology and comparisons with assumed screening criterion

Nuclide	Activity released (Ci)*	Screening factor (risk per Ci)†	Screening risk‡	Ratio to screening criterion§
Br-84	1.7×10^{4}	6.1×10^{-11}	1.0×10^{-6}	0.1
Kr-87	4.0×10^{5}	9.7×10^{-12}	3.9×10^{-6}	0.39
Kr-88	7.4×10^{5}	3.7×10^{-11}	2.8×10^{-5}	**2.8**
Sr-89	1.2×10^{3}	1.6×10^{-7}	2.0×10^{-4}	**20**
Sr-90	9	5.1×10^{-6}	4.6×10^{-5}	**4.6**
Sr-91	1.2×10^{4}	1.1×10^{-9}	1.3×10^{-5}	**1.3**
Sr-92	2.2×10^{4}	9.7×10^{-11}	2.1×10^{-6}	0.21
Y-91	1.2×10^{3}	1.0×10^{-7}	1.3×10^{-4}	**13**
Y-93	1.2×10^{4}	4.0×10^{-10}	4.8×10^{-6}	0.48
Zr-95	1.3×10^{3}	6.0×10^{-8}	7.8×10^{-5}	**7.8**
Zr-97	7.9×10^{3}	2.2×10^{-9}	1.8×10^{-5}	**1.8**
Mo-99	4.1×10^{3}	3.9×10^{-9}	1.6×10^{-5}	**1.6**
Ru-103	9.1×10^{2}	4.2×10^{-8}	3.8×10^{-5}	**3.8**
Ru-106	1.8×10^{1}	7.2×10^{-7}	1.3×10^{-5}	**1.3**
Te-131	1.1×10^{4}	2.4×10^{-9}	2.5×10^{-5}	**2.5**
Te-131m	3.5×10^{2}	6.0×10^{-9}	2.1×10^{-6}	0.21
Te-132	2.8×10^{3}	4.2×10^{-8}	1.2×10^{-4}	**12**
Te-133m	1.1×10^{4}	9.0×10^{-10}	9.7×10^{-6}	0.97
Te-134	2.2×10^{4}	7.5×10^{-11}	1.7×10^{-6}	0.17
I-131	6.2×10^{3}	1.1×10^{-6}	6.9×10^{-3}	**690**
I-133	3.6×10^{4}	1.8×10^{-8}	6.4×10^{-4}	**64**

Table is continued on following page.

Table 3-2. (Continued)

Nuclide	Activity released (Ci)*	Screening factor (risk per Ci)†	Screening risk‡	Ratio to screening criterion§
I-134	1.5×10^{5}	6.9×10^{-11}	1.0×10^{-5}	**1**
I-135	7.4×10^{4}	4.2×10^{-10}	3.1×10^{-5}	**3.1**
Xe-135	7.6×10^{5}	2.8×10^{-12}	2.2×10^{-6}	0.22
Xe-138	1.4×10^{5}	3.4×10^{-11}	4.8×10^{-6}	0.48
Cs-137	1.0×10^{1}	1.3×10^{-6}	1.4×10^{-5}	**1.4**
Cs-138	2.3×10^{5}	4.9×10^{-11}	1.2×10^{-5}	**1.2**
Ba-140	3.1×10^{3}	1.9×10^{-7}	5.8×10^{-4}	**58**
La-141	1.9×10^{4}	1.2×10^{-10}	2.3×10^{-6}	0.23
La-142	2.5×10^{4}	9.7×10^{-11}	2.4×10^{-6}	0.24
Ce-141	1.8×10^{3}	2.0×10^{-8}	3.7×10^{-5}	**3.7**
Ce-143	5.4×10^{3}	4.8×10^{-9}	2.6×10^{-5}	**2.6**
Ce-144	3.0×10^{2}	2.7×10^{-7}	8.2×10^{-5}	**8.2**
Pr-143	2.6×10^{3}	2.9×10^{-8}	7.4×10^{-5}	**7.4**
Others			$< 1.0 \times 10^{-6}$	< 0.1

* Source terms are estimated releases from selected IETs combined. Source term for each radionuclide listed is based on re-analyses of releases from selected IETs (Behling and Mauro 2005) and is intended not to underestimate actual releases. Radionuclide is listed only if calculated screening risk is 10% of assumed screening criterion of 10^{-5} or greater.

† Lifetime risks of cancer incidence per unit activity released calculated using the screening methodology and obtained from Table 4-1 of Kocher (2005). Values may differ slightly from those given by Kocher (2005), due to differences in procedures used to round off products of different terms that comprise the screening factor.

‡ Product of estimated release and screening factor.

