Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

SAND94-0261C
Conf-940553--28

ANALYSES OF RELEASES DUE TO DRILLING AT THE POTENTIAL YUCCA MOUNTAIN REPOSITORY[a]

R. W. Barnard
Sandia National Laboratories
P. O. Box 5800, M/S 1326
Albuquerque, NM 87185
(505) 848-0738

ABSTRACT

Radionuclide releases due to drilling into the potential Yucca Mountain nuclear-waste repository have been evaluated as part of a recent total-system performance assessment. The probability that a drilling event intersects a waste package is a function of the sizes of the drill bit and the waste package, and the density of placement of the containers in the repository. The magnitude of the releases is modeled as a random function that also depends on the amount of decay the radionuclides have undergone. Four cases have been analyzed, representing the combinations of two waste-package designs (small-capacity, thin-wall, vertically emplaced; and large-capacity, thick-wall, horizontally emplaced) and two repository layouts (lower thermal power dissipation, low waste-package placement density; and higher thermal power dissipation, high waste-package placement density). The results show a fairly pronounced dependence on waste-package design and slight dependence on repository layout. Given the assumptions in the model, releases from the larger containers are 4–5 times greater than from the smaller packages.

I. INTRODUCTION

One of the disruptive scenarios investigated in the total-system performance assessment (TSPA-93)[1] recently completed by Sandia National Laboratories is human intrusion. This scenario assumes that, at some time in the future, inadvertent drilling activities may take place at the potential Yucca Mountain, Nevada, nuclear-waste repository site. As a consequence of a drill intersecting a waste package, nuclear waste can be brought directly to the surface in the drilling operation. The magnitude of the surface release of radioactive contaminants is modeled probabilistically.

Although there are serious concerns about attempting to predict future human behavior and technology, this analysis makes assumptions about both. On the basis of on regulatory guidance[2], we assume that 20th-century drilling techniques are used (i.e., rotary drilling with fluid-lubricated bits), and that a maximum of 3 drillholes per km^2 of repository area over 10,000 years are drilled.

A. Probability of Releases

The probabilities of this scenario occurring depend on several factors. For these analyses, it is assumed that there is a probability of 1.0 that people would be drilling at the site in the future. The probability of a drill bit intersecting waste packages in the repository is based on two assumptions. The probability of a hit is assumed to be proportional to the horizontal projections of the areas of the drill and the waste package. The probability also depends on the emplacement density of the waste packages in the repository.

B. Magnitude of Releases

The analyses done for TSPA-93 make several simplifying assumptions. First, it is assumed that if a drill bit intersects a waste container, it will penetrate

[a] This work as performed under the auspices of the U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Project, under contract DE-AC04-76DP00789.

it. The circulating drilling fluid can entrain a random amount of the waste in the package, bringing from 0% to 100% of the contents to the surface. In addition, the drill can pass near a waste package that has degraded; the drilling operation can in this case bring to the surface a random amount of contaminated rock (a "near miss").

The amount of radioactivity released at the surface depends on the factors given above, and on the amount of decay the waste has undergone. To model this, the radionuclide inventory at time of emplacement is specified, and the amount of decay (including ingrowth of decay-chain members) to the time of the drilling incident is calculated.

II. TSPA-93 ANALYSIS CONFIGURATIONS

The nuclear waste inventory in the repository is assumed to be primarily spent fuel from both pressurized-water reactors (PWRs) and boiling-water reactors (BWRs). About 10% of the total inventory is vitrified defense high-level waste (HLW). Based on simulations of projected waste-receipt schedules at the potential repository, the average age, burnup, and mix of reactor types is specified. The radionuclide inventory is assumed to consist of approximately 31% BWR spent fuel (25 years old, 30 GWd/MTU burnup), 59% PWR fuel (25 years old, 40 GWd/MTU burnup), and 10 HLW.

As part of an investigation by the Yucca Mountain Site Characterization Project of alternative waste-package designs and alternative repository configurations, we have analyzed two types of waste-package emplacements and two repository configurations in TSPA-93. One waste package is constructed of a thin wall (~1 cm) of stainless steel, and holds about 2.0 tonnes of spent fuel or HLW. It is emplaced vertically in boreholes drilled into the floor of the repository emplacement drifts (the "borehole" emplacement scheme). The other waste-package design we analyzed is constructed of a thick (~10 cm) layer of mild steel that acts as a corrosion-allowance material, with an inner layer of 1-cm-thick stainless steel. This container holds between 7.5 and 9 tonnes of spent fuel, depending on reactor type. Because of its size and weight, these waste packages are assumed to be located directly on the floors of the emplacement drifts (the "in-drift" emplacement scheme).

