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November 8, 2000
Contract No. NRC-02-97-002
Account No. 20.01402.671

U.S. Nuclear Regulatory Commission
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Subject: Programmatic Review of Abstracts

Dear Mrs. DeMarco:

The enclosed abstracts are being submitted for programmatic review. These abstracts are for submission for presentation at the 2001 International High-Level Radioactive Waste Management Conference to be held in Las Vegas, Nevada on April 29–May 3, 2001. The titles of these abstracts are

Methodology for Assessment of Preclosure Safety for Yucca Mountain Project by B. Dasgupta, D. Daruwalla, R. Benke, A.H. Chowdhury and B. Jagannath

Preliminary Aircraft Crash Hazard Assessment at Proposed Yucca Mountain Repository by A. Ghosh and B. Sagar.

Preliminary Assessment of Waste Package Response to Rock Block Impacts by D. Gute, T. Krauthammer, S.M. Hsiung and A.H. Chowdhury

Please advise me of the results of your programmatic review. Your cooperation in this matter is appreciated.

Sincerely yours,

Budhi Sagar
Technical Director

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METHODOLOGY FOR ASSESSMENT OF PRECLOSURE SAFETY FOR YUCCA MOUNTAIN PROJECT

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Introduction

The proposed geologic repository at Yucca Mountain (YM) will be designed for the permanent disposal of about 70,000 MTU of spent nuclear fuel and high-level nuclear waste (HLW). During the preclosure period, the facility will receive and handle casks containing the waste in sealed disposal canisters or in the form of spent nuclear fuel assemblies. Using a series of remote operations, the waste will be transferred into disposal waste packages (WP) and transported underground for emplacement into drifts. As part of its application for a license to construct a HLW geologic repository at YM, the U.S. Department of Energy (DOE) must conduct and present a Preclosure Safety Analysis (PCSA) of the proposed geologic repository operations area (GROA) for the period until permanent closure to demonstrate compliance with the preclosure performance objectives outlined in the proposed 10 CFR Part 63. The NRC has adopted a risk-informed performance-based (RIPB) approach in developing and implementing its regulations and focuses its review on structures, systems, and components (SSCs) important to safety.

The main hazards associated with the preclosure phase of this project stem from (i) the large inventory of radioactive wastes that will be progressively accumulated on site; (ii) the large number of surface processing operations that will have to be performed, many in parallel, to repackage the waste; and (iii) the subsurface operations involving transportation and emplacement of WPs in the underground drifts. The purpose of the PCSA is to ensure that all relevant hazards that could result in an unacceptable radiological consequence have been evaluated and appropriate protective measures identified that meet the requirements specified in the proposed 10CFR63.112, and to demonstrate compliance with the preclosure performance objectives outlined in the proposed 10CFR63.111. The PCSA accomplishes this by identifying the SSCs that are important-to-safety and demonstrate with reasonable assurance that the GROA complies with the preclosure performance objectives.

This paper describes the development of a risk-informed, performance-based review methodology and a preclosure safety analysis software tool (PCSAT) that can be used by the U.S. Nuclear Regulatory Commission (NRC) to assess, through independent analysis of critical parts of DOE PCSA, that the identification of SSCs important-to-safety and calculation of dose consequences to workers and the public by the DOE are acceptable.

Requirements of Proposed 10CFR Part 63

The PCSA addresses complience with the performance objectives of the GROA for the preclosure period. As defined in the proposed 10 CFR 63.2 and 63.102, the PSCA constitutes a systematic examination of the site; the design; and the potential hazards, initiating events, event sequences, and dose consequences to workers and the public. An objective of the analysis is to identify SSCs important to safety. The definition of SSCs important-to-safety as given in the proposed 10 CFR 63.2 are those engineered features of the GROA whose function is to (i) provide reasonable assurance that HLW can be received, handled, packaged, stored, emplaced, and retrieved without exceeding the requirements of the proposed10 CFR 63.111(b)(1) for Category 1 event sequences; or (ii) prevent or mitigate Category 2 event sequences that could result in doses equal to or greater than the values specified in the proposed 10 CFR 63.111(b)(2) to any individual located on or beyond any point at the boundary of the site.

The flow chart shown in figure 1, describes the PCSA process. The steps involved in the PCSA are: (1) Identification of naturally occurring and human-induced events external to the facility that may initiate events inside the facility, (2) Description of the process activities at the GROA and equipment associated with SSCs, (3) Identification of human-induced events in the facility by systematic analysis of the hazards, (4) Identification of potential event sequences, (5) Categorization of the event sequences based on Category 1 and Category 2 event frequencies stipulated in the proposed 10 CFR 63.2, (6) Evaluation of radiological dose consequences to the public and to workers for Category 1 and Category 2 event sequences and identification of those event sequences that do not meet the dose requirements of 10 CFR Part 20 and the proposed 10 CFR 63.111(a) and (b), and (7) Identification of SSCs important-to-safety on the basis of each SSC's contribution to meeting the dose requirements of the previous step.

