ELECTRIC POWER RESEARCH INSTITUTE

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Subject: Revised Branch Technical Position on Concentration Averaging and Encapsulation of Low-Level Radioactive Waste.

Dear Mr. Persinko,

The Electric Power Research Institute (EPRI) is an independent non-profit organization that conducts scientific research and development relating to the generation, delivery and use of electricity for the benefit of the public. We thank the NRC for allowing EPRI to provide comment on a revision to the *Branch Technical Position (BTP) on Concentration Averaging and Encapsulation of Low-Level Radioactive Waste.*

The purpose of this letter is summarize some of the technical conclusions from EPRI low-level waste (LLW) research, to identify areas for improvements in the 9/6/2011 draft revision of the BTP, and to transmit to the USNRC an alternative well drilling scenario developed by EPRI.

The disposal of low-level waste is considered safer and more desirable than interim storage. With the 9/6/2011 draft revision of the BTP, the NRC made significant progress in developing guidance to address stakeholder concerns. However, EPRI research indicates that additional changes to the current Branch Technical Position can be achieved without adverse impact to public safety and remain consistent with the Environmental Impact Statement. These changes will balance the risks and benefits of LLW disposal and the potential hazard to an inadvertent intruder following disposal site closure while reducing actual collective radiation dose to workers, minimizing the need for on-site storage of waste, and minimizing the creation of orphaned wastes.

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EPRI has analyzed LLW disposal in the United States since 2005 to determine if improvements in the BTP guidance could improve access to LLW disposal facilities, including:

- Full reviews of both NUREG-0782 Draft Environmental Impact Statement (DEIS) and NUREG-0945 Final Environmental Impact Statement (FEIS), which form the basis for the USNRC LLW disposal regulation (10 CFR Part 61), collectively referred to as the EIS.
- The subsequent guidance to Part 61 contained in the Branch Technical Positions (BTP) related to waste form and concentration averaging (1983, 1991 & 1995).
- Development of a four-year (2003-2006) actual disposed waste database for nuclear power plant waste.
- A detailed analysis of actual disposed wastes compared to the waste disposal quantities and properties assumed in the EIS.
- A detailed analysis of the averaging constraints established in the BTP as compared to the EIS methodology.

EPRI LLW research has identified areas for improvements in the 9/6/2011 draft revision of the BTP. The current draft BTP introduces what EPRI considers an:

- overly conservative domestic well drilling scenario that overemphasizes the importance of homogeneity,
- unrealistic tests for homogeneity (standard error applied to liner surveys),
- unnecessary exclusion of cartridge filters from "homogenous wastes,"
- insufficient relaxation of the "single component" constraint over activated hardware blending that is contrary to collective ALARA principles, and
- absence of specificity in an acceptable minimum waste to binder ratio for encapsulation and solidification.

To address these issues, the following improvements to the draft BTP could be made:

1. An alternative drilling scenario eliminates the need for further tests of homogeneity in wastes that are already considered (pre-defined) homogenous. EPRI research concludes that cable tool and auger drilling are not feasible drilling methods for a domestic water well as this type of drilling method will generally not drill to the necessary depths. Further, based on interviews with drilling experts, this method is too inefficient to be the selected technology for drilling domestic water wells.

   Additionally, a reasonable drilling scenario either involves only class A waste or it involves Class A waste and the class B/C waste barriers installed for the purposes of providing stability. The design of these barriers is bounded by approved High Integrity Containers (HICs) or approved encapsulation and solidification topical reports. In other words, it should be assumed that there is a concrete, metal or other structural barrier over Class B/C waste because it is required for structural stability. Therefore, a reasonable

drilling scenario will encounter an intact stability barrier at 100 years if Class B/C waste is present. These structural barriers will result in 'reject' to the drilling apparatus and the drilling operation will be moved.

EPRI has developed a research-based domestic well drilling scenario (Attachment 1) whereby the exhumed waste (as drill cuttings) is homogenized by the most probable and efficient drilling method for such a well (rotary mud). The homogenized cuttings are then buried in a mud pit because their clay-like nature is not desirable for any subsequent use.

This drilling scenario represents a conservative residential well drilling scenario, and would result in a maximum dose to an intruder that is well below 500 mrem/year even when nuclides are set to 99% of the class A concentration limits. Given that a probabilistic risk assessment approach is not being applied, this deterministic approach is considered to represent a 'reasonable' and still very conservative assessment of the potential hazard.

2. For any waste predefined as homogenous, homogeneity exists at the point of generation and further tests or consideration for further tests should not be necessary. To imply that additional considerations should be made is not warranted because of the nature of the waste and individual plant design constraints. Disposal liners containing waste predefined as homogenous will commonly exhibit varying dose rates caused by waste layering from multiple plant sources. These layered dose rates will not pass the proposed standard error test and cannot be avoided by design. Many stations would need to undertake extensive modifications to further homogenize waste such that it would not be layered in disposal liners to pass the implied need for investigation, when previously it has always been considered a homogenous waste from an acceptable process by design. The well drilling scenario conducted by the NRC staff drives the need for the very arduous and complex homogeneity tests, but if a more realistic well drilling scenario is applied, then this need is removed.

3. Because cartridge filters do not present a gamma dose hazard, cartridge filters should be considered homogenous. The absence of long-lived gamma activity in filters results in cartridge filters not posing any more of a carry away hazard than other metal items in DAW which could be unearthed. Cartridge filters do not pose a gamma dose concern as compared to activated hardware or gamma sources for the following reasons:

    a. Cs-137 is highly soluble and very little is actually captured on filters. This is evident by the absence of any Cs-137 of significance in historical disposed filters. For approximately 50,000 filters in approximately 500 shipments over four years, the sum of the Cs-137 activity in all of these filters was approximately 171 Curies and the average Cs-137 in a single filter was approximately 2.9 milliCuries.

Additionally, over the same four years, more than 95% of the Cs-137 sent for disposal was contained in waste already considered homogenous (i.e., resin).

b. Nb-94 is primarily present in activated metals, and very little is present in filtered streams as a corrosion product. Nb-94 is only applicable to activated hardware in Table 1 of Part 61, it is not a filter classification nuclide, and very little Nb-94 is actually present in historical disposed filters. For approximately 50,000 filters in approximately 500 shipments over four years, the sum of the Nb-94 activity in these filters was approximately 0.29 Curies and the average Nb-95 in a single filter was approximately 0.5 microCuries.

Excluding cartridge filters from the definition of homogenous waste is not technically justified from a risk perspective as the gamma source term of concern is not present. This cartridge filter restriction in the BTP creates an unnecessary burden on sampling, characterization and packaging and results in additional dose to actual people. This restriction is not warranted because the long-lived gamma dose rate hazard to an inadvertent intruder from an unearthed cartridge filter following disposal site closure is minimal.

4. Extend the activated hardware averaging constraints to permit averaging over "similar and adjacent components" rather than the current and proposed "individual component." An example of the collective dose benefit resulting from this treatment is the Trojan reactor project, which averted significant occupational dose to real people. Had this been done with the Rowe reactor, about 100 person-rem would have been averted, most likely without any postulated additional dose to the public or to an inadvertent intruder. Long-lived gamma emitters do not drive the waste classification of activated hardware in which the classification is primarily driven by non-gamma emitting nuclides of nickel (predominantly Ni-63). The gamma dose rates from activated hardware are dominated by the short-lived gamma emitter Co-60. Consequently, activated hardware in general does not pose a tremendous long-lived gamma dose rate concern to an inadvertent intruder. Moreover, significant collective dose to real individuals can be saved by expanding the averaging constraints to permit averaging over "similar and adjacent" components rather than assuming an arbitrary volume based on whatever size a single activated component (>0.01 ft^3) happens to be regardless of the component's size, quantity or position axially and radially in the reactor flux.

5. Specify a minimum acceptable (>14%) waste loading to binder ratio in the body of the BTP that is acceptable to the NRC for encapsulation of waste and is independent of the container size. The >14% waste value is based on the 55 gallon drum example in Appendix C of the existing BTP which has been scaled up and approved in subsequent NRC topical reports on the encapsulation of waste. The purpose and guidance for the encapsulation of sources should be separate in the BTP because sources are encapsulated

primarily for gamma dose concerns and for isolation (sealed sources are typically of a special form design and not readily dispersible) and secondarily for concentration averaging. Whereas waste is encapsulated primarily to mitigate dispersion and for averaging purposes, a secondary role of the encapsulation may be to provide stability

The results of EPRI research related to this topic have been published in several publicly available technical reports:

- *An Evaluation of Alternative Classification Methods for Routine Low Level Waste from the Nuclear Power Industry.* EPRI, Palo Alto, CA; 2007, 1016120
- *Proposed Modifications to the NRC Branch Technical Position on Concentration Averaging and Encapsulation (BTP): Technical Bases and Consequence Analysis.* EPRI, Palo Alto, CA; 2008, 1016761
- *Options for Improved Low Level Waste Disposal Using 10 CFR 61.58.* EPRI, Palo Alto, CA; 2010. 1021098.
- In 2012, another technical report will be published providing more detailed analysis of these recommendations.

Thank you for consideration of this letter in the future Draft BTP for comment to be published in April 2012.

Best Regards,
Lisa Edwards

LMEdwards

EPRI Senior Program Manager
Chemistry, Low Level Waste and Radiation Management

cc: Larry Camper USNRC
James Kennedy USNRC
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Attachments:

1. "Residential Water Well Drilling Scenario Parameters for Low Level Radioactive Waste Disposal Site Development - An Analysis for the Electric Power Research Institute"; 35 pp.

