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U.S. Nuclear Regulatory Commission
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Subject: Transmittal of Contract NRC-02-97-001 Deliverable 08801.081.002, Review of the Draft NUREG-1640, "Radiological Assessments for Clearance of Equipment and Materials From Nuclear Facilities"

Reference 1: February 1, 2001 Letter From Catherine Haney to John L. Russell.

Dear Ms. Knox-Davin:

The subject report completes Deliverable 08801.081.002, Review of the draft NUREG-1640, "Radiological Assessments for Clearance of Equipment and Materials From Nuclear Facilities". This deliverable was produced for Task Order 08 of Contract NRC-02-97-001 of the Center for Nuclear Waste Regulatory Analyses (CNWRA) Technical Assistance for Reviewing Licensee Submittals concerning Decommissioning project for the Nuclear Regulatory Commission (NRC).

The enclosed report resulted from the CNWRA review of the draft NUREG-1640 entitled, "Radiological Assessments for Clearance of Equipment and Materials From Nuclear Facilities" and copies of the Science Applications International Applications (SAIC) technical and quality program files associated with the development of the draft NUREG. The CNWRA also reviewed the SAIC spreadsheet calculations for analyses used in the draft NUREG. These calculations were transmitted by the NRC to the CNWRA on compact disks. The enclosed report includes changes to our previous document (Deliverable 08801.081.001) in response to Reference 1 and subsequent interactions between the CNWRA and NRC staffs.



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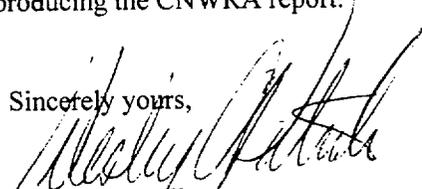
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Edna T. Knox-Davin
April 12, 2001
Page 2

Please contact Mr. James Weldy at (210) 522-6800 or me at (301) 881-0289 if there are questions concerning this report. James Weldy is the principal investigator for task order producing the CNWRA report.

Sincerely yours,



John L. Russell
Project Manager

JLR/cw
Enclosure

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**REVIEW OF DRAFT NUREG-1640, RADIOLOGICAL
ASSESSMENTS FOR CLEARANCE OF
EQUIPMENT AND MATERIALS FROM
NUCLEAR FACILITIES**

Prepared for

**Nuclear Regulatory Commission
Contract NRC-02-97-001**

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**Center for Nuclear Waste Regulatory Analyses
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April 2001

ABSTRACT

This report summarizes the results of a technical review that the Center for Nuclear Waste Regulatory Analyses (CNWRA) performed on draft NUREG-1640. Draft NUREG-1640 was developed by Science Applications International Corporation (SAIC) to determine the limiting pathway and dose of the unrestricted release of slightly contaminated materials from the decommissioning of nuclear reactors. The draft NUREG analyzed the potential dose from releasing unit concentrations of radionuclides in steel, copper, aluminum, and concrete so that if the Commission approves the unrestricted release of slightly contaminated materials from nuclear reactors based on an acceptable dose limit, the methods of draft NUREG-1640 can be used to convert the dose limit to a corresponding concentration limit.

The review revealed that, in general, SAIC performed a high-quality analysis in draft NUREG-1640. The CNWRA reviewers examined the scenarios proposed, the modeling, and the data selection in the draft NUREG. The reviewers also performed a vertical slice check of SAIC's calculations and Quality Assurance (QA) program. The review resulted in the identification of a number of issues in the areas of the scenarios considered, scenario modeling, parameter value selection, and performance of the calculations. Based on these issues, a number of recommendations are made for additional work that could enhance the overall quality of the draft NUREG. The CNWRA review of the QA program that SAIC used in the development of the draft NUREG revealed that it was appropriate and effectively implemented throughout the development of the document.

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This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under Contract No. NRC-02-97-001. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of Waste Management. The report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

The authors appreciate the technical reviews performed by M. Smith, D. Daruwalla, O. Pensado, and B. Mabrito, the editorial review by A. Woods and B. Ford, and the programmatic reviews by J. Russell and B. Sagar. The authors also would like to thank P. Houston and C. Weaver for their secretarial support.

QUALITY OF DATA AND CODE DEVELOPMENT

Data: CNWRA-generated original data contained in this report meet quality requirements described in the CNWRA Quality Assurance Manual. Sources for other data should be consulted for determining the level of quality for those data.

Analyses and Codes: The MCNP-4A computer code (Los Alamos National Laboratory, 1993) was used to perform calculations described in this report. MCNP-4A is controlled under the CNWRA Software Configuration Procedures. Additionally, the Crystal Ball software package (Decisioneering, Inc., 1998) was utilized to check the spreadsheets provided by Science Applications International Corporation, but no independent calculations were performed with the Crystal Ball software. Although the Crystal Ball software is not controlled under the CNWRA Software Configuration Procedures, sufficient testing of the software was performed to ensure that the software was operating properly for the purpose for which it was being used.

1 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) is considering alternatives for establishing control for release of solid materials from licensed facilities and to provide a regulatory framework more consistent with existing NRC requirements on radionuclide concentrations in effluent air and water. Licensee requests for release of solid materials are presently evaluated on a case-by-case basis using existing guidance or case-specific criteria. In February 1999, the NRC published draft NUREG-1640, Radiological Assessment for Clearance of Equipment and Material from Nuclear Facilities (McKenzie-Carter et al., 1999a,b), to provide a technical basis for determining potential doses to individuals from a range of potential scenarios involving contact with material released for unrestricted use from NRC-licensed nuclear facilities. Dose factors were derived in the draft NUREG based on contact with surficial and volumetric radioactivity from contaminated iron (steel), copper, aluminum, and concrete. An analysis of material flow models based on the recycling and reuse industry in the United States is also provided in draft NUREG-1640 in conjunction with radiological pathway-dose assessments. Draft NUREG-1640 was developed for the NRC Office of Nuclear Regulatory Research by Science Applications International Corporation (SAIC). This Center for Nuclear Waste Regulatory Analyses (CNWRA) report supports the NRC in conducting a review to confirm the technical validity of the SAIC analyses and to determine the feasibility of using the draft NUREG as a basis for making regulatory decisions.

Enhanced public participatory activities were initiated by the NRC in 1999 to solicit public input to its decision-making process. Public comments on an NRC issues paper were requested in a June 30, 1999, Federal Register notice (64 FR 35090). The NRC issues paper presented issues and alternatives related to control of solid materials and referred to draft NUREG-1640 as providing a technical basis for assessing impacts of controlling release of solid materials. Public comments were also received during Fall 1999 at four public meetings. Public access to information and opportunity for commenting was provided on an NRC website and list server. In March 2000, SECY-00-0070 (U.S. Nuclear Regulatory Commission, 2000) informed the Commission of public input on the issues paper, the status of technical analyses supporting decision-making, and staff recommendations for addressing control of solid materials. On May 3, 2000, the NRC staff briefed the Commission on SECY-00-0070. This briefing was followed on May 9, 2000, by certain stakeholders briefing the Commission on control of solid materials.

The CNWRA was contracted by the NRC to perform a technical review of the draft NUREG. The review looked at whether the assumptions, conceptual and mathematical models, parameters, and data were appropriate for making regulatory decisions, whether the calculations in the draft NUREG were performed correctly, and whether the quality assurance program used by SAIC meets industry standards. This report presents the findings of this review. Chapter 2 of this report summarizes the content of the draft NUREG. Chapter 3 describes the scope of the CNWRA review, including a description of the spreadsheets and geometry factors that were checked in the risk-informed vertical slice review of the SAIC calculations. Chapter 4 reports the review findings, including comments on alternative exposure scenarios that were not considered in the draft NUREG, the conceptual and mathematical models used to assess the dose from the exposure scenarios considered in the draft NUREG, selection and justification of parameter values, and inconsistencies in the document and supporting calculations. Chapter 4 also summarizes the results of the CNWRA review of the SAIC quality assurance (QA) program. Chapter 5 presents recommendations for additional work that could be performed to improve the draft NUREG. Finally, Chapter 6 consists of a summary of the principal findings of this report.

2 SUMMARY OF DRAFT NUREG

The draft NUREG-1640 documents the technical basis for the NRC to use in developing regulatory

standards for clearing equipment and materials with residual radioactivity from nuclear facilities. In addition to equipment reuse, the analysis identifies material flow models, based on U.S. industry practices, for recycling steel, copper, aluminum, and concrete. Using information from the materials flow models, likely potential exposure scenarios were realistically modeled for recycling these materials. Scenarios for copper, aluminum, and concrete were based on the steel scenarios but were modified to reflect differences in each industry, and additional exposure scenarios unique to each material were included. The modeling includes all significant exposure pathways. The scenarios include handling and processing, storage, transportation, product use, and disposal. The results of the analyses are expressed in both mass and surficial units. Using Monte Carlo techniques, distributions of radionuclide concentrations were estimated in the material flow model, and concentrations at selected points in the process were used as inputs to the dose assessment model for each scenario. Probability distributions for dose factors (along with the mean, median, and 5th and 95th percentile values) were estimated for all radionuclides and all scenarios. For each material (e.g., steel), a critical group was identified for each radionuclide, which represents the scenario with the highest mean dose factor. Appendices containing details of the analyses and tabulations of results are included.

