USE OF ICRP-72 AND AGE-BASED DOSES FOR DECOMMISSIONING - A REAL-WORLD EXAMPLE

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ABSTRACT

The NRC staff recently reviewed a plan for the Kerr-McGee Technical Center in Oklahoma City, OK, to decommission the site and relinquish their license to possess radioactive materials, but maintain it as a general research facility. The licensee chose to evaluate site cleanup levels based on ICRP-72, using doses for adults, although ICRP-72 calls for evaluation of a range of ages. Prior to this review, NRC has evaluated decommissioning plans using the older ICRP-30 methodology. The NRC staff lacks specific guidance on the use of ICRP-72 dosimetry in its regulations, and the exposure of children. Since this license termination was unconditional, we performed calculations involving ICRP-72 dosimetry and exposure to children, and compared the results to doses calculated from the methods normally used. Results of the NRC=s analysis showed that annual doses for children using ICRP-72 were generally significantly higher than for adults using the same dosimetry, especially for contamination from indoor surfaces. However, annual doses using ICRP-72 dosimetry were generally significantly smaller than those using ICRP-30.

Since the risk to a person is generally considered to be proportional to the cumulative dose received since birth rather than the dose in a single year, we calculated integrated dose over 30 years. For the purposes of this demonstration we make simplifying assumptions concerning the cleanup levels, dose pathways, radionuclides involved, and minimum age considered. Integrating the dose rates for the age categories over 30 years and comparing it to the integrated dose received by an adult in the same period results in an increased risk of only about 28%, demonstrating that there is only a relatively small effect of ignoring age compared to other uncertainties in the analysis.

On the basis of the calculations and on the strength of the arguments for the likely future use of the site, we agreed with the licensee that the adult, as the average member of the critical group, is generally protective of all age groups likely to use the site. Furthermore, scenarios for which the site occupants would differ from the chosen scenario would be less likely, and therefore could receive a lower weight than the main scenario when risk is considered.

INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) staff recently reviewed a plan for the Kerr-McGee Technical Center in Oklahoma City, OK, to decommission the site and relinquish its license for radioactive material, but to maintain the site as a general research facility. The site is located northwest of Oklahoma City, Oklahoma, on approximately 160 acres (65 hectares). Operations involving radioactive materials were confined to portions of several buildings on the site, and to the uranium calibration test pits, which were used to calibrate instruments for uranium prospecting. Contamination at this site consisted mainly of natural uranium and thorium in the form of ores and process intermediates from former fuel-cycle facilities.

The licensee performed their analysis to specify Derived Concentration Guideline Levels (DCGLs) based on ICRP-72 dose factors. Although ICRP-72 stipulates the calculation of age-specific doses in 6 age groups, the licensee chose only to evaluate doses for adults.

Since this license termination was unconditional, and involved the first-of-its-kind decommissioning using ICRP-72 methodology, we performed calculations using the new dosimetry and exposure to children, and to compare those to doses calculated from the ICRP-30 dosimetry normally used. These calculations, and insights drawn from them, are presented below.

Licensee=s Justification of the Adult as the average member of the critical group

The licensee states that the Technical Center is the primary laboratory for research for the Chemical Division and will remain so for the foreseeable future. The laboratory employs approximately 85 people, who do not deal directly with radioactive substances. Only adults will be employed, and the presence of younger individuals will be only on an occasional basis, for short periods of time. The licensee argues that Kerr-McGee is not ignoring other age groups, but after deliberate consideration has decided that the adult was the likely age group for evaluating the site. Further, they argue that NRC guidance does not demand that the maximally exposed group has to be chosen for the purposes of dose assessments or that a Aworst case@ analysis has to be performed; only that the licensee has to consider expected exposure to the group that is most likely to use the facility.

The licensee considered the scenario for reversion of the laboratory sometime in the future to another use involving children. They argue that modification of areas of the laboratory where radioactive materials were used or stored would require significant new construction materials that would reduce the potential for exposure.

