RESPONSE TO THE CITY OF TULSA, OKLAHOMA, REGARDING POTENTIAL CONSTRUCTION OF A STORMWATER DETENTION POND AT THE FORMER KAISER ALUMINUM SITE

1.0 Key Points

- Projected worker dose depends on the time spent in the excavation, the time spent in the vicinity of contaminated excavation spoils, and whether the depth of the excavation exceeds the minimum 3.05 m (10 foot) clean cover depth; however, most excavation scenarios do not cause a worker dose concern.
    - If at least 0.305 m (1 foot) or more of the clean cover remains in place, the projected worker dose is significantly less than the dose criterion for unrestricted release (i.e., 25 millirem per year (mrem/yr)), even if conservative assumptions are made about radionuclide concentrations, shielding, and time spent on the site (i.e., an entire work year spent in the excavation site).
    - If the excavation removes all of the clean cover and proceeds into the contaminated material, the projected worker dose is still expected to remain less than 25 mrem/yr if a worker spends less than a full work year (i.e., less than 2000 hours) in the excavation site after the clean cap is removed; however, the projected dose could exceed 25 mrem/yr if a worker spends an entire work year in the excavation site after the clean soil cover is removed.
- Based on evidence of significant infiltration from the former retention pond into the shallow and deep aquifers at the site, NRC staff recommends that the effects of the proposed stormwater detention pond on local hydrology be considered.
    - If the water table does not rise over the contaminated soil, projected doses from groundwater contamination are expected to remain below 25 mrem/yr
    - Simplified screening analyses indicate the potential for doses above 25 mrem/yr to result if the contaminated soil is submerged below the water table
    - More detailed groundwater modeling would reduce the uncertainty in the projected potential groundwater contamination

2.0 Background

The Kaiser Aluminum and Chemical Corporation (Kaiser) facility processed magnesium-thorium alloy from 1958 through 1970 and Kaiser's Atomic Energy Commission license was terminated in 1971 at Kaiser's request. In 1993, the NRC detected surface contamination on, and adjacent to, the Kaiser property. The principle radionuclides in the contamination are thorium-232 (Th-232), Th-230, Th-228, radium-228 (Ra-228), Ra-226, and lead-210 (Pb-210). Kaiser conducted off-site remediation activities from October 2000, through May 2001. Remediation activities primarily involved excavating affected soil and moving it onto Kaiser's property. In March 2002, NRC informed Kaiser that the adjacent land areas met NRC's criteria for unrestricted release.

Enclosure

Kaiser conducted on-site decommissioning activities from June 2003 to June 2006. During decommissioning, soil radioactivity was scaled to Th-232 concentrations[1]. Soil with more than 31.3 picocuries per gram (pCi/g) Th-232 was sent off-site for disposal, while soil with a lower Th-232 concentration was used to backfill a retention pond onsite. The contaminated backfill was then covered with a minimum of 3.05 m (10 feet) of clean soil before the site was released (Kaiser, 2006a, 2006b; (Agencywide Documents Access and Management System (ADAMS) Accession No. ML062650439, ML061990526). Because some of the contaminated soil was less concentrated than the 31.1 pCi/g threshold value, Kaiser determined that the average Th-232 concentration in the contaminated backfilled soil was no greater than 7.0 pCi/g (Kaiser, 2006a; ML061990535).

In 2006, Kaiser submitted a Final Status Survey Report (FSSR) for the Kaiser Tulsa site[2] to demonstrate that the facility and site meet the criteria for unrestricted release. NRC conducted a number of independent confirmatory surveys to verify the final status survey results obtained by Kaiser. Confirmatory surveys consisted of surface scans for beta and gamma radiation, direct measurements for total beta activity, collection and analysis of soil samples for thorium, and collection of smear samples for determining removable radioactivity levels. In 2007, the NRC concluded the Kaiser Tulsa Site was suitable for unrestricted release.

In December, 2016, the City of Tulsa sought guidance from the NRC on the potential construction of a stormwater detention pond at the Kaiser Tulsa site. The City requested information on any radiological hazard that could be caused by excavating in the area in which the contaminated soil had been used as backfill. Specifically, the City requested information about ". . . how deep, or to what elevation, we could excavate for the detention pond without causing a radiation problem/concern." This document is the NRC staff's response to that request.

3.0 NRC Staff evaluation

In the FSSR, the licensee used RESRAD (Version 6.3) to model the dose to a resident farmer. The calculation was separated into three scenarios with the following names and descriptions:

> Kaiser Scenario 1a: Exposure during crop cultivation, including external gamma, plant ingestion, meat ingestion, and milk ingestion;
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> Kaiser Scenario 1b: Exposure while in a basement built directly above the contaminated soil including external gamma exposure only; and
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> Kaiser Scenario 2: Doses from water-dependent pathways, including drinking water ingestion as well as consumption of milk and meat contaminated through water-dependent pathways.