A. Emplacement Configurations

The two repository configurations modeled are based on alternative designs for the thermal output of the repository. The areal power density (APD) of the repository caused by decay heat from the waste can be controlled by the spacing of the waste packages. The original design for a potential repository at Yucca Mountain specified a thermal APD of 141 kW/hectare (57 kW/acre). Preliminary analyses[3,4] have modeled hydrothermal processes such as dryout of rock adjacent to the waste, formation of a condensation cap, and resaturation of rock as the thermal output decays. These studies have been done at both 141 kW/hectare and 282 kW/ha (114 kW/acre). TSPA-93 used these two thermal outputs.

B. Repository Layouts

The choice of emplacement configuration and thermal APD constrains the area of the repository. The number of waste packages is determined by the emplacement configuration. Both the number of containers and the area of the repository determine the probability that a drilling event will intersect a waste package. The maximum number of holes drilled into the repository over 10,000 years is also a function of the repository area. Table 1 gives the probabilities of a hit (P_{hit}) and the maximum numbers of holes drilled (N_{Max}) for the four analysis cases.

Table 1. Parameters of the four analysis cases for TSPA-93.

Emplacement Configuration	Repository Area (km^2)	P_{hit}	N_{Max}
Borehole, 141 kW/ha	4.61	0.013	14
Borehole, 282 kW/ha	3.14	0.019	10
In-Drift, 141 kW/ha	4.63	0.028	14
In-Drift, 282 kW/ha	2.33	0.056	7

The lower-APD repository layouts have a maximum of 14 holes drilled into them, while fewer holes are drilled into the higher-APD repositories. The probability that a drilling event hits the smaller, vertically emplaced waste package is lower than for the in-drift containers.

III. METHOD OF ANALYSIS

Releases due to drilling have been calculated by modeling 10,000-year histories of the repository. For each modeling period, up to N_{Max} holes may be drilled into the repository at randomly selected times. If a drilling event results in either a direct hit or a near miss, the amount of radioactive waste brought to the surface is recorded. Total releases for a 10,000-year period are given by the sum of the releases for each drilling event. Releases are normalized to the limits specified by regulation[2]. Generally, 20,000 Monte Carlo simulations of the repository history are done to provide a statistical distribution of releases. These results are presented as cumulative complementary probability densities (CCDFs). These functions give the probability that a release is below a given magnitude.

Releases have been calculated for both 10,000 years and 1,000,000 years. Releases for the latter period are estimated by combining 10,000-year analyses that are run with starting times ranging from 0 to 990,000 years. The uncertainties regarding future human activities mentioned above are even greater for 1,000,000-year periods, so we do not place very much weight on these results.

The lifetime of the waste container is a factor in calculation of near misses, since the processes causing contamination of the surrounding rock cannot occur until the container is breached. Container failure, and other near-field processes, are modeled with the code YMIM[5]. Container degradation is assumed to occur when the stainless-steel container wall has corroded. The corrosion process is modeled as being strongly temperature- and water-dependent. Table 2 gives the range of container failure times for the four analysis cases. The ranges arise because of variations and uncertainties in the time–temperature profiles that the containers are exposed to, and because of uncertainties in the amount of water that may contact the containers during the times they are strongly susceptible to corrosion.

Table 2. Container lifetimes for the four analysis cases.

Configuration	Start of Earliest Failure (years)	End of Latest Failure (years)
Borehole, 141 kW/ha	475	5000
Borehole, 282 kW/ha	2450	7500
In-drift, 141 kW/ha	950	10000
In-drift, 282 kW/ha	3050	8000

Our model predicts that containers fail rapidly if the temperature is in the range 70°C to 100°C and there is water present to permit corrosion. These conditions can occur as early as 475 years at some locations in the repository for the 141 kW/ha, borehole-emplacement case; conversely, the higher temperature of the 282 kW/ha cases delays the time before the temperature drops below 100°C and when liquid water can contact the containers.

IV. RESULTS

The 20,000 runs comprising an analysis are distributed among direct hits, near misses, and complete misses. Figure 1 shows a histogram of releases for the borehole-emplacement, 141 kW/ha case for the first 10,000-year period. The peak located at -1 on the abscissa in Figure 1 (a normalized release value of 10^{-1}) is due to direct hits on spent fuel. Direct hits on the HLW and near-miss releases from spent fuel have about the same magnitude (approximately -3 on the abscissa), but the frequency of HLW direct hits is much lower. The peak at approximately -5 in Figure 1 is due to HLW near misses.