Staff=s Analysis of Licensee=s Use of ICRP-72, and Adult as Average Member of Critical Group

The staff lacks specific guidance on the use of ICRP-72 dosimetry in its regulations, and especially the exposure of children. There has been some reviews of licensed facilities using ICRP-72, but they always involved workers, and hence only dealt with adults. We conducted analyses to determine the differences in results from the use of ICRP-72 and the ICRP-30 dosimetry normally used in these decommissioning reviews, and how protective would be the use of the adult as the average member of the critical group for all age groups. These calculations were performed mainly to highlight differences in doses among the age groups rather than to calculate DCGLs for site cleanup. Therefore, we were more concerned with the relative values of DCGLs rather than absolute values calculated in this exercise.

The analysis consisted of a set of deterministic and probabilistic runs using the RESRAD [1] and RESRAD-BUILD [2] codes, comparing instantaneous doses for adults versus children, both using ICRP-72 dose factors for the respective age categories. For general soil contamination, we considered doses from the standard set of RESRAD pathways for the resident farmer scenario, which included direct γ radiation, inhalation of dust, and ingestion of plants, meat, milk, aquatic food, drinking water and soil. For the contaminated uranium pits, we considered the same resident farmer scenario, except the contaminated area covered only a 100 m^2 versus the 10,000 m^2 for the soil case. In addition, the contaminated soil for the test pits was assumed to be buried under 3.66 meters of soil, whereas it was assumed to be on the surface for the soil decontamination case.

For indoor exposures, we used the standard set of RESRAD-BUILD pathways, including direct γ radiation and inhalation, but no direct ingestion. The licensee presented data on the removable fraction for contaminated surfaces based on surface swipes and the ratio between fixed plus removable β surveys and β smear surveys. The highest removable fraction found in their survey was about 10 percent, and the minimum was zero. The average removable fraction deduced from these measurements was 0.007.

Most of the RESRAD and RESRAD-BUILD runs were probabilistic, using mostly parameter ranges from NUREG/CR-6755 [3]. However usage factors for inhalation and ingestion were kept at fixed values for each age category to simplify the interpretation of age-dependent results. For the probabilistic results, only mean dose values were reported.

Dose Factors from ICRP-72

Ingestion and inhalation dose factors are presented in Table I for ICRP-72. The inhalation dose factors represent the worst-case absorption for each age category. Currently, RESRAD Version 6.23 allows the definition of a new dose factor library, so an ICRP-72 was created for these cases. RESRAD-BUILD version 3.1 does not have the same provision, and the file NUCDCF.DAT had to be edited manually to include the new dose factors.

Table I. Dose factors, Sv/Bq from ICRP-72, most conservative inhalation absorption class

