Development of Site-Specific Shielding Factors for Use in Radiological Risk Assessments—10112

Cynthia Barr, Duane Schmidt, and Sami Sherbini
United States Nuclear Regulatory Commission

ABSTRACT

External gamma shielding factors (or transmission factors) are typically used in decommissioning dose assessments to account for attenuation of gamma radiation by building materials and the resulting reduction in dose to a potential receptor while indoors (e.g., resident in his home or industrial worker in a building). The shielding factor is one of the most important parameter values impacting dose for those cases where the external dose pathway dominates the risk from residual soil contamination (e.g., cases where no soil cover exists and penetrating gamma-emitting radionuclides are the primary residual radioactivity at the site). In cases where the external pathway dominates the dose, the choice of an appropriate shielding factor for conditions found at the site can mean the difference between compliance and non-compliance with radiological criteria for license termination for a decommissioning licensee. Default parameter values used in decommissioning dose modeling codes such as RESRAD are typically pessimistic. Parameter distributions developed for probabilistic assessments are necessarily based on national statistics on building types/materials and a few “representative” radionuclides. Thus, the generic parameter distributions may either over- or under-estimate the potential dose compared to dose estimates that consider the actual mix of radionuclides and types of buildings expected to be constructed at the site.

Shielding calculations were performed using the MCNPX Monte Carlo radiation transport code to estimate gamma shielding factors for use in RESRAD to reduce the uncertainty in dose estimates for a thorium contaminated site. Regional-specific information was used to evaluate the types of buildings or residences expected to be potentially constructed in the area. Additional considerations included the impact of (i) in-growth of daughter products that introduced changes in gamma energy distributions over time, (ii) potential changes in source/receptor geometries over time due to leaching and erosional processes, and (iii) heterogeneity of contaminant distributions. This work was performed to explore the feasibility of calculating, and using, site-specific shielding factors and to study the impact of shielding factors on the resultant doses and decommissioning decisions. Application of this approach was appropriate and timely because of certain characteristics of the test case used in this work. This case presented conditions that led to fairly significant uncertainties in the dose estimates, and developing site-specific shielding factors was one method used to reduce this uncertainty.

INTRODUCTION

The AAR Manufacturing, Inc. site is located in Livonia, MI just outside of the Detroit metropolitan area. The site is contaminated with natural thorium (and associated daughters that have grown in since the site began operations in the late 1950s) as a result of manufacturing processes using thorium alloys to produce products such as ingots. Soil contamination is confined to the upper two meters of the site with concentrations in the upper meter significantly greater than concentrations in the one to two meter interval (i.e., heterogeneity in the source term exists). The groundwater pathway was eliminated from consideration based on hydrogeological considerations and evaluation of reasonably foreseeable land use scenarios (e.g., local and state code restrict the use of shallow drinking water wells in the area). Although the site is zoned industrial, a resident gardener scenario was evaluated as the critical group to demonstrate compliance against the United States Nuclear Regulatory Commission’s (NRC’s) radiological criteria for license termination based on an evaluation of reasonably foreseeable land use. Previous dose assessments performed for the site using the Residual Radioactivity or RESRAD code indicated that the external gamma pathway and the plant ingestion pathway were the most significant for the site and mix of radionuclides expected to be present following remediation. Due to conditions existing at this site, it is expected that restrictions will be needed to ensure that doses associated with residual contamination in the western portion of the site will be less than 0.25 mSv/yr (25 mrem/yr) total effective dose equivalent (TEDE) to the average member of the critical group, and less than 1 mSv/yr (100 mrem/yr) TEDE in the event institutional controls (or restrictions) fail, as specified in the license termination rule found in 10 CFR 20, Subpart E for restricted release (10 CFR 20.1403). Because dose estimates showed a large amount of uncertainty with respect to the site's ability to meet license termination rule (LTR) criteria, recent NRC staff evaluations have focused on reducing the uncertainty associated with dose estimates for residual contamination and associated compliance with LTR criteria.

Because under certain assumptions[1], the external gamma dose dominates the peak of the mean dose, which is used as the metric to demonstrate compliance with LTR criteria in probabilistic assessments, NRC staff attempted to reduce the uncertainty associated with the single-most important parameter affecting this pathway, the external gamma shielding factor.[2] This paper presents the approach used to develop site-specific shielding factors for the AAR site located in Livonia, MI, results of the site-specific analysis, and conclusions regarding the general applicability of this approach to other complex decommissioning projects.