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[1] Th-230 was found to be present at approximately 3.6 times the concentration of Th-232. Ra-228 and Th-228 were found to be in secular equilibrium with Th-232, whereas Ra-226 and Pb-210 and their progeny were present due to ingrowth from Th-230 since the time of original material generation (i.e., from 1958 to 1970).

[2] The FSSR for the adjacent areas had been submitted in 2001.

NRC staff has previously reviewed the Kaiser dose model for the Tulsa, Oklahoma site (NRC, 2003). This NRC staff assessment did not re-evaluate Kaiser's dose model. Instead, NRC used Kaiser Aluminum's evaluation of these pathways and its own independent analyses to evaluate potential doses to workers involved in the detention-pond construction as well as off-site residents exposed by drinking contaminated groundwater.

In the models used to support the FSSR, Kaiser assumed the Th-232 concentration in the backfilled material was 31.1 pCi/g because that was the cut-off value used to keep contaminated soil on site. Kaiser scaled the other radionuclide concentrations to that concentration of Th-232. However, Kaiser determined that the average concentration of Th-232 in the contaminated backfill did not exceed 7.0 pCi/g Th-232 (Kaiser, 2006a; ML061990535). The dose projections in this analysis are linearly related to the assumed concentrations. Because a worker could spend time in areas that have up to the threshold concentration, NRC staff reported dose projections based on both inventory assumptions.

Projected or bounding doses to construction workers were reported for this year; these projected doses did not change significantly with time for several years (i.e., approximately 10 years). Projected doses from the drinking water pathway generally increased with time. Therefore, these doses were reported at 30 years and at the time of the greatest projected dose within 1000 years, which was 1000 years in all cases.

3.1 Worker Dose During Detention Pond Construction

In its request, the City of Tulsa indicated that, if the City were to use the site for a detention pond, it could excavate to a depth of 3.05 to 4.57 m (10 to 15 feet). The City also indicated that a shallower excavation of 1.52 to 1.83 m (5 to 6 feet) may be possible if necessary to avoid the site contamination. Because the City expressed a preference for the deeper excavation, the NRC staff considered two cases:

(1) Excavation to 2.74 m (9 feet), leaving 0.305 m (1 foot) of clean cover in place;
(2) Excavation to 4.57 m (15 feet), intruding 1.52 m (5 feet) into the contaminated soil.

A 2.74 m (9 foot) excavation depth was considered because it was closer to the City of Tulsa's preferred range (i.e., 3.05 to 4.57 m [10 to 15 feet]) than a 1.52 to 1.83 (5 to 6 foot) excavation and did not cause significantly more worker dose than the shallower excavation. The results of this scenario depend on the presence of at least 0.305 m (1 foot) soil cover; therefore, the City may choose a shallower depth to ensure that that this depth of soil cover remains in place, given the expected degree of precision of the excavation operations. In the second case, a 4.57 m (15 foot) excavation was modeled to demonstrate the effects of excavating to the deepest depth suggested by the City.

For both of these cases, the projected dose depends on how long a worker spends in the excavation area. This exposure time depends on many site-specific parameters, including the number of personnel and types of excavators involved, as well as other construction logistics. The total exposure time would, therefore, be a significant source of uncertainty in any dose projection. However, because the projected dose is proportional to the exposure time, it can easily be calculated from an hourly exposure rate once more specific construction information becomes available. Therefore, NRC staff calculated hourly dose rates with which the City of Tulsa can calculate dose estimates. NRC staff also calculated bounding annual dose

projections based on the assumption a worker spends an entire work year (i.e., 2000 hours) in the excavation site.

To evaluate the first case above (i.e., a 2.74 m excavation), the NRC staff first replicated the RESRAD results of Kaiser Scenarios 1a and 1b from the FSSR using RESRAD Version 7.2. After replicating Kaiser's results, NRC staff modified parameters to reflect worker exposure during excavation to 2.74 m (9 feet). For this case, NRC staff considered only the direct gamma exposure pathway, because, if at least 0.305 m (1 foot) of clean cover is left in place, no contaminated soil would be exposed to contribute to an inhalation or incidental soil ingestion pathway. Furthermore, the milk, meat, and plant ingestion pathways included in Kaiser Scenario 1b were not applicable to a construction worker scenario. Therefore, NRC staff started with the RESRAD file corresponding to Kaiser's Scenario 1b (i.e., exposure in a basement) and made the following changes:

- All pathways other than direct gamma exposure were suppressed;
- The clean cover depth was set to 0.305 m (1 foot), representing the minimum amount of cover that would remain with a 2.74 m (9 foot) excavation depth;
- The density of the cover material was set to 1.7 to match the density of contaminated soil Kaiser used in its analysis[3];
- The indoor occupancy fraction was reduced to zero;
- The outdoor occupancy fraction was set to 1.142×10^{-4}, representing 1 hour of exposure, to obtain an hourly dose rate

The dose rates based on the average and maximum radionuclide concentrations are provided in Table 1. As shown in Table 1, even if the maximum radionuclide concentrations are assumed and a worker is assumed to spend an entire work-year in the excavation, the total projected dose is 2.75 mrem/yr, which is well below the release criterion of 25 mrem/yr. The main dose contributions were from Th-232+D, Th-228+D, and Ra-228+D[4]. This dose projection also contains the conservatism that only a single foot of cover was present during the entire excavation time, whereas, in reality, significantly more clean cover material would be present at the beginning of the excavation. This modeling simplification was acceptable because the dose projections were significantly less than the 25 mrem/yr release criterion. Thus, this dose rate bounds the expected dose to a construction worker excavating from the surface to 2.74 m (9 feet) as long as approximately 0.305 (1 foot) of clean cover remains in place.

For the second case (i.e., excavation to 4.57 m), hourly exposure rates were calculated for exposures once the entire clean cover had been removed. Exposure was assumed to result from time in the excavation site as well as time spent in the vicinity of a spoils pile containing contaminated soil. Thus the dose rate for case 2 has three components: exposure in the excavation before the clean cover is removed, exposure in the excavation after the clean cover is removed, and exposure from contaminated spoils while onsite but outside of the excavation itself. To arrive at a dose estimate, each of these exposure rates is multiplied by the applicable amount of time and the results are summed. That is

$$projected\ dose = ET_{0\ to\ 9\ feet} \cdot DR_{case\ 1} + ET_{9\ to\ 15\ feet} \cdot DR_{case\ 2\ excv.} + ET_{spoils} \cdot DR_{spoils}$$

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[3] The value had been set to 1.9 in Kaiser Scenario 1b to represent a concrete basement floor.
[4] The dose from progeny with half-lives less than 180 days were included with the dose of these parents.

Where $ET_{0\ to\ 9\ feet}$ is the estimated excavation time from 0 to 2.74 m (0 to 9 feet), $DR_{case\ 1}$ is the dose rate from case 1 above, $ET_{9\ to\ 15\ feet}$ is the estimated excavation time from 2.74 m (9 to 15 feet), $DR_{case\ 2\ excv.}$ is the dose rate for time spent in the excavation site after the clean cover is removed, ET_{spoils} is the time spent on the construction site while contaminated spoils remain on site, and DR_{spoils} is the dose rate from the contaminated spoils. Table 1 provides the projected dose rates. Although some cover would be present for the excavation from 2.74 to 3.05 m (9 to 10 feet), the dose rate would be between the dose rates for case 1, which assumed an entire 0.305 m (1 foot) of cover remained in place, and the dose rate for the excavation portion of case 2, which assumed no cover remained in place. For conservatism, that part of the excavation time should be included with the dose rate for the excavation portion of case 2.

To calculate the dose rate for time spent in the excavation after the clean cover is removed ($DR_{case\ 2\ excv.}$) additional pathways and exposure geometries were considered. Until the cover is breached, the only applicable pathway for a construction worker is direct gamma exposure. After the clean cover is breached, exposure through inhalation of resuspended contaminated soil and incidental ingestion of contaminated soil also are applicable. In addition, if the excavation proceeds into the contaminated soil, a worker can be exposed to gamma radiation from the ground as well as the portion of the walls of the excavation that extend into the contaminated soil. To address this case, NRC staff used two models:

(1) A RESRAD model including direct gamma radiation, inhalation, and incidental ingestion and assuming no clean cover exists; and

(2) A MicroShield® (Grove Software, 2007) model run to account for gamma radiation from the walls of the excavation.