Methodology for Independent Review of DOE PCSA

The Center for Nuclear Waste Regulatory Analyses (CNWRA) is currently developing a software named PCSAT[1] to be used to review DOE PCSA[2]. The PCSAT is a review tool intended to keep track (book keeping) of all the phases of review activity from system description to the consequence analyses. Further, the tool can be applied to review all or selected components of the DOE's safety analysis, such as hazard analysis, event tree, fault tree analyses, or consequence analyses.

The PCSAT will use the review methods and applicable Acceptance Criteria from the Yucca Mountain Review Plan, which is currently under development. The PCSAT consists of seven modules as shown in figure 2. Each of the module stores data and results of review of the items selected for review by the staff. Results of the review will be abstracted, as appropriate, for use in other modules of this tool. This abstraction and input to next module is not automatic, but the information is fed in manually which will enable the staff to tailor their review to the importance of the item. ~~review selected items from the license application.~~ The modules are briefly described in the following paragraphs.

Functional area or process module: The facility and operations in the GROA can be divided into functional areas by specific function, physical area of the facility, or process. For the selected functional area, design information such as system description, process flow diagram, mechanical flow diagram, and conceptual description of the operations in the functional area will be used for the safety analysis.

Identification of naturally occurring and human-induced external events module: The naturally occurring events, such as seismic, tornado, wind, or flood, and human induced external events, such as aircraft crash, or fire, are addressed in this module. The data on geologic, seismologic, hydrologic, and meteorologic characteristic of the site, and specialized calculations to determine frequency of occurrence of these events will be reviewed and documented in this module. A screening process is developed in the software to identify the credible events.

Identification of human-induced internal events module: This module constitutes a major portion of the PCSAT and consists of two submodules: system description and hazard analysis. In addition, the failure rate and failure check list database are adjunct submodules that provide inputs to this module. Each of the submodules is further described next.

- System Description: Information required for safety analysis is compiled in this submodule. Descriptions include the functions of the SSCs within the system, detailed operation sequences, and human interactions. The inventories of cask and canisters handled in this part of the operations are also documented.

- Hazard Analysis: Hazard analysis is performed in this submodule using either What-If Analysis or Failure Modes and Effects Analysis (FMEA). The What-If Analysis focuses on human error analysis, whereas the FMEA analyzes the hardware and equipment failures that may result in radiological consequences.
- Failure Rate and Failure Mode Database: The failure rate database is a comprehensive database of equipment failure rates from actuarial data and are used to determine the probability of failure of the SSCs during the preclosure period. A failure mode list database library, containing the equipment failure modes, is used to assist in hazard analysis.

This module identifies the internal events that may lead to potential radiological dose to the public and workers.

Identification of event sequence module: Event scenarios are postulated based on the hazard analysis, and the initiating event and subsequent event sequences are identified for further analysis using event tree and fault tree analysis. Event trees and fault trees are used to estimate the frequencies for the event sequences and the results are documented in this module.

Categorization of events module: Event sequences are categorized in this module as Category 1 or Category 2 events, as defined in the proposed 10 CFR 63.2. Category 1 event sequences are those event sequences that have a frequency of occurrence greater than or equal to 10^{-2}/yr. Category 2 event sequences are other event sequences that have a frequency of occurrence less than 10^{-2}/yr but greater than or equal to 10^{-6}/yr.

Analysis of consequence module: The consequence analysis module evaluates the radiological dose to the public and workers. The PCSAT allows dose calculations for the pathways of inhalation, ingestion, ground surface exposure, and air submersion. The dose calculation requires parameters such as the inventory of radionuclides released, meteorological data, and receptor information.

Compilation and interpretation of results module: The final step in performing the PCSA is to integrate the data obtained in the various modules and interpret the results. Event sequence frequencies and dose consequences are tabulated and analyzed to determine the category of the event sequence and the dose. The data in this module can be used to identify SSCs important-to-safety and their safety significance. This information may further be used in categorization of SSCs important-to-safety for QA purpose.

Conclusions and Discussions

The power of the PCSAT software lies in its ability to enable the user to keep track of the review performed, and document independent and confirmatory analyses of the DOE PCSA, for the entire system or a component of the system, in a quick and systematic manner. This tool will enable the NRC to perform an expeditious and thorough review of the DOE PCSA. Further, the tool will enable the NRC to update the model as the DOE design evolves and carry forward the review from the Construction Authorization (CA) to the Receive and Possess Waste (R&PW) phase of licensing.

Acknowledgment

This paper was prepared to document work under development by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the Nuclear Regulatory Commission (NRC) under Contract No. NRC-02-97-009. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of Waste Management. This paper is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC.

References

1. B.Dasgupta, D. Daruwalla, R. Benke, and A.H. Chowdhury, Development of a Tool and Review Methodology for Assessment of Preclosure Safety Analysis-Progress Report. San Antonio, TX:

Center for Nuclear Waste Regulatory Analysis. September, 2000.