Residential Water Well Drilling Scenario Parameters for Low Level Radioactive Waste Disposal Site Development
An Analysis for the Electric Power Research Institute.

Purpose

The purpose of this analysis is to identify common practices and regulatory requirements to develop plausible assumptions for a domestic water well-drilling scenario for radiation exposure modeling at a theoretical Low Level Radioactive Waste Disposal Site. The assumptions and scenario, when fully developed, could then be applied to an evaluation of an actual disposal site. The assumptions developed from the data collected are representative of equipment and methods in use at the current time and are expected to be applicable in the foreseeable future.

Summary

Water well drilling is a highly regulated and controlled activity. Regulatory requirements come from the Federal, State and Local levels. Industry trade groups also establish standards that are used throughout the industry and in some cases incorporated into licensing requirements for professional drillers. While there is no single set of standards or regulations apply universally, most States establish similar requirements. Overall, Federal regulations apply when water well drilling is performed in or near designated hazardous sites which would include any site currently used for disposal of Low Level Radioactive Waste.

The requirements and practices discovered during this investigation lead to the following general conclusions:

1. Water well drilling is a highly regulated activity. Most States require the use of professional drilling operators and / or require a permit be obtained from the regulating agency to conduct drilling operations.
2. Professional certifications for well-drillers and permitting requirements in most States address the potential for encountering hazardous material sites and direct compliance with stringent regulations for sampling, handling and disposal of drilling materials in a hazardous site.
3. All States require data collection and submittal of documentation of well drilling activities including the documentation of any problems or anomalies encountered.
4. Most States require testing of well water prior to issuing occupancy permits for dwellings. Standards for radioactive material in water exist as part of testing requirements.
5. All methods of drilling water wells require specific knowledge of the sub-strata expected to be encountered so that the correct equipment selections are made.
6. All methods of drilling water wells use equipment and techniques that cause significant mixing of the drill tailings with other materials.
7. A common practice for all well drilling techniques is to collect and bury tailings as the material is not typically suitable for finished grade. In the case of drilling on or near a hazardous site, collection and disposal of drill tailings is required.

Using this data as a basis, reasonable assumptions for a water well-drilling scenario can be developed and applied to a dose model. The results are well within the performance criteria identified in NUREG-0782.

Residential Water Well Drilling Scenario Parameters for Low Level Radioactive Waste Disposal Site Development
An Analysis for the Electric Power Research Institute.

Analysis

Water well-drilling practices were researched using internet searches and direct contact methods. The National Ground Water Association was contacted, and they identified that well-drilling is regulated by individual States and the Occupational Safety and Health Standards (OSHA), 29 CFR 1910.120-for Hazardous Waste Operations. [1] In addition, standard practices that are identified and recommended by institutions like the National Ground Water Association are used by many professional well-drillers as a means to ensure practices are consistently implemented and in compliance with general standards.

State regulations were reviewed for commonalities and requirements. In addition, several well-drilling companies were contacted directly to establish the level of knowledge of requirements and confirm assumptions on well-drilling implementation.

State Regulations

Water well drilling is regulated by the individual states. Each state has a water well driller regulator, who can be contacted in order to get the most accurate and up-to-date regulations.

While every state has its own regulations, all states require that a water well log be submitted within a certain period of time after completion of a well. These well logs provide the state with accurate information about every water well within that state (1).

All 50 States' well drilling regulations were reviewed, and put into categories: requires a licensed contractor to drill a well; the owner of a property can drill his own well, for single family usage, but still must comply with state regulations; no regulations on a property owner drilling their own well for single family usage; unclear who is permitted to drill, but regulations are to be followed and/or permits are required; and unknown private well drilling regulations.

The following States require a licensed contractor to drill a water well:

- Alabama (2)
- Arizona (4)
- Arkansas (7)
- California (9)
- Connecticut (11)
- Indiana (13) (14)
- Kentucky (16)
- Louisiana (18)
- Maine (a minimum of an apprenticeship license is needed to participate in drilling activities) (20)
- Michigan (3)
- Nebraska (5) (6)
- New Jersey (8),
- New Mexico (10)
- South Carolina (12)
- Tennessee (15)
- Utah (unless the well is less than 30 feet deep) (17)
- Wyoming (19)

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[1] On October 22, 2004, the U.S. Department of Labor clarified that any employer that engages in drilling operations, which includes the water well drilling industry, shall comply with OSHA.

South Carolina was found to have a distance requirement of at least 100 feet from a "radioactive waste landfill" (12).

The following States allow property owners to drill their own wells, but still must comply with some or all regulations:

- Colorado (permit required) (21) (22)
- Delaware (must follow construction regulations) (25) (26)
- Georgia (must comply with State standards) (28) (29)
- Hawaii (permit and a certificate of water use required) (31)
- Idaho (only without the aid of power-driven mechanical equipment) (34)
- Iowa (must comply with State standards) (36) (37)
- Kansas (location must be pre-approved of by the Municipal and County Governments) (39)
- Minnesota (must notify the Commissioner) (23) (24)
- Missouri (must comply with all regulations of a licensed well driller) (27)
- Oregon (permit required) (30)
- Rhode Island (must comply with all regulations of a licensed well driller) (32) (33)
- Texas (must comply with regulations) (35)
- Washington (must comply with standards and provide State with a notification of well construction) (38)

The following States' water well drilling regulations exclude an individual who drills a water well on his or her own property, for single family usage:

- Illinois (40)
- Pennsylvania (41)

The following States' water well drilling regulations were unclear about who specifically is permitted to drill a well, but regulations are to be followed and/or permits are required:

- Florida (statewide regulation requires a permit, but five districts regulate water well drilling) (42)
- Maryland (permit required) (44)
- Montana (location regulations) (46)
- Nevada (must submit an intent to drill) (48)
- New Hampshire (standards apply) (50)
- New York (permit required and must submit an application to construct) (52)
- Ohio (permit required) (43)
- Oklahoma (location regulations) (45)
- South Dakota (permit required) (47)
- Vermont (some private wells require permits, State construction standards are to be followed) (49)
- Virginia (permit required, and inspection required prior to use) (51)
- West Virginia (permit required) (53)

- North Carolina (permit required, unless the design capacity is less than 100,000 gallons per day) (54)
- North Dakota (permit required) (56) (57)
- Wisconsin (must comply with drilling regulations) (55)

The following States were placed in a miscellaneous category:

- Alaska (individual well owner regulations are unknown) (58)
- Massachusetts (each town makes their own regulations) (60)
- Mississippi (an individual landowner can drill a well on his/her own property, for single family use, without a license but it is unknown if a permit is required) (59)

Private water well drilling regulations in all States, except Illinois and Pennsylvania, contain location requirements from potentially hazardous materials. In order to avoid potentially dangerous materials, well drillers must examine the location the well is to be drilled on and gain approval from the State Regulator. Once a potentially hazardous situation is identified, the National regulations found in OSHA are required to be followed.

Industry Standards and OSHA Requirements with Potentially Hazardous Sites

Industry standards and regulations for determining a drilling location on a potentially dangerous site require pre-fieldwork planning, in order to determine a safe location for the well. Typical pre-fieldwork planning involves: obtaining maps and figures showing underground and aboveground equipment, piping, utilities, and/or any surface or subsurface hazards; obtaining historic site information, such as maps, photos, and files; obtaining site as-built drawings; obtaining historic plot plans; obtaining elevations and coordinate maps; contacting the local *ONE CALL* (Dig-Safe) Utility Locate Service; and occasionally individuals who may have historical site information are interviewed (61).

During the pre-planning fieldwork, standard practice is to seek out potential underground structures. Typical underground facilities that are looked for routinely include, but are not limited to: pipelines of all types, utilities, electrical conduits, overhead structures, fiber optic lines, and tanks. Many instruments are used to locate such underground facilities. Typical instruments for locating underground facilities include:

Ground Penetrating Radar	• Used for investigating shallow, geologic, and hydrologic features. • Useful in locating man-made features (such as buried drums, tanks, pipes, or other metallic objects).
Pipe Tracing Transmitter and Receiver	• Used to detect and trace metallic utilities, utility tracing wires, or warning tapes. • Limited to metallic objects and is not useful for plastic, ceramic, or fiberglass utilities.

Electromagnetic Utility Tracing Receiver	• Locates buried materials having a high conductance. • Good at locating buried pipes, tanks, drums, and other metallic objects, leachate plumes, salt water intrusions, acid mine drainage, and other ground water contamination problems. • Quick and economical site assessment of areas with variable bedrock topography. • Limitations that can adversely affect electromagnetic measurements include power lines, metal fences, metal debris, and utilities.
Deep Focused Sensing Metal Detector	• Acts as a pipe and cable locator and tracer to detect and trace metallic utilities, utility tracing wires, or warning tapes. • Not useful for plastic, ceramic, or fiberglass utilities.
Vibrocator	• Used to detect and trace fluid-filled, non-metallic utilities.

(61)

OSHA requirements, as applied to water well drilling, state that "a preliminary evaluation of a site's characteristics shall be performed prior to site entry by a qualified person in order to aid in the selection of appropriate employee protection methods prior to site entry. Immediately after initial site entry, a more detailed evaluation of the site's specific characteristics shall be performed by a qualified person in order to further identify site hazards and to further aid in the selection of the appropriate engineering controls and personal protective equipment for the tasks to be performed" (62). It is also required by OSHA that the following information be obtained by the employer, to the extent possible, prior to letting employees enter the site to drill the well: location and approximate size of the site, description of the response activity and/or the job task to be performed, duration of the planned employee activity, site topography and accessibility by air and roads, safety and health hazards expected at the site, pathways for hazardous substance dispersion, present status and capabilities of emergency response teams, and hazardous substances and health hazards involved or expected at the site and their chemical and physical properties. If the pre-fieldwork planning does not produce enough information to determine the risks of the work-site, direct reading instruments are to be used to appropriately identify immediately dangerous to life and health conditions.