APPROACH

Sensitivity analyses showed that the external gamma shielding factor and radium plant transfer factors were the most important parameters impacting the peak of the mean dose. When uncertainty in the radium plant transfer factor was reduced with the most up-to-date information available in the literature and regional-specific ingestion rates of plant products based on information provided in the US Environmental Protection Agency (EPA) Exposure Factors Handbook [1], most of the readily reducible uncertainty in the dose predictions rested with the external gamma shielding factor. Sources of uncertainty in this factor included lack of consideration of radionuclide-specific gamma energy distributions and variability in potential building types (and associated receptor/source geometries) that might be constructed at the site[3]. It is important to note that the RESRAD code used to perform the dose calculations does not perform shielding calculations on its own. Instead, RESRAD uses the external gamma shielding factor to account for the reduction in dose to a receptor while indoors due to shielding from building materials. This shielding factor is calculated external to RESRAD. The default parameter value in RESRAD is 0.7, which results in a thirty (30) percent reduction in the dose due to shielding afforded by the residence. The default parameter distribution in probabilistic RESRAD is represented by a bounded lognormal distribution that varies between 0.044 and 1.0 with a mean and standard deviation of the underlying normal distribution of -1.3 and 0.59, respectively [2]. This parameter distribution was constructed using Bayesian techniques and based on a number of assumptions regarding the types of residences expected to be constructed (e.g., brick or wood-framed; wood flooring or concrete base slab or basement) and five receptor locations. Furthermore, only a handful of radionuclides (i.e., Cs-137, Co-60, Mn-54, U-238, and Ra-226) were considered. Therefore, it was not clear if use of the default external gamma shielding factor parameter distribution in RESRAD would lead to peak of the mean doses that

---

[1] The plant pathway may also dominate the risk for the site under certain assumptions (e.g., plant ingestion rates) and considering the uncertainty in plant transfer factors for contaminants remaining at the site. However, in recent assessments the uncertainty in this pathway was reduced and found to contribute much less to the peak dose compared to earlier assessments.

[2] It is important to note that occupancy factors (i.e., indoor and outdoor time fractions) have a large influence on the external dose pathway; however, these parameters are fixed by the scenario being evaluated (e.g., resident gardener) and thus do not add to the uncertainty in the dose predictions (see NUREG/CR-5512, Volume 3).

[3] The default external gamma shielding factor parameter distribution available in RESRAD considers national statistics on building types to evaluate a sub-set of shielding materials and a sub-set of radionuclides that may be present at a decommissioning site (i.e., the parameter distribution is not radionuclide-specific).

would tend to over- or under-estimate the potential dose as compared to use of shielding factors that considered the actual mix of radionuclides (and expected building types) present at the site. In an attempt to reduce the level of uncertainty introduced by using the generic RESRAD shielding factors, NRC staff decided to explore the use of site-specific factors instead.

Initially, NRC staff used the MicroShield software [3] to calculate shielding factors. However, it was determined that the geometries available in the MicroShield software were too limited to evaluate particular configurations (e.g., a receptor located inside a house with a basement, where contamination surrounded the house but was not underneath the house). With the exception of the crawlspace scenario discussed below and due to the limitations associated with the Microshield code, NRC staff decided to use the Monte Carlo N-Particle eXtended transport code or MCNPX code (version 2.5.0) [4] to calculate shielding factors due to its flexibility to model more complex geometries and due to the availability of staff expertise in this area. The MCNPX code is a Monte Carlo radiation transport code that enables modeling of realistic geometries of considerable complexity and in great detail, including the distribution of contaminant in the soil and the details of building materials and construction. Furthermore, use of the MCNPX would also allow comparison to be made against similar Microshield calculations for verification purposes in situations where suitable realistic geometries were available in Microshield. This section summarizes the selection of a sub-set of building configurations based on regional-specific information and provides details related to the MCNPX calculations used to estimate shielding factors for use in RESRAD.