Nuclide	**3mo**	**3mo**	**1yr**	**1yr**	**5yr**	**5yr**	**10yr**	**10yr**	**15yr**	**15yr**	**adult**	**adult**
	Ingest	**Inhale**	**Ingest**	**Inhale**	**Ingest**	**Inhale**	**Ingest**	**Inhale**	**Ingest**	**Inhale**	**Ingest**	**Inhale**
Pb210	8.4e-6	1.8e-5	3.6e-6	1.8e-5	2.2e-6	1.1e-5	1.9e-6	7.2e-6	1.9e-6	5.9e-6	6.9e-7	5.6e-6
Ra226	4.7e-6	3.4e-5	9.6e-7	2.9e-5	6.2e-7	1.9e-5	8.0e-7	1.2e-5	1.5e-6	1.0e-5	2.8e-7	9.5e-6
Ac227	3.3e-5	1.7e-3	3.1e-6	1.6e-3	2.2e-6	1.0e-3	1.5e-6	7.2e-4	1.2e-6	5.6e-4	1.1e-6	5.5e-4
Th228	3.7e-6	1.8e-4	3.7e-7	1.5e-4	2.2e-7	8.3e-5	1.4e-7	5.5e-5	9.4e-8	4.7e-5	7.2e-8	4.0e-5
Th230	4.1e-6	2.1e-4	4.1e-7	2.0e-4	3.1e-7	1.4e-4	2.4e-7	1.1e-4	2.2e-7	9.9e-5	2.1e-7	1.0e-4
Th232	4.6e-6	2.3e-4	4.5e-7	2.2e-4	3.5e-7	1.6e-4	2.9e-7	1.3e-4	2.5e-7	1.2e-4	2.3e-7	1.1e-4
Pa231	1.3e-5	2.2e-4	1.3e-6	2.3e-4	1.1e-6	1.9e-4	9.2e-7	1.5e-4	8.0e-7	1.5e-4	7.1e-7	1.4e-4
U234	3.7e-7	3.3e-5	1.3e-7	2.9e-5	8.8e-8	1.9e-5	7.4e-8	1.2e-5	7.4e-8	1.0e-5	4.9e-8	8.4e-6
U235	3.5e-7	3.0e-5	1.3e-7	2.6e-5	8.5e-8	1.7e-5	7.1e-8	1.1e-5	7.0e-8	9.2e-6	4.7e-8	8.5e-6
U238	3.4e-7	2.9e-5	1.2e-7	2.5e-5	8.0e-8	1.6e-5	6.8e-8	1.0e-5	6.7e-8	8.7e-6	4.5e-8	8.0e-6

Usage Factors for Adults and Children

Usage factors were compiled from several sources. Table II shows the ratios of usage factors for inhaled air, ingested water, food calories and cow=s milk, derived from Eckerman [4]. This table assumes that an adult is the average of a 20-year old male and female user, and gives the ratio of usages for average members of each age group to the adult user. Ratios from Table II are then used to generate age-specific inputs for outdoor soil and groundwater DCGLs. We used a somewhat different set of references for inhalation for the indoor surface DCGL=s, because inhalation rates are likely to be lower for indoor activities. For indoor surface DCGLs, we used breathing rates directly from EPA [5], averaged for males and females. All of the derived usage factors for RESRAD and RESRAD-BUILD calculations are given in Table III.

Table II Usage Factor Ratios from Table 3.1 in Eckerman [4]

Age group	Air Ratio	Water Ratio	Food Calories	Cow=s Milk
Adult	1	1	1	1
15 yr	0.895	0.856	0.873	1.32
10 yr	0.765	0.729	0.738	1.38
5 yr	0.44	0.551	0.815	1.24
1 yr	0.26	0.233	0.316	1.07
0 yr	0.145	0.201	0.194	1.04

Table III Usage Factors for Age Groups 1 year to Adult

Usage	1 year	5 year	10 year	15 year	Adult
Breathing Rate, Farm m^3/yr	2180	3700	6430	7520	8400
Breathing Rate, Indoor m^3/yr	2154	3249	4928	5146	4836
Exposure Duration, Yr	69	65	60	55	50
Fruits and Vegetables, Kg/yr	52.5	102	123	145	166
Leafy Vegetables, Kg/yr	3.5	6.8	8.1	9.6	11
Milk, Liters/yr	107	124	138	132	100
Meat and Poultry, kg/yr	19.9	38.7	46.5	55	63
Fish, Kg/yr	1.7	3.3	4	4.7	5.4
Other seafood, Kg/yr	0.28	0.55	0.66	0.79	0.9
Outdoor soil ingest, gr/yr	66.6	66.6	66.6	18.25	18.25
Drinking Water, liters/yr	170	402	532	625	730
Indoor ingest, m^2/yr	0.011	0.011	0.011	0.00011	0.00011

Other fixed factors for RESRAD-BUILD analysis of indoor surfaces:

Time for release = 365 days
Release fraction 0.007
6 sources
250 total days per year
Fraction inside = 0.685
Room height = 3 M
Room area = 36 M^2