The draft NUREG analyzed a total of 79 exposure scenarios for recycling of cleared steel, copper, aluminum, and concrete for 85 radionuclides. The report concludes that the majority of clearance levels are based on critical groups that involve either commercial truck drivers or workers at processing facilities, and the recycle (volumetric) critical group dose factors are more restrictive than the equipment reuse (surficial) clearance levels, primarily because of the much smaller amount of radioactivity involved in the equipment reuse scenario analyses.

3 SCOPE OF REVIEW

The scope of the review of the draft NUREG included a thorough check of the analyses. Areas of the analyses that were reviewed included the scenarios that were proposed, the models used to calculate the redistribution of the contaminated material during material processing and the doses for each scenario, the level of justification for the parameter values used in the models, as well as an independent check of the calculations of the external geometry factors, and the spreadsheets used to perform the material processing and dose calculations.

The review of the draft NUREG-1640 was conducted in a risk-informed manner. That is, the scenarios that resulted in the limiting doses for a large number of radionuclides were probed most deeply. For example, the scrap transport scenario was the limiting scenario for many radionuclides for all of the metals. Because of the significance of this scenario, it was checked by reviewing the models, checking the justification for the data values used in the calculations, independently calculating the geometry factor using the MCNP-4A code (Los Alamos National Laboratory, 1993), including sensitivity analyses conducted to assess the effect of assumptions made in SAIC's modeling, and checking the spreadsheet FE-SCRIP-TRANSP0-W (tmu01fex.ps3). The spreadsheet was checked to ensure the proper data were used, the data were transferred properly within the spreadsheet, the formulae were entered properly in the spreadsheet, and the probabilistic results of the spreadsheet calculations using the Crystal Ball software (Decisioneering, Inc., 1998) were properly reported in the NUREG. Other less important scenarios were reviewed to ensure that appropriate models were used and that parameter values were defined appropriately, but detailed checks of the geometry factors and implementation in the spreadsheets were not performed. Therefore, for those scenarios that were not checked in detail, there is a possibility that an error in the spreadsheet or in the geometry factor calculation could cause that scenario to become the limiting scenario for some radionuclides.

The models proposed, the formulae used to describe the models, and the parameter values used in the models, as described in volume 1 of the draft NUREG, were all reviewed in detail by CNWRA reviewers. Detailed reviews were also performed for the following spreadsheets to confirm that they had been implemented correctly: FE-SCRIP-TRANSP0-W, FE-SCRIP-HANDLIN-W, BOFREV3P.UNC, and CU-REVS-HANDLIN-W. Additionally, independent calculations were performed with the MCNP-4A code (Los Alamos National Laboratory, 1993) to confirm the calculation of the geometry factors associated with several important scenarios. The geometry factors that were independently checked for several representative radionuclides included GF-1, GF-4, GF-5, and GF-12. Although only a limited number of spreadsheets and calculations were reviewed in detail due to the limited scope of the review, this vertical slice form of review is likely to identify systematic errors in the analyses and any biases in the analyses toward unrealistically conservative or nonconservative results.

4 REVIEW FINDINGS

4.1 ALTERNATIVE SCENARIOS

The CNWRA reviewers reviewed the scenarios that were proposed in the draft NUREG to assess whether these scenarios comprehensively address all potential exposure scenarios associated with the clearance of steel, copper, aluminum, and concrete. The reviewers identified a number of additional exposure pathways that are not specifically mentioned in the draft NUREG-1640.

The draft NUREG did not include any discussion on the exposure of workers on a ship constructed at least partially out of contaminated material. Product use exposure scenarios were limited to a small metal object (like a belt buckle), a large metal object (like a refrigerator), automobile parts, and steel support beams in a residence. For product use scenarios, the exposure to workers on a ship may be a more limiting external exposure scenario for nonworkers than any of these exposure scenarios as these members of the public would be exposed to a large quantity of metals and would have very long exposure times. A European study on the recycle of contaminated materials (Simon and Janssens, 2000) concluded that this exposure scenario was limiting for many radionuclides. Additionally, a conservative scoping calculation performed by the CNWRA indicated that this pathway could be significant. This calculation was performed for ^{60}Co assuming a sailor spends a full year on a ship constructed with 10 percent recycled steel, which yielded a dose conversion factor of about 0.68 mrem/yr/pCi/g from external exposure, which is slightly less than the limiting dose conversion factor for ^{60}Co from the scrap transportation scenario.

For the copper scenarios, the draft NUREG did not include potential exposure to a musician playing a large brass instrument, such as a tuba. Although this scenario is similar to the large metal object scenario, which was not limiting for any of the radionuclides, the exposure distance for the instrument would be much closer than the 2 m assumed in the large metal object scenario. Therefore, the dose from the instrument could be much larger than was assumed in the large metal object scenario. A scoping calculation was performed to determine the dose from a 20 lb tuba composed of 75% contaminated copper and 25% clean zinc which is played for 18 hr/wk. For at least one radionuclide, ^{93}Mo , this resulted in a dose factor 15% higher than the limiting dose factor in draft NUREG-1640. This indicates that this pathway may be important for certain radionuclides.

The product use scenarios in the draft NUREG only consider external exposure pathways (with the exception of the road construction activities using refinery slag). Scenarios involving large ingestion potentials from metal objects, such as orthodontic braces or metal eating utensils, have not been considered. Although orthodontic braces may not relate as well to the average member of the critical group as metal eating utensils do, braces imply much longer exposure times and greater ingestion potential. A scoping calculation by the CNWRA estimated the dose factors for radionuclide ingestion from the corrosion of recycled stainless steel in orthodontic braces. Ingestion was the only pathway considered in the scoping calculation. The small metal object scenario considered a much larger mass of steel compared to braces and, therefore, is expected to bound the external pathway for the orthodontic braces scenario. For steel recycling, the small metal object scenario was identified, in Table 4.10 on page 4-115 of the draft NUREG, as the limiting scenario for only one radionuclide, ^{93}Mo . The orthodontic braces were modeled as two sets of eighteen brackets and one wire. Each bracket was modeled as a stainless steel block with a length of 4 mm, width of 5 mm, and depth of 3 mm. Each wire was assumed to have a radius of 1 mm and length of 15 cm. Corrosion was calculated along the entire surface of the steel wire and on all surfaces of the steel brackets, except no corrosion was assumed for the surfaces where the steel brackets contact the teeth. A conservative corrosion rate of 1.0 $\mu\text{m}/\text{yr}$ (Muller et al.,

1990) was assumed, which resulted in an annual ingestion rate of 36 mg of stainless steel, for a density of 7.86 g/cm³. For this conservative scoping calculation of radionuclide ingestion from the corrosion of orthodontic braces, the resulting dose factors were significantly smaller (by a factor of 140 or more) than the mean dose factors for the limiting steel recycling scenarios in Table 4.10 of the draft NUREG. Because the dose factors were so much smaller for the orthodontic brace scenario than for the limiting scenarios, it is determined that more detailed calculations of the orthodontic brace scenario are not required.

The draft NUREG indicates that typical end products for recycled concrete include the base for roads, a stabilizer for asphalt, and an aggregate for nonstructural materials. The report states that recycled concrete is not used as aggregate for structural concrete, such as that used in houses or buildings. Although this statement is correct under present conditions, the use of recycled concrete aggregate (RCA) in new concrete manufactured for structural purposes is possible in the near future as costs, government regulations, land-use policies, and social acceptance of more sustainable natural resource practices make the option more viable. U.S. producers of natural aggregates and independent entrepreneurs are beginning to consider the recycling of construction and demolition debris as one option for material use (Wilburn and Goonan, 1998). In some other industrialized countries such as Germany, the Netherlands, and Japan, where waste volumes are high and natural resource availability is low, the rates of waste concrete recycling is particularly high, reaching up to 50 percent. Recent literature suggests that there is interest in expanding the application of RCAs beyond the lower valued product applications in road construction, particularly outside the United States. For example, the University of Dundee conducts research to examine the use of RCA in concrete construction, in response to the U.K. government's active encouragement of the use of RCA as an alternative to natural aggregates, wherever it is acceptable (Dhir and Limbachiya, 2000). Some of the University of Dundee results show that up to 30 percent RCA content had little effect on the strength of high-strength concrete, and that high-strength RCA concrete will have equivalent durability and performance to concrete made with natural aggregates. Other studies also point to the interest in using RCA for structural concrete (Dosho et al., 1998; Di Niro et al., 1998; Van Acker, 1996). On the basis of these studies, it is possible that RCA also could be used in the United States in the manufacture of structural concrete in the future. Because the design objective of NUREG-1640 is to model U.S. industry processes and practices as they exist at present, scenarios that include the use of contaminated RCA for construction of buildings and houses need not be considered. However, changes in industry processes and practices should be monitored to determine the potential for the use of contaminated RCA becoming a likely exposure scenario.

