EFFECT OF KRYPTON-85 RELEASES FROM FUEL ROD CONSOLIDATION ON PRECLOSURE REPOSITORY OFFSITE DOSES

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ABSTRACT

The consequences of releases of ^{85}Kr during preclosure periods at a geologic repository site were evaluated to determine if ^{85}Kr treatment facilities are needed to mitigate doses to offsite individuals. Inhalation lung and immersion whole body doses were found to be well below the offsite regulatory dose limits given in 10CFR60 and 40CFR191 for the range of credible ^{85}Kr releases. Skin doses were found to be 50 to 70 times larger than lung and whole body doses. Because of the lack of current regulatory guidance on allowable offsite skin doses for repositories, definitive conclusions cannot be reached regarding the acceptability of these skin doses and allowable ^{85}Kr releases. Nevertheless, it can be presumed that no special design features for ^{85}Kr treatment would be required at a geologic repository site to reduce offsite doses from ^{85}Kr, even if fuel consolidation operations, with the associated higher risk of producing ^{85}Kr releases from ruptured fuel cladding, were to be performed on site.

GENERAL DESCRIPTION

As part of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project, the U.S. Department of Energy (DOE) Nevada Operations Office (NVO) is studying the possibility of siting a geologic repository in tuff near the southwestern corner of the Nevada Test Site (NTS). Sandia National Laboratories, Bechtel National, Inc., and other contractors, under the direction of NVO, are preparing to develop an advanced conceptual design for this prospective facility.

A geologic repository is designed to receive, handle, package, and dispose of commercial reactor spent fuel, defense high level waste forms, and other types of commercial radioactive wastes. Dry fuel consolidation is being evaluated and developed as one means of reducing the volume of spent fuel and hence the number of canisters requiring handling, packaging, and disposal.[1,2]

Dry rod consolidation processes have the potential for generating airborne radioactive contamination from spent fuel assemblies during consolidation and fuel handling operations. Operations that cause a puncture and breach of the fuel cladding will result in the release of the gaseous fission product, ^{85}Kr, into a process hot cell. Because ^{85}Kr is a noble gas, it is not removed by conventional air filtration systems. Therefore, unless additional ^{85}Kr treatment systems are incorporated into the consolidation equipment and hot cell ventilation systems, any ^{85}Kr that is released from spent fuel rods will be discharged to the atmosphere. Depending upon the magnitude and frequency of the releases, the amount of dispersion in the atmosphere and the potential offsite dose consequences to the public, releases of ^{85}Kr may or may not be acceptable. The purpose of this study was to determine whether special treatment facilities or design features for ^{85}Kr removal or collection will be required as a result of rod consolidation in order to comply with regulatory limits for offsite doses during repository preclosure operations.

Dry fuel consolidation is a new, relatively undemonstrated technology about to undergo development;[1] hence, the rate of cladding breaches during consolidation, as well as other repository handling operations with spent fuel, is uncertain. Therefore, whole body, organ, and skin ^{85}Kr doses to a maximally exposed offsite individual were calculated as a function of the number of breached fuel rods. These results can be compared with the Environmental Protection Agency (EPA) limit of 25 mrem/yr for the whole body, or any organ (other than the thyroid), from normal operations[3] or the Nuclear Regulatory Commission (NRC) value of 500 mrem to the whole body, or any organ, per accident[4] at a repository site. The results of these comparisons can be used in conjunction with other factors to judge if special design features for ^{85}Kr removal or collection due to fuel consolidation would be needed to ensure regulatory compliance. Any structure, system, or component incorporated in the facility design to mitigate or prevent ^{85}Kr releases during accidents that could cause offsite doses greater than 500 mrem would be classified for design as important to public safety.