Building Types and Geometries Evaluated

The staff evaluated the likelihood of different foundation types being used in resident construction. Residences of interest are only new construction, as resident buildings do not presently exist on the AAR site. The U.S. Census tracks data on foundation types used in new home construction. The data are generally available for regions of the U.S., but not for individual States or local areas. Staff obtained data for the Midwest region, for the period 1971–2007 [5]. For this complete period, the foundation types for new homes averaged 78% basements, 12% slab (or other), and 11% crawl space (sum exceeds 100% due to rounding). From these data, use of crawl space construction shows a decreasing trend over time, with the average for the last five years of the period being 6%. NRC staff contacted the City of Livonia, Michigan, to discuss types of foundations used in Livonia. The plan reviewer for resident building permits stated that no houses have been built with crawl spaces in Livonia for many years [6]. Based on this information about foundations in Livonia, and on the decreasing trend in the use of crawl spaces regionally, the NRC staff considers the use of crawl spaces for future construction to be less likely but plausible. With this designation, doses will be calculated for this foundation configuration to inform the decision in the AAR case, but are not considered required for compliance. Foundation types of a slab and a basement are considered reasonably foreseeable and are analyzed for compliance.

In addition, NRC staff has considered different types of siding that may be used on houses. Staff has chosen to consider two different types—wood-sided and brick-sided houses. These variations are considered only for the slab foundation type, as discussed in the following section. For other building types, the more conservative[4] wood-sided house was considered.

With the exception of the crawlspace building type, calculations were performed for local or elevated areas of contamination (assumed to be located directly underneath or side-gradient to the residence) and for general contamination assumed to be located underneath and surrounding the house (house is located in the center of a 10,000 m^2 area of contamination) that is essentially infinite in extent (the source

[4] For the purposes of this paper, the term "conservative" is used to imply that the doses are expected to be over- rather than under-predicted with all other factors being equal.

becomes infinite at around 500 m^2 and 0.3 m thick). When smaller elevated areas of contamination are assumed, the doses are added to doses from the larger area general contamination in attempt to account for the potential increase in dose due to “hot spots” or elevated areas.

Slab Foundation Geometry and Parameters

The first building type evaluated was the residence built on a slab foundation with various types of siding. According to the Michigan Resident Code of 2003, requirement R506.1, concrete slabs for resident spaces must be a minimum of 8.9 cm (3.5 inches) thick. Based on information provided in the Michigan Resident Code, the staff has assumed that a typical slab foundation would include a 10-cm (4-in) slab on ground with a gravel sublayer of 10 cm (4 in). Additional details of the geometry are as follows. The house is a one-floor house, with the concrete slab and gravel layer on top of existing ground level. The gravel was considered to have the same composition and density of the soil. Parameters for the slab foundation scenario are listed in Table I.

Table I. Description of Parameters Used for the Slab Foundation Shielding Factor Calculations

Slab Foundation	
Parameter	**Description**
Basic geometry	house sits above the grade of the contaminated soil
Footprint area of house	10 m × 10 m (33 ft × 33 ft)
Size of contaminated area-for elevated area assessment	equal to footprint of house
Size of contaminated area for general area assessment	100 m × 100 m (330 ft × 330 ft)
Thickness of contaminated area	2 m (6.6 ft)
Foundation and floor	10 cm (4 inch) thick layer of gravel, density 1.5 g/cm^3; 10 cm (4-inch) thick concrete slab floor, density 2.25 g/cm^3.
Height of walls	2.5 m (8 ft)
Windows	2 panes of glass, each 0.6 cm (0.25 inches) thick, size 4 m × 1.25 m (13 ft × 4 ft) (a single window representing multiple actual windows), density 2.2.3 g/cm^3.
Wood-sided house: wall construction	wood siding on wood sheathing, effective thickness 2.54 cm (1 inch), density 0.7 g/cm^3; gypsum inner wall 1.25 cm (0.5 inch) thick, density 2.32 g/cm^3.
Brick-sided house: wall construction	brick siding, thickness 10 cm (4 inches), density 2.25 g/cm^3.