2. U.S. Department of Energy, Preliminary Preclosure Safety Assessment for Monitored Geologic Repository Site Recommendation. TDR-MGR-SE-000009 Rev 00 ICN 01. Las Vegas, NV: Civilian Radioactive Waste Management System Management and Operating Contractor, August, 2000.

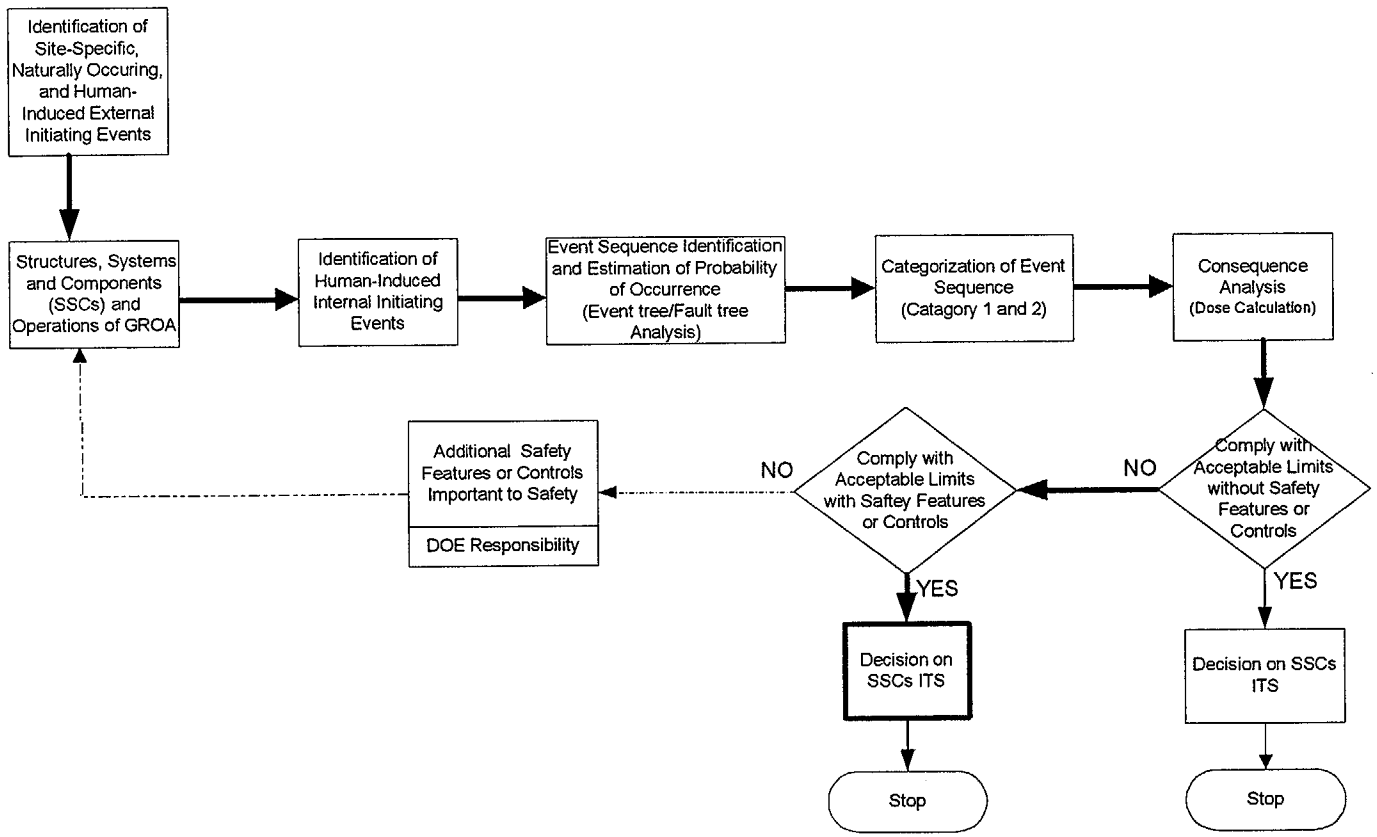

Figure 1. Preclosure safety analysis methodology flow chart

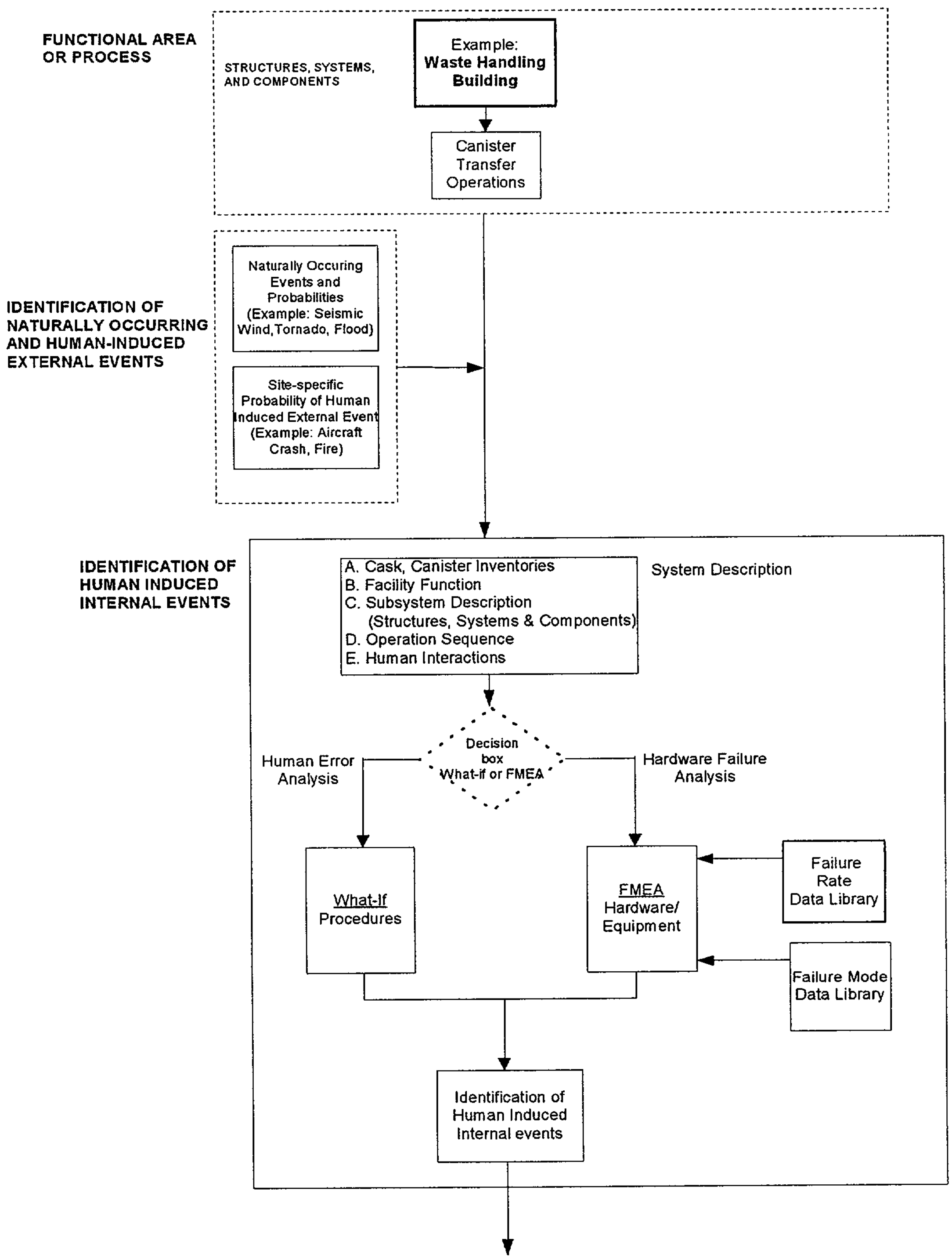

Figure 2. Preclosure safety analysis tool structure and modules

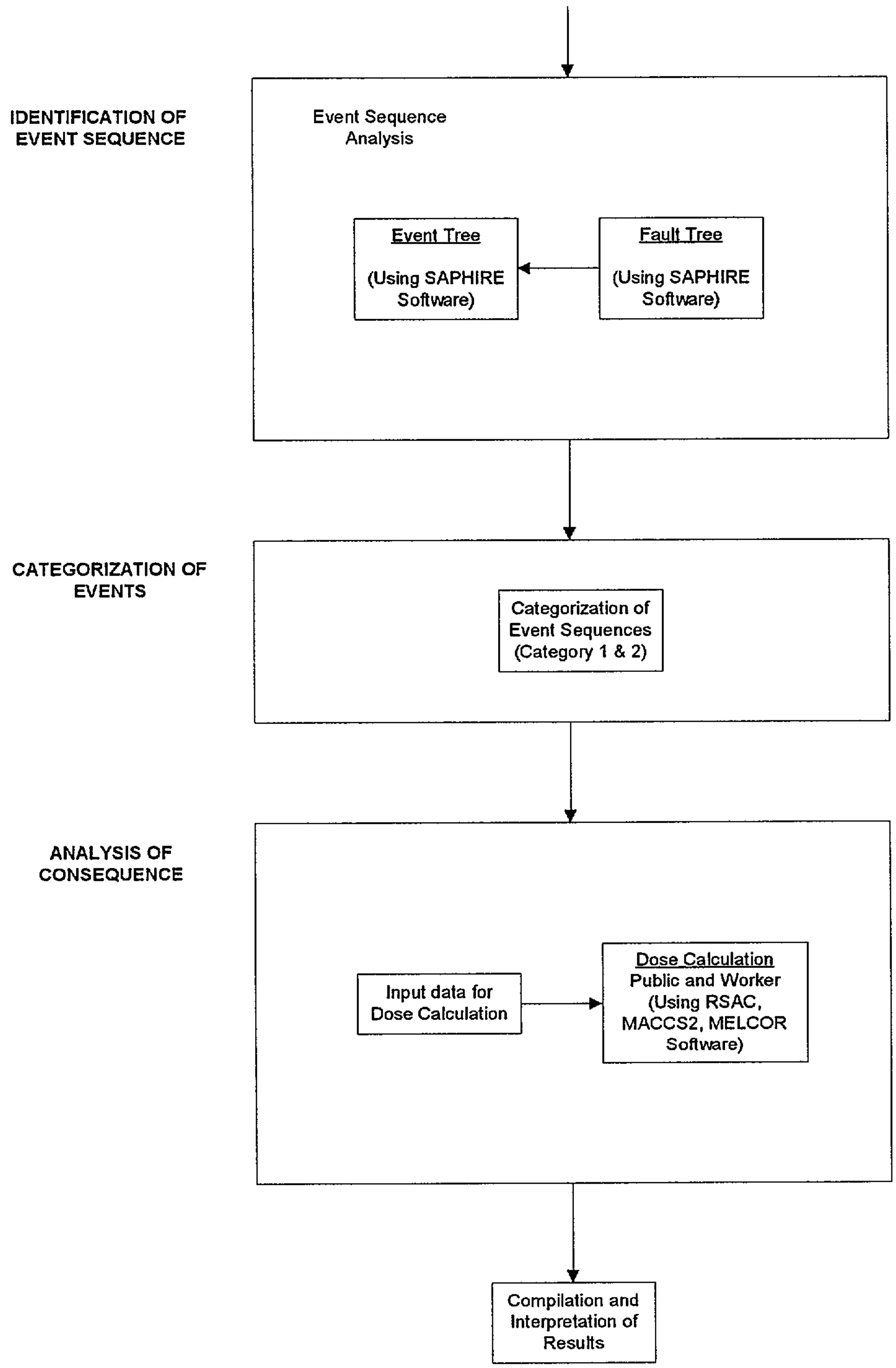

Figure 2. Preclosure safety analysis tool structure and modules (contd.)

PRELIMINARY AIRCRAFT CRASH HAZARD ASSESSMENT AT PROPOSED YUCCA MOUNTAIN REPOSITORY

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Introduction

The proposed geologic repository at Yucca Mountain will be designed for permanent disposal of high-level nuclear waste. The Department of Energy (DOE) has conducted analyses to identify natural and human-induced hazards and their potential for becoming initiating events that may lead to radiological release during the operations period prior to permanent closure. The proposed site lies beneath the R4808N airspace of the Nellis