CALCULATIONAL METHODS

Calculation Approach

Doses to a maximally exposed offsite individual due to ^{85}Kr releases from breached fuel rods were calculated for normal and accident conditions. Dose rate calculations depend primarily on the quantity of radionuclide inventory released, local meteorological conditions, duration of the release, release height, and the distance between the release and dose receptor points. Whole body and skin doses due to immersion in a semi-infinite cloud were calculated, as were organ doses (e.g., lung, bone, thyroid, etc.) due to inhalation.[5,6]

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The equation used for calculating whole body doses from external gamma radiation at a depth of 5 cm into the body due to immersion in a semi-infinite cloud is as follows:[6]

$$D^{WB}_{max} = (\frac{X}{Q}) \times (WF)^{-1} \times (R) \times (DF)^{cloud}$$

where,

D^{WB}_{max} = the whole body gamma dose due to immersion in a semi-infinite cloud containing a radionuclide (rem)

$\frac{X}{Q}$ = the atmospheric dispersion factor used to calculate the average ground-level concentration of a radionuclide (sec/m^3)

WF = the building wake factor for ground level releases (dimensionless)

R = the quantity of a radionuclide released (Ci)

$(DF)^{cloud}$ = the gamma dose conversion factor for a uniform semi-infinite cloud containing a radionuclide $(\frac{\text{rem-m}^3}{\text{sec-Ci}})$

The equation used for calculating inhalation doses to each applicable organ is as follows[6]:

$$D^{Inh}_{max} = (\frac{X}{Q}) \times (B) \times (WF)^{-1} \times (R) \times (DF)^{Inh}$$

where,

D^{Inh}_{max} = the 50 yr dose commitment to a maximally exposed individual (rem)

B = the maximally exposed individual's breathing rate (m^3/sec)

$(DF)^{Inh}$ = the 50 yr dose commitment factor for each organ due to inhalation of a radionuclide (rem/Ci)

The skin doses were calculated at a depth of 7 mg/cm^2 of tissue using dose conversion factors for both the gamma and beta contributions.[6]

For nuclear facilities other than repositories, regulatory guidance exists for specifying appropriate values for the above dose rate calculational parameters. Values and assumptions used for normal operational conditions are different from those used for accident conditions. For this study, Ref. 6 was used as a guide to derive most parameters for normal conditions and Ref. 7 was used as a guide for accident conditions. Values for *specific* ^{85}Kr radionuclide decay energies and properties were taken from Ref. 8. Dose conversion factors were taken from Refs. 6 and 9. These items are discussed further below.

Source Term Data

A repository is expected to receive 3,000 MTU of spent fuel per year.[2] This corresponds to an annual facility throughput of approximately 1.4 million individual fuel rods, if one assumes the following: 264 rods per PWR assembly of 0.462 MTU, 62 rods per BWR assembly of 0.186 MTU, 60 percent of the receipts (MTU basis) are PWR assemblies, and 40 percent of the receipts (MTU basis) are BWR assemblies. Although only PWR rods were considered in the dose calculations below, the results would be similar if BWR assemblies had been included.

The ^{85}Kr (10.7-year half-life) source terms for the repository were based on 2,300 Ci of ^{85}Kr in a 10-year-old 15 x 15 PWR assembly with a 33 GWD/MTU burnup.[10] Each assembly was assumed to contain 208 rods of actual spent fuel, with the remainder being nonfuel-bearing rods. A single fuel rod contained 2.5 kg of UO$_2$ and 11 Ci of ^{85}Kr. A maximum of 30% of the total ^{85}Kr activity within a fuel rod was assumed to be released if a fuel rod was breached.[11]

Normal Condition Calculations

Doses were determined for the whole body, critical organs, and skin from annual ^{85}Kr releases as a function of the number of breached individual PWR fuel rods. The atmospheric dispersion coefficients (X/Q) were calculated at varying distances from the site assuming a ground level release, a wind speed of 3 m/sec, and a Pasquill Type D stability class. This is a very conservative assumption and is used solely to provide a preliminary estimate prior to the collection of statistically significant, site-specific meteorological data. Additional dispersion, due to the turbulent wake of the building, was estimated, as allowed in Refs. 6 and 12 for ground level releases. The building wake factors were established assuming an average building size of 140 m x 134 m x 12 m and a shape factor of 0.5.[13] A linear interpolation between the 500 m^2 and 1,000 m^2 curves in Fig. 2 of Ref. 7 was used to calculate the wake factors, which varied from a maximum of 1.7 at 0.5 mile to 1.0 at 2 miles or more. The adult breathing rate of 8,000 m^3/yr was assumed for the inhalation dose calculations.[6] No credit for depletion (plateout) was assumed.