As indicated in Table I, two types of outer siding are considered: wood and brick. For the wood-sided house, the walls of the house are made up of an outer layer of wood, 2.54 cm (1 inch) thick and an inner layer of gypsum, 1.25 cm (0.5 inch) thick. For the brick sided house, the brick siding is considered to be 10 cm (4 inches) thick. Each of the four walls has a window located centrally in the wall (a single window representing multiple actual windows), covered with a glass pane about 0.6 cm (0.25 inch) thick with the outer glass surface flush with the outer wall surface of the house. A composite of the two types of siding for slab houses is also calculated for use in the dose modeling. An NRC technical report that details development of parameter distributions in probabilistic RESRAD [2] provides a breakdown of the principal building materials for exterior walls. Based on data from the late 1990s, 27% of homes had brick or stone (assumed similar to brick for shielding); 56% had wood or vinyl or aluminum (the latter two are assumed similar to wood for shielding); and the remaining 17% had stucco (also assumed similar to wood for shielding). Based on this breakdown, a composite shielding factor is based on weighting factors of 27% for brick siding and 73% for wood siding.

Basement Geometry and Parameters

The house with a basement is different from the slab foundation house. The basement is assumed to be 2.5 m (8 ft) in height, and fully below grade. The house has two floors above the basement. The construction of the walls and windows for the first and second floor are identical to those of the one-floor house with wood-siding. The basement walls and floor are made of 10 cm (4 inch) concrete, with no windows. The parameters for the basement scenario are listed in Table II.

Table II. Description of Parameters Used for the Basement Foundation Shielding Factor Calculations

Basement Foundation	
Parameter	**Description**
Basic geometry	house sits *in* the ground, so no contaminated material is below the basement floor; contaminated soil is next to (for elevated area contamination) or surrounds (for generalized contamination) the basement walls
Depth of basement floor	2.5 m (8 ft) below grade
Footprint area of house	10 m × 10 m (33 ft × 33 ft)
Size of contaminated area-for elevated area assessment	equal to footprint of house
Size of contaminated area-for for general area assessment	100 m × 100 m (330 ft × 330 ft)
Thickness of contaminated area	2 m (6.6 ft)
Basement walls	10 cm (4 inch) thick concrete walls, density 2.25 g/cm^3.
Height of walls for each level of house	2.5 m (8ft)
Windows on first and second floors of house	2 panes of glass, each 0.6 cm (0.25 inches) thick, size 4 m × 1.25 m (13 ft × 4 ft) (a single window representing multiple actual windows), density 2.2.3 g/cm^3.
Wood-sided house: wall construction	wood siding on wood sheathing, effective thickness 2.54 cm (1 inch), density 0.7 g/cm^3; gypsum inner wall 1.25 cm (0.5 inch) thick, density 2.32 g/cm^3.
Floors in house (e.g., between basement and first floor)	wood floor assumed, effective thickness 2.54 cm (1 inch), density 0.7 g/cm^3

Crawl Space Geometry And Parameters

The staff evaluated the crawl space foundation as a 1-meter crawl space with a 5 cm (2 in) thick drainage layer. For the crawlspace configuration, some type of subfloor must be used, and a total thickness of 2.5 cm (1 in) of wood (subfloor plus finished floor) is assumed. The crawl space geometry was only evaluated for elevated area contamination (elevated area assumed to be coincident with the footprint of the house). Parameters for the crawl space scenario are listed in Table III.

Table III. Description of Parameters Used for the Crawl Space Foundation Shielding Factor Calculations

Crawl Space Foundation	
Parameter	**Description**
Basic geometry	house sits above the grade of the contaminated soil
Footprint area of house	10 m × 10 m (33 ft × 33 ft)
Size of contaminated area-for elevated area assessment	equal to footprint of house
Thickness of contaminated area	1 m (3.3 ft)
Foundation and floor	5.0 cm (2 inch) thick layer of gravel drainage layer, density 1.8 g/cm^3; 2.5 cm (1-inch) thick wood floor, density 0.6 g/cm^3.

Geometry of Receptor Locations

The specific location of a receptor within the house can make a significant difference in the shielding provided by floors and walls. In this assessment, the NRC staff makes an assumption that the average member of the critical group would spend equal amounts of time in all areas of the main living floors of a house. For the slab foundation house, this simply means equal amounts of time in all areas of the single floor house. For the basement foundation house, the staff assumes that essentially all time is spent on the first floor above the basement (with equal amounts of time in all areas of that floor). Preliminary calculations included calculations of the shielding factor for receptors in the basement floor, first floor, and second floor, and the results were that the first floor shielding factor is between those of the basement and second floors, with lower shielding factors (thus less dose transmitted) for the basement. Thus, the staff believes this assumption about location (the first floor) is reasonable.