For the RESRAD model run corresponding to (1) above, the projected dose rate was evaluated with the same parameters described for case 1, above, except the following changes were made:

- The cover depth was set to 0 m to represent excavation into the contaminated soil;
- The incidental soil ingestion pathway was included;
    - The soil ingestion rate was set to 20 mg/day based on a mean value for adults (EPA, 2011);
- The inhalation pathway was included;
    - The breathing rate was set to 13,140 m^3/yr to represent a medium breathing rate for a construction worker (i.e., 1.5 m^3/hour) (NRC, 1999);
    - The mass loading for inhalation was set to 6 x 10^{-4} g/m^3 to represent mass loading at a construction site (Yu et al., 2015);

The thickness of the contaminated zone was left unchanged at 3.05 m (10 feet) because the entire thickness would be present when the excavator first reached the top of the contaminated soil. In practice, even though the contaminated zone would become thinner as excavation proceeds, there is no significant difference in gamma exposure from a 3.05 m (10 feet) thick contaminated zone as compared to a 1.52 m (5 foot) thick contaminated zone.

Once the excavation reaches the contaminated soil, it is possible to receive gamma radiation from the sides of the excavation as well as the floor of the excavation. Because this configuration is not modeled in RESRAD, NRC staff checked the potential contribution of gamma radiation from the walls of the excavation with MicroShield® (Version 10.0) (Grove Software, 2007). To verify that the staff was using comparable source terms in RESRAD and MicroShield®, NRC staff first modified the RESRAD file for case 1 above to reflect no clean cover, without adding additional pathways (i.e., only exposure to gamma radiation was included). NRC staff then created a similar scenario in MicroShield® using a dose point 1 m above the circular end of cylindrical volumetric source representing the ground. The cylindrical source was 3.05 m (10 feet) thick with a radius of 15 m (i.e., effectively infinite). For the source material, NRC staff created a custom material to represent soil based on the soil composition in Table II.3 of Federal Guidance Report 12 (Eckerman and Ryman, 1993). Effective dose rates based on ICRP 74 assuming an isotropic geometry were used. NRC staff obtained results within 10 percent of the comparable RESRAD run.

Then to assess the potential contribution from shine from the walls of the excavation, NRC staff evaluated the dose to an individual in an annular cylinder with radioactive material in the walls of the cylinder. NRC staff used the same custom material to represent soil as previously used for the cylindrical source. For a large excavation (i.e., acres), the dose to an individual in the center of the excavation is dominated by the radiation from the ground and the walls have a negligible contribution. However, if the excavation is smaller (e.g., for a smaller detention pond or at the beginning of the excavation) the contribution from the walls can be more significant. In addition, if the worker spends time near the walls rather than in the center of the excavation, which may be a reasonable assumption depending on how the excavation proceeds, the contribution from the walls increases.

For this analysis, NRC staff evaluated the dose to a worker who spent all of his time positioned 3 m (10 feet) from a side wall. This distance was expected to be a reasonably conservative assumption for a worker using large construction equipment. The dose rate from the walls is dominated by the nearest wall, but the remainder of the walls has a contribution that decreases with the assumed size of the excavation. For conservatism, NRC staff chose to represent the excavation with a radius of 15 m (49 feet). This size is expected to represent a smaller excavation or the smaller beginning of a larger excavation and is therefore expected to be reasonably conservative. NRC staff recognizes this is a subjective choice. It serves the purpose of providing a reasonable contribution from the walls instead of neglecting them; however, as shown in Table 1, the direct gamma radiation from the ground is expected to have a more significant contribution to dose.

The final contribution to dose for case 2 results from exposure to the excavated contaminated soil in a spoils pile. NRC staff assumed that the contaminated soil would be mixed in the same spoils pile as the clean cover soil. Therefore, to estimate the dose rate from exposure to the spoils pile, NRC staff reduced the radionuclide concentrations by a factor of 3 (i.e., assuming a total excavation of 4.57 m (15 feet), 1.52 m (5 feet) of which is contaminated). The geometry of the spoils pile was represented as rectangular volume with a length of 40 m (131 feet), a width of 20 m (66 feet), and a height of 10 m (33 feet). The dose rate was insensitive to changes in these dimensions in a relatively wide range. For example, doubling each of these dimensions increased the dose rate by only 7 percent, and halving each of these dimensions decreased the dose rate by 15 percent. In each case, the worker was assumed to be located at the center of the longer wall, 2 m (6.6 feet) from the pile, at a height of 1 m (3.3 feet).