CNWRA reviewers initially postulated that uptake of metal by canned foods or soda in cans could lead to significant doses because the long contact time between the food and the metal could lead to significant uptake of the metal by the food. Research into this issue, however, found that the inside surfaces of these cans are coated with an epoxy resin to prevent contact between the food and the metal (Ball Corporation, 2000). Direct contact could only occur if the can was physically damaged such that the coating was disrupted. As such, this scenario is not likely to lead to significant doses to members of the public.

4.2 MODELS

The review of the models used to determine the dose to the receptor from the proposed scenarios generally found that the models used were reasonable and appropriate. In both the materials processing and the dose modeling, however, several issues were identified about the applicability or the sufficiency of the models used.

4.2.1 Material Processing

The mass and elemental partitioning analyses performed in the report for the copper processing (Sections 5.2.3 and 5.3 and Figure 5.1 of draft NUREG-1640) are based on the primary smelter process and are therefore not applicable to the copper recycling in a secondary smelter.

There are two kinds of smelters, primary smelter and secondary smelter. The primary smelter processes copper concentrates (sulfide minerals) received from the mining operations. The output from the reverberatory furnace in a primary smelter is a matte, which is a mixture of copper and iron sulfides. The matte requires further oxidation to form metal copper, called blister copper, in a converter (Howe-Grant, 1996a). The secondary smelter processes low-grade recycled metal scraps that contains 15–70 percent copper (Howe-Grant, 1996b). A blast furnace is usually used in the smelting operation of a secondary smelter. The blast furnace produces a black copper that contains about 80 percent copper and balance of impurity metals such as Fe, Zn, Sn, and Ni. The black copper is further converted to blister copper by selective oxidation of the impurity metals in a converter. The majority of the copper scraps is processed in refineries by melting and electrorefining or fire-refining, or in ingot makers, brass mills or foundries by melting to directly form new alloys.

According to the Copper Development Association (2000), of the 1,466,000 tons of scraps recovered in 1999, only 226,000 tons were smelted in the smelters. The percentage of smelted copper scrap is about 15.4 percent. Furthermore, the analyses performed in the report only considered the smelter processes (reverberatory, converter, and electrorefiner). As the majority of the scrap is recycled in brass mills, refineries, and ingot makers, where only melting and minor refining are involved, the mass and elemental partitioning factors should be separately assessed, and the mass balance should be separately analyzed. For the mass partitioning factors¹ for copper, the report has used 90–96 percent for the reverberatory furnace, 90–96 percent for the converter (matte to blister), 98 percent for the electrorefiner, and a maximum of 90 percent was used as the total mass partitioning factor for the refining in the probabilistic analysis (see volume 2, page B-14 of the draft NUREG). As there is no smelting involved in the brass mill and refineries, the total mass partitioning factor in the refining process should be more than 95 percent. The lower mass partitioning factor used in the draft NUREG may lead to the underestimation of the radionuclide concentrations in the copper products.

The draft NUREG did not consider the potential for buildup of contamination in recycled materials due to the material being recycled multiple times. However, CNWRA analyses, which are described in appendix A of this report, indicate that the effect of buildup in recycled materials is negligible because the amount of released materials from nuclear facilities is much smaller than both the total inventory currently in circulation and the amount of the materials leaving the circulation cycle such as by corrosion loss or refining loss.

4.2.2 Dose Modeling

In contrast to the resident on a closed landfill scenario, the slag storage scenario only considers the drinking water pathway from a contaminated well (see Table 4.8, page 4-33 of the draft NUREG). It would seem reasonable to include the ingestion pathway from a home garden irrigated with contaminated

¹ Mass partitioning factors should be called mass ratios; see page 4-6 of this report.

well water. A contaminated garden may also require consideration of the inhalation pathway from resuspension of soil, as well as the external exposure pathway, as the soil could become contaminated following irrigation with this contaminated groundwater. The draft NUREG indicates that the Total Dissolved Solids (TDS) content of the aquifer beneath the slag pile is tracked, and the scenario is ended if the TDS content exceeds a level that would allow it to be used as drinking water. Exposure from these additional pathways, however, could continue even if the water contained high TDS content, extending the length of time that the scenario would need to be tracked. Additionally, the justification for excluding animal ingestion pathways for this scenario and for the landfill resident scenarios in the draft NUREG is insufficient. Although it may be appropriate to exclude the animal ingestion pathway for the average resident in the United States, the development of a distribution of doses from the release of cleared material may need to include the animal ingestion pathway to appropriately determine the largest doses.

It does not appear that the emanation of noble gases from contaminated surfaces was considered in the development of the inhalation dose. Because the resuspension factor was radionuclide independent, it seems that the models for predicting dose for materials contaminated with uranium and its decay products do not account for the emanation of noble gases from contaminated surfaces. This pathway could potentially contribute to the inhalation dose. A scoping calculation indicated that the dose factors for surface contamination of ^{226}Ra and ^{227}Ac may be underestimated by at least one order of magnitude from neglecting noble gas emanation in the direct reuse scenario. Smaller underestimations were realized, within a factor of less than five, for the dose factor of ^{228}Th .

The draft NUREG indicates that a small fraction of electric arc furnace (EAF) baghouse dust is used as fertilizer for crops to be consumed by humans. However, the analysis of dose from the baghouse dust stops at the transport of the dust to the fertilizer manufacturer in the draft NUREG. Other potential exposure pathways from this dust would include dose to workers who apply the fertilizer to the crops and the consumption of foods grown using EAF dust fertilizer. However, the SAIC's QA records² indicate that these pathways were analyzed, but were apparently screened from further analyses based on the low dose associated with these pathways. The draft NUREG would be clearer if it discussed all pathways considered and indicated the rationale for screening pathways from the final analyses.

The external exposure pathway only considered the dose contribution from gamma ray and bremsstrahlung. Dose contributions from beta particles were not considered. There are several radionuclides analyzed in the draft NUREG that emit beta particles with significant energies. The fraction of incident beta particle energy converted into bremsstrahlung photons can be estimated using the following formula (Cember, 1992):

$$F = 3.5 \times 10^{-4} Z E_{\text{max}}$$

(4-1)
where,

F - The fraction of incident beta particle energy converted into bremsstrahlung photons

² EDFs 2467-114, Reuse and Recycle Scenario Naming Convention, and 2467-089, Scenario Sorting for Uncertainty Analysis.

Z	-	The atomic number of the absorber
E_{max}	-	The maximum energy of the beta particle [MeV]

The fraction of the beta energy that is converted to bremsstrahlung is generally only a few percent. Because the fraction of the energy converted to bremsstrahlung is small, considering bremsstrahlung alone would underestimate the dose from beta particle emissions. Beta particles affect the dose to the skin. External dose to the skin is expected to be the most important for pure beta emitters that do not emit gamma rays. The very short range of beta particles in solid materials causes the dose from beta particles to be of practical concern only for surface contamination. Because the draft NUREG does not assess skin doses separately, the health effects and dose factors from surface contamination of pure beta-emitting radionuclides may be underestimated in the direct reuse scenario. Although the protection of skin has historically and generally been based on a higher dose criterion than that for the whole body, assessment of skin doses from surface contamination of pure beta-emitting radionuclides would improve the draft NUREG as a technical basis document for the direct reuse scenario. Limited assessments of skin doses could be converted into a contribution to the whole body dose by using a tissue weighting factor of 0.01 for the skin (International Commission on Radiological Protection, 1990). Additional discussion on the significance of this pathway for several beta emitters is included in appendix B.

The draft NUREG indicates that the landfill resident scenarios were judged to be too unlikely to be used in the determination of the limiting concentrations for the release of contaminated materials. It is not clear why this scenario was considered too unlikely to be used in the determination of limiting concentrations for the metal scenarios but not the concrete scenario. Although this disposed material could be held to a different standard than the other more direct scenarios (like the 25 mrem/yr 10 CFR 20 Subpart E limit for dose from decommissioned sites), completely neglecting these pathways in the determination of limiting release concentrations could unintentionally result in higher doses. Since this pathway leads to limiting doses for many radionuclides (^{14}C , ^{36}Cl , and ^{41}Ca , for example), these scenarios should be addressed further.

4.3 PARAMETER VALUES

The selection of appropriate parameter values is crucial to derive reasonable results. The draft NUREG generally clearly describes and references the basis for the selection of parameter values used in the analyses. Additionally, the QA program employed by SAIC ensured that the analyses were traceable, so that it was easy for a reviewer to trace data values used in the calculational spreadsheets back to the reports that defended the selection of these data values. This clarity of presentation of the source of data used in the analyses is to be commended and makes the results of the analyses much more easily understood by the reader. The review resulted, however, in the identification of a number of areas in which the selection of parameter values did not appear to be appropriate.