To implement the assumption that equal time is spent in all areas of a floor, the staff made the simplifying assumption that the 10 m ×10 m (33 ft × 33 ft) house is composed of 25 equal-sized compartments. Figure 1 depicts these compartments and the labels given to each unique compartment.

A	B	C		
	D	E		
		F		

Fig. 1. Illustration of Unique Receptor Locations within a 100 m^2 Square Residence and with Contamination (Not Depicted) either (i) Underneath the Residence or (ii) Underneath and Surrounding the Residence

The labeled locations (A–F) would have different time weighting factors, based on the number of similar subgrids within the overall floor. These weighting factors are applied to shielding factors calculated for each individual receptor location.

For the case of a basement foundation and an elevated area located next to the house rather than underneath the house, six receptor points are insufficient, because symmetry does not exist in both x and y directions. For this case, shielding factors must be calculated for 15 of the 25 equal sized compartments, as indicated in Figure 2 (column and row indices provide spatial information).

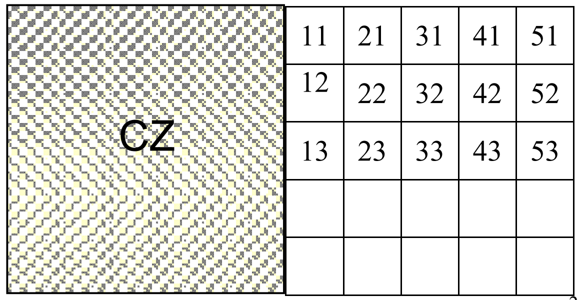

Fig. 2. Illustration of Unique Receptor Locations within a 100 m^2 Square Residence and with the Contamination Zone (CZ) Side-Gradient of the Residence

Radionuclides Considered

The radionuclides of interest are the Th-232 series and Th-230 and its progeny. These radionuclide chains have relatively similar energies for the gamma emissions. Preliminary calculations using the MicroShield code indicated very small differences between shielding factors for the Th-232 series emissions and the Th-230 progeny emissions, but the shielding is less effective for the Th-232 emissions. A complication of the RESRAD runs is that the relative contributions of Th-232 series and Th-230 progeny vary with time for some of the scenario calculations, which could involve variation in the shielding factor over time. To avoid this, a single shielding factor, from a single set of radionuclides, is desired. Therefore, for the MCNPX runs, photon energies for the Th-232 series were used. This is conservative for cases when Th-230 progeny are important.

Other Considerations

Another consideration related to the development of site-specific shielding factors was the change in source geometry over time due to various transport processes. For example, RESRAD considers depletion of the source/thickness over time due to removal (erosional) processes. Similarly, leaching results in the transport of contaminants out of the source area and into the vadose zone assumed to be located directly underneath the contamination zone, while the shielding factors calculated for this assessment considered time-invarient source/receptor geometries. This approach is considered acceptable because (i) surface contamination contributes most significantly to dose and shielding factors are not sensitive to source thickness beyond some nominal thickness (around 0.3 m), and (ii) shielding factors calculated assuming no leaching are expected to err on the side conservatism as compared to shielding factors calculated assuming contamination is transported below the surface where surface soils provide additional shielding. Therefore, consideration of time-invarient shielding factors in this manner is considered conservative.

Dose modeling for the AAR site also considered the heterogeneity of contaminant distributions in the subsurface (i.e., concentrations in the 0 to 1 meter interval were significantly higher than the 1 to 2 meter interval). However, shielding factors were calculated assuming no heterogeneity in contaminant concentrations. This assumption is considered acceptable because deeper contamination in the 1 to 2 meter interval is not expected to contribute significantly to dose and as stated above, shielding factors are expected to err on the side of conservatism for deeper contamination (e.g., higher (more conservative) shielding factors representative of the 0 to 1 meter interval were used for the 1 to 2 meter interval [1 to 2 meter interval shielding factors would be expected to be lower]).