After the pre-fieldwork planning has been completed, but prior to the drill being lowered to begin drilling the well, the site must be cleared of obvious issues. The goal is to verify that there is an absence of subsurface structures in order to avoid damaging the equipment, the property, the environment, and avoid injury to workers or others. The depth and diameter of the well also go through a clearance procedure, with it being preferable to drill a hole to about 120% of the diameter of the largest tool used for drilling in order to identify any structures that are slightly tangential to the borehole, that might have been missed during the pre-fieldwork planning (61).

Once drilling has begun, OSHA requires constant monitoring of the work-site. The following monitoring is to be done when the pre-fieldwork planning produces information that suggests there is a potential for ionizing radiation of immediately dangerous to life and health conditions, or when the site information is not sufficient to eliminate the possibility of such conditions: monitoring with direct reading instruments for hazardous levels of ionizing radiation, monitoring the air with the appropriate

direct reading test equipment for immediately dangerous to life and health conditions (combustible or explosive atmospheres, oxygen deficiency, toxic substances), and visually observing for signs of actual or potential immediately dangerous to life and health or dangerous conditions. An ongoing monitoring program is to be implemented after the site characterization is completed in the pre-fieldwork planning (62).

OSHA requires specific monitoring of the well drilling site during certain times, including: upon initial entry, representative air monitoring shall be conducted to identify any immediately dangerous to life and health conditions, exposure over permissible exposure limits or published exposure levels, exposure over a radioactive material's dose limits, or other dangerous conditions such as the presence of flammable atmospheres or oxygen-deficient environments; and periodic monitoring shall be conducted when the possibility of an immediately dangerous to life and health condition or flammable atmosphere has developed or when there is an indication that exposures may have risen over permissible exposure limits or published exposure levels since prior monitoring. Situations in which it is considered possible that exposure limits have risen include: when work begins on a different portion of the site, when contaminants other than those previously identified are being handled, when a different type of operation is initiated, and when employees are handling leaking drums or containers or working in areas with obvious liquid contamination (62).

In accordance with OSHA requirements concerning site monitoring, industry monitoring standards include: monitoring the site for the potential dangers from fire, explosion, airborne contaminants, radiation, or oxygen deficient atmospheres; and when radiation may be encountered at a site, a Geiger-Mueller detector for beta and gamma radiation should be used to monitor airborne levels (61).

Once the drilling has begun, there are housekeeping rules that the drillers must follow. The industry standards for housekeeping include: dirty or contaminated pipe, drill rods, augers, or sampling equipment are to be moved away from the work area to prevent possible exposure to non-protected personnel and also to prevent cross-contamination of clean materials; wastewater and drilling fluids must be properly contained, labeled, and stored out of the operational area; empty bags or other containers which have held drilling mud, cement, or other dust producing materials, are to be removed and disposed of; workers are to remove cuttings with a long-handled shovel, not with the hand or foot; if drilling with air, the exhaust and cuttings are to be directed away from the workers; cuttings are to be contained in drums or plastic sheeting; and the soil cuttings and ground water should be contained in the same manner as other waste material generated during the drilling operations (61). OSHA also requires, in addition to the industry standards, that drums and containers containing radioactive wastes shall not be handled until a time in which their hazard to employees can be properly assessed (62).

Drilling Methods

The type of equipment used to drill a well depends on a number of factors, including but not limited to water bed levels, top soil conditions, and geologic conditions. Due to the variability of these conditions, it is not possible to generalize a specific drilling method that is used across the U.S. However, state water well drilling regulators may have some trending data for their specific state. A site specific analysis is completed during the pre-planning fieldwork to determine the best drilling method to use for each job. Below is a table listing common drilling methods used.

Cable Tool	• Breaks or crushes to consolidate rock into small fragments. When drilling unconsolidated formations, the bit primarily loosens material, and creates a slurry at the bottom of the borehole. • Highly suitable for remote settings, as there is low fuel consumption, small needs for water and other materials, and reliable. • Low investment and inexpensive to operate. • Particularly suited to poor water access. • Low productivity rate. Hard rock penetration rate is very low. • Slurry pits are used to contain cuttings.
Auger Drilling	• Often used for site investigation, environmental and geotechnical drilling and sampling, and boreholes for construction purposes. • Low operating costs. • Fast penetration rates in suitable formations. • Difficult to impossible to penetrate bouldery formations. • Cannot drill hard-rock formations. • Generally poor, or cessation of, performance deeper than 100 feet.
Rotary Drilling	• Uses a sharp, rotating drill bit to dig down through the Earth's crust. • The spinning of the drill allows for penetration of even the hardest rock. • Fluids are used to keep the hole clean, and a slurry pit is used to contain cuttings. • 4 drill bits are used (# 1 and 2 are the most commonly used): ○ 1. Blade or drag bits- cuts surfaces for drilling unconsolidated formations. ○ 2. Steel tooth rotary bits- cutting action is through a crushing and chipping action. ○ 3. Polycrystalline diamond compact bits- primarily in oil and gas industry and applications in the directional drilling sector. ○ 4. Diamond bits- can be used to drill through extremely hard rock without dulling overly quickly. Used in geophysical drilling for coring applications.
Mud Rotary	• Water or water with additives (mud) is pumped down the drill pipe and out through the ports or jest in the drill bit. • Is the most popular form of the rotary drilling methods. • Cuttings are carried into the drill rods and discharged back into the mud pit.
Reverse Mud Circulation	• These drill rigs are far larger than those used for domestic purposes. • Cuttings are carried into the drill rods and discharged back into the mud pit. • Near-well area of the borehole is relatively undisturbed and uncontaminated with drilling additives. • Most geologic formations can be drilled, with the exception of igneous and metamorphic rocks. • Rigs are large and expensive.
Direct Air Rotary Drilling	• Air alone lifts the cuttings from the borehole. • The cuttings are blown out the top of the hole and collected at the surface around the borehole. • Provides excellent information concerning what is happening within the hole. • Fast penetration and hit bit life. • Expensive to own and operate.

Reverse Air Drilling	• Most successful when drilling in soft, sedimentary rock and unconsolidated sand and gravel. • An air assisted lift is created up the drill pipe, drawing cuttings from the borehole through the bit and ejecting them at the exit hose attached to the top of the swivel and into the holding pond (rapid removal of cuttings). • Seen as an excellent approach for municipal supply wells. • Seldom used in small diameter wells.
Down the Hole Air Hammer	• Air activated percussive drilling bit, which operates in the same manner of the jack hammer commonly seen in surface construction. • Corrosion is common in drill. • After each piston stroke air is exhausted from the bit face, cuttings are cleared and removed from the borehole from the outside of the drill pipe. • More efficient than the traditional cable tool method. • Is the fastest hard formation penetration method. • Expensive to own and operate.
Jet Drilling	• Often used in drilling shallow irrigation wells. • Water circulates through the rods, washing cuttings from in front of the bit. The cuttings flow up the annular space and in a settling pit so that the water can be recirculated. • Can go to depths of 1,000 feet.

(63)

Well-Driller Contacts

Five well drillers were contacted and asked several questions regarding current well drilling practices. (64) (65) (66) (67) (68)The respondents indicated that the equipment used and methods employed would be based on the expected conditions in the area. Typically this would mean the most cost-effective method for the soil conditions. Equipment that is more robust is typically more expensive and would not be employed except in special circumstances. The circumstances would necessarily involve additional site research that would reasonably be expected to preclude an inadvertent intrusion into a LLRW Disposal Site.

It was determined that the most common method of drilling for soil conditions typical at an abandoned waste site involves the use of mud rotary equipment. In this method, a fluid is pumped down the inside of the drill pipe, forced out the cutting head, and returned to the surface between the drill pipe and the bore hole. The fluid brings the drill cuttings to the surface and discharged into the first of a series of two portable pits where they settle out. The fluid flows into the second pit to allow any additional particulates settle before it is pumped down the drill pipe again. The fluid used can be clear water, water mixed with bentonite (an absorbent clay material) or water mixed with other biodegradable materials.

In addition to drilling, a casing must be inserted into the bore hole, the screen must be installed, the well must be grouted and time given for all the grout to set and the pump must be installed. Trenches for the supply lines must also be dug, the lines must be placed and the trenches then filled. The depth of the trenches range from as deep as six feet in colder climates, to as shallow as one foot in warmer climates.

Residential Water Well Drilling Scenario Parameters for Low Level Radioactive Waste Disposal Site Development
An Analysis for the Electric Power Research Institute.