4.3.1 Material Processing

The estimation of the elemental partitioning factors for some elements is based on the physical properties, (i.e., boiling temperatures of the elements or their products formed in the refining furnace). The activity, or concentration of the elements or their products, also plays important roles. In general, the concentrations of the impurities of concern in the recycled metals are low and close to the concentrations in the metals (from which the scraps originated) when the metals just came out of the refining furnaces. Therefore, most of these impurities should end up in the metal product stream. For instance, some commercial carbon steels may contain 0.040 wt % of P (American Society for Metals International, 1987). Table 4.5, however, assumed that only 0–10 percent of P would be partitioned into the metal

products. This value range may be too low if the concentration of P in the scrap is close to 0.040 wt %. A higher value range should be used in the analysis to produce a result that is conservative for the metal products. Similarly, the value range of 0-1 percent for Ac, Am, Ba, and Zr may be too low.

The draft NUREG obtains the high-end single charge mixing by dividing the reasonable truck load for aluminum by the typical load (not the minimum load) of a reverberatory furnace for aluminum. This analysis may underestimate the radionuclide concentrations in the mixed material entering the furnace and is not consistent with the analyses for copper and steel where the minimum load (instead of typical) was used in the denominator.

The mixing assumptions for copper and aluminum scrap stated that the maximum annual mass of copper and aluminum scrap postulated to be available from NRC licensees is approximately 8,000 ton/yr and 200 ton/yr, respectively (see page D-6 of volume 2 of the draft NUREG). Pages 5-3 and 6-3 of volume 1, however, stated that increased dismantling and decommissioning activities could result in approximately 18,000 ton/yr of copper scrap and 4,500 ton/yr of aluminum scrap for a limited number of years. Therefore, these higher annual recycle quantities should be used as the maximum annual mass in the analysis. The analyses performed in the draft NUREG may underestimate the radionuclide concentrations in the various products from the furnaces that process the cleared scraps by a factor of 2.2 for copper and 22.2 for aluminum.

In the probabilistic analysis, M_0 and M_{NC} were allowed to change independently. When the Crystal Ball software selects the lower or higher end values for both M_0 and M_{NC} , the total charge, M_1 ($M_1 = M_0 + M_{NC}$), can be extremely small or large and out of the industry furnace size range. A more realistic approach may be to allow M_1 and either M_0 or M_{NC} to change independently and let the remaining M_0 or M_{NC} be an dependent variable. The inclusion of this dependency would increase the variability in the results, since larger quantities of contaminated material would be mixed with smaller quantities of clean material and smaller quantities of contaminated materials would be mixed with larger quantities of clean material. However, it would probably not significantly affect the mean results because only a small fraction of the samples taken by the Crystal Ball software may have a total charge M_1 outside of furnace size range.

The mass partitioning factors used in the report should be called mass ratios. For steel recycling, if pig iron is used in the refining process, the equations used to calculate the mass partitioning factors are confusing and conflict with the definition of the partitioning factor in the text of the report (page 4-15 of the draft NUREG). This confusion arises because the amount of pig iron entering the furnace also contributes to the values of M_{dust} and $M_{steel\ produced}$, but they are not accounted for in the denominator of the equations (pages 4-16 and 4-18 of the draft NUREG). The partitioning factors obtained by these equations can be more than 100 percent, which is misleading. For example, in the spreadsheet file for the Fe mass balance calculations, File BOFRE3P.unc (page 4 of the spreadsheet, Parameter definitions and References of the draft NUREG), the mass partitioning factor for metal product, f_{pl} , was 2.75 or 275 percent. The equations used to calculate mass partitioning factors are simply the ratios of masses, and they do not mean the same as the partitioning factors for elements used throughout the report. Therefore, these mass partitioning factors (f_{pl} , f_{sl} , f_{dl} , f_{gl}) should be called mass ratios, and the symbols for these parameters should be changed, say to r_{pl} , r_{sl} , r_{dl} , r_{gl} , throughout the report to avoid possible confusion with the elemental partitioning factors (f_p , f_s , f_d , f_g).

Although the clarity of the justification of the parameter values used in the analyses was typically very good, there were several parameters and assumptions made in the draft NUREG that should have additional justification. These parameters include

- The assumptions and range of parameters (such as M_0 and M_{NC}) in the calculation of radioactivity concentrations at an EAF refinery should be described or referenced in the appropriate sections of volume 1 or volume 2
- The annual average throughput of copper and aluminum in the calculation of the annual charge mixing
- The annual quantity of copper that is recycled
- The quantity of aluminum processed in a single charge

4.3.2 Dose Modeling

To calculate the dose from the resuspension of material from a contaminated surface, the draft NUREG utilizes a resuspension factor. Several references are cited for representative indoor resuspension data. However, another draft NUREG under development at the NRC to establish an indoor resuspension factor for the screening analysis of the building occupancy scenario³ is based on eight references judged to be most representative of the assumed scenario. Of these eight references, only one is included in the list for NUREG-1640. The reuse scenario of NUREG-1640 and the draft resuspension factor NUREG both assume that the cleaning of surfaces has been performed prior to clearance and release to remove the readily removable contamination. At a minimum, NUREG-1640 should consider the references selected in the draft resuspension factor NUREG to determine the indoor resuspension factor for the building occupancy scenario (Breslin et al., 1966; Eisenbud et al., 1954; Jones and Pond, 1967; Ruhter and Zurliene, 1988).^{4,5} Other resuspension reviews would also be useful to consider (Sehmel, 1980; U.S. Department of Energy, 1994). Referenced in NUREG-1640, the indoor resuspension data ranged from $2 \times 10^{-8} \text{ m}^{-1}$ to $4 \times 10^{-3} \text{ m}^{-1}$. For residual surface radioactivity, however, a lognormal distribution was assigned to the resuspension factor with a geometric mean of $1 \times 10^{-8} \text{ m}^{-1}$, which is outside the range of referenced data. The main arguments given in NUREG-1640 for selecting a resuspension factor outside the range of the referenced data are (i) readily removed contamination has been removed prior to clearance, and (ii) contamination that remains after preclearance cleaning is the least susceptible to resuspension. In regard to argument (i), the building occupancy scenario in the draft NUREG under development to establish an indoor resuspension factor also assumes surface cleaning before release and therefore can serve as a sound comparison. The draft NUREG on the indoor resuspension factor has indicated a geometric mean of $25 \times 10^{-8} \text{ m}^{-1}$ and 90th percentile (suggested as the screening value) of $70 \times 10^{-8} \text{ m}^{-1}$ for a lognormal distribution based on the mean values of five data sets.

³ Eid R., R. Codell, N. Eisenger, T. Harris, and S. McGuire. *Re-evaluation of the Indoor Resuspension Factor for the Screening Analysis of the Building Occupancy Scenario for NRC's License Termination Rule*. Draft. Washington, DC: U.S. Nuclear Regulatory Commission. Unpublished, 1999.

⁴ Nardi, A.J. Operational Measurements and Comments Regarding the Resuspension Factor. *Presentation at NRC Decommissioning Workshop*. March 18, 1999. Rockville, MD. 1999.

⁵ Spangler, D.L. Re-suspension factor determination and comparison using data from an operating licensed facility. *Presentation at NRC Decommissioning Workshop*. December 1, 1998. BWX Technologies, Inc. 1999.

A resuspension factor 25 times larger than that used in NUREG-1640 implies a severe underestimation of the reuse dose factor. In regard to argument (ii), insufficient information has been provided to justify it. In addition, the potentially large driving forces expected for a truck driver using the air conditioning or heating systems and uncertainty involved with the degree of source depletion expected under larger driving forces do not support selecting a resuspension factor outside the range of the referenced data. The resuspension factor also impacts the effective transfer rate for secondary ingestion. The effective transfer rate for ingestion was assigned a lognormal distribution with a geometric mean that was deduced from the mean resuspension factor. A directly proportional relationship was suggested between the effective ingestion transfer rate and resuspension factor. Therefore, an increase in the mean resuspension factor not only results in a larger dose factor due to inhalation, but also implies a proportional increase in the effective ingestion transfer rate and a larger ingestion dose factor. It should be noted that the resuspension factor for residual surface radioactivity in the direct reuse scenarios was assigned a lognormal distribution with a geometric mean of $1 \times 10^{-8} \text{ m}^{-1}$, which is more than three orders of magnitude lower than the fixed value of $5.0 \times 10^{-5} \text{ m}^{-1}$ assigned to the other scenarios. Therefore, the concerns about the selection of the geometric mean for the resuspension factor only apply to the direct reuse scenario. Because the resuspension factor can be much greater in dusty work environments, the resuspension factor for cleaned surface contamination would be expected to be lower in the direct reuse scenario. However, the draft NUREG would be strengthened if the values selected for the direct reuse resuspension factor were supported better by the referenced data or additional rationale.