§ Assumed screening criterion is lifetime risk of cancer incidence of 10^{-5} (Kocher 2005). Calculated risks equal to or greater than screening criterion are indicated in bold face.

3.3 Summary and Discussion of Results of Radionuclide Screening

The radionuclides of concern in releases from the ICPP during the years 1957-1959 and releases from selected IETs in the ANP Program between February 1956 and March 1958, as identified by the screening analysis summarized in Tables 3-1 and 3-2, are listed in Table 3-3. The half-life of each radionuclide is given in parentheses.

Table 3-3 Listing of radionuclides of concern in releases from Idaho Chemical Processing Plant and selected initial engine tests in the Aircraft Nuclear Propulsion Program*

Releases from ICPP†		Releases during selected IETs†	
Sr-89 (50.5 days)	I-133 (20.8 hours)	Kr-88 (2.84 hours)	I-131 (8.04 days)
Sr-90 (29.1 years)	Ba-140 (12.74 days)	Sr-89 (50.5 days)	I-133 (20.8 hours)
Y-91 (58.5 days)	Ce-141 (32.5 days)	Sr-90 (29.1 years)	I-134 (0.876 hours)
Zr-95 (64.0 days)	Ce-144 (284 days)	Sr-91 (9.63 hours)	I-135 (6.61 hours)
Nb-95 (35.1 days)	Pr-143 (13.6 days)	Y-91 (58.5 days)	Cs-137 (30.0 years)
Ru-103 (39.3 days)	Pu-238 (87.7 years)	Zr-95 (64.0 days)	Cs-138 (33.41 min)
I-131 (8.04 days)		Zr-97 (16.74 hours)	Ba-140 (12.74 days)
		Mo-99 (2.75 days)	Ce-141 (32.5 days)
		Ru-103 (39.3 days)	Ce-143 (33.04 hours)
		Ru-106 (1.01 years)	Ce-144 (284 days)
		Te-131 (25.0 min)	Pr-143 (13.6 days)
		Te-132 (3.26 days)	

* Radionuclides selected on basis of screening analysis summarized in Tables 3-1 and 3-2.
† Half-life of radionuclide is given in parentheses.

In general, estimated releases of radionuclides from the selected IETs in the ANP Program given in Table 3-2, which are intended not to underestimate actual releases, are higher than the corresponding upper confidence limits of estimated releases from the ICPP given in Table 3-1. In addition, the results in Table 3-2 indicate that many shorter-lived radionuclides that were unimportant in releases from the ICPP were potentially important in releases from the selected IETs. The difference in importance of those radionuclides is due to the much shorter delay times between their production and release in the IETs.

4.0 CONSIDERATION OF OTHER EXPOSURE SCENARIOS

As summarized in Section 2, the screening analysis to select radionuclides of concern in atmospheric releases at INEL is based in part on an assumption that an exposed individual was a largely self-sufficient homesteader who resided at the INEL site boundary. However, other scenarios involving exposure of the public at locations within the site boundary and closer to the sources of concern also have been considered in a dose reconstruction for releases at INEL (Apostoaei and Reed 2005). Since airborne concentrations of radionuclides increase with decreasing distance from a source, application of the screening methodology to scenarios involving onsite exposure could result in the selection of additional radionuclides of concern.

The following sections present simple scoping analyses to investigate whether additional radionuclides could be important in scenarios involving exposure of the public within the INEL site boundary. The scenarios considered involve (1) an onsite farmer or rancher, (2) a hunter who consumes meat from game that grazed on the INEL site, and (3) a regular visitor to the INEL site (Apostoaei and Reed 2005).

4.1 Onsite Rancher or Farmer

Portions of the INEL site were open to controlled grazing of beef cattle and sheep during the period of operations at the Idaho Chemical Processing Plant (ICPP) and in the Aircraft Nuclear Propulsion (ANP) Program. Limited farming also may have taken place at onsite locations where water was available. In an analysis of releases from the ICPP, it has been assumed that this scenario occurred at locations close to the Big and Little Lost River sink area (Apostoaei and Reed 2005), which is about 13 km (8 miles) southeast of Howe, Idaho, and about 16-24 km (10-15 miles) north-northeast of the ICPP. For purposes of screening, we make the pessimistic assumption that exposures occurred at an average distance of 15 km (9 miles) from the ICPP. The assumed distance from the source also should be less than the average distance from the location of releases in the ANP Program.