Although the dose rate was calculated assuming a worker is located 2 m (6.6 feet) from the pile, the entire time on the construction site after contaminated soil is excavated, except for time spent in the excavation itself, should be used to calculate a projected dose from this dose rate. This time estimate is appropriate because a worker would receive some dose from the spoils pile, albeit at a lower rate, when located at a greater distance from the pile. For example, at a distance of 10 m (33 feet), the dose rate is diminished by 78 percent. Exposures at greater distances can conservatively be accounted for by assuming all time spent on site after contaminated soil is excavated, excluding time in the excavation itself, is subject to the dose rate at 2 m (6.6 feet). Time spent closer to the pile than 2 m (6.6 feet) was assumed to be minimal, but the increased dose rate at distances less than 2 m (6.6 feet) also is addressed, approximately, by assuming an average 2 m (6.6 feet) distance when much of that exposure is expected to take place at a greater distance. In addition, assuming the dose rate for exposure 2 m (6.6 feet) from the spoils pile applies to all of the time onsite after contaminated soil is excavated, except for time in the excavation itself, helps account for shine from within the excavation to workers outside of the excavation.

Because the RESRAD model for the time spent in the excavation after the clean cover was removed showed that direct gamma radiation was responsible for 97 percent of the dose rate, only direct gamma radiation was included in the dose rate for exposure to the spoils pile. Therefore, to estimate the dose rate from exposure to contaminated soil in the spoils pile, NRC staff used a MicroShield® model similar to the model used to estimate the dose rate from the walls of the excavation, with the following changes:

- The spoils pile was represented as a rectangular volume with a length of 40 m (131 feet), a width of 20 m (66 feet), and a height of 10 m (33 feet)
- The receptor was assumed to be located 2 m from the center of the longer wall at a height of 1 m
- Radionuclide concentrations were reduced by a factor of 3 to account for mixing of the contaminated soil with the clean soil cover

The dose rates for the model runs based on the average and maximum radionuclide concentrations are provided in Table 1. For the RESRAD Run (Case 2, first configuration) even though the inhalation rate and mass loading rate were chosen to be reasonably conservative, the dose was mostly attributable to exposure to gamma radiation (97 percent), with much smaller contributions from incidental soil ingestion (1.6 percent) and inhalation (1.3 percent). As shown in Table 1, if the maximum radionuclide concentrations are assumed and the worker is assumed to spend an entire work year in the excavation site after the clean cover is removed, doses exceeding the release criterion could occur. However, if the average concentrations are assumed, the projected dose rate is significantly reduced. Because it seems likely that significantly less than a full working year would be spent in the excavation site during the time the excavation depth exceeded the clean cover depth, the resulting dose projection based on average backfill concentrations is expected to be less than 25 mrem/yr.

Table 1. Projected worker dose rates and bounding doses for 2000 hours exposure for different excavation depths.

Cases and Pathways	Projected Dose Rate (mrem/hour)		Applicable Exposure Time	Bounding Dose for 2000 hours exposure (mrem/yr)	
	Average Concentration	Maximum Concentration		Average Concentration	Maximum Concentration
Case 1 Excavation to 2.74 m (9 feet)					
Direct gamma radiation	3.10×10^{-4}	1.31×10^{-3}	Time required to excavate from the ground surface to 2.74 m (9 feet)	0.62	2.75
Case 2 Excavation from 2.74 to 4.57 m (9 to 15 feet)					
direct gamma from ground, inhalation, and incidental soil ingestion	1.32×10^{-2}	5.86×10^{-2}	Time required to excavate from 2.74 to 4.57 m (9 to 15 feet)	26	117
direct gamma from excavation walls,	3.24×10^{-3}	1.44×10^{-2}		6.5	29
Total Case 2 Excavation	1.64×10^{-2}	7.3×10^{-2}		33	146
Case 2 Exposure to Contaminated Spoils					
Direct gamma from spoils pile	2.71×10^{-3}	1.21×10^{-2}	Time on the site after the clean cover has been removed, while not in the excavation itself	5.4	24

3.2 Water-dependent Pathways

The NRC Safety Evaluation Report (SER) for the Phase 2 Kaiser Decommissioning Plan (NRC, 2003) indicates that at the time of the SER, the future use of the site was expected to be commercial or light industrial use. Construction of a stormwater detention pond on the site was

not envisioned in the Kaiser Decommissioning Plan or NRC's SER. Therefore, although Kaiser analyzed water-dependent pathways in the FSSR, those analyses did not account for standing water, such as a stormwater detention pond, directly above the contaminated soil. The City of Tulsa indicated that it might consider including an engineered barrier at the bottom of the proposed retention pond, which could significantly limit the pond's effect on contaminant transport. NRC staff analyzed the potential effects of an unlined pond on groundwater contamination to provide information for the City to use to determine if such a barrier is cost effective.