Air Force Range. Crash of aircraft is considered to be one of the initiating events that has potential for radiological release. If the estimated frequency of potential aircraft crashes onto structures containing radioactive materials exceeds 10^{-6} per year, a consequence analysis is necessary. Additionally, significant modifications of the facility design may be necessary if the consequence analysis shows the dose limits proposed in10 CFR Part 63 may be exceeded. In this paper, a preliminary analysis of the aircraft crash hazard is presented. This analysis, based on published information, will help the Nuclear Regulatory Commission staff to determine whether the aircraft crash hazard is appropriately analyzed and whether it has the potential to exceed the proposed dose limits.

Methodology

The proposed site for a high-level waste repository at Yucca Mountain does not satisfy requirement 1(b) of NUREG-0800[1] that states, "The plant is at least 5 statute miles from the edge of military training routes, including low-level training routes, except for those associated with a usage greater than 1,000 flights per year, or where activities (such as practice bombing) may create an unusual stress situation." As the number of annual flights in 1996 (the latest year for which data were available) through the restricted area R4808N significantly exceeded 1,000, a detailed review of aircraft crash hazard of the site is required for all potential sources of aircraft[1]. Potential crash probabilities of all types of aircraft (commercial, chartered, general aviation, and military) flying in the vicinity of the proposed site should be summed to estimate the total probability of aircraft crash.

The crash probability, P_{FA}, of aircraft flying federal airways or aviation corridors is[1]

$$P_{FA} = N \times C \times \frac{A_{eff}}{W} \tag{1}$$

where,

C	=	inflight crash rate per mile for a given aircraft
N	=	number of flights per year along the airway
A_{eff}	=	effective area of the plant in square miles
W	=	width of the airway (plus twice the distance from the airway edge to the site when the site is outside the airway) in miles.

NUREG-0800 states that this methodology "gives a conservative upper bound on aircraft impact probability if care is taken in using values for the individual factors that are meaningful and conservative."