Credit can be taken for additional dispersion of the plume since the wind direction varies greatly over a year of normal operations.[6,12] This was accomplished by reducing the doses calculated (assuming no variations in wind direction) by a factor of 5, which corresponds to a wind frequency of 20% for the worst sector. This assumption is both conservative and consistent with preliminary meteorological data compiled for Yucca Mountain, Nevada.[14]

Since the site of a prospective repository has not been established and the design of the repository is in the conceptual stage, the distance from the site boundary to potential release points has not been fixed. As a result, the calculations assumed various distances between the release points and the dose receptor points ranging from 0.5 to 6.2 miles. This approach allows the results to be used by any of the potential repository sites as they are established in the future and before site-specific meteorological data are available.

Accident Condition Calculations

Doses were determined for the whole body, critical organs, and skin for various ^{85}Kr releases. The atmospheric dispersion coefficients (X/Q) were based on accident conditions that assumed a ground level release for less than 8 hours, a constant wind direction, a wind speed of 1 m/sec, and a Pasquill Type F stability class.[7,15] No variation in wind direction was assumed for the duration of the release. An adult breathing rate of 11,000 m^3/yr was assumed for the calculation of inhalation doses.[7] Doses were calculated at varying distances between the release and dose receptor points.

RESULTS AND DISCUSSION

Initial calculations of inhalation doses indicated that the lung is the only organ that needs to be considered. Whole body immersion cloud doses were 83% less for normal conditions and 61% less for accident conditions than the lung inhalation doses. Skin immersion cloud doses, on the other hand, were 69 times greater than the lung doses during normal conditions and 51 times greater during accident conditions. Although no limit for skin dose has been established, there would be no cause for concern even if the limit were set equal to that for lung dose. At least 10,000 fuel rods would have to be breached in order to produce the maximum permissible dose for either normal or accident conditions. For normal conditions, this represents nearly a 1% failure rate, which is unacceptable from an operational point of view. Under accident conditions, 6% of the total spent fuel inventory present in the surface facilities of the repository could be breached without exceeding the dose limit.

The following ^{85}Kr release assessments are generally applicable to any facility or operation involved with spent fuel handling.

Normal Operation

Figure 1 shows, for routine ^{85}Kr releases, the number of individual PWR fuel rods that must be breached to produce an annual 25 mrem offsite lung dose versus the distance between the release and dose receptor points. The lower bound of the curve is based on the assumption that 100% of the ^{85}Kr released into the hot cells escapes and that the wind blows continuously in one direction toward the dose receptor point for an entire year. The upper bound of the curve is more realistic, yet conservative, and is based on the assumption that the ^{85}Kr releases drift over a single stationary dose receptor point only 20% of the time during a year. For a site boundary distance of 1 mile, between 0.7 and 4 million individual fuel rods would have to be breached annually before the calculated offsite lung or whole body ^{85}Kr dose approached 25 mrem.

Figure 2 shows the number of breached PWR fuel rods versus the calculated lung and skin doses at 1 mile from the ^{85}Kr release point (assuming the wind is directed towards the worst sector 20% of the time). The whole body doses are 83% less than the lung doses. The right-hand ordinate indicates the percentage of the annual repository inventory throughput that would have to be breached to cause the corresponding dose on the abscissa. Assuming an annual repository throughput of 1.4 million fuel rods (3,000 MTU), all of the fuel rods received could in principle be breached during normal repository operations, including any fuel consolidation operations, without exceeding a 25 mrem lung dose. However, no process or handling operations, including fuel consolidation, resulting in failure rates approaching 100% would be acceptable.