In the screening methodology summarized in Section 2, it is assumed that a member of the public was exposed at a distance of 19 km from the source. At that distance, the atmospheric dispersion factor, P/Q, which gives the concentration of a radionuclide in air at a receptor location (Bq/m^3) per unit release rate (Bq/s) and is calculated using Equations 4 and 6 in Kocher (2005), is 6.4×10^{-8} s/m^3. At the distance of 15 km from a source assumed for purposes of screening in an onsite farmer-rancher scenario, P/Q is 9.1×10^{-8} s/m^3, or a factor of 1.4 higher. Thus, if all exposure pathways that were assumed to occur in a scenario for exposure of a resident homesteader at the site boundary were assumed to apply to an onsite farmer or rancher, additional radionuclides would be selected by screening only if the calculated screening risk is within a factor of 1.4 of the screening criterion of 10^{-5}. As shown by the results of the screening analysis in Tables 3-1 and 3-2, the following radionuclides meet this condition:

- Releases from ICPP – Ru-106, Te-132, Cs-137, and La-140
- Releases during selected IETs – Te-133m

The following discussion considers whether the calculated risk for those radionuclides would equal or exceed the screening criterion—i.e., whether the screening risk would be reduced by no more than a factor of 1.4—when relevant pathways in the assumed scenario are evaluated.

The screening methodology developed by the IAEA (2001) and used in this analysis (Kocher 2005) includes exposure factors that give the effective dose (Sv) per unit activity concentration of radionuclides in air (Bq/m^3) at an assumed receptor location. As noted in Section 2, the IAEA's exposure factors include external exposure, inhalation, vegetable, milk, and meat pathways. In an onsite rancher-farmer scenario, an exposed individual is assumed to obtain meat from livestock that graze at the assumed distance from a source of 15 km. However, the vegetable and milk pathways are not relevant in that scenario, because gardens presumably were not located on the site and livestock that grazed on the site would not have included dairy cows.[2] In addition, the fraction of the time that a farmer or rancher spent on the INEL site presumably did not exceed 25% (i.e., about 2,000 hours per year), and an assumption of this exposure time reduces contributions to exposure factors from external exposure and inhalation pathways by a factor of about four. On the basis of the models for each exposure pathway assumed in the screening methodology (IAEA 2001), these considerations affect calculated exposure factors and, therefore, screening risks for the radionuclides listed above as follows:

- Elimination of the vegetable and milk pathways reduces calculated screening risks by a factor of 1.7 for Ru-106, about a factor of 10 for Te-132 and Te-133m, and a factor of 6 for La-140.

- Reduction of the onsite exposure time to 25% and elimination of the vegetable and milk pathways reduces the calculated screening risk for Cs-137 by more than a factor of 2.

Since all these reduction factors are greater than 1.4, consideration of a rancher-farmer scenario would not result in selection of any additional radionuclides in a screening analysis.

4.2 Hunter of Onsite Game

Hunting was not permitted on the INEL site during the period of operations at the ICPP and in the ANP Program. However, a hunter beyond the site boundary could have consumed meat from game, such as prong-horned antelope, that ranged over the site as well as outside the site boundary, and such a scenario has been considered in a dose reconstruction for releases at INEL (Apostoaei and Reed 2005). For purposes of screening, we assume that game grazed at an average distance of 15 km (9 miles) from a source, which should be pessimistic for free-ranging animals, and that a hunter beyond the site boundary relied on game as a primary source of meat.

The distance of 15 km from a source assumed in a scenario for a hunter of onsite game is the same as that assumed in the onsite rancher-farmer scenario discussed in the previous section. Therefore, the same radionuclides are potentially of concern, based on the consideration that

[2]Onsite farmers or ranchers may have maintained a garden and backyard dairy cow at their locations of residence beyond the INEL site boundary, and vegetable and milk pathways would be included in a resident-homesteader scenario for those individuals.

additional radionuclides could be selected by screening only if the calculated screening risk is within a factor of 1.4 of the screening criterion of $10^{!5}$.

In the assumed hunter scenario, the only relevant exposure pathway is consumption of contaminated meat; other exposure pathways included in the screening methodology could occur only at locations beyond the INEL site boundary. On the basis of the models for each exposure pathway assumed in the screening methodology (IAEA 2001), elimination of all pathways except the meat pathway reduces calculated screening risks by factors of 2 for Ru-106, 3 for Cs-137, and 30 or more for Te-132, Te-133m, and La-140. Therefore, the calculated screening risk in the hunter scenario would be less than $10^{!5}$ for all potential radionuclides of concern, and no additional radionuclides would be selected in a screening analysis.

4.3 Onsite Visitor

Members of the public presumably visited the INEL site during the period of operations at the ICPP and in the ANP Program. An exposure scenario for an onsite visitor that has been considered in a dose reconstruction for releases from the ICPP involves an assumption that a delivery person, who was not employed at INEL, made regular trips to the Central Facilities Area (CFA) to unload such products as office supplies or food and drink for a cafeteria or vending machines (Apostoaei and Reed 2005). Such a regular visitor would have received much higher doses than occasional or one-time visitors who participated in tours of the site, for example, or individuals who drove across the site on public roadways. We also assume that an exposure scenario for a frequent visitor to the CFA would result in higher doses than those that would have been received by visitors near the location of the initial engine tests (IETs) in the ANP Program.