Deposition velocity = 3.9×10^{-4} M/s
Resuspension rate = 6.26×10^{-8} /s
No direct ingestion
Removable fraction 0.007
Removal time = 365 days
Fraction released to air = 0.1

Although it would have been possible to calculate a dose for the 3-month age category, its meaning and usefulness to the present analysis were questionable. We reasoned that children so young are likely to be carried in arms, receive only a milk diet, and generally would not be exposed by way of ingestion from hand-to-mouth as would older children. For this reason, we report only doses from one year old children and older, and grouped infants with the one-year olds.

Correction Factors for Direct Radiation

Neither RESRAD nor RESRAD-BUILD currently allows modification to dose weighting factors for direct radiation. Therefore, direct radiation doses to children were adjusted using guidance from NCRP Report 129 [6], which suggests that children will receive from 10 to 30 percent higher doses than for typical adults, with a larger ratio for low-energy γ, β and x-ray emitters. The direct exposure doses to all children was therefore increased by 30 percent.

Soil DCGLs

We conducted a set of deterministic and probabilistic RESRAD runs comparing cleanup levels for the three radionuclide series; (1) uranium series isotopes U-238, U-235 and U-234 plus progeny, (2) Th-232, Th-228 and Ra-228 and progeny, and (3) Th-230, Ra-226 and progeny. These runs were for all age categories greater than or equal to one year using age-specific dose conversion factors from ICRP-72, In addition, we chose age-specific usage factors, and worst-case inhalation absorption factors from ICRP-72. Differences between the probabilistic and deterministic runs were minor, so we present here only the probabilistic mean results. The soil DCGLs for the three radionuclide groups were: (1) Uranium series - 210 pCi uranium/gram (7.8 Bq/gram); (2) Th-232 and progeny - 6.4 pCi thorium/gram (0.25 Bq/gram); and (3) Th-230 and progeny - 3.73 thorium/gram (0.14Bq/gram).

Age-dependent doses - Table IV shows the doses to the adult resident farmer relative to those for five of the six age classes stipulated in ICRP-72, using ICRP-72 dose factors. Assumptions about age-specific usage factors are shown in Table III.

Table IV Age Related Doses for Soil using ICRP-72

Age Category	U series and Progeny-mrem/pCi U	Ratio to Adult	Th-232, Th228 and Ra-228, mrem/pCi Th	Ratio to Adult	Th-230, and progeny mrem/pCi Th	Ratio to Adult
Adult	0.06262	1	3.097	1	4.518	1
15 yr old	0.0787	1.26	3.98	1.29	6.44	1.43
10 yr old	0.0958	1.53	4.02	1.3	6.52	1.44
5 yr old	0.101	1.61	4.02	1.3	6.7	1.43
1 yr old	0.111	1.77	4.02	1.3	6.7	1.48

Contaminated Soil in Uranium Pit

Our deterministic DCGL using ICRP-72 was 136 pCi uranium/gram (5 Bq/gram). The relative doses for all age category are summarized in Table V. The largest dose from these calculations was for the 15-yr old age category, due mainly to Ra-226.

Table V Age related doses for groundwater contamination at uranium pit using ICRP-72

Age Category	Dose mrem/pCi	Ratio to Adult Dose
Adult	0.1839	1
15 yr old	0.2791	1.52
10 yr old	0.219	1.19
5 yr old	0.1942	1.06
1 yr old	0.1258	0.684

Dose from Exposure to Contaminated Surfaces in Buildings

Uranium series - The calculated deterministic surface DCGLs for the radionuclide groups using ICRP-72 were: (1) uranium series -146,200 DPM/100 cm^2; (2) Th-232 and progeny - 11,100 DPM/100 cm^2; and (3) Th-230 and progeny -16,100 DPM/100 cm^2. Doses to the five age categories are given in Table VI for indoor exposure from contaminated surfaces, relative to the adult dose. Doses for children are up to a factor of about 2.5 larger than the adult.