Crash Probability Estimation Using Available Information

Estimation of aircraft crash probability requires reliable information on the parameters of Eq. (1). In addition, justifiable information on types of aircraft and flight activities is required for military aviation, especially when a facility is inside a restricted airspace.

Commercial and limited charter aircraft takeoff or land at McCarran International, North Las Vegas, and Tonopah airports. These airports are beyond 30 mi from the proposed facility. General aviation aircraft primarily use McCarran International, North Las Vegas, Beatty, Frans Star, and Jackass airports[2]. The last three airports are more than 10 mi from the proposed facility. Military aircraft use Nellis Air Force Base, Tonopah Test Range, and Indian Springs Air Force Auxiliary Base airports located at distances greater than 30 mi from the proposed site. DOE aircraft use Desert Rock, Yucca, and Pahute Mesa airfields within the NTS. Military aircraft along with DOE aircraft and aircraft chartered by DOE fly through the R4808N airspace. The number of commercial and general aviation aircraft taking off and landing at these airports currently is small (less than $1000D^2$, where D is the distance between an airport and the site) and allows their exclusion from the hazard estimation[1]. However, if the projected growth at any of these airports increases traffic significantly such that the criterion in [1] is exceeded, a detailed analysis may become necessary.

DOE aircraft use federal airway V105-135 to reach the Desert Rock airfield. The proposed repository surface facilities are 11 statute miles away from the nearest edge of this 10 mi wide airway. The types of aircraft used by DOE flying though this airspace have not been indicated in [2]. As many of these flights use charter aircraft, we have assumed that the aircraft would be similar to commercial aircraft ("Air Carrier" in the DOE Standard[3]) in crash statistics. However, this assumption should be verified in the license application. Crash rate, C, for commercial aircraft is 4×10^{-10} per flight mile[1]. As this is a heavily traveled air corridor (more than 100 daily flights), a detailed analysis may also be required in the future to more accurately estimate the crash rate[1].

Approximately 54,000 annual flights of DOE aircraft utilize the three airfields – Desert Rock, Yucca, and Pahute Mesa[2]. However, information is not available about the number of annual flights to each of these airfields. To make a conservative estimate of the crash probability, we have assumed that all 54,000 flights use Desert Rock airfield. We have also made another estimate assuming one-third of the 54,000 flights for each airport. Better information on the number of flights for each airport is needed for future analysis.

The effective area of the surface facilities at the proposed repository is calculated as the sum of the effective area of each of the five structures where radioactive materials can be potentially located[2]. Based on the parametric values given in the DOE Standard[3], the representative values used in estimating the effective areas for wingspan, WS, cotangent of the impact angle, cot f, and mean skid distance, S, are 98 ft, 10.2, and 1440 ft, respectively. Using the formula given in the DOE Standard and proposed building dimensions[2], the estimated effective areas are given in Table 1.

Table 1. Estimated effective area of the target structures for DOE aircraft

Structure	Length (ft)	Width (ft)	Height (ft)	Effective Area (ft^2)	Effective Area (mi^2)
Waste Handling Building	540	536	117	2,625,703	0.094
Waste Treatment Building	260	200	60	957,273	0.034
Carrier Preparation Building	160	120	33.17	567,960	0.020
Truck Parking	200	100	10.5	535,089	0.019
Rail Parking	1200	150	15	2,291,764	0.082
Total Effective Area of Surface Facilities					0.251

The width of the airway, W, is 10 + 2 × 11 or 32 mi. Therefore, the annual probability of crash from DOE chartered aircraft is

$$P_{FA} = 54000 \times 4 \times 10^{-10} \times \frac{0.251}{32} = 1.7 \times 10^{-6}.$$

Assuming only one-third of the aircraft use Desert Rock airfield, the annual crash probability is 6×10^{-7}.

Any aircraft in the inventory of the Department of Defense or other NATO countries can fly through the restricted airspace of R 4808N. As the probability of aircraft crash onto the proposed facility is directly proportional to the number of aircraft flying nearby, it is necessary to get a good estimate of the number of aircraft overflights in the vicinity of the proposed site. Considerable uncertainty also exits in the estimated number of military aircraft overflights in restricted airspace R 4808N[5]. A previous study estimated the annual number of military overflights of restricted airspace R 4808N to be approximately 73,000[3]. Estimates over the years vary as the mission of Nellis Air Force Base Range evolves. Only 6 months of flight data has been given in [2]. The number of flights per year, N, has been estimated to be (i) 12,716 (mean), (ii) 17,542 (90% confidence), and (iii) 18,910 (95% confidence)[2] by fitting a normal distribution to the six months' data. Fitting a normal distribution to six data points leaves too few degrees of freedom to carry out any meaningful statistical analysis[4]. Additional work is necessary to monitor the level of flights and to re-estimate the aircraft crash probability at the proposed repository site.