When assessing radiological doses from the inhalation pathway, the draft NUREG reduces the inhalation exposure for the worker scenarios, multiplying it by the respirable fraction of resuspended material, which is the fraction of airborne material that is less than $10 \mu\text{m}$ in diameter. Although very little material greater than $10 \mu\text{m}$ in diameter will reach the deep parts of the lung, particles up to about $100 \mu\text{m}$ are able to be deposited in the nasopharyngeal portion of the lung (International Commission on Radiological Protection, 1979; Morrow, 1964) and can contribute to the total dose from inhalation. The magnitude of the contribution to dose of these larger particles varies by radionuclide and can be significant for soluble radionuclides.

The range of uncertainties developed for several of the geometry factors are based on subjective estimates of uncertainty in the mass of the object and the relative position of the exposed individual (large pile, small metal object, large metal object, small metal object close to the body), and, therefore, there is little justification for the selection of the value. Although it would be difficult to create a strong basis for the range of geometry factors used, with this weak basis for the uncertainty in the geometry factors, the distribution selected for the uncertainty in external exposure rates (U_{gr}) should have a mean of one to prevent it from affecting the mean results of the calculation.

The draft NUREG lists both the highest inhalation and ingestion dose conversion factors from FGR-11 (U.S. Environmental Protection Agency, 1988) and the dose conversion factors for the oxide form of the radionuclide. It appears that the dose conversion factors for the oxide form of the radionuclides were used in the calculation of dose. Because the oxide form of the radionuclide does not always yield the limiting dose for the radionuclide and can be as much as a factor of 100 lower than the limiting chemical form, justification needs to be provided for this assumption.

The DIET parameter in Eq. 4.71 on page 4-88 of the draft NUREG appears inconsistent with the PF_n and PF_i terms by not being specific to the ingestion of non-irrigated and irrigated foods like in Eqs. 4.67 and 4.68. A summation of the nonirrigation and irrigation ingestion models yields the total ingestion model. Therefore, it would appear that the $DIET \times (PF_n + PF_i)$ quantity should be replaced by

$(DIET_n \times PF_n) + (DIET_i \times PF_i)$. An evaluation of the SAIC spreadsheet, Ddu17feg.ps3, verified that Eq. 4.71 was used for the total ingestion model, but an error was discovered in the spreadsheet's equation. The $C_{sg} \times U_{soil}$ quantity in the spreadsheet's equation for the total ingestion model was mistakenly entered as $C_{sg} \times DIET$.

The daily exposure time, t_{xs} , used for the truck driver in the cleared truck scenario was assigned a triangular distribution with a minimum of 1 hr/day, mode of 4 hr/day, and maximum of 8 hr/day. The geometry depicted in Figure C.10 of the draft NUREG, however, is a large interstate truck, and truck transport is stated on page 4-42 of the draft NUREG as having a high-dose potential from long exposure times and small distances from the driver receptor to the source truck. Therefore, the daily exposure times are thought to be too low for a typical interstate truck driver, which would result in an underestimation of the reuse dose factors for all radionuclides considered. Further discussions supporting the selection of this value would be beneficial.

The draft NUREG indicates that the average windspeed for each stability class was calculated by neglecting the lowest and highest windspeed categories. The significance of omitting the lowest and highest windspeed categories on the calculated average windspeeds should be discussed in the draft NUREG. However, because the air dispersion pathway is not the limiting pathway for any radionuclide and the inclusion of the lowest and highest windspeeds would not be expected to significantly change the results of the calculation, this issue does not seem to be very significant.

4.4 INCONSISTENCIES IN REPORT AND SUPPORTING CALCULATIONS

The detailed review of the spreadsheets provided by SAIC, which contained the calculations performed to determine the dose from the various scenarios of exposure to contaminated materials, resulted in a small number of concerns being identified by the CNWRA reviewers. It is noted, however, that the majority of the calculations performed and spreadsheets used by SAIC that were checked by CNWRA reviewers were implemented as intended and their accuracy was confirmed by CNWRA reviewers.

The independent calculation of the geometry factors for the truck driver (GF-4) and member of the public on the side of a truck (GF-5) yielded fairly good results for radionuclides with high-energy gamma emissions for all materials. However, radionuclides that were checked that had predominantly low-energy gamma emissions (^{186}Re and ^{141}Ce) resulted in much poorer agreement for the copper and aluminum scenarios. The check of the spreadsheets found that SAIC utilized the same geometry factors for all metals for a given exposure scenario. The probability of photoelectric absorption increases as the atomic number to the fourth power, and copper has a slightly higher atomic number than iron, whereas aluminum has a much lower atomic number. Therefore, the dose to the truck driver would be slightly overestimated for low-energy gamma emitters for the copper scenario (by about 20 percent), whereas the dose to the truck driver would be significantly underestimated for low-energy gamma emitters for the aluminum scenario (by as much as a factor of 2.5). Since dose increases linearly with the geometry factors, and the transportation of scrap is the limiting scenario for many radionuclides, this assumption could make a substantial change in the results of the analyses. It is also likely that a similar discrepancy will be present for all scenarios in which the contaminated object provides a significant amount of self-shielding. The radionuclides that are low energy gamma-emitters for which direct exposure is the only contributor to the limiting scenario for aluminum include the following: ^{57}Co , ^{67}Cu , ^{93}Mo , ^{93m}Nb , ^{125}I , ^{141}Ce , ^{144}Ce , ^{155}Eu , ^{186}Re , ^{223}Ra , ^{227}Th , ^{231}Th , and ^{234}Th .

Justification needs to be provided for selecting the limiting scenarios presented in Tables 4.10 and 4.11 of the draft NUREG. The slag handling scenario was selected as the limiting scenario for ^{241}Am . Compared to the slag handling scenario in Table F.2, however, the slag processing scenario in Table F.9 exhibited higher mean, higher 5th percentile, and higher 95th percentile values of the dose factor. Inconsistencies in the selection of the limiting scenario were also seen for $^{93\text{m}}\text{Nb}$, ^{227}Ac , ^{229}Th , ^{238}Pu , ^{242}Pu , and ^{244}Cm .

The number of melting cycles per year in a nonintegrated steel mill does not appear to be consistent with the length of the average melting cycle. On pages 4-9 and 4-10 of the draft NUREG, the average melting cycle was stated to range from 25 to 45 min for integrated steel mills, but from 1.5 to 5 hr for nonintegrated steel mills. Despite the large time difference in the average melting cycles, an average of 5,580 charges/yr for one refinery is listed for both mill types. The average of 5,580 charges/yr with the longer melting cycle of the nonintegrated steel mill appears inconsistent with the number of hours in a year as 5,580 charges would take more than one year of continuous melting (e.g., a 2-hr melting cycle implies a maximum of 4,380 charges/yr). The correction of this inconsistency may reduce the through-put, but is not expected to affect the assumed dilution or radionuclide concentrations. A decrease in the through-put may result in the reduction of the dose factor for process activities.

The daily exposure time (t_{e}) for the worker handling scrap iron in Table B.7 of the draft NUREG does not match the value range used in the Excel spreadsheet, hmu01fei.ps3. This spreadsheet references the calculation package 2467-078 (SAIC-071279), which indicates that the yearly exposure time for a slag handler (a scrap iron handler is not referenced in this report) is between 1,000 and 2,000 hr/yr, or between 4 and 8 hr/day, using 250 days of exposure per year. Table B.7, however, indicates that the daily exposure time is only between 0.06 and 1.2 hr/day.

The daily exposure time for the disposal scenarios seems unrealistically small. Page 4-95 of NUREG-1640 indicates that these values were determined by dividing the amount of material available by the capacity of the landfill. This results in exposure times that range from a few seconds per day to a few minutes per day. It seems that the NUREG is accounting for the dilution of the contaminated material with uncontaminated material using the exposure time rather than a separate dilution parameter, since these times are unrealistically short.

The tap water intake quantities for a nonworker exposure scenario are not consistent. The copper pipe scenario has a mean tap water intake of 1.4 L/day (DI_w) whereas the iron scenario has a mean of 0.957 L/day (U_w).

Checks were performed on the surface contamination geometry factors for ^{59}Fe , ^{60}Co , ^{103}Ru , ^{106}Ru , ^{131}I , ^{134}Cs , and ^{231}Th . The surface contamination geometry factors computed from MCNP simulations were compared to those presented in Table C.14 on pages C-54 and C-55 of the draft NUREG. The surface contamination geometry factors appeared to be calculated correctly, except for ^{231}Th . It seems that the x-ray emissions from ^{231}Th were neglected in the calculation of the surface contamination geometry factor. Because the significant gamma ray emissions have energies less than 100 keV, and the x-ray intensities are large relative to the gamma ray intensities (Brookhaven National Laboratory, 2000), neglecting the x-ray dose contributions for ^{231}Th results in an underestimation of the surface contamination geometry factor by about one order of magnitude. Additionally, the surface contamination geometry factors were reported as zero for ^3H , ^{41}Ca , ^{55}Fe , ^{59}Ni , and ^{63}Ni in Table C.14 of the draft NUREG. In fact, many of the tables in Appendixes C and F of the draft NUREG report values

of zero for these radionuclides. It is expected that the surface contamination geometry factors would be greater than zero due to the beta particle emissions and bremsstrahlung from these radionuclides. It is recommended that the zero values be replaced in Table C.14 of the draft NUREG with a reference to a footnote with a more detailed explanation.