Plausible Well-Drilling Analysis

Assumptions

The following assumptions are made based on the above information:

1. The placement of a dwelling on the site is assumed to be determined prior to drilling. Construction of the dwelling is assumed not to begin until after an adequate well is drilled. If adequate water is not found, there no longer is a need for construction of the dwelling.
2. The diameter of the hole is assumed to be 8" (0.2032 m).
3. The drilling depth is assumed to penetrate the first saturated zone by a distance of 32.808' (10 m).
4. The size of the portable mud pit is assumed to be 8' long (2.4384 m) by 6' (1.5240 m) wide by 4' (1.2192 m) deep. After the supply lines are dug, the material in the mud pit is shoveled into the trench.
5. The trench will be dug to a depth of 4' (1.12192 m) and a width of 2' (0.6096 m).
6. The well is assumed to be placed 20' (6.096m) away from the home.
7. If resistance, such as hitting an engineered barrier or reinforced concrete, is met within 30' (9.144 m) of the surface, the driller will move several meters laterally and restart. If resistance is met repeatedly, the driller will stop drilling altogether and research the site before proceeding.
8. If unexpected material, such as large pieces of material that are not consistent with the soil type, is brought up by the drill, the driller will stop drilling altogether and research the site before proceeding.
9. The drilling of the well, installation of the casing and the screen, grouting and setting, installation of the pump, and digging and placing of the supply line is assumed to take 12 hours (1.369E-03 years).

The assumptions are based on interviews of the professional well drillers and represent common drilling practices for residential water wells.(64), (65), (66), (67) (68)

Source Term

The source term used was derived from the source term that was developed for EPRI Report 1021098, *Options for Improved Low Level Waste Disposal Using 10 CFR 61.58* (69). Only Class A waste process waste was used based on the assumption that drilling into any reinforced material or metal would result in the halting of drilling as is stated above (Number 8). The initial source term containing all radionuclides was decayed 100 years from the closure of the site to account for decay during the period of institutional control. The radionuclides were then screened to remove any radionuclides with activities less than 1.00E-10 Ci. The activities were then adjusted to account for dilution due to the fact that of the total volume of material removed by the drilling, only the material removed from the 8 meter waste zone is contaminated. Each site has a different source term as a result of the differences in drilling depths to the aquifer that is part of the site assumptions from NUREG 0782. (70) The source terms for the dry climate site are shown in Table 1 and the wet climate site is shown in

Table 2.

Table 1: Source term for the Dry Climate Site

Nuclide	EPRI Report 1021098 Class A (Ci)	EPRI Report 1021098 Class A (pCi/g)	Drilling Scenario Source Term (Ci)	Drilling Scenario Source Term (pCi/g)
AM-241	4.16E+00	2.72E+00	3.46E-01	2.26E-01
C-14	1.38E+03	9.01E+02	1.15E+02	7.49E+01
CM-243	5.20E-02	3.40E-02	4.32E-03	2.83E-03
CM-244	1.12E-02	7.33E-03	9.32E-04	6.10E-04
CO-60	7.91E-03	5.17E-03	6.58E-04	4.30E-04
CS-137	4.11E+02	2.69E+02	3.42E+01	2.24E+01
FE-55	2.53E-09	1.65E-09	2.10E-10	1.38E-10
H-3	2.24E+00	1.46E+00	1.86E-01	1.22E-01
NB-94	3.62E-01	2.37E-01	3.01E-02	1.97E-02
NI-59	1.59E+02	1.04E+02	1.32E+01	8.66E+00
NI-63	2.90E+03	1.90E+03	2.42E+02	1.58E+02
PU-238	8.17E-01	5.34E-01	6.79E-02	4.45E-02
PU-239	6.38E+00	4.17E+00	5.31E-01	3.47E-01
PU-241	1.87E-01	1.23E-01	1.56E-02	1.02E-02
SR-90	4.74E+00	3.10E+00	3.94E-01	2.58E-01
TC-99	2.83E+02	1.85E+02	2.35E+01	1.54E+01
Class A Waste Volume			1.02E+06	m^3
Drilled Material Volume			3.114	m^3
Contaminated Drilled Material Volume			0.259	m^3
Dilution Factor			8.32E-02	

Table 2 Source Term for the Wet Climate Site

Nuclide	EPRI Report 1021098 Class A (Ci)	EPRI Report 1021098 Class A (pCi/g)	Drilling Scenario Source Term (Ci)	Drilling Scenario Source Term (pCi/g)
AM-241	4.16E+00	2.72E+00	1.23E+00	8.05E-01
C-14	1.38E+03	9.01E+02	4.08E+02	2.67E+02
CM-243	5.20E-02	3.40E-02	1.54E-02	1.01E-02
CM-244	1.12E-02	7.33E-03	3.32E-03	2.17E-03
CO-60	7.91E-03	5.17E-03	2.34E-03	1.53E-03
CS-137	4.11E+02	2.69E+02	1.22E+02	7.96E+01
FE-55	2.53E-09	1.65E-09	7.49E-10	4.90E-10
H-3	2.24E+00	1.46E+00	6.63E-01	4.33E-01
NB-94	3.62E-01	2.37E-01	1.07E-01	7.00E-02
NI-59	1.59E+02	1.04E+02	4.71E+01	3.08E+01
NI-63	2.90E+03	1.90E+03	8.60E+02	5.63E+02
PU-238	8.17E-01	5.34E-01	2.42E-01	1.58E-01
PU-239	6.38E+00	4.17E+00	1.89E+00	1.24E+00
PU-241	1.87E-01	1.23E-01	5.54E-02	3.63E-02
SR-90	4.74E+00	3.10E+00	1.40E+00	9.18E-01
TC-99	2.83E+02	1.85E+02	8.38E+01	5.48E+01
Class A Waste Volume			1.02E+06	m^3
Drilled Material Volume			0.8748	m^3
Contaminated Drilled Material Volume			2.96E-01	m^3
Dilution Factor			2.96E-01	

RESRAD INPUTS

The site input parameters for the scenario are summarized below in Table 3 for the dry climate site and Table 4 for the wet climate site. For both sites, the contaminated zone is determined by the volume of the drill cuttings, spread in a 12" (0.3048 m) layer over the bottom of the supply line trench immediately next to the well.

Table 3: Dry climate site Parameters

Parameter	RESRAD Input Value	Unit	Value from
1. Contaminated Zone			
a. Area	10.214	$meters^2$	Calculated from total volume drill cuttings (96 m deep hole, 0.1016 m radius) divided by the thickness of the zone
b. Thickness	0.3048	meters	From assumptions above
c. Length parallel to aquifer flow	16.76	meters	Conservative assumption based on 0.6096 m wide trench
2. Cover & Hydrological data			
a. Cover depth	0.9144	meters	Depth of the trench minus waste depth
b. Density of cover material	1.5	g/cm^3	RESRAD default
c. Cover erosion rate	0.001	meters/year	RESRAD default
d. Density of contaminated zone	1.50E+00	g/cm^3	NUREG 0782 Appendix J
e. Contaminated zone erosion rate	0.001	meters/year	RESRAD default
f. Contaminated zone total porosity	0.42		From RESRAD Table E.8 for Clay. NUREG 0782 Appendix J Section 1.4.1 states the upper 15m of the formation is a caliche (sandy clay that acts as a hardpan) underlayed by 15m of dense brown clay.
g. Contaminated zone field capacity	0.2		RESRAD default
h. Contaminated zone hydraulic conductivity.	4.05E+01	meters/year	From RESRAD Table E.2 for Clay
i. Contaminated zone b parameter	11.4		From RESRAD Table E.2 for Clay
j. Humidity in air	4.7	g/m^3	From RESRAD figure L.1

Parameter	RESRAD Input Value	Unit	Value from
k. Evapotranspiration coefficient	0.999		Calculated value using RESRAD Formula E.4 solving for C_e using the infiltration rate (percolation rate) of 1mm/year from NUREG 0782 Section 1.4.3
l. Wind speed	6.4	meters/s	NUREG 0782 Appendix J Section 1.4.5
m. Precipitation	0.485	meters/year	NUREG 0782 Appendix J Section 1.4.5
n. Irrigation	1	meters/year	RESRAD value for arid regions
o. Irrigation mode (overhead or ditch)	overhead		RESRAD default
p. Runoff coefficient.	0.2		NUREG 0782 Appendix J Section 1.4 description of site topography & soil.
q. Watershed area for nearby stream or pond	899,000	$meters^2$	RESRAD minimum value equivalent to area of contaminated zone. There is no nearby stream or pond with continuous water identified in NUREG 0782 Appendix J Section 1.4.4
r. Accuracy for water/soil computations.	0.001		RESRAD default
3. Saturated zone hydrologic data			
a. Density of saturated zone	1.5	g/cm^3	RESRAD default and typical of medium sand as identified in NUREG 0782 Appendix J Figure J.7
b. Saturated zone total porosity	0.4		RESRAD default and typical of medium sand as identified in NUREG 0782 Appendix J Figure J.7
c. Saturated zone effective porosity	0.32		From RESRAD Table E.8 for medium sand as identified in NUREG 0782 Appendix J Figure J.7
d. Saturated zone field capacity	0.2		RESRAD default
e. Saturated zone hydraulic conductivity	2.97E+03	meters/year	NUREG 0782 Appendix J Section 1.4.3

Parameter	RESRAD Input Value	Unit	Value from
f. Saturated zone hydraulic gradient	0.02		RESRAD default
g. Saturated zone b parameter	4.05		From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix J Figure j.7
h. Water table drop rate	0.001	meters/year	RESRAD default
i. Well pump intake depth (below water table)	10	meters	RESRAD default
j. Model for water transport parameters (Non dispersion / mass balance)	Non dispersion		RESRAD default
k. Well pumping rate.	250	meters/year	RESRAD default
4. Uncontaminated Unsaturated zone parameters			
Zone 1			
a. Thickness	20	meters	NUREG 0782 Appendix J Section 1.4.3. Sum of caliche and clay layers minus waste depth.
b. Density	1.2	g/cm^3	Average density of Clay soils.
c. Total porosity	0.42		From RESRAD Table E.8 for Clay as identified in NUREG 0782 Appendix J Figure J.7
d. Effective porosity	0.06		From RESRAD Table E.8 for Clay as identified in NUREG 0782 Appendix J Figure J.7
e. Field capacity	0.2		RESRAD default
f. Hydraulic conductivity	4.05E+01	meters/year	From RESRAD Table E.2 for Clay as identified in NUREG 0782 Appendix J Figure J.7
g. b parameter	11.4		From RESRAD Table E.2 for Clay as identified in NUREG 0782 Appendix J Figure J.7