For purposes of screening, we assume that a delivery person spent two hours per working day at the CFA throughout the period of releases from the ICPP. The assumed exposure time corresponds to two visits per week and five hours per visit, and should be a pessimistic representation of actual exposure times for a delivery person. In addition, it is unlikely that the same individual would have been involved in all deliveries over an extended period. The only relevant pathways in the assumed scenario are external exposure and inhalation.

The CFA is located about 3.4 km (2.1 miles) from the ICPP. At this distance, calculated concentrations of radionuclides in air per unit release rate, P/Q (s/m^3), are a factor of 14 greater than values at a distance of 19 km on the site boundary, as assumed in the scenario for a resident homesteader used in the screening methodology. However, the assumed exposure time for a delivery person, which corresponds to 500 hours in a year (allowing for vacation time), is a factor of 17 less than the exposure times of 8,400 and 8,760 hours assumed in the external exposure and inhalation pathways, respectively, in the screening methodology (IAEA 2001). Therefore, since external exposure and inhalation are the only relevant pathways, application of the screening methodology to a scenario involving frequent exposure of a delivery person would not result in selection of any additional radionuclides, without the need to subtract contributions to exposure factors from the vegetable, milk, and meat pathways.

The consideration that external exposure and inhalation are the only relevant pathways for exposure of onsite visitors also is potentially important. For many radionuclides released to the atmosphere at INEL, external exposure and inhalation are unimportant in exposure factors calculated by the IAEA (2001) for purposes of screening, compared with the vegetable, milk, and meat pathways. Furthermore, when external exposure and inhalation are important pathways for a given radionuclide, the exposure factor often is relatively low, compared with values for other radionuclides, due to their shorter half-lives (IAEA 2001). Thus, for many radionuclides, consideration of relevant exposure pathways would reduce calculated screening risks to a frequent onsite visitor still further below the screening criterion.

4.4 Summary

We have shown that application of the screening methodology described in Section 2, which is based in part on an assumed exposure scenario for a resident homesteader at the INEL site boundary, to other scenarios involving exposure of the public at locations within the site boundary and closer to a source would not result in selection of additional radionuclides of concern in routine releases from the ICPP or releases from selected IETs in the ANP Program. This outcome essentially is due to the limited number of exposure pathways in scenarios for onsite exposure and the lower exposure times in those scenarios compared with a resident-homesteader scenario at the site boundary. These factors more than compensate for the higher concentrations of radionuclides in air at assumed locations of onsite exposure.

REFERENCES

Apostoaei AI and Reed WE, 2005. Exposure Scenarios for Use in Estimating Radiation Doses to the Public from Historical Atmospheric Releases of Radionuclides at INEL. Final Report. S. Cohen and Associates, McLean, VA. February 2003.

Behling UH and Mauro J., 2005. A Critical Review of Source Terms for Selected Initial Engine Tests Associated with the Aircraft Nuclear Propulsion Program at INEL. Final Report. S. Cohen and Associates, McLean, VA. July 2005.

DOE (U.S. Department of Energy), 1991. Idaho National Engineering Laboratory Historical Dose Evaluation. Volume 2: Appendices, DOE/ID-12119 Vol 2. Idaho Falls, ID. 1991.

EPA (U.S. Environmental Protection Agency), 1999. Estimating Radiogenic Cancer Risks. Addendum: Uncertainty Analysis, EPA 402-R-99-003. Washington, DC.

IAEA (International Atomic Energy Agency), 2001. Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment, Safety Reports Series No. 19. International Atomic Energy Agency, Vienna, Austria.

ICRP (International Commission on Radiological Protection), 1991. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Pergamon Press, Oxford, U.K.

Kocher DC., 2005. Method of Screening of Radionuclides Released to the Atmosphere from Facilities at INEL. Final Report. S. Cohen and Associates, McLean, VA. July 2005.

Wichner RP, Renier J.-P. and Anspaugh L., 2005a. Atmospheric Source Terms for the Idaho Chemical Processing Plant, 1957-1959. Final Report. S. Cohen and Associates, McLean, VA. July 2005.

Wichner RP, Renier J.-P. and Anspaugh L., 2005b. Aerosol Releases from the Idaho Chemical Reprocessing Plant, 1957-1959. Final Report. S. Cohen and Associates, McLean, VA. July 2005.