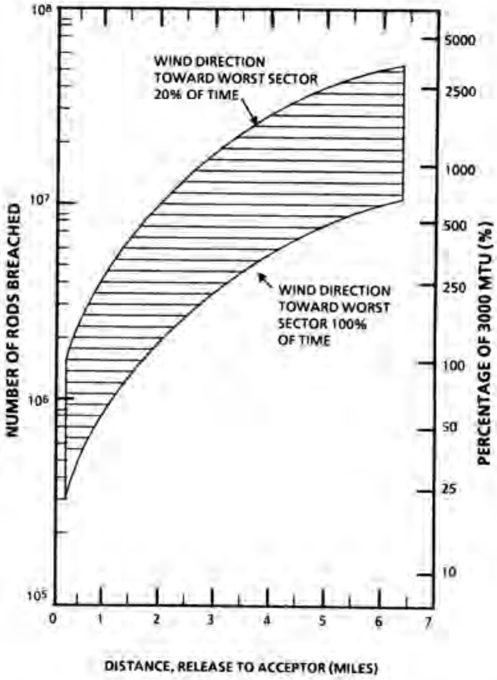

Fig. 1. Number of Breached Rods Required to Produce an Annual 25 mrem Lung Dose Due to Inhalation Versus the Distance Between the Release and Dose Receptor Points for Routine ^{85}Kr Releases.

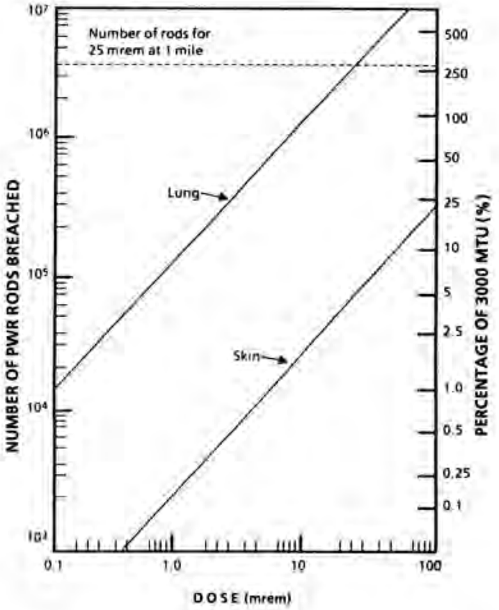

Fig. 2. Number of Breached Rods Versus Calculated Doses for a 1-Mile Distance Between Release and Dose Receptor Points for Routine ^{85}Kr Releases.

Accident Conditions

Figure 3 shows the number of PWR fuel rods that must be breached in a single accident to cause a 500 mrem lung dose at varying distances between the accident release point and the offsite dose receptor. The calculations assume that the ^{85}Kr is released over a period of less than 8 hours. At a distance of 1 mile between release and receptor points, 787,000 PWR fuel rods would have to be simultaneously breached to cause an offsite ^{85}Kr lung dose of 500 mrem to a maximally exposed individual.

Figure 4 shows the number of breached PWR fuel rods versus the calculated lung and skin doses when the distance between the release point and the dose receptor is 1 mile. The percentage of the annual repository inventory, assuming 1.4 million spent fuel rods per year, that could be breached without exceeding a 500 mrem lung dose from ^{85}Kr is more than 50% of the annual inventory. Because a spent fuel inventory of this size would never be present in the surface facilities of a repository at any given time (i.e., waste is transported to the underground shortly after its arrival), no accident scenario involving only ^{85}Kr releases could produce an organ dose of 500 mrem or greater. The ^{85}Kr whole body dose from cloud immersion was found to be only 61% of the calculated lung doses. Therefore, it is unlikely that structures, systems, or components important to public safety, as defined in 10CFR60,[4] will be required in facility designs for ^{85}Kr treatment based on calculated organ and whole body doses.