In the absence of specific information about the flight activities, it is conceivable that the aircraft fly in "Special" inflight mode in R4808N (low level and maneuvering operations in restricted area)[6]. It has been assumed in [2] that 29 percent of all aircraft will be F-16s, 63 percent F-15s, and 7 percent A-10s. However, adequate justification is lacking for the assumed distribution of these aircraft into these three types.

The estimated effective areas of the surface facilities are given in Table 2 using the DOE Standard[3]. Using special inflight crash rates for the F-16, F-15, and A-10[6], the estimated probabilities of crash for special flight modes are given in Table 3. A few scenarios using the normal inflight crash rates have also been given in Table 3 for comparison. This sensitivity analysis shows the importance of having justifiable information on the number of military aircraft flights with associated activities by different aircraft types.

Table 2. Estimated effective area for the target structures for F-16, F-15, and A-10 aircraft

Aircraft	WS (ft)	Cot f	S (ft)	Total Effective Area (mi²)
F-16	33	8.4	246	0.091
F-15	43	8.4	246	0.093
A-10	57.5	8.4	246	0.096

Table 3. Estimated probabilities of crash for military aircraft for different scenarios

Total Number of Aircraft	F-16 (%)	F-15 (%)	A-10 (%)	Flight Mode	Annual Crash Probability
12716	29	63.9	7.1	Special	3.8×10^{-6}
17542	29	63.9	7.1	Special	5.2×10^{-6}
18910	29	63.9	7.1	Special	5.6×10^{-6}
12716	100	0	0	Special	4.5×10^{-6}
18910	100	0	0	Special	6.7×10^{-6}
12716	100	0	0	Normal	1.5×10^{-6}
18910	100	0	0	Normal	2.3×10^{-6}
12716	50	40	10	Special	4.0×10^{-6}
18910	50	40	10	Special	5.9×10^{-6}
12716	50	40	10	Normal	1.0×10^{-6}
18910	50	40	10	Normal	1.5×10^{-6}

Conclusions

Results of this preliminary investigation confirm that lack of specific information about the flight environment in the vicinity of the proposed repository site does not allow a defensible estimation of potential hazards associated with aircraft crash. The preliminary estimates of the annual probability of aircraft crash vary by a factor of 10, and under several possible scenarios exceed the threshold criterion of 10^{-6} per year. More information is needed on the number of annual flights by each type of aircraft, better definition of the flight path(s), and flight activities of military aircraft to develop a reasonable annual crash hazard estimation. Better information on the flight environment is necessary in the license application to reduce some of the uncertainties in this estimation.

Acknowledgment

This work was performed by the CNWRA for the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Material Safety and Safeguards, Division of Waste Management under Contract No. NRC-02-97-009. The work is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

References

[1] Nuclear Regulatory Commission. 1981. *Aircraft Hazards.* Section 3.5.1.6, Standard Review Plan, NUREG-0800. Washington, DC: Nuclear Regulatory Commission.

[2] Morissette, R. 1999. *MGR Aircraft Crash Frequency Analysis.* ANL-WHS-000001 Rev. 00. Las Vegas, NV: Civilian Radioactive Waste Management System Management and Operating Contractor.

[3] U.S. Department of Energy. 1996. *DOE Standard: Accident Analysis for Aircraft Crash Into*

Hazardous Facilities. DOE-STD-3014-96. Washington, DC: U.S. Department of Energy.

[4] Scheaffer, R.L., and J.T. McClave. 1999. *Statistics for Engineers*, Boston, MA, Duxbury Press.

[5] Kimura, C.Y., D.L. Sanzo, and M. Sharirli. 1998. *Crash Hit Frequency Analysis of Aircraft Overflights of the Nevada Test Site (NTS) and the Device Assembly Facility (DAF)*. UCRL-ID-131259 Rev. 1. Livermore, CA: Lawrence Livermore National Laboratory.

[6] Kimura, C.Y., R.E. Glaser, R.W. Mensing, T. Lin, T.A. Haley, A.B. Barto, and M.A. Stutzke. 1996. *Data Development Technical Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard*. UCRL-ID-124837. Livermore, CA: Lawrence Livermore National Laboratory.

Preliminary Assessment of Waste Package Response to Rock Block Impacts

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Introduction

The proposed high-level waste geologic repository at Yucca Mountain (YM), Nevada employs an engineered barrier system in concert with the desert environment and geologic features of the site with the intent of keeping water away from the waste for thousands of years[1]. The primary component of the engineered barrier system is a long-lived waste package (WP). The WP design includes materials chosen to be compatible with the underground thermal and geochemical environment.

Through successive evaluations and improvements, the repository design evolved to the Viability Assessment (VA) reference design[1,2]. This reference design represented a snapshot of the ongoing design process, thus providing a frame of reference to describe how a proposed repository at YM could work. The WP in the VA reference design has two layers: a thick outer layer made of carbon steel that provides structural strength and delays contact of water with the inner, thinner layer made from a corrosion resistant alloy after the outer layer is penetrated. After the License Application Design Selection process was completed by the DOE, the Enhanced Design Alternative II (EDA II) version of the WP was identified by the DOE as the preferred design[3]. Unlike the VA WP design, the EDA II WP uses a corrosion resistant high nickel alloy for the outer barrier and stainless steel for the inner barrier.