Within the report, there is a discrepancy in the slag elemental partitioning factor for sulfur and rhenium between Table B.3 and Table 4.5 of the draft NUREG:

$$f_s \text{ (for S)} = 0.03 \text{ to } 0.77 \text{ in Table B.3 and}$$
$$f_s \text{ (for S)} = 0.03 \text{ to } 0.00 \text{ in Table 4.5}$$

$$f_s \text{ (for Re)} = 0.00 \text{ to } 0.03 \text{ in Table B.3 and}$$
$$f_s \text{ (for Re)} = 0.03 \text{ to } 0.87 \text{ in Table 4.5}$$

Finally, external dose calculation in spreadsheet hsu02cui.ps3, CU-REVS-HANDLIN-W, does not properly use the density of the material in the input data section of the spreadsheet. Instead, the calculation forces the density of the material to be 1.6 g/cm³, which seems to be inconsistent with Table B.7 of the draft NUREG.

4.5 QUALITY ASSURANCE

The NRC contract with SAIC included provisions for QA. Specifically, contract modification number 1 required SAIC to develop an overall QA/quality control program for the project in support of Tasks 2–5. Additional criteria for computer code development were also provided in modification 1. Contract modification number 14 restated the program requirements as "to ensure that the thoroughness and bases and rationales of analyses, models, and regulatory products are readily traceable and reproducible."

The review was conducted to determine whether controls were defined that were appropriate for the activities associated with preparation of the draft NUREG, and whether the defined controls were effectively implemented. Specific areas of review were

- The NRC Reuse and Recycle Project Task 2 Quality Control Plan (dated August 1995)
- The QA-related sections of draft NUREG–1640, volume 1
- Pertinent SAIC supporting documentation that had been delivered to the NRC

4.5.1 Evaluation of the Quality Control Plan

The project Quality Control Plan describes "Design Controls" that were to be applied to the analyses performed in development of the draft NUREG. Policies and procedures were provided in the plan addressing

- QA Document Control and Configuration Management
- QA Review of Technical Information
- QA Review of Other Computer Codes (e.g., codes not specifically identified in the

Programming Approach section of the Quality Control Plan)

- Problem Reporting and Corrective Action
- Record keeping: Project Engineering Cabinet

The Quality Control Plan appears to provide appropriate controls that, if properly implemented, should achieve the objectives of contract modification numbers 1 and 14. Requirements for independent technical reviews, for records organization and maintenance, and for computer code development and configuration management are highly relevant to the type of technical activities that were conducted during preparation of the draft NUREG.

4.5.2 Evaluation of the Quality Assurance-Related Portions of the Draft NUREG

The draft NUREG provided a summary of the QA-related activities that took place during development of the draft NUREG. The sections pertinent to QA generally follow the organization of the Quality Control Plan:

- 8.2, Quality Requirements
- 8.3, Document Review, Control, and Configuration Management
- 8.4, QA Review of Technical Information
- 8.5, Record Keeping: Project Engineering Cabinet.

The QA-related sections of the draft NUREG state that the controls described in the Quality Control Plan had been followed. While the contract required the draft NUREG to describe its implementation of the Quality Control Plan, this document does not provide adequate information for an independent determination of the effectiveness of the QA program.

4.5.3 Review of Supporting Documentation Delivered to the U.S. Nuclear Regulatory Commission by Science Applications International Corporation

The supporting documentation provides an opportunity for an independent assessment of the implementation of the Quality Control Plan. The Quality Control Plan required that certain documentation be prepared that provide objective evidence that required activities were performed.

The supporting documentation was organized into individual packages, most of which were Engineering Design Files. Other files appeared to be for supplemental analyses contributing to the technical material covered in the Engineering Design Files. The files contained a variety of Scenario Spreadsheets, parameter selections, technical text, or similar technical content. Each file was verified as having evidence of internal technical reviews and approvals. Document packages were located corresponding to the 128 Engineering Design File numbers that had been assigned.

4.5.4 Overall Assessment of the Quality Assurance Program

The QA program applied to the preparation of the draft NUREG appeared to be appropriate and effectively implemented.

5 RECOMMENDATIONS FOR FUTURE WORK

Based on the issues identified earlier in this report and the results of the limited scoping calculations performed to assess the effect of these issues, a number of recommendations can be made for additional analyses that could be performed to improve the thoroughness and accuracy of the draft NUREG.

It is recommended that two additional exposure scenarios be considered. The first would involve exposure of sailors on a ship at least partially constructed out of contaminated metal. Although it may be unlikely that an entire ship could be constructed out of contaminated materials due to the large mass of steel needed for the construction of the ship, this pathway could lead to significant doses because of the large amounts of time that sailors could be exposed to the radiation source in a year. An appropriate analysis may assume that the walls around the location where the sailor sleeps are contaminated and make reasonable assumptions for the amount of time that the sailor is exposed to the source in a year. A scoping calculation was performed by the CNWRA for ^{60}Co assuming a sailor spends a full year on a ship constructed with 10-percent recycled steel. This calculation yielded a dose conversion factor of about 0.68 mrem/yr/pCi/g from external exposure, which is slightly less than the limiting dose conversion factor for ^{60}Co from the scrap transportation scenario. The second additional exposure scenario would involve a musician playing a large brass instrument, such as a tuba, and should account for the very small distance between the instrument and the receptor. Scoping calculations for ^{93}Mo indicate that this could be a significant pathway.

It is recommended that additional exposure pathways be included in two of the exposure scenarios. The analysis of the slag storage scenario should account for dose pathways other than the ingestion of contaminated water, such as dose resulting from the irrigation of a small garden with the contaminated water. For the equipment reuse scenario, it is recommended that the increased release of gaseous decay products be considered for radionuclides that include daughter products that are likely to be in a gaseous form.

It is recommended that independent geometry factors for copper and aluminum be calculated using the proper material in the model instead of using the geometry factor developed for steel. The highest priority for recalculation would be for those aluminum scenarios that involved a significant amount of source self-shielding and for radionuclides that emit low-energy gamma rays.

It is recommended that the draft NUREG be revised to address the inconsistencies noted in this report to improve the overall quality and credibility of the analyses.

Finally, the applicability of the draft NUREG could be expanded by increasing the number of radionuclides for which the calculations are performed. The draft NUREG-1640 considers the 85 nuclides most likely to be associated with scrap and equipment from nuclear facilities. For the recycling of metals from nuclear installations, the European Commission (1998) considered 104 radionuclides, of which 42 were not considered by the draft NUREG-1640. Those excluded radionuclides are listed in table 5-1. The International Atomic Energy Agency (1996) considered 6 additional radionuclides not considered by the draft NUREG-1640, which are presented in table 5-2.

Table 5-1. Radionuclides considered in European Commission (1998), but not in the draft NUREG-1640

⁴⁶ Sc	¹¹³ Sn	¹⁶⁰ Tb	²⁰⁴ Tl	²⁴³ Am	²⁴⁸ Cf
⁵³ Mn	^{123m} Te	¹⁷⁰ Tm	²⁰⁷ Bi	²⁴³ Cm	²⁴⁹ Cf
⁵⁶ Co	^{127m} Te	¹⁷¹ Tm	²³² U	²⁴⁵ Cm	²⁵⁰ Cf
⁷³ As	¹³⁵ Cs	¹⁸² Ts	²³⁶ U	²⁴⁶ Cm	²⁵¹ Cf
⁹³ Zr	¹³⁹ Ce	¹⁸¹ W	²³⁶ Pu	²⁴⁷ Cm	²⁵² Cf
⁹⁷ Tc	¹⁵¹ Sm	¹⁸⁵ W	²⁴⁴ Pu	²⁴⁸ Cm	²⁵⁴ Cf
^{97m} Tc	¹⁵³ Gd	¹⁸⁵ Os	^{242m} Am	²⁴⁹ Bk	²⁵⁴ Es

Table 5-2. Radionuclides considered in International Atomic Energy Agency (1996), but not in the draft NUREG-1640

²⁴ Na	^{99m} Tc	¹¹¹ In	¹²³ I	¹⁹⁸ Au	²⁰¹ Tl
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6 SUMMARY AND CONCLUSIONS

The review of draft NUREG-1640 found that SAIC generally performed a high-quality analysis in draft NUREG-1640. The review of the QA program found that it was appropriate for the analyses that were performed and was effectively implemented.