Figure 2 shows CCDFs for the two borehole-emplacement cases after 10,000 years. The highest-magnitude/lowest-probability releases are almost the same. The more probable releases (i.e., below an EPA sum of about 10^{-3}) show more of a difference

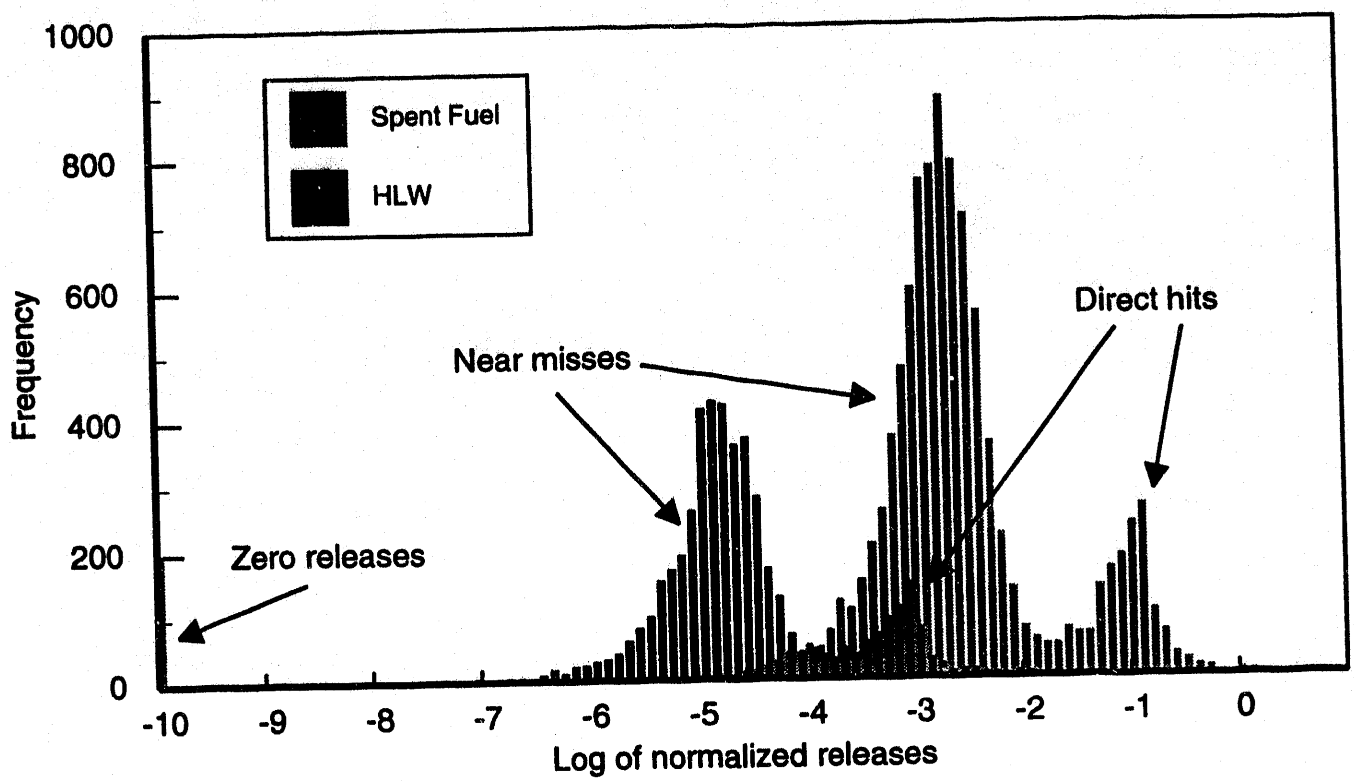

Figure 1. Distribution of surface releases from human intrusion.