Parameter	RESRAD Input Value	Unit	Value from
Zone 2			
a. Thickness	56	meters	NUREG 0782 Appendix J Section 1.4.3. Distance to water table is 84m from surface - disposal trench depth of 8m - Zone 1
b. Density	1.5	g/cm^3	RESRAD default and typical of medium sand as identified in NUREG 0782 Appendix J Figure J.7
c. Total porosity	0.43		From RESRAD Table E.8 for fine sand as identified in NUREG 0782 Appendix J Figure J.7 (Medium sand with fines)
d. Effective porosity	0.33		From RESRAD Table E.8 for fine sand as identified in NUREG 0782 Appendix J Figure J.7 (Medium sand with fines)
e. Field capacity	0.2		RESRAD default
f. Hydraulic conductivity	5.55E+03	meters/year	From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix J Figure j.7
g. b parameter	4.05		From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix J Figure j.7
5. Carbon 14			
C-14 evasion flux rate from soil	3.80E-07	sec-1	From RESRAD Appendix L Table L.2 for clay soils as identified in NUREG 0782 Appendix J Figure J.7

Parameter	RESRAD Input Value	Unit	Value from
1. Contaminated Zone			
a. Area	2.87	$meters^2$	Calculated from total volume drill cuttings (27 m deep hole, 0.1016 m radius) divided by the thickness of the zone
b. Thickness	0.3048	meters	From assumptions above

Parameter	RESRAD Input Value	Unit	Value from
c. Length parallel to aquifer flow	4.69	meters	Conservative assumption based on 0.6096 m wide trench
2. Cover & Hydrological data			
a. Cover depth	0.9144	meters	Depth of the trench minus waste depth
b. Density of cover material	1.5	g/cm^3	RESRAD default
c. Cover erosion rate	0.001	meters/year	RESRAD default
d. Density of contaminated zone	1.5	g/cm^3	NUREG 0782 App J
e. Contaminated zone erosion rate	0.001	meters/year	RESRAD default
f. Contaminated zone total porosity	0.42		From RESRAD Table E.8 for Clay. NUREG 0782 App E figure E.7 pg. E-23 identifies the layer as compact sandy clay. Use parameters for cover as baseline value.
g. Contaminated zone field capacity	0.2		RESRAD default
h. Contaminated zone hydraulic conductivity.	6.84E+01	meters/year	From RESRAD Table E.2 for Sandy Clay as identified in NUREG 0782 App E figure E.7 pg. E-23. Use parameters for cover as baseline value.
i. Contaminated zone b parameter	10.4		From RESRAD Table E.2 for Sandy Clay as identified in NUREG 0782 App E figure E.7 pg. E-23. Use parameters for cover as baseline value.
j. Humidity in air	10.6	g/m^3	From RESRAD figure L.1 using mean value of higher humidity region of SC
k. Evapo-transpiration coefficient	0.8321		Calculated value using RESRAD Formula E.4 solving for C_e using the infiltration rate (percolation rate) of 180 mm/year from NUREG 0782 Appendix E Section 3.1 pg. E-16.
l. Wind speed	3.61	meters/s	NUREG 0782 App E pg. E-19 given

Parameter	RESRAD Input Value	Unit	Value from
			average value of 13 km/hr
m. Precipitation	1.168	meters/year	NUREG 0782 App E pg. E-16
n. Irrigation	0.2	meters/year	RESRAD default for humid regions with limited growing season. This is used due to lack of site specific data.
o. Irrigation mode (overhead or ditch)	overhead		RESRAD default
p. Runoff coefficient.	0.3		NUREG 0782 Appendix E Section 3.1.1 and 3.1.2 pg. E-21 - E-23 description of site topography & soil.
q. Watershed area for nearby stream or pond	899,000	$meters^2$	RESRAD minimum value equivalent to area of contaminated zone. The nearest stream is 1000m SE of the site as identified in NUREG 0782 Appendix E Section 3.2.6 pg. E-25.
r. Accuracy for water/soil computations.	0.001		RESRAD default
3. Saturated zone hydrologic data			
a. Density of saturated zone	1.5	g/cm^3	RESRAD default and typical of sand as identified in NUREG 0782 Appendix E Figure E.7.
b. Saturated zone total porosity	0.39		From RESRAD Table E.8 for coarse sand. NUREG 0782 Appendix E Figure E.7 identifies the layer as coarse to fine sand.
c. Saturated zone effective porosity	0.3		From RESRAD Table E.8 for coarse sand. NUREG 0782 Appendix E Figure E.7 identifies the layer as coarse to fine sand.
d. Saturated zone field capacity	0.2		RESRAD default
e. Saturated zone hydraulic conductivity	5.55E+03	meters/year	From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix E Figure E.7 pg. E-24.
f. Saturated zone hydraulic gradient	0.02		RESRAD default

Parameter	RESRAD Input Value	Unit	Value from
g. Saturated zone b parameter	4.05		From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix E Figure E.7 pg. E-24.
h. Water table drop rate	0.001	meters/year	RESRAD default
i. Well pump intake depth (below water table)	10	meters	RESRAD default
j. Model for water transport parameters (Non dispersion / mass balance)	Non dispersion		RESRAD default
k. Well pumping rate.	250	meters/year	RESRAD default
4. Uncontaminated Unsaturated zone parameters			
Zone 1			
a. Thickness	4	meters	NUREG 0782 App E section 3.2.2 pg. E-23. Sum of sandy minus waste depth.
b. Density	1.2	g/cm^3	Average density of clay soils
c. Total porosity	0.42		From RESRAD Table E.8 for Clay. NUREG 0782 App E figure E.7 pg. E-23 identifies the layer as compact sandy clay.
d. Effective porosity	0.06		From RESRAD Table E.8 for Clay. NUREG 0782 App E figure E.7 pg. E-23 identifies the layer as compact sandy clay.
e. Field capacity	0.2		RESRAD default
f. Hydraulic conductivity	6.84E+01	meters/year	From RESRAD Table E.2 for Sandy Clay as identified in NUREG 0782 App E figure E.7 pg. E-23
g. b parameter	10.4		From RESRAD Table E.2 for Sandy Clay as identified in NUREG 0782 App E figure E.7 pg. E-23
Zone 2			
a. Thickness	3	meters	NUREG 0782 Appendix E Section 3.2.5 pg E-23. Distance to water table ranges from

Parameter	RESRAD Input Value	Unit	Value from
			12m-17m. Use an average distance to water table of 15m from surface - disposal trench depth of 8m - Zone 1
b. Density	1.5	g/cm^3	RESRAD default and typical of sand as identified in NUREG 0782 Appendix E Figure E.7.
c. Total porosity	0.39		From RESRAD Table E.8 for coarse sand. NUREG 0782 Appendix E Figure E.7 identifies the layer as coarse to fine sand.
d. Effective porosity	0.3		From RESRAD Table E.8 for coarse sand. NUREG 0782 Appendix E Figure E.7 identifies the layer as coarse to fine sand.
e. Field capacity	0.2		RESRAD default
f. Hydraulic conductivity	5.55E+03	meters/year	From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix E Figure E.7 pg. E-24.
g. b parameter	4.05		From RESRAD Table E.2 for Sand as identified in NUREG 0782 Appendix E Figure E.7 pg. E-24.
5. Carbon 14			
C-14 evasion flux rate from soil	3.81E-07	sec-1	From RESRAD Table L.2 for Clay. NUREG 0782 App E figure E.7 pg. E-23 identifies the layer as compact sandy clay. Convert value of 12 from yr^{-1} to sec^{-1}.

The RESRAD User's Manual indicates that an area of 2 hectares is required to supply a family of four with all of its meat and milk requirements and 50% of its fruit and vegetable requirements. (71) It is assumed that the fraction of supportable diet will scale linearly downward as the size of the contaminated zone decreases. The small areas of the contaminated zones in this study eliminate the food ingestion pathways. The scenario parameters are summarized in Table 5.