To assess the potential for an unlined stormwater detention pond to increase infiltration through the contaminated soil, NRC staff referred to observations of the former retention pond in the hydrologic and geologic study of the site submitted by Kaiser in support of its Decommissioning Plan (A&M Engineering and Environmental Services, 1999). That report explains that hydraulic measurements on the site indicate there is "a strong potential for significant flows from the Retention Pond into both deep and shallow groundwater in the eastern portion of the Retention Pond." The report also states that, in addition to the hydraulic data, groundwater quality data also support the conclusion that a significant amount of water flowed from the retention pond into both the deep and shallow aquifers. Although those groundwater quality data did not indicate significant migration of radionuclides had occurred from the contaminated soil at the time of site release, general water characteristics, such as concentrations of major cations, indicated the water in the aquifers had infiltrated through the dross. Based on these observations of the former retention pond, NRC staff determined that infiltration from an unlined stormwater detention pond through the contaminated soil should be considered.

A site hydrologic study (A&M Engineering and Environmental Services, 1999) also described observations from an extreme rain event in October 1998. Those observations provided an estimate of potential infiltration from the retention pond:

> "During the month after this rain event, the water level in the Retention Pond dropped more than 3.4 feet. Estimates of evaporation from nearby lakes in the Tulsa area indicate a potential evaporation from the pond of approximately 3 to 4 inches . . . . Thus, the losses from the Retention Pond during this period far exceed any potential losses from evaporation and indicate that significant leakage occurred from the Pond during this period."

The report indicates that the soil under the retention pond is primarily silty clay, with an estimated hydraulic conductivity of 10^{-6} and 10^{-8} cm/sec. The report notes the inconsistency between this relatively low hydraulic conductivity and the observed leakage from the pond and provides evidence that the leakage is due to areas of more permeable material under the retention pond. Specifically, the report states:

> " . . . An infiltration rate of approximately 3 feet over a one-month period does not appear consistent with this range of permeabilities. The presence of higher permeability materials beneath limited areas of the Retention Pond is possible, particularly beneath the old Fulton Creek channel. The geologic log for monitoring well MWS-4 indicates the presence of a gray silt with sand and organic fibers at this location (see boring logs in Appendix A). Monitoring well MWS-4 is located in the general vicinity of the old Fulton Creek channel and may indicate the presence of higher permeability material beneath the Retention Pond. The deltaic deposits identified along the northern boundary in the

> historical aerial photographs may also contain higher permeability material that could permit greater leakage from the Retention Pond."

Because of the evidence of significant infiltration from the former retention pond to the shallow and deeper aquifers on the site, NRC staff evaluated the potential effects of significant infiltration from the proposed stormwater detention pond, through the contaminated soil, to the aquifer. To evaluate this possibility, NRC staff adapted the Kaiser RESRAD model for water-dependent pathways. First, NRC staff used RESRAD (Version 7.2) to replicate the results obtained by Kaiser for Scenario 2 in Appendix E of Volume VI of the FSSR (Kaiser, 2006c; ML060890767). NRC staff then adapted the model to represent potential infiltration from a stormwater detention pond above the contaminated soil.

For this scenario, only the drinking water pathway was considered. Drinking water was assumed to be taken from a well immediately down-gradient of the contaminated soil. The milk, meat, and crop ingestion pathways were suppressed because the proposed use of the site would preclude agricultural use. The thickness of the clean cover was set to zero to simulate water from the detention pond directly above the contaminated soil, however, it did not significantly affect dose because the direct gamma pathway was not included. Water in the retention pond would effectively eliminate the direct gamma pathway. Inhalation and inadvertent soil ingestion were suppressed because receptors would not be in contact with the contaminated soil.

In the RESRAD analyses supporting the Decommissioning Plan and FSSR (Kaiser, 2001; Kaiser 2006c), Kaiser based the radionuclide concentrations on the threshold value of Th-232 (31.1 pCi/g). As discussed in Section 2.0, Kaiser indicated that the average radionuclide concentrations were a factor of 4.4 lower than the values based on the Th-232 threshold value. In general, NRC staff expects that, in many cases, it is appropriate to use average radionuclide concentrations when considering projected doses from groundwater pathways if the scale of the variability is small compared to the well capture area, because water is physically mixed as it flows through the contamination and is pumped from a well. One exception would be contamination that is vertically stratified such that higher radionuclide concentrations occur near the bottom of the contaminated soil, in areas more likely to become saturated by water table fluctuations. Therefore, to determine if it would be appropriate to use the average radionuclide concentrations, NRC staff evaluated the FSSR sub-reports for each of the survey units for the contaminated backfill and determined that, within the contaminated backfill, the radionuclide concentrations were not correlated with soil depth. Therefore, NRC staff determined it was appropriate to use the average radionuclide concentrations rather than the values based on the threshold concentration of Th-232.