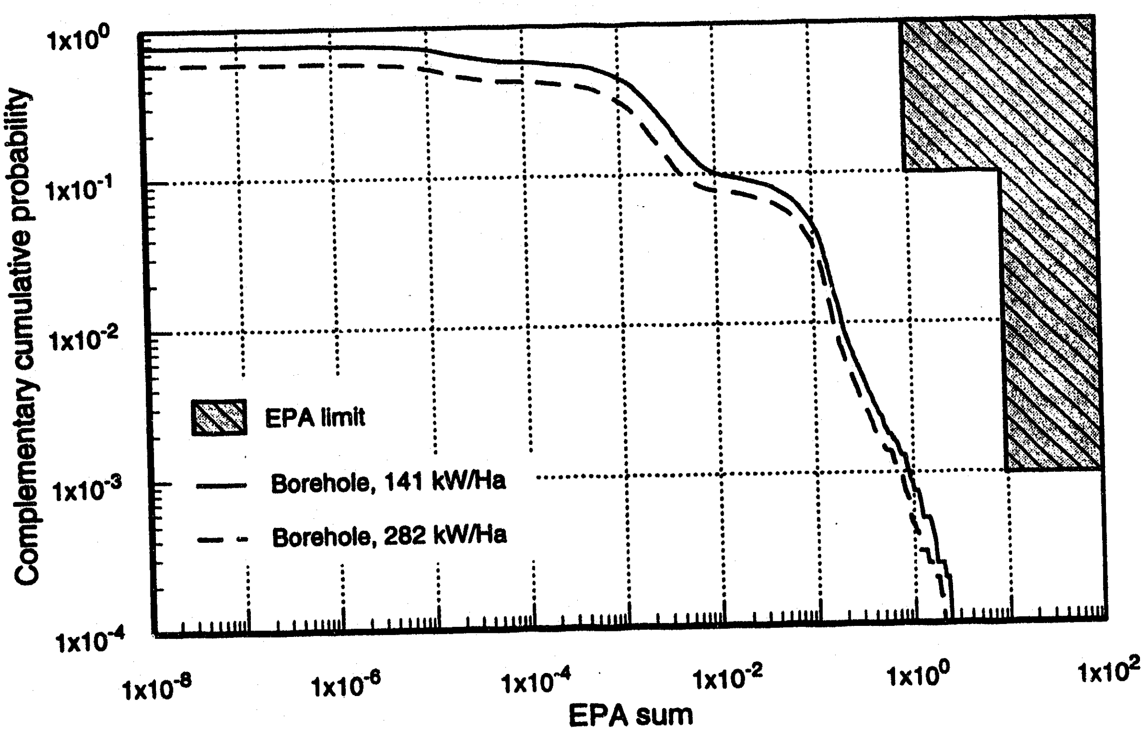

Figure 2. Conditional CCDFs for surface releases for borehole-emplacement configurations.

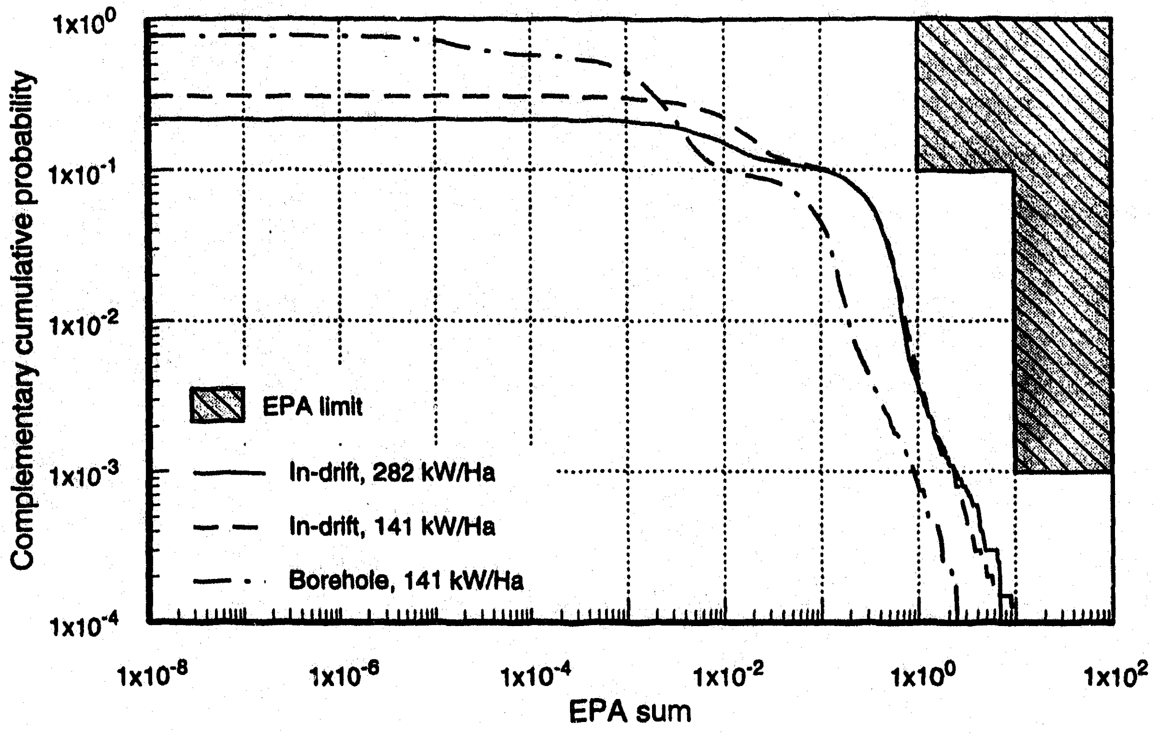

Figure 3. Conditional CCDFs for surface releases for in-drift-emplacement configurations.

between the two cases. Releases in this range are due to near misses, so the 141 kW/ha releases have higher probabilities of occurrence because more holes are drilled into the larger repository.