RESULTS OF SHIELDING CALCULATIONS

The shielding factors are the ratios of doses at the various receptor points within the house with shielding to the dose at the location “F” in Figure 1 or location “33” in Figure 2, which represents the reference points in the center of the house where RESRAD evaluates dose, with no shielding. Results are provided in Table IV. The weighted mean shielding factors are based on the weighting factors for locations A–F in Figure 1 (or for the fifteen locations calculated for the basement case with elevated area contamination side-gradient to the house illustrated in Figure 2). The weighted mean shielding factors are used in the dose assessment.

For the crawl space geometry, the MicroShield Code (version 7) [3] was originally used to calculate shielding factors. This was done because (i) the geometries available within the MicroShield code are adequate to represent the crawl space geometry for elevated area contamination and (ii) the crawl space geometry is used for a scenario that is considered less likely, so the results are not used for compliance; this calculation is thus less critical than for other scenarios, and the MicroShield results are considered acceptable.

Results of the analysis are provided in Table IV. In general, shielding factors calculated for this assessment are larger (more conservative) than the mean shielding factor used in RESRAD (mean of the default lognormal distribution). This result is significant as it supports development of site-specific shielding factor parameter distributions for use in probabilistic RESRAD to ensure that the default parameter distribution available in RESRAD does not underestimate the potential dose from this pathway. The results also show that the basement (most likely) and concrete base slab scenarios (realistically conservative case) provide virtually the same level of protection for the general contamination case (configurations 2 and 5 in Table IV). As expected, brick walls provide significant shielding as compared to wood framed homes (see for example difference in configurations 2 and 4 in Table IV). Concrete base slabs provide significant shielding for elevated area contamination located directly underneath a residence (see configuration 1 in Table IV; only 10 percent of the dose is realized), while crawlspace homes results in doses that are significantly higher than those for a concrete base slab (compare for example configuration 1 to configuration 7 in Table IV; crawlspace doses are expected to be three to four times higher than doses to receptors that live in a home with a concrete base slab).

Some interesting results were observed for the concrete slab simulations with wood frame home for elevated areas of contamination. As expected, for contamination directly underneath and coincident with the footprint of the house, the largest dose was associated with the receptor location at the center of the residence (location F in Figure 1). However, the largest shielding factors were associated with receptor locations at the corner of the residence (location A in Figure 1), if a reference point in the same location as the receptor was assumed. This results because shielding is less effective at the corner of the residence with a greater fraction of gamma radiation able to expose a receptor at higher energies. When the reference point is located in the center of the house; however, the lower dose associated with the corner receptor location (because this receptor is surrounded by clean soil on most sides) results in a lower shielding factor compared to other receptor locations. Thus, the reference point is an important consideration for elevated areas[5]. On the other hand, for the case of general contamination, receptor locations located near the center of the house (location F in Figure 1) resulted in lower doses and shielding factors to the receptor, while locations located near the edge of the house resulted in higher doses and shielding factors (location A in Figure 1), as expected.

---

[5] The observations regarding shielding factors using the same reference point as the receptor location were included for discussion purposes only. The reference point should always be consistent with the reference point assumed in RESRAD (the center of the residence) to ensure that the appropriate reduction in dose from attenuation in building materials is assigned. Results are only provided for these center references in Table IV.

Table IV. Results of Shielding Factor Calculations for Various Building Types and Receptor Locations

Shielding Factors						
Individual Receptor Locations (Weighting Factor)						Weighted Mean
A (0.16)	**B (0.32)**	**C (0.16)**	**D (0.16)**	**E (0.16)**	**F (0.04)**	
Configuration 1. Slab on grade with wood siding: with elevated area contamination						
0.086	0.101	0.101	0.114	0.116	0.116	0.104
Configuration 2. Slab on grade with wood siding: with general contamination						
0.458	0.403	0.391	0.295	0.286	0.272	0.369
Configuration 3. Slab on grade with brick siding: with elevated area contamination						
0.088	0.103	0.103	0.115	0.118	0.116	0.105
Configuration 4. Slab on grade with brick siding: with general contamination						
0.247	0.255	0.280	0.213	0.202	0.202	0.241
Configuration 5. Basement foundation, receptor in first floor: with general contamination (a)						
0.445	0.380	0.376	0.304	0.292	0.274	0.359
Configuration 6. Slab on grade, composite of wood houses and brick houses: general contamination (b)						
						0.334
Configuration 7. Crawl space foundation: with elevated area contamination						
0.253	0.326	0.341	0.422	0.441	0.462	0.356
(a) For the basement geometry, the reference case (for calculating the shielding factors) is a receptor above generalized contaminated soil (100 m × 100 m (330 ft × 330 ft)) that is surrounded by contaminated soil.						
(b) Composite based on 27% brick siding houses and 73% wood siding houses.						