The CNWRA review, however, did identify a number of areas that could be improved in the draft NUREG-1640. The most significant comments involved the identification of two exposure scenarios that were not analyzed in the draft NUREG, additional dose pathways not considered in the analysis, and simplifications made in the calculations that could affect the results.

Scenarios that were identified as not being considered by the draft NUREG that could be significant include the exposure of a sailor who spends significant amounts of time on a ship constructed of contaminated material, and a musician playing a large instrument constructed of contaminated copper. Other potential exposure scenarios, such as canned foods and orthodontic braces were considered, but scoping calculations indicated that these pathways were not likely to result in limiting doses.

Concerns identified regarding the modeling of the materials processing included an error in the assumed flowsheet for copper that would affect the calculation of the mass and elemental partitioning factors and the failure to consider the buildup of radionuclides in the metal through time due to repeated recycling. However, CNWRA calculations indicate that the error in the copper flowsheet would only affect results by 10-15 percent, and the buildup of radionuclide through repeated recycling cycles would not have a significant effect on the calculated results. For the dose modeling, it was identified that the slag storage scenario should consider additional exposure pathways resulting from the irrigation of a small garden with contaminated water. Also, the equipment reuse scenario for uranium and its daughters should account for the release of gaseous decay products rather than simply using a resuspension factor to determine the quantity of airborne radioactive material.

The review of the parameter values selected for the material processing analysis identified significant concerns in the selection of values for the elemental partitioning factors for phosphorus, actinium, americium, barium, and zirconium and in the maximum annual quantity of scrap to be released in the mixing assumptions for copper and aluminum. For the dose modeling, concerns were raised about the selection of values for the resuspension factor, respirable fraction, uncertainty range for the geometry factors, and chemical form selected to determine the dose conversion factor.

The review of the calculations found that the same geometry factors were used for all three metals, which is not appropriate for radionuclides that emit low-energy gamma rays in scenarios involving a significant amount of source self-shielding. A number of other inconsistencies in the report were also noted.

It is recommended that some additional work be performed to address some of the comments identified in this report. This additional work would strengthen the technical basis for the values derived in the analysis to translate concentrations of radionuclides in released materials into doses to members of the public.

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APPENDIX A

APPENDIX A

Analysis of the Effect of Continued Recycling of Contaminated Metals on the Concentration Build-up of Radionuclide Materials in the Metal Products

Copper recycling has been chosen to analyze the effect of continued recycling of contaminated metals on the concentration build-up of radionuclide materials in the metal products because data on the copper circulation cycle in the United States are most readily available. It is expected that the results for copper will be similar to the results for iron or aluminum. Due to the uncertainties in some of data used in the analysis, this section provides only a scoping calculation and should not be used directly as the basis for decision making.

The copper circulation cycle in the United States is represented in Figure A-1. The mass balance on the radionuclides can be expressed as (neglecting the decay effect):

Input-Output = Accumulation

$$[M_0 C_0 + M_r C_t + M_{im} C_{im}] - [C_t (M_{ex} + M_{nr}) + M_r C_t] = M_t dC_t / dt$$

(A-1)

where

M_0	–	mass of cleared copper (tons/yr)
C_0	–	original radionuclide concentration in the cleared copper (Bq/kg)
M_{im}	–	mass of imported copper (tons/yr)
C_{im}	–	radionuclide concentration in imported cleared copper (Bq/kg)
M_r	–	mass of recycled copper (tons/yr)
M_{ex}	–	mass of recycled copper exported to other countries (tons/yr)
M_{nr}	–	mass of copper that is non-recyclable (disposed in landfills or dissipated to the environment and is not readily recovered) (tons/yr)
M_t	–	total mass of copper in circulation (in use or available for recycling) (tons/yr)
C_t	–	average concentration of radionuclides in the copper that is in circulation (Bq/kg)
t	–	time (yr)

It is assumed that the radionuclide concentration in the imported copper, $C_{im} = C_t$, i.e. no copper contains radionuclide concentrations greater than the domestic copper is allowed to enter the country. Rearranging Eq. (A-1):

$$dC_t / [M_0 C_0 - C_t (M_{ex} - M_{im} + M_{nr})] = dt / M_t$$

(A-2)

Figure A-1 The Copper Circulation Cycle in the United States
Total Copper in Circulation, M_t :

The total copper in circulation is approximated by the total historical and future mine production of copper in the United States. According to the Copper Development Association Inc., the world mine production of copper has been increased exponentially from 400×10^3 tons/yr to 14000×10^3 tons/yr in the time period from 1890 to 2000 (Copper Development Association Inc., 2000b). Therefore, the yearly world production of copper can be estimated by:

$$\log M'_t(\text{world}) = kt + \text{constant} \quad (\text{A-3})$$

where M'_t is the yearly mine production rate (tons/yr), $k = 0.01404$ 1/yr.

It is assumed that the production growth of copper in the United States has followed the same trend, Eq. (A-3) is used to determine the historical yearly mine production of copper in the United States. According to the copper production data in the United States from 1979 to 1999 (Copper Development Association Inc., 2000a), it is assumed that the domestic production in 2000 is 2500×10^3 tons. Therefore, the historical yearly mine production rate for copper in the United States can be estimated by:

$$M'_t(\text{U.S.}) = 71.48 \times 10^3 \times 10^{0.0140(t-1890)} \left(\text{tons / yr} \right) \quad (\text{A-4})$$

Integration of Eq. A-4 yields the total accumulative mine production of copper in the United States from 1890 to 2000:

$$\begin{aligned} M_t(t=2000) &= 71.48 \times 10^3 \times [10^{0.01404 \times 110} - 1] / (0.01404 \times \ln(10)) \\ &= 75232 \times 10^3 \text{ tons} \end{aligned}$$

(A-5)

As the assumptions for other parameters (yearly values of copper consumption, export/ import, and recycle) used in this analysis are based on the present data, which are not functions of time; the predicted future yearly copper mine production rate is also assumed a constant, M_a . The total copper in the United States is (neglecting the exports/imports and non-recyclables before year 2000):

$$M_t = 75,232 \times 10^3 + (M_a - M_{ex} + M_{im} - M_{nr})(t - 2000)$$

(A-6)

where $t > 2000$.

Radionuclide Concentrations in Future Copper Products

Substitute Eq. (A-6) into Eq. (A-2):

or

$$\begin{aligned} dC_t / [M_0 C_0 - C_t (M_{ex} - M_{im} + M_{nr})] \\ = dt / [75232000 + (M_a - M_{ex} + M_{im} - M_{nr})(t - 2000)] \end{aligned}$$

(A-7)

$$dC_t / (M_0 C_0 - AC_t) = dt / (B + C(t - 2000))$$

(A-8)

where

A	-	$(M_{ex} - M_{im} + M_{nr})$	tons/yr
B	-	75,232,000	tons
C	-	$M_a - M_{ex} + M_{im} - M_{nr}$	tons/yr

Assuming the recycling of the copper cleared from the nuclear facility starts at year t' ($t' > 2000$) and $C_t(t = t') = 0$, integration of Eq. (A-8) yields:

$$-\frac{1}{A} \ln(M_0 C_0 - AC_t) \Big|_{C_t(t=t')}^{C_t} = \frac{1}{C} \ln[B + C(t - 2000)] \Big|_{t'}^t$$

(A-9)

$$C_t = \frac{M_0 C_0}{A} \left\{ 1 - \left[\frac{(B + C(t - 2000))}{(B + C(t^2 - 2000))} \right]^{-A/C} \right\}$$

(A-10)

According to Eq. (A-10), for positive A values, the maximum concentration of radionuclides in future copper products would be (when t is equal to infinity):

$$C_t(\text{max}) = C_t(t = \infty) = M_0 C_0 / A \tag{A-11}$$

rearrange Eqs (A-10) and (A-11):

$$C_t = \frac{M_0 C_0}{M_{\text{ex}} - M_{\text{im}} + M_{\text{nr}}} \left\{ 1 - \left[\frac{(75.2 \times 10^6 + (M_a - M_{\text{ex}} + M_{\text{im}} - M_{\text{nr}})(t - 2000))}{\left(\left[75.4 \times 10^6 + (t^2 - t)(M_a - M_{\text{ex}} + M_{\text{im}} - M_{\text{nr}}) \right] \right)^{\left(\frac{M_{\text{ex}} - M_{\text{im}} + M_{\text{nr}}}{M_a - M_{\text{ex}} + M_{\text{im}} - M_{\text{nr}}} \right)}} \right] \right\} \tag{A-12}$$

$$C_t(\text{max}) = \frac{M_0 C_0}{M_{\text{ex}} - M_{\text{im}} + M_{\text{nr}}} \tag{A-13}$$

Scoping Calculations:

Annual Mass of Cleared Copper, M_0

The annual mass of the cleared copper from the nuclear facilities is estimated at 1,100 tons/year (page 5-3 of draft NUREG),

Annual Mass of Copper Production M_a :

The annual mass of primary copper production is estimated at 2,500,000 ton/yr according to the production in year 2000 (see Eq A-4). The copper consumption in 1999 was 4,489,900 tons (Copper Development Association Inc., 2000a). Therefore, the annual copper production rate is about 56% of the total consumption rate.