Because of the large differences in transport characteristics (i.e., sorption coefficients) between some of the parent radionuclides and their progeny, NRC staff also evaluated the effect of changing the half life cut-off at which progeny are evaluated separately rather than being included in the dose of the parent radionuclide. NRC staff found that, for this scenario, changing the half life cut-off from 180 days (the default value) to 1 day slightly decreased the dose projection (i.e., by approximately 10 percent). NRC staff confirmed that further reducing the cut-off value to 0.1 days did not affect the projected peak dose[5].

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[5] Decreasing the cut-off value to 0.01 days appeared to cause numerical instability in the model.

Because changing the cut-off value added new principle radionuclides to the transport calculation, it was necessary to add sorption coefficients for those radionuclides. For Ra-224, NRC staff added a Kd value of 3584 mL/g to be consistent with the value Kaiser used for Ra-226 and Ra-228. For Po-210 and Bi-210 NRC staff used the median values from the lognormal distributions provided in NUREG-6697 (NRC, 2000) (i.e., 181 mL/g and 105 mL/g, respectively). For Rn-222, NRC staff used the RESRAD default value of 0 mL/g, which is appropriate for Rn-222 because it is transported as a dissolved gas.

Thus, the projected dose from water-dependent pathways was evaluated as in the Kaiser Scenario 2, except the following changes were made:

- Only the drinking water pathway was considered;
- Radionuclide concentrations were based on their average concentrations rather than the Th-232 threshold concentration;
- The half life cut-off was set to 1 day;
- Sorption coefficients (Kd values) were provided for the additional principle radionuclides that resulted from the change in the half life cut-off;
- The milk and meat pathways were removed because the proposed site use would preclude agricultural use;
- The cover depth was set to zero to represent the pond excavated to the top (or into) the contaminated soil;
- The runoff coefficient, evapotranspiration coefficient, water table drop rate, and contaminated zone erosion rate were set to zero to represent a contaminated zone under a stormwater detention pond;
- The irrigation rate was set to zero; and
- The precipitation rate was varied to adjust the infiltration rate, as described below.

RESRAD does not directly accept an infiltration rate. Instead, the infiltration rate is calculated from the precipitation rate, the amount of water lost through evapotranspiration, and the amount of water lost as runoff. To represent infiltration from a pond, which would not be diminished by runoff or evapotranspiration, the runoff and evapotranspiration coefficients were set to zero. The infiltration rate could then be set by setting the precipitation rate and irrigation rates. Because the terms are additive, there was no difference in setting the infiltration by adjusting the precipitation or the irrigation rate once the runoff and evapotranspiration coefficients were set to zero. Therefore, NRC staff chose to set the irrigation rate to zero and, therefore, to set the infiltration rate by setting the precipitation rate. Although the infiltration was determined indirectly by setting the value for precipitation, the infiltration value used by the code is reported in the “Detailed Report” output of RESRAD (Version 7.2). NRC staff used the “Detailed Report” output to verify that the infiltration rate was set to the intended value for each model run.

Based on observations from the retention pond described above, it appeared possible that water could infiltrate from an unlined detention pond at a rate of approximately 1 m (3 feet) per month. NRC staff recognizes that this infiltration rate from the retention pond corresponded to an unusual event. However, it demonstrates a potential infiltration rate that could occur, depending on how the dentition pond water levels were managed. To evaluate the potential effects of increased infiltration through the contaminated soil, NRC staff ran screening analyses using RESRAD with precipitation rates ranging from 0.001 to 10 m/yr.

In the RESRAD analyses supporting the Decommissioning Plan and FSSR (Kaiser, 2001; Kaiser 2006c), Kaiser assumed the contaminated soil was above the water table. As explained in DP Section 5.2.3.2, Kaiser determined it was conservative to model the site without an unsaturated zone between the contaminated soil and saturated zone (i.e., with the soil just above the saturated zone), but expected that the water table could drop in response to closing the freshwater pond onsite, creating an unsaturated zone between the contaminated soil and the saturated zone. Because the proposed detention pond appears to have the potential to locally affect the depth of the water table, two different assumptions about the location of the contaminated soil relative to the water table were used. In the first set of model runs, the contaminated soil was modeled directly above the saturated zone, and in the second set, it was assumed to be in the saturated zone.