Scenario Pathways	NUREG 0782 Intruder Agriculture		Parameter Justification
External gamma	Yes		Not applicable (see above)

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Scenario Pathways	**NUREG 0782 Intruder Agriculture**		**Parameter Justification**
Exposure			
Inhalation of dust	Yes		Not applicable (see above)
Radon Inhalation	Yes		Not applicable (see above)
Ingestion of plant foods	No		Not applicable (see above)
Ingestion of meat	No		Not applicable (see above)
Ingestion of milk	No		Not applicable (see above)
Ingestion of fish	No		Not applicable (see above)
Ingestion of soil	Yes		NUREG 0782 Intruder Agriculture
Ingestion of water	Yes		NUREG 0782 Intruder Agriculture
Exposure Parameters		Unit	
Exposure duration	30	years	RESRAD default value
Inhalation rate	8,400	m^3/yr	RESRAD default value
Mass loading for inhalation	0.0001	g/m^3	RESRAD default value
Fraction of time indoors	0.500		NUREG 0782 value of 4380 hrs indoors
Fraction of time outdoors	0.205		NUREG 0782 value of 1800 hrs outdoors
Indoor dust filtration factor	0.400		RESRAD default value
External gamma shielding factor	0.030		NUREG 0782 Appendix G
Contaminated fractions of food			
Plant food	0		Not applicable (see above)
Milk	0		Not applicable (see above)
Meat	0		Not applicable (see above)
Aquatic food	0		Not applicable (see above)
Soil ingestion	36.5	g/yr	RESRAD default value for Resident Farmer Scenario Table 2.3

Scenario Pathways	NUREG 0782 Intruder Agriculture		Parameter Justification
Drinking water intake	510	L/yr	RESRAD default value for Resident Farmer Scenario Table 2.3
Analysis Duration	1000	yr	PG-8-08 Scenarios for Assessing Potential Doses Associated with Residual Radioactivity, May 1994

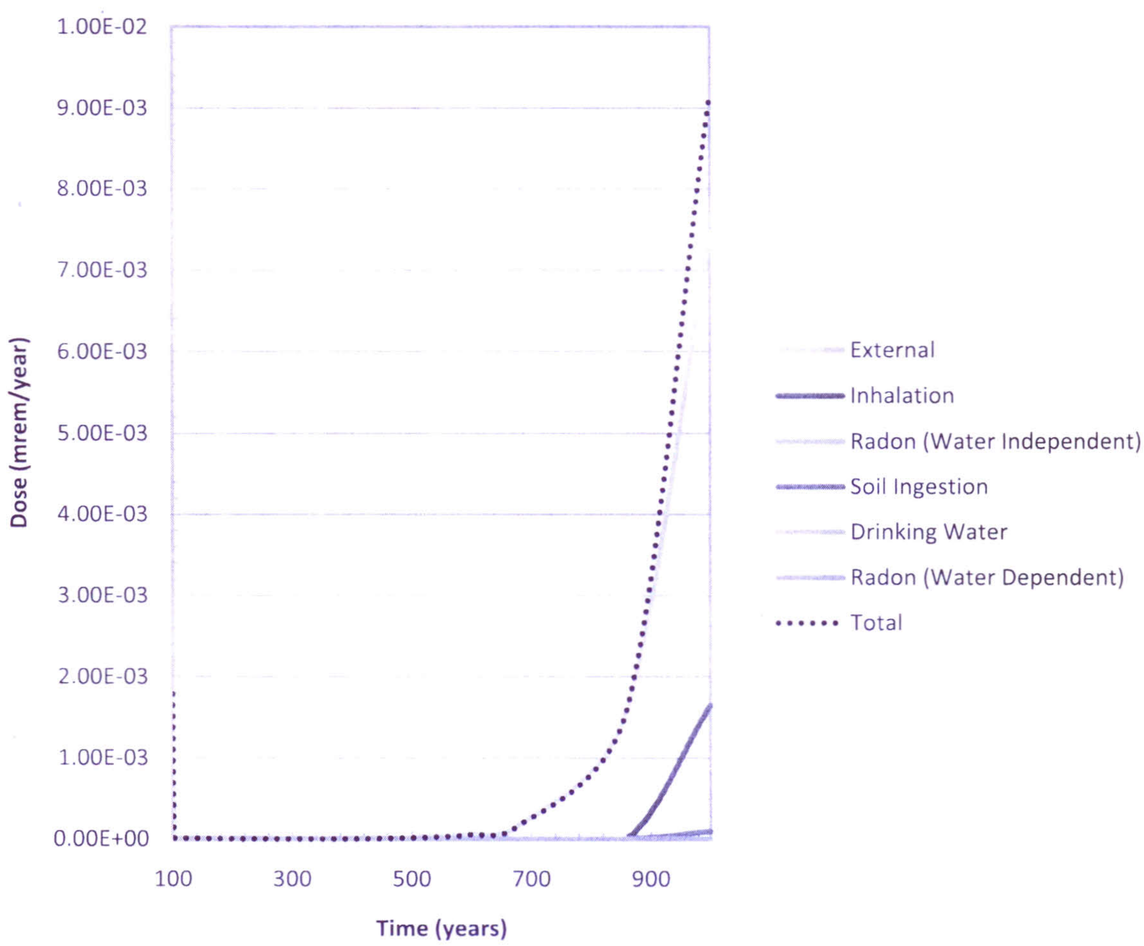
Results

During the drilling of the well on the either site, each worker observes a maximum dose rate of 1.48E-04 mrem/hr, or a total of 1.78E-03 mrem total. The dose is from direct exposure to the drill cuttings in the mud pit. The drill cuttings are buried as part of the drill construction making the observed dose relevant only during the time of construction of the well. Individuals who occupy the site at times before or after the construction of the well will observe maximum dose rates much lower than those of the drilling crew. The dose contribution to the well driller can be seen in Figure 1 and Figure 2 for the Dry Climate Site and the Wet Climate Site respectively.

Residential Water Well Drilling Scenario Parameters for Low Level Radioactive Waste Disposal Site Development
An Analysis for the Electric Power Research Institute.

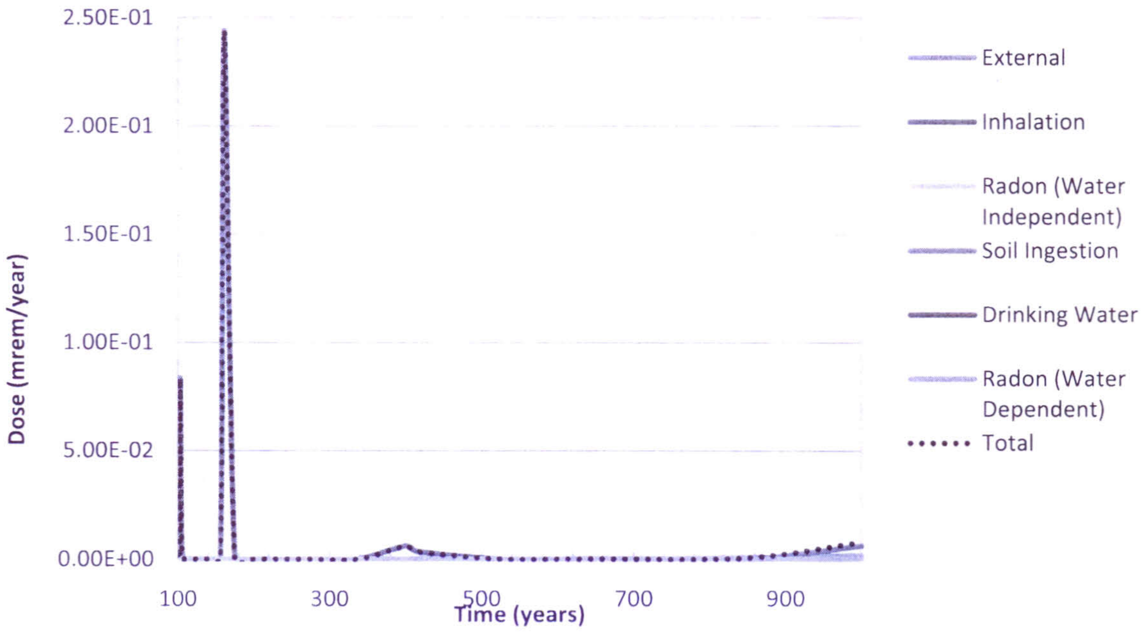
The Dry Climate Site shows a peak dose of 9.178E-03 mrem/year occurring at or beyond 1000 years. Direct exposure from Nb-94 accounts for 81% of the total dose while inhalation of particulates and ingestion of soil containing Pu-239 accounts for 16.5% and 1% respectively of the total dose. A plot of dose from each pathway over time is shown in Figure 1.

Figure 1: Dry Climate Site Total Dose Plot



The Wet Climate Site shows peaks occurring at two different times. The first peak occurs just after 3 years. The entire dose of 8.32E-02 mrem/year is from Tc-99 in drinking water. The second peak occurs just before 62 years. The entire dose of 2.44E-01 mrem/year is from C-14 in drinking water. A plot of dose from each pathway over time is shown in Figure 2.

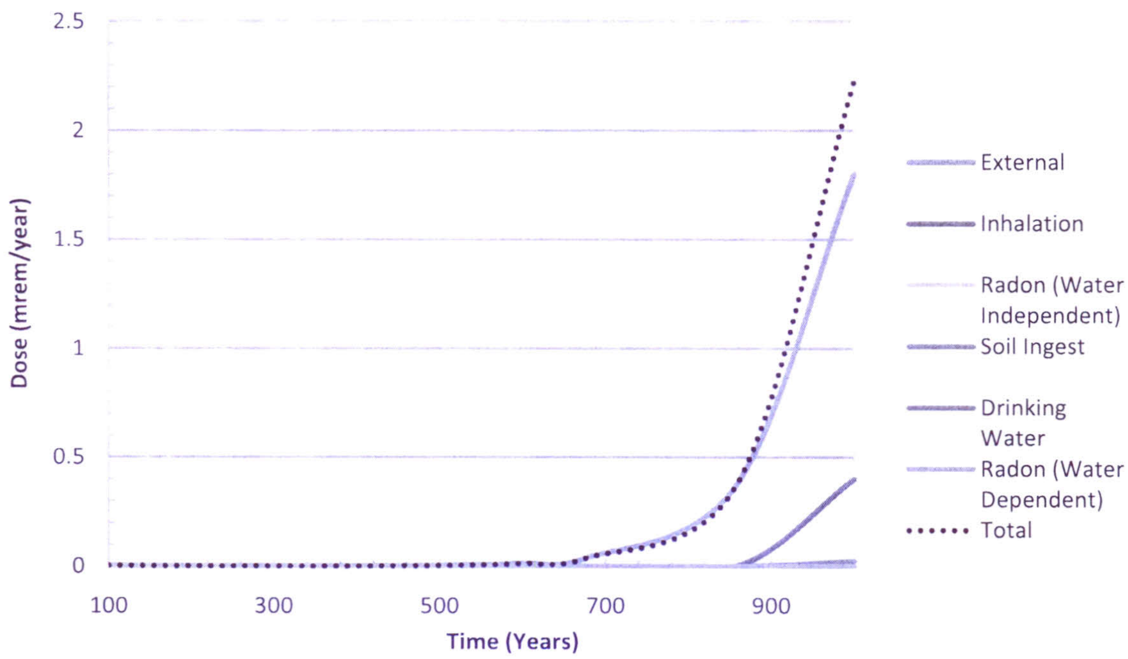
Figure 2: Wet Climate Site Total Dose Plot