Figure 3 compares the results for the two in-drift analysis cases with the borehole-emplacement, 141 kW/ha case. The maximum releases for the in-drift cases are about five times greater than for the borehole case, but there are almost no near-miss releases. (The plots show that there is a 30% probability that releases are less than about 10^{-4}, meaning that many of the drilling events produce no releases at all.)

The 1,000,000-year releases for the four analysis cases are all higher than the corresponding 10,000-year runs. Maximum releases do not increase significantly (because the major contributors to the high releases decay away in 1,000,000 years). Drilling into the repository for 1,000,000 years practically assures that at least some contaminated rock will be hit. As a result, near-miss releases are quite probable.

V. DISCUSSION AND CONCLUSIONS

Based on the modeling assumptions for transport of waste to the surface by drilling operations, the maximum surface releases due to drilling depend on the type of waste package hit. The larger in-drift packages release about 4 to 5 times as much radioactivity on average as do the smaller borehole-emplaced packages. There is not a strong dependence on the repository layout. Although the smaller (282 kW/ha) repository has a higher probability that a single drilling event will intersect a waste package (0.056 *vs.* 0.028, for the in-drift cases), fewer holes are drilled over 10,000 years, partially compensating for the increased probability.

This model shows that results are not strongly dependent on the geological or physical characteristics of the Yucca Mountain site. Previous analyses of human intrusion have shown that the results are strongly sensitive to the number of holes drilled over 10,000 years[3]. The factors that can influence the number of holes drilled are the presence or absence of economically important minerals near or below the potential repository. If resource evaluations of the Yucca Mountain area show that there are no economically important minerals beneath the site, then the 3 boreholes/km^2/10,000 years guidance used for these analyses may be a reasonable upper bound. Furthermore, if we assume that there are no attractive minerals at the site, we can reduce our estimate of the probability that anybody will be drilling at the site at all (currently the probability is 1.0). This shifts the CCDF curves downward, towards lower probabilities for the same magnitude of release.

Conversely, if there are attractive minerals present, the maximum number of drillholes would probably be greater than 3/km^2/10,000 years. This would cause the CCDF curves to shift to the right, increasing the magnitude of releases for a given probability.

REFERENCES

1. M. L. Wilson, J. H. Gauthier, R. W. Barnard, G. E. Barr, H. A. Dockery, E. Dunn, R. R. Eaton, D. C. Guerin, N. Lu, M. J. Martinez, R. Nilson, C. A. Rautman, T. H. Robey, B. Ross, E. E. Ryder, A. R. Schenker, S. A. Shannon, L. H. Skinner, W. G. Halsey, J. D. Gansemer, L. C. Lewis, A. D. Lamont, I. R. Triay, A. Meijer, D. E. Morris, Total-System Performance Assessment for Yucca Mountain — SNL Second Iteration (TSPA-1993), SAND93-2675, Sandia National Laboratories, Albuquerque, NM, (1994).

2. Environmental Protection Agency, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," *Code of Federal Regulations*, Title 40, Part 191 (1985).

3. T. A. Buscheck and J. J. Nitao, "Repository-Heat-Driven Hydrothermal Flow at Yucca Mountain, Part I: Modeling and Analysis," *Nuclear Technology*, 104(3), pp. 418-448, (1993).

4. E. E. Ryder, "Comparison of Predicted Far-Field Temperatures for Discrete and Smeared Heat Sources," in *High Level Radioactive Waste Management, Proceedings of the Fourth Annual International Conference*, Las Vegas, Nevada, American Nuclear Society, La Grange Park, IL, (1993).

5. A. D. Lamont and J. D. Gansemer, "Integrated Modeling of Near-Field and Engineered Barrier Processes," in *High Level Radioactive Waste Management, Proceedings of the Fifth Annual International Conference*, Las Vegas, Nevada, American Nuclear Society, La Grange Park, IL, (1994).

6. R. W. Barnard, M. L. Wilson, H. A. Dockery, J. H. Gauthier, P. G. Kaplan, R. R. Eaton, F. W. Bingham, T. H. Robey, *TSPA 1991: An Initial Total-System Performance Assessment for Yucca Mountain*, SAND91-2795, Sandia National Laboratories, Albuquerque, NM, (1992).

DATE
FILMED
8/3/94

END