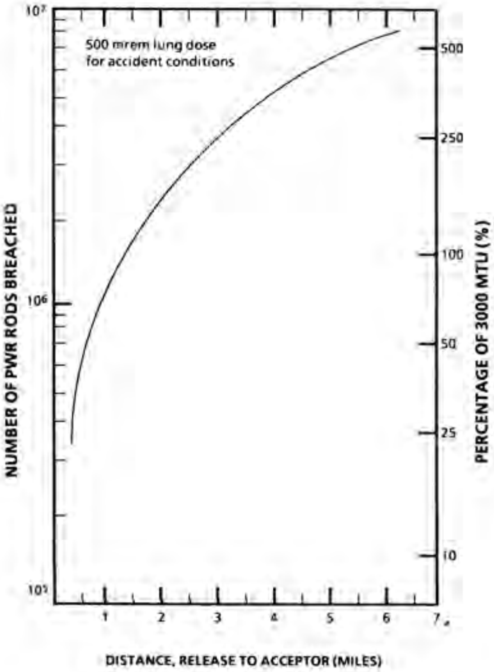

Fig. 3. Number of Breached Rods Required to Produce a 500 mrem Lung Dose During Accident Conditions Versus the Distance Between the Release and Dose Receptor Points for ^{85}Kr Releases.

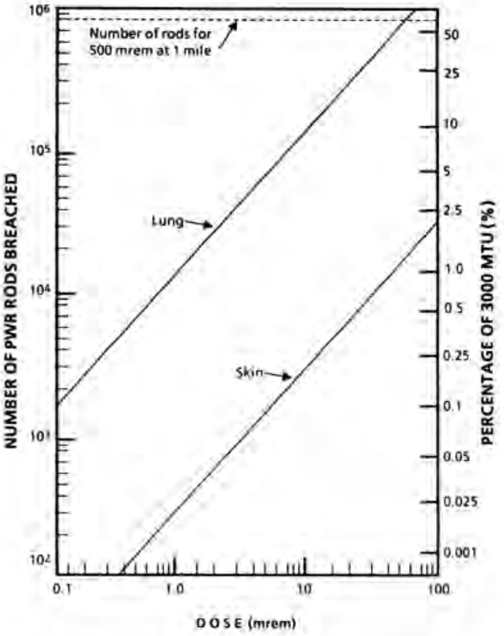

Fig. 4. Number of Breached Rods Versus Calculated Doses for a 1-Mile Distance Between Release to Dose Receptor Points for ^{85}Kr Releases from Accidents.

CONCLUSIONS

^{85}Kr has little penetrating gamma radiation compared to its beta radiation. Therefore, the skin dose accounts for the great bulk of the dosage. There is currently no explicit regulatory guidance as to allowable offsite skin doses for a repository; however, NRC guidance for other types of facilities has treated the skin dose with less stringent standards than whole body or organ doses. The requirements have ranged from factors of 3 to 10 times greater allowable skin doses than whole body or organ doses (3 in 10CFR50 Appendix I, 6 in 10CFR20,[16] 10 in the new proposed 10CFR20[16]). As a result of this uncertainty in allowable skin doses, the conclusions are focused on lung and whole body doses.

Annual releases of ^{85}Kr during normal repository handling operations, including rod consolidation, will produce insignificant offsite whole body or organ doses. ^{85}Kr releases during credible accident conditions cannot produce offsite whole body or organ doses approaching 500 mrem owing to the limited amount of spent fuel inventory in the surface facilities. For either normal or accident conditions, if the site boundary is at least 1 mile from potential release points, more than 50% of the total annual spent fuel inventory has to be breached in order for organ and whole body doses to approach regulatory limits. Repository designs and spent fuel handling operations, including rod consolidation, that result in breaches of close to 50% of the total annual spent fuel inventory are not acceptable. Based on the calculated whole body and lung doses, no special design features for capturing ^{85}Kr will be necessary at a geologic repository to ensure future regulatory compliance.

The NRC will probably require a lower limit than a 25 mrem organ dose from ^{85}Kr releases from a repository to ensure compliance with the EPA limits. Still, it is reasonable to conclude that ^{85}Kr releases caused by fuel consolidation or other spent fuel handling operations are not likely to require special facility design provisions for ^{85}Kr removal or collection. This conclusion is based on the large number of cladding breaches required to produce significant doses.

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