Table VI Summary of RESRAD-BUILD Results using ICRP-72

Age Class	U Series - mrem/pCi U	Ratio to adult	Th-232 mrem/pCi Th	Ratio to adult	Th230 mrem/pCi Th	Ratio to adult
Adult	1.71E-4	1	2.25E-3	1	1.55E-3	1
15 yr	2.17E-4	1.27	2.91E-3	1.29	1.86E-3	1.2
10 yr	3.5E-4	2.05	3.59E-3	1.6	3.6E-3	2.32
5 yr	3.92E-4	2.29	3.77E-3	1.68	3.85E-3	2.48
1 yr	4.15E-4	2.43	3.48E-3	1.55	3.67E-3	2.37

Protectiveness of Adult Dose Applied to Children

The question of whether the choice of the adult as the average member of the critical group is protective of children has been considered in formulating other NRC regulations, particularly 10CFR63 for the proposed Yucca Mountain high-level waste repository. In response to questions asked during the rule-making period, NRC responded that:

- The purpose of the public dose limit is to limit the lifetime risk from radiation to a member of the general public. The conversion factor used to equate dose into risk is based on data from various populations exposed to very high doses of radiation such as the atomic bomb survivors, and these populations contained individuals of all ages. Therefore, variation of the sensitivity to radiation with age and gender is built into the standards which are based on a lifetime exposure. A lifetime exposure includes all stages of life from birth to old age...@ [7].

Several other reasons can be cited to support the notion that the use of the adult as the average member of the critical group is appropriate:

- The concept of an Aaverage member of the critical group@ recognizes that the there will be a range of individuals in that group, some more affected by radiation and some less. If children are more affected by some of the radionuclides by factors of less than 3, it could be argued that they are still members of the critical group, just not the average member.

- The facility is being used as a laboratory by adults, and no children would be expected to stay in the building or grounds other than for short visits.

- Should the facility convert to some other purpose in the future that would allow significant use by children (e.g., a day care center), it would probably involve renovation, including replacement, painting, sealing or renewal of walls, ceilings, and floors.

- The dose a person receives in a single year contributes to an overall risk over their lifetime. Risk to a person is proportional to the cumulative dose he or she received since birth. In the Statement of Consideration for the License Termination Rule, risks were estimated assuming a 30-year lifetime exposure A...from contaminated sites based on the assumption that it is unlikely that an individual will continue to live or work in the same area for more than 30 years@[8]. Applying this same philosophy of a 30-year accumulation of risk, it is possible to demonstrate the difference in assuming that the exposed person is always an adult, versus assuming age-based doses in each category.

  For the purposes of this demonstration we make the following simplifying assumptions:

  - The site has been cleaned-up precisely to the DCGLs for soil, groundwater and building surfaces.

  - The person gets an equal dose from the soil, groundwater and building-surface pathways.

  - The person gets an equal dose from each of the three radionuclide groups; i.e., U-238 through U-234, Th-232 and progeny, and U-230 and progeny.

  - Children in the first year (i.e., 0 to 1 year) receive the same dose as the one-year old child.

Figure 1 shows the ratio of child to adult doses averaged over all radionuclides and pathways for ages zero to 30 years. We determined the average dose by trapezoidal integration under this curve. Integrating the dose rates for the age categories from zero to 30 years and comparing it to the doses received to an adult in the same period results in an increased risk of about 28 percent, which is relatively small when other uncertainties in the model and inputs are taken into account. The modest increase in integrated risk to children demonstrates that there is only a small effect of ignoring age-related dose in setting the DCGLs.