Shielding Factors (with weighting factor in parentheses) calculated for basement house type for elevated area contamination or configuration 8 (c)					
	1	**2**	**3**	**4**	**5**
1	0.0185 (0.08)	0.0278 (0.08)	0.0418 (0.08)	0.0728 (0.08)	0.162 (0.08)
2	0.0208 (0.08)	0.0312 (0.08)	0.0507 (0.08)	0.0910 (0.08)	0.206 (0.08)
3	0.0216 (0.04)	0.0329 (0.04)	0.0533 (0.04)	0.0960 (0.04)	0.214 (0.04)
weighted mean					0.0745
(c) For the basement geometry for elevated area contamination, the reference case (for calculating the shielding factors) is a receptor above a 10 m × 10 m (33 ft × 33 ft) area of contaminated soil.					

Preliminary simulations also indicated that although the dose is slightly higher if windows are considered (versus no windows), the difference is not as significant as one might expect (shielding factors are less than 10 percent less). Slab or gravel layer thickness had a much larger affect on the shielding factors.

Other parameters including density of the concrete slab and location of the slab (above or below grade) were studied but also had a relatively small impact on the shielding factors.

Results for the basement scenarios (configuration 5 in Table IV) showed that the shielding factors for the second floor receptor were significantly higher then the other two floors (see Figure 3), while the doses associated with a receptor in the basement were significantly lower due to the shielding afforded by the concrete walls of the basement. To avoid making complicated assumptions regarding the amount of time a receptor would be expected to be located on each floor, which also entails making assumptions regarding whether the basement was finished and the percent of homes expected to contain a second floor), an assumption was made that the receptor spent all of his time on the main floor. This assumption was expected to be reasonable as the shielding factors for the first floor fell approximately mid-way between the shielding factors for the basement and second floor (and averaging second floor and basement shielding factors would also tend to result in shielding factors near the first floor results). As the majority of homes constructed in the Livonia, MI area are expected to include a basement, this building configuration is expected to be most likely. As it turned out, the calculated shielding factor for the basement scenario was approximately equal to the shielding factor calculated for the slightly more conservative, basecase scenario of concrete base slab with wood frame house (0.36 [basement] versus 0.37 [wood frame]; configurations 2 and 5 in Table IV).