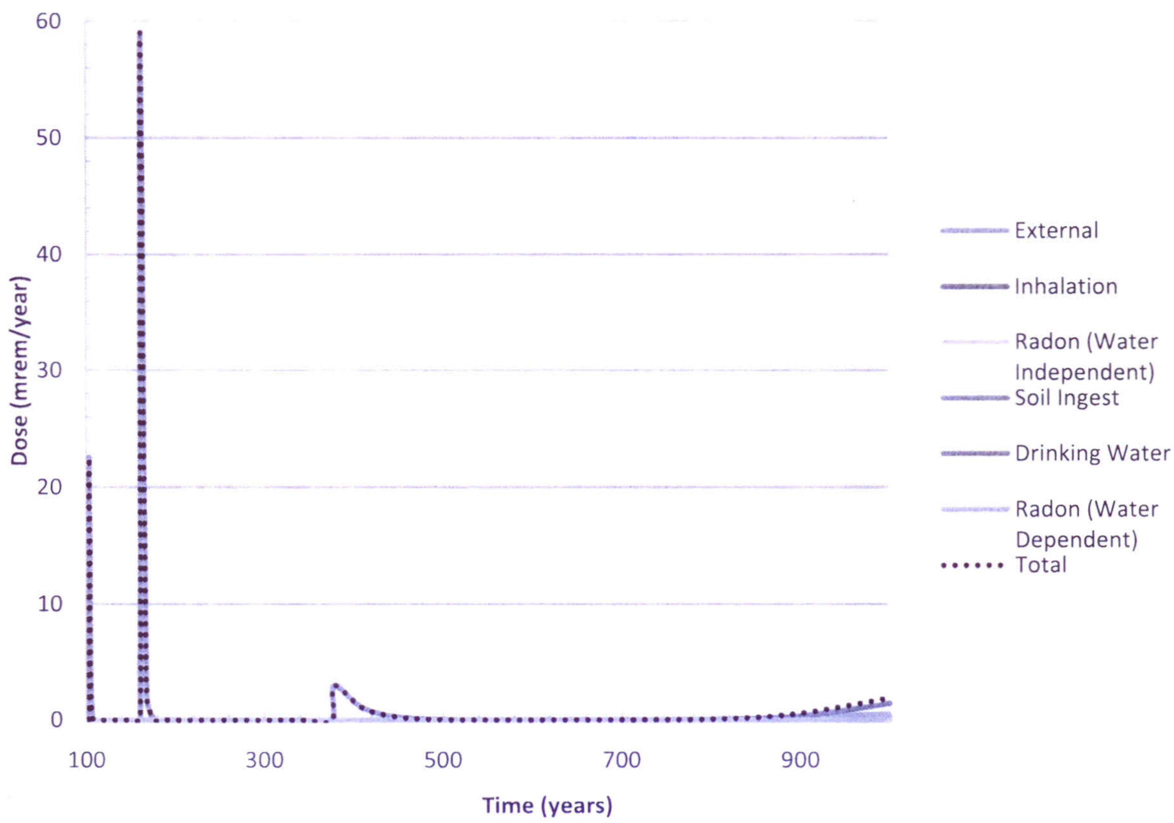
Bounding Case

An analysis was performed with the source-term radionuclide distribution scaled up to values such that the total sum of fractions was at 99% of the Class A limit. The results for the Dry Climate Site are shown in Figure 3. The plot shows a peak dose of 2.22 mrem/year occurring at or beyond 1000 years. Direct exposure from Nb-94 accounts for 81% of the total dose while inhalation of particulates and ingestion of soil containing Pu-239 accounts for 16.5% and 1% respectively of the total dose.

Figure 3. Dry Climate Site, Radionuclide Distribution at 99% of the Class A Limit



The results for the Wet Climate Site are shown in Figure 4. The plot shows peaks occurring at two different times. The first peak occurs just after 3 years. The entire dose of 22.4 mrem/year is from Tc-99 in drinking water. The second peak occurs just before 62 years. The entire dose of 59.02 mrem/year is from C-14 in drinking water.



An analysis was performed with the source-term radionuclides at their Class A limits at the time of disposal. The source term radionuclides described above were all entered at the Class A concentration. This is not a possible scenario as any mixture of radionuclides could not under current regulations have a sum of the fractions greater than 1, i.e. all radionuclides in a mixture cannot ,by definition, be at the Class A limits. The concentrations were decayed to 100 years. Each radionuclide was analyzed individually to see what the impact on dose each would have if disposed of at the Class A concentration. The results for the Dry Climate Site are shown in
Figure 5 and

Table 6. The radionuclides that have peak dose rates above 1.0 E-01 are Am-241, Ni-59, Pu-239 and Nb-94. Inhalation and Soil Ingestion pathways dominate the exposure for Am-241, Ni-59, and Pu-239 while direct exposure pathways dominate for Nb-94.

Figure 5: Dry Climate Site: All Radionuclides at Class A Limit

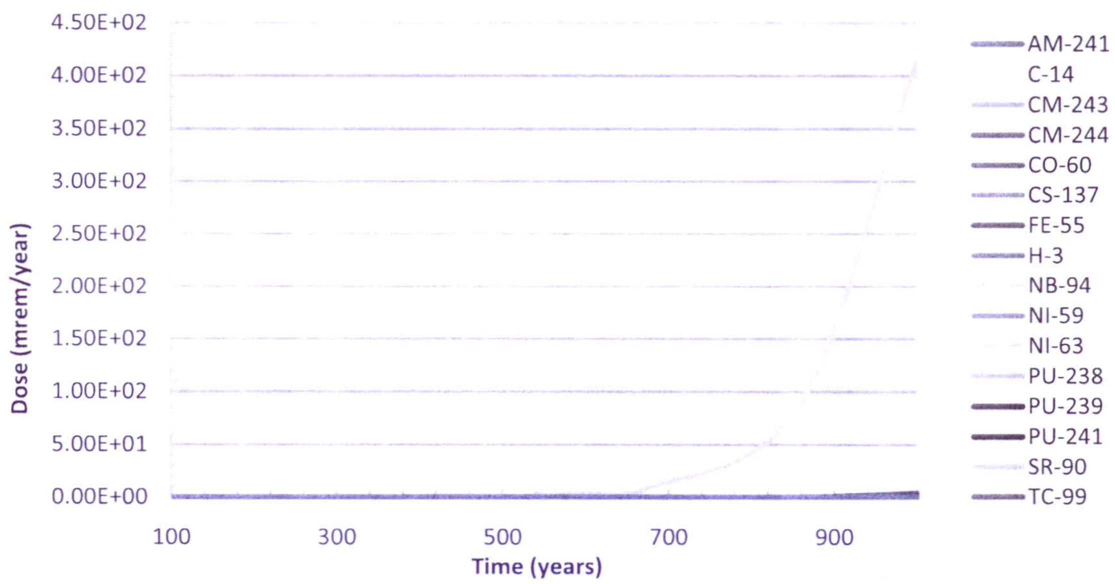


Table 6 Dry Climate Site, All Radionuclides at Class A Limit Dose Rates

Nuclide	Peak Dose (mrem/year)	Time of Peak Dose Post Site Closure (years)	Dominant Exposure Pathway
AM-241	7.06E-01	1000+	Inhalation and Soil Ingestion
C-14	3.34E-09	675	External
CM-243	4.23E-04	100+	Inhalation
CM-244	2.15E-04	1000+	Inhalation
CO-60	1.86E-03	101	External
CS-137	3.56E-03	101	External
FE-55	0.00E+00	NA	NA
H-3	0.00E+00	NA	NA
NB-94	4.14E+02	1000+	External
NI-59	3.74E+00	1000+	External
NI-63	1.54E-05	1000+	External
PU-238	1.35E-03	1000+	Inhalation and Soil Ingestion
PU-239	3.83E+00	1000+	Inhalation and Soil Ingestion
PU-241	8.14E-03	1000+	Inhalation and Radon
SR-90	1.30E-08	101	Inhalation
TC-99	4.34E-05	1000+	Inhalation and Soil Ingestion

The results for the Wet Climate Site are shown in Figure 5 and

Table 6. The radionuclides that have peak dose rates above 1.0 E-01 are Pu-241, H-3, Ni-59, Pu-239, Am-241, Tc-99, C-14 and Nb-94. The dominant exposure pathway for Am-241, C-14, H-3, Pu-241, and Tc-99 is through drinking water. Inhalation pathways dominate for Ni-59 and Pu-239. Direct exposure pathways are dominant for Nb-94.