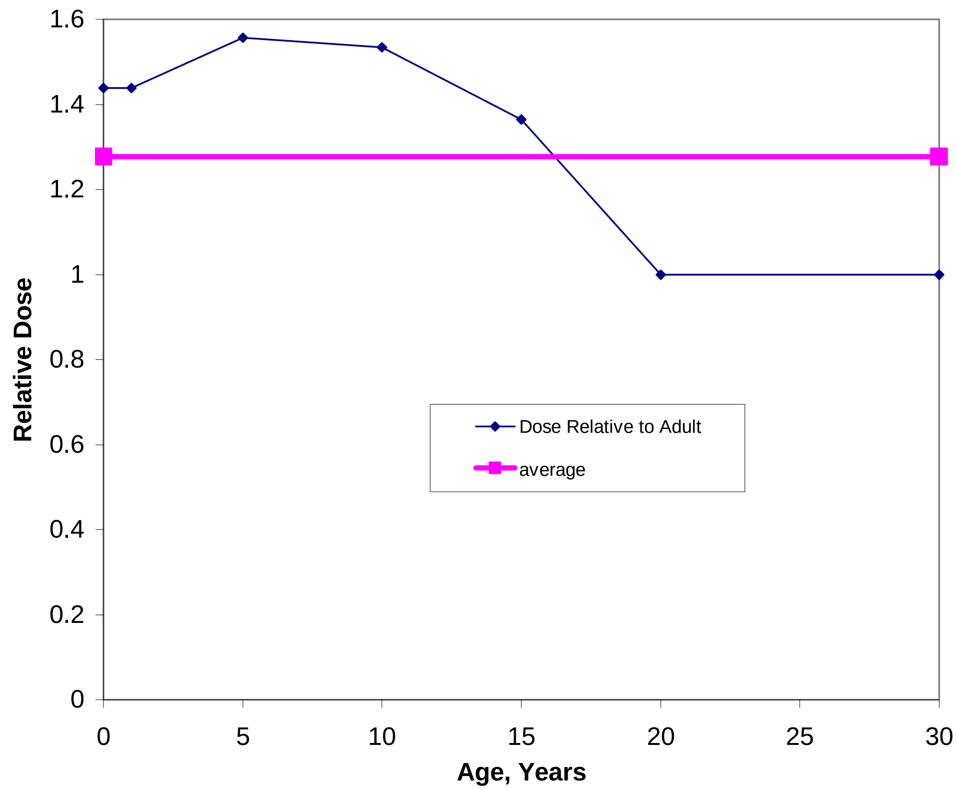

Fig. 1 Integration of Relative Dose over 30 Years

Comparison of ICRP-72 Dosimetry and Standard Approach

Table VII shows the comparisons for doses for the adult age group calculated from RESRAD and RESRAD-BUILD using the ICRP-72 and the default ICRP-30 dosimetries. All runs presented in this table were deterministic, although probabilistic runs for RESRAD gave similar results. The higher allowed DCGLs resulting from ICRP-72 reflect their generally smaller dose factors.

Table VII Comparison of Adult Doses from ICRP-72 Dosimetry and ICRP-30 Dosimetry for Soils and Surfaces

Radionuclide Group	Ratio ICRP-30 results to ICRP-72 results - RESRAD soil	Ratio ICRP-30 results to ICRP-72 results RESRAD-BUILD surfaces
Uranium Series	2.31	2.73
Th-232 Series	1.04	0.97
Th-230 Series	1.2	1.8

CONCLUSIONS AND RECOMMENDATIONS

We believe that it is appropriate to use the adult as the average member of the critical group in this example, and that it is generally protective of all age groups likely to use the site. Furthermore, scenarios for which the site occupants would be different from the chosen scenario would be less likely, and therefore could receive a lower weight than the main scenario when risk is considered. We caution that conclusions drawn from the present study may not necessarily apply to all other sites, Therefore NRC we will continue to evaluate each site on an individual basis.

Disclaimer

The conclusions drawn in this paper are solely the opinions of the authors, and do not necessarily represent the opinions of the Nuclear Regulatory Commission.

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