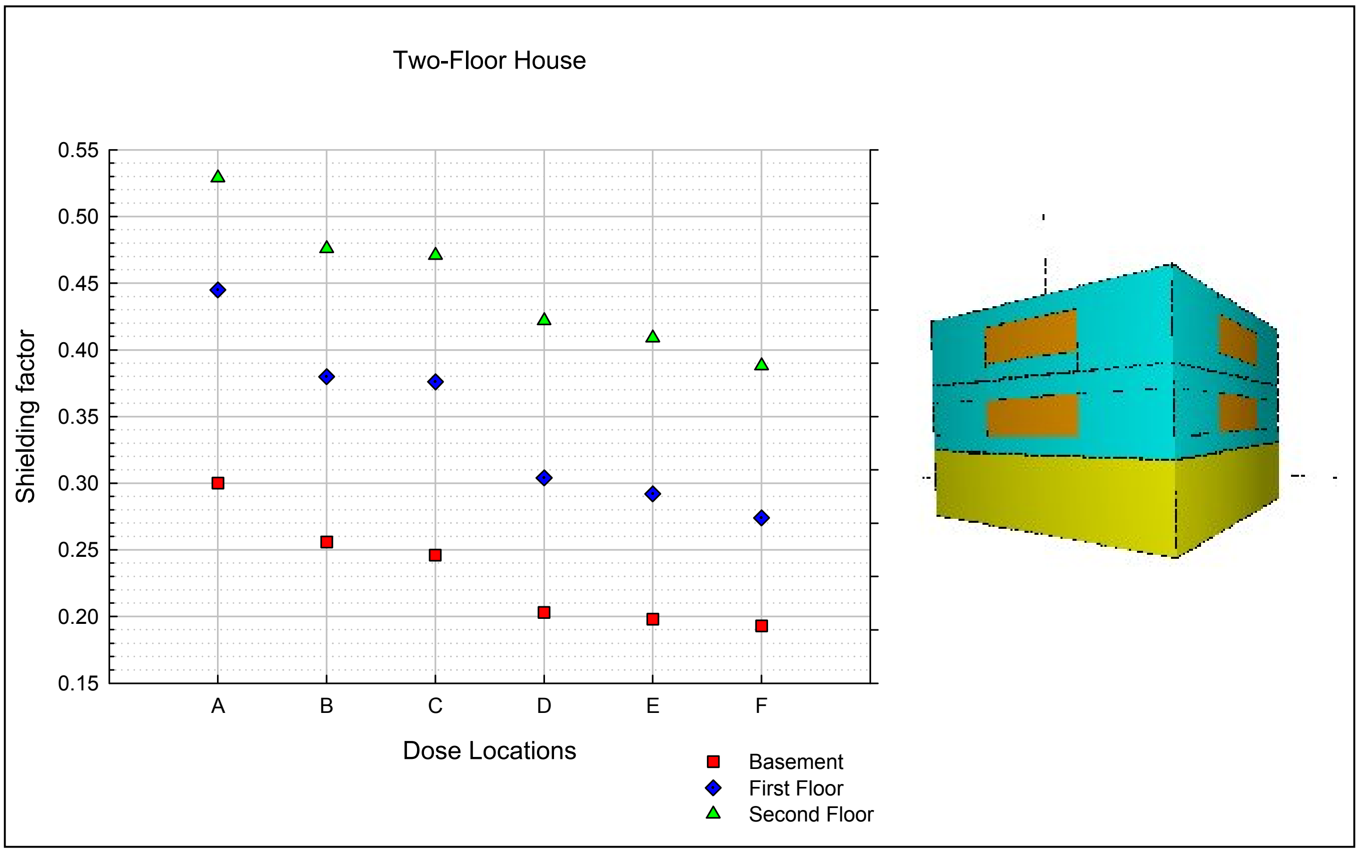

Fig. 3. Basement Shielding Factor Results and Residence Illustration

CONCLUSIONS

Development of site-specific external gamma shielding factors are recommended for those cases where the external dose pathway dominates the dose and more refined estimates of risk are needed to inform decision-making against radiological criteria for license termination. The modeling approach and risk analysis discussed in this paper could be widely applicable to other decommissioning sites. NRC staff plan to extend this evaluation to additional radionuclides and sites and if appropriate, provide additional information in future updates to NRC's decommissioning guidance. Because site-specific calculations using the approach discussed above is time-consuming, it is suggested that site evaluations use the commonly accepted practice of initial screening. In this approach, the site is evaluated using conservative default parameters (deterministic value) and if these assessments show the site to be well within acceptable criteria, then no further calculations would be deemed necessary. However, for sites that show borderline or unacceptable results, site-specific, hence more realistic and potentially less conservative, calculations may be warranted. Additionally, the results show that central values of the default parameter distribution available in RESRAD may tend to underestimate the potential dose to a receptor compared to use of shielding factors that consider the actual mix of radionuclides present at the site. Therefore, additional justification may be needed to support use of the default parameter distributions provided in probabilistic RESRAD to demonstrate compliance with LTR criteria.

REFERENCES

1. U.S. EPA, "Exposure Factors Handbook," EPA/600/P-95/002Fa, U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C., August (1997).

2. U.S. Nuclear Regulatory Commission, "Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes," NUREG/CR-6697, December (2000).

3. Grove Software, Microshield 7.02, www.radiationsoftware.com (2008).

4. LANL, "MCNPX™ User's Manual, Version 2.5.0," LA-CP-05-0369, University of California at Los Alamos National Laboratory, Los Alamos, New Mexico, April (2005).

5. U.S. Census, "Characteristics of New Housing," (updated through 2007): http://www.census.gov/const/www/charindex.html Released/updated June 2 (2008).

6. K.L., Banovac, "Telephone Call Log with City of Livonia, Michigan, Plan Examiner Regarding Resident Building Foundation Types, Related to AAR manufacturing, Inc., Site," Internal Memorandum to File (ML083460004), U.S. NRC, dated December 17 (2008).