Figure 6: Wet Climate Site. All Radionuclides at Class A Limit

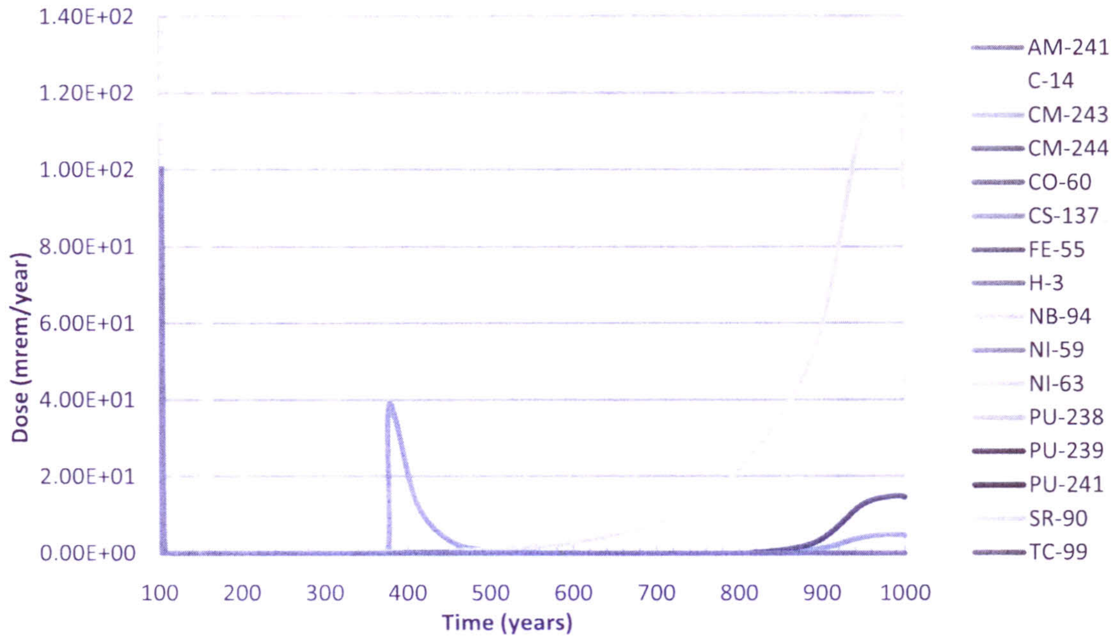


Table 7: Wet Climate Site. All Radionuclides at Class A Limit Dose Rates

Nuclide	Peak Dose (mrem/year)	Time of Peak Dose Post Site Closure (years)	Dominant Exposure Pathway
AM-241	3.88E+01	378	Drinking Water
C-14	1.23E+02	162	Drinking Water
CM-243	1.55E-03	100+	Inhalation
CM-244	8.40E-04	1000+	Inhalation
CO-60	5.25E-03	101	External
CS-137	1.01E-02	101	External
FE-55	0.00E+00	NA	NA
H-3	3.66E+00	102	Drinking Water
NB-94	1.23E+02	1000+	External
NI-59	4.90E+00	1000+	Inhalation and Soil Ingestion

Nuclide	Peak Dose (mrem/year)	Time of Peak Dose Post Site Closure (years)	Dominant Exposure Pathway
NI-63	3.83E-05	1000+	Inhalation and Soil Ingestion
PU-238	5.15E-03	1000+	Inhalation
PU-239	1.49E+01	1000+	Inhalation
PU-241	1.86E-01	410	Drinking Water
SR-90	4.40E-05	540	Drinking Water
TC-99	9.97E+01	103	Drinking Water

Conclusion

The water well drilling industry is highly regulated on a State basis and, once a potentially hazardous site is encountered, on a National basis. The regulatory framework currently in place imposes a number of restrictions and requirements that would reduce the probability of a well being drilled as assumed in the Well Drilling Scenario of the Draft Revision to the BTP.

The NRC Draft BTP Revision's Well Drilling Scenario assumes that an individual will unknowingly drill a well into a waste site, which will expose the well driller and the future inhabitant of the home to radiation and radioactive materials. The assumptions of the scenario include several that are taken as essentially certainties in the course of the analysis (i.e. a probability of occurrence of 1). (65)

- The intrusion occurs.
- The intrusion occurs at the immediate end of the institutional control period (100 years for Class A waste, 500 years for Class C waste).
- The drilling methods used leave the drill cuttings on the surface where they are distributed and accessible to the resident, plants and animals.
- The intrusion access a "hot spot" in the waste container that is 1 foot thick and 10 times the Classification Limit.

Based on the research to date, the data does not support an assumption that these are high probability events worthy of consideration as the limiting scenario. The assumptions should only be considered worst-case possibilities with the probability of occurrence factored into the assessment of risk.

The first assumption, that the intrusion occurs, requires that all knowledge of the LLRW disposal facility is lost or forgotten as a reasonable person would not choose to build on such a site if they knew about it. Prior to the construction of a residence and drilling of a residential water well, the land needs to be declared or zoned for residential use. As the current LLRW disposal sites are not declared residential zoning, the State or Municipality would have to change the zoning of these sites. It is reasonable to assume that each State or Municipality will maintain documentation of a LLRW disposal site for review prior to making the decision to change the type of zoning of a piece of land. The data indicates these kinds of records are routinely collected with procedures and bureaucracies in place to maintain the records and provide for their review as part of any change decision. . It cannot be reasonably assumed

that a residential water well location would be given approval when there is documentation that a radioactive waste disposal site was once located on the proposed drilling site. In the case where a hazardous site is known, the required pre-fieldwork planning involves obtaining historical site information, and seeking out potential unknown subsurface objects. OSHA also requires that there be constant monitoring for potential risks. Looking for radiation levels is specifically described in both OSHA and the industry standards. With these factors in mind, it is highly unlikely that a well driller will unknowingly encounter radioactive waste. While there may be exceptions, the probability of intrusion into a documented LLRW disposal site must be considered less than 1 and most likely significantly less than one; i.e. close to 0.

The second assumption, that the intrusion occurs at the immediate end of the institutional control period, requires that knowledge of the LLRW disposal site is terminated at a specific time. There is no identified technical basis for defining the point at which such knowledge could be eliminated. Given the data, loss of knowledge of the disposal site would more likely occur over a long period of time during which a myriad of public records, zoning and land-use designations and other data would need to be lost, archived or otherwise ignored. Given the fact that land use, property deeds and other such community records exist in the United States as far back as the Revolution and in Europe for much longer, it is more reasonable to assume that knowledge of a LLRW disposal facility and the associated hazards would gradually fade over a long period of time. As with the first assumption, the probability of occurrence is most certainly not 1 at the end of the institutional control period and more likely to be 0. The probability of intrusion may approach one over much longer time periods (e.g., 1,000 years).

The third assumption, that drill cuttings will be spread over the surface, is not supported by the data as a high probability event. Standards and regulations are in place to contain all cuttings in order to prevent possible contamination to the environment and the persons at the site at designated Hazardous sites. The practice of containing the cuttings is prevalent with the types of drilling methods commonly used at non-hazardous sites as well because the clay like properties of the cuttings render them undesirable for re-use. While the possibility of spreading the cuttings may be maintainable, it would more likely be an example of a failure instead of a regular practice.

The fourth assumption, that drilling (if it occurs) will encounter a hot spot in the waste container, requires that a) the hot spot exists and persists in the first place and b) the intruder encounters it. Both of these assumptions are arguable as high-probability or likely events. The process of inter-diffusion has been shown to occur between mating surfaces of adjacent solid materials (73). During the process, atoms from material A will migrate into material B and atoms from material B will migrate into material A. This exchange will continue to occur over time until an equilibrium of atom concentration is established between the two materials. This leads to an increase of global homogeneity of concentration within the materials and a reduction in the presence of localized pockets of high concentration. More data is needed to effectively determine a probability.

When comparing the current research to the assumptions found within the NRC Draft BTP Revision's Well Drilling Scenario, it can be concluded that the Draft BTP well drilling scenario is not a reasonably foreseeable. It is not possible, with the current research in mind, to assume a probability of one that the intrusion will occur. The NRC Draft BTP Well Drilling Scenario needs to be revisited to accurately determine the feasibility of this scenario actually occurring.

This analysis proposes a set of plausible and reasonable parameters for a well-drilling scenario for a Low Level Radioactive Waste disposal site. The parameters are based on information from personnel who

currently work performing the task postulated in the scenario and are therefore considered to be reliable. The information obtained leads to the following basic assumptions for the scenario:

1. The basic position of a well on a potential resident site including the depth, bore size and amount of material excavated can be reasonably calculated.
2. Well drilling techniques will be suitable for the expected conditions in the surrounding area. These conditions are consistent and are based on ease and cost of construction which indicates that ordinary and low-cost drilling methods would be used.
3. The use of equipment and methods suitable for a typical building site would not be ordinarily capable of penetrating any kind of barrier or waste form that is distinctly more resistant than the surrounding soil conditions. Therefore, a well-drilling scenario would not be applicable to LLRW that conforms to current Class B or Class C stability requirements. This would include Class A waste disposed in a similar manner.
4. When evaluated at the limits of current Class A concentrations, the radionuclides responsible for the majority of the radiation exposure are those that are least likely to be present at their limits.
5. Radiation exposures from other radionuclides in a plausible well-drilling scenario would not be significant and would not exceed the basis for the current Class A limits.

This analysis represents a conservative residential well drilling scenario whereby a plausible, albeit unlikely, maximum dose to an intruder is reasonably calculated with peaks well below 500 mrem/year even when all classification nuclides are set to their individual concentration limits (i.e., sum of the fractions is greater than one).

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