Projected doses from the screening calculations are provided in Table 2. Maximum doses for all model runs occurred at the maximum simulation time (i.e., 1000 years). As shown in Table 2, NRC staff found that the assumption about the location for the contaminated soil with respect to the saturated zone had a much bigger effect on projected dose than any assumptions about the infiltration through the contaminated soil. If the contaminated soil was assumed to be above the saturated zone, the maximum projected dose for any infiltration rate tested with the maximum inventory assumption was approximately 10 mrem/yr at 1000 years. That maximum dose projection occurred for precipitation rates of approximately 6 m/yr. Although these are unrealistic rates for precipitation, they were used to vary the infiltration rate to evaluate potential effects of increasing infiltration through the contamination soil by placing a source of water (i.e., a detention pond) directly above the contaminated soil.

Projected doses from the screening calculations increased if the contaminated soil was modeled as intersecting the saturated zone at the beginning of the model run. However, the projected doses provided in Table 2 have the significant limitation that they were evaluated with a dose assessment model, which uses a relatively simple approach to groundwater modeling, rather than a detailed hydrologic model. For example, the model does not account for the significant dilution that would occur if contamination entered the stream. The projected doses in Table 2 also are based on the assumption that an individual consumes most of their water from a drinking water well immediately downgradient of the contaminated soil. The City of Tulsa could consider the likelihood of that scenario in interpreting the values in Table 2. However, the sensitivity of the screening model doses to whether the contaminated soil is below the water table suggests that it could be beneficial to conduct a more detailed groundwater model of the potential effects of a stormwater detention pond on the local hydrology.

Table 2. Screening calculation dose to an off-site member of the public from the drinking water pathway, 30 and 1000 years in the future, for different assumptions about hydrologic conditions of the contaminated due to potential infiltration from the proposed stormwater detention pond

Infiltration through contaminated soil (m/yr)	Projected Annual Dose if Contaminated Soil is in the Saturated Zone (mrem/yr)		Projected Annual Dose if Contaminated Soil is above the Saturated Zone (mrem/yr)	
	30 years	1000 years	30 years	1000 years
0.001	6.1	74	2.2×10^{-5}	8.6×10^{-4}
0.5	6.1	71	9.9×10^{-3}	0.41
1	6.1	68	2.0×10^{-2}	0.77
3	5.9	58	5.6×10^{-2}	1.9
5	5.4	48	9.0×10^{-2}	2.25
6	5.4	45	0.10	2.25
7	5.2	41	0.12	2.23
8	5.2	38	0.13	2.14
10	5.0	32	0.14	1.91

4.0 Conclusions

In response to a request from the City of Tulsa, NRC staff considered potential doses that could occur if a stormwater detention pond is located at the former site of a retention pond at the Kaiser Tulsa, Oklahoma site. NRC staff evaluated projected doses to a construction worker working in the excavation site and exposed to contaminated soil in a spoils pile. NRC staff also evaluated the projected dose to an off-site member of the public who consumes drinking water from a well immediately downgradient of the contaminated soil.

Projected worker dose depends on the time spent in the excavation, the time spent on site after contaminated soil is placed in the spoils pile, and whether the depth of the excavation exceeds the minimum 3.05 m (10 foot) clean cover depth. Most of the construction scenarios evaluated do not cause a worker dose concern. Specifically, if at least 0.305 m (1 foot) or more of the clean cover remains in place, projected doses are significantly less than the dose criterion for unrestricted release (i.e., 25 millirem per year (mrem/yr)), even if conservative assumptions are made about radionuclide concentrations, shielding, and time spent on the site (i.e., an entire work year spent in the excavation site). If the excavation removes all of the clean cover and proceeds into the contaminated material, projected doses are still expected to remain less than 25 mrem/yr if workers spends less than a full work year (i.e., less than 2000 hours) in the excavation site after the clean cap is removed; however, the projected dose could exceed 25 mrem/yr if a worker spends an entire work year in the excavation site after the clean soil cover is removed.

A site hydrologic study indicated that there was significant infiltration from the former retention pond into both the shallow and deep aquifers at the site. Thus, it appears the effects of the proposed stormwater detention pond on local hydrology should be considered. Groundwater monitoring at the time of site release showed little migration of the contaminants from the contaminated soil. This observation is consistent with the relatively high sorption coefficients expected for thorium and radium in most soils. If the water table does not rise over the contaminated soil, projected doses from groundwater contamination are expected to remain below 25 mrem/yr. However, based on simplified screening analyses conducted with RESRAD, it appears that groundwater contamination resulting in doses above 25 mrem/yr could result if the contaminated soil is submerged below the water table. This result depends on the potential effect of the proposed detention pond on local groundwater flow, which was evaluated with a relatively simple approach using a dose assessment model rather than a detailed hydrologic model. More detailed groundwater modeling would reduce the uncertainty in the potential groundwater contamination and help to determine whether designing the detention pond to limit infiltration would be cost effective.

5.0 References

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