Annual Mass of Net Exporting $M_{\text{ex}} - M_{\text{im}}$

According to a publication by Copper Development Association Inc (2000a), Table A-1 shows the statistics for 1999.

Table A-1. Copper exporting and importing (1000 tons)

	Ore	Scrap	Blister	Refined	Mill Products *	Sum**
Net Import	80.7		178.2	895.2	193.5	1266.9
Net Export		158.9				158.9

increase in C_1 would be slow. C_1 equals 0.25% of the original radionuclide concentration, C_0 , only after 5000 years. Eq (A-12) also shows that the rate of increase in C_1 decreases with the annual copper production rate, M_a , i.e., the greater the M_a , the slower the rate of increase.

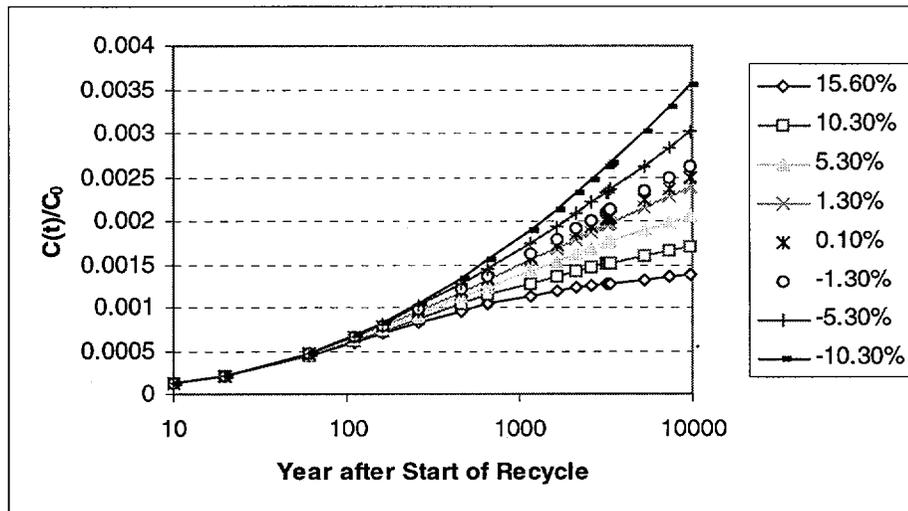


Figure A-2. The effect of $(M_{ex} - M_{im} + M_{nr})$ on the radionuclide concentration.

Note: The values in the legend are the parameters of $(M_{ex} - M_{im} + M_{nr})$ as percentages of copper consumption (4,489,000 tons); net import is 24.7% of consumption; copper production is 56% of consumption.

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APPENDIX B

APPENDIX B

Analysis of the Significance of External Dose from Beta Particles

Because of short range in human tissue, beta particle irradiation results in considerable doses to the skin. Using Eq. (4-1), approximately 2% of the energy from ^{90}Y beta particles is converted into bremsstrahlung photons in iron, which has an atomic number of 26. This estimate agrees fairly well with Chilton et al., (1984), who reports that 1 MeV beta particles lose 2.31% of their energy to bremsstrahlung in iron. Because ^{90}Y does not emit gamma rays, the draft NUREG only considers the external dose from bremsstrahlung. Therefore, beta particles from ^{90}Y could lead to significantly more dose than has been considered in the draft NUREG.

Using the dose coefficients of U.S. Environmental Protection Agency (1993), comparisons can be made to estimate the contribution of beta particles to the skin dose relative to gamma rays or bremsstrahlung. The Radiological Health Handbook states that the beta dose can be five times the gamma dose for ^{198}Au under certain conditions (Bureau of Radiological Health, 1970). The decay characteristics of ^{198}Au are presented in table B-1. The following assumptions are made: (i) the beta particles only contribute to the skin dose, (ii) the total dose to the skin arises from beta particle, bremsstrahlung, and gamma ray irradiation, and (iii) the gamma ray and bremsstrahlung irradiation results in a nearly uniform irradiation to the internal body organs (i.e., not skin). The third assumption is supported by the fact that the dose factors for the individual internal organs are within 5% of the effective dose factor, with the exception of the bone surface, for exposure to ^{198}Au contamination on the ground surface (U.S. Environmental Protection Agency, 1993). The ^{198}Au dose factor from beta particle irradiation was estimated by subtracting the effective dose factor from the skin dose factor, yielding 2.13×10^{-15} Sv/s per Bq/m². By calculating the ratio of the dose factor from beta particle irradiation to that from gamma rays and bremsstrahlung ($2.13 \times 10^{-15}/4.01 \times 10^{-16}$), the beta dose factor is found to be approximately 5.3 times larger to the skin than the gamma ray and bremsstrahlung dose factors, which compare well to the factor of five stated in the Radiological Health Handbook (Bureau of Radiological Health, 1970).

Due to the more energetic beta particle emissions from ^{90}Y and lack of gamma ray emissions, the beta dose from ^{90}Y is expected to represent a much larger fraction of the skin dose than for ^{198}Au . A comparison of the beta and bremsstrahlung contributions to the skin dose from ^{90}Y is presented below. The average energy of bremsstrahlung is about 300 keV for a $^{90}\text{Sr}/^{90}\text{Y}$ source (Bureau of Radiological Health, 1970). Because ^{51}Cr decays by electron capture and emits a single gamma ray at 320 keV with a 9% yield, ^{51}Cr was selected to approximate the bremsstrahlung hazard. Converting the 320-keV gamma ray yield from 9% to 100% (i.e., one 320-keV gamma ray emitted per decay) results in an estimated skin dose factor of 4.1×10^{-16} Sv/s per Bq/m² from bremsstrahlung. Based on the same three assumptions from the previous ^{198}Au comparison, the ^{90}Y dose factor from beta particle irradiation was estimated by subtracting the skin dose factor from bremsstrahlung from the ^{90}Y skin dose factor and yielding 1.00×10^{-14} Sv/s per Bq/m². The ratio of the skin dose factor from beta particle irradiation to that from bremsstrahlung ($1.00 \times 10^{-14}/4.1 \times 10^{-16}$) is found to be approximately 25 for ^{90}Y . This factor of 25 provides a rough indication of the degree to which the skin dose factor would be underestimated when the dose from beta particles is neglected.

Table B-1. Decay characteristics and dose coefficients for ^{198}Au , ^{90}Y , and ^{51}Cr

Radionuclide	^{198}Au	^{90}Y	^{51}Cr
Decay Type	Beta particle emission	Beta particle emission	Electron capture
Average Beta Particle Energy in MeV	0.3	0.93	none
Significant Gamma Ray Emissions Gamma Ray Energy in MeV (Yield)	0.412 (95%)		
	0.676 (1%)	none	320 (9%)
	1.088 (0.2%)		
Effective Dose Coefficient (Sv/s per Bq/m ²)*	4.01×10^{-16}	5.32×10^{-18}	3.08×10^{-17}
Skin Dose Coefficient (Sv/s per Bq/m ²)*	2.53×10^{-15}	1.05×10^{-14}	3.68×10^{-17}
*The dose coefficients were obtained for exposure to contaminated ground surface from U.S. Environmental Protection Agency (1993).			

The beta dose to the skin was found to be limiting for ^{99}Tc and ^{147}Pm (European Commission, 1998) and for several pure beta emitters (Simon and Janssens, 2000). In addition, the beta dose to the skin was found to be limiting for ^{124}Sb (with a maximum beta energy of 2.31 MeV), despite the fact that ^{124}Sb also emits significant energetic gamma rays.

Adopting an arbitrary reduction factor of 10, the International Commission on Radiological Protection recommends public dose limits of 1.5 rem to the lens of the eye and 5 rem to the skin (International Commission on Radiological Protection, 1990). In comparison, 10 CFR Part 20 does not assign separate dose limits to the lens of the eye and to the skin for members of the public. Section 20.1301 of 10 CFR Part 20 stipulates an annual dose limit of 100 mrem for individual members of the public, where the external dose rates for an individual continuously present in an unrestricted area must not exceed 2 mrem in an hour and 50 mrem in a year. Section 20.1301, however, also includes that a licensee or license applicant can apply for annual dose limits to the public up to 500 mrem, which would be subject to additional conditions.

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From: Robert Meck
To: E-RIDS1; Golden, Betty
Date: 4/19/01 2:40PM
Subject: Please enter document into docket of comments

Dear Betty [and other],
Please add the attached file to the docket of comments on draft NUREG-1640. The request for comments reference is

64FR14952, March 29, 1999

Thanks,

Bob

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