The performance and safety assessment of the proposed repository at YM must consider both the probability and consequences of potentially disruptive events, such as seismicity, faulting, and igneous activity. Therefore, an assessment of the WP performance over the 10,000 yr lifetime of the repository must consider the different loading conditions on the WP created by these naturally occurring events in conjunction with possible manufacturing defects, residual stresses created at the time of fabrication (e.g., welding and shrink fits), and temporal degradation of the WP materials caused by various corrosion processes.

The objective of this study was to perform a preliminary assessment of the potential consequences of seismically induced rockfall on the WP by using the finite element (FE) method to evaluate the effects of various rock block shapes and impact orientations at different locations on the WP. The VA version of the 21 Pressurized Water Reactor (PWR) WP conceptual design was used as the basis for the study. The impact load caused by seismically induced rockfall may affect the confinement capabilities of the WP in two ways. The first is a catastrophic rupture of the WP. The second is that rockfall may cause damage to the container in a manner that will accelerate the WP corrosion process.

Finite Element Modeling Methodology

The WP is an assemblage of several individual structural components[4] (see figure 1). Table 1 identifies the WP materials, relevant properties of these materials[5, 6], and the specific WP components fabricated from them. These materials were modeled as elastic-perfectly plastic materials at room temperature.

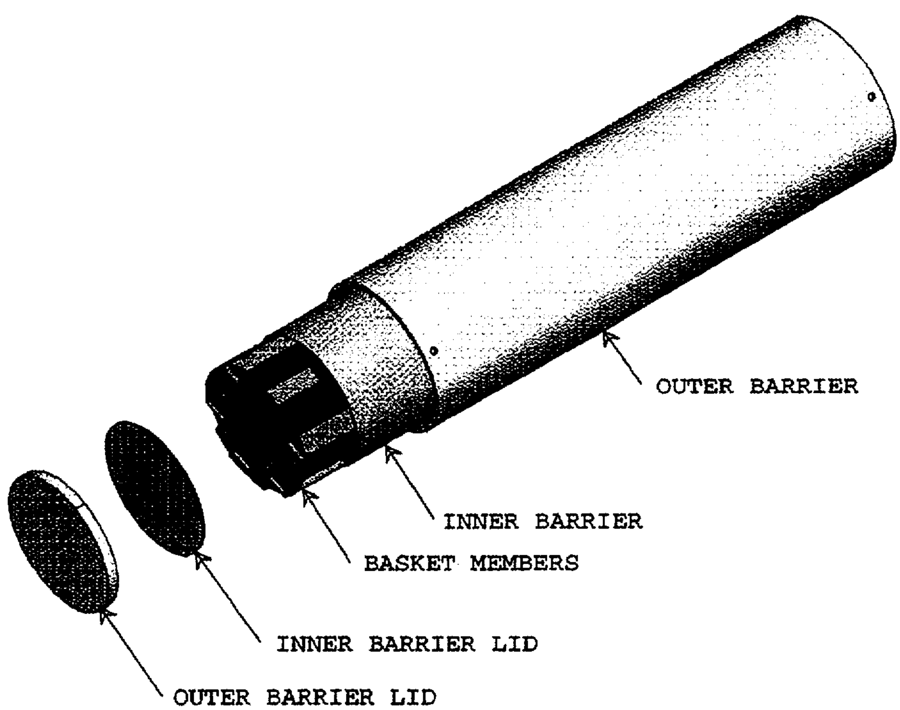

Figure 1. Major components of 21 pressurized water reactor uncanistered fuel assembly waste package

Table 1. Material properties

Material	Components	Yield Strength (MPa)	Young's Modulus (GPa)	Density (kg/m^3)	Poisson's Ratio
A516	Outer barrier and outer barrier lid	205	206	8,131	0.30
Alloy 825	Inner barrier, inner barrier lid, thermal shunt guides/caps, structural stiffener, and basket guides	338	206	8,140	0.42
Al 6063	Thermal shunt	276	68.3	2,690	0.33
316L Stainless Steel	Basket tube	172	195	7,953	0.40

A simple approximation of the effect of seismic ground motion was considered in the FE model by adjusting the rock block and WP impact velocities. Assuming a fall height of 3.2 m and no initial velocity, it can be shown that the velocity of the rock block when it hits the WP will be approximately 7.9 m/s. If the rock block were to begin falling with an initial downward velocity equal to the peak vertical ground velocity of the postulated seismic event, 1 m/s for example, the velocity of the rock block when it impacts the WP will be nearly 8.0 m/s. This represents an increase of only 2.6 percent of the rock block kinetic energy at impact (i.e., from 62.4 kJ to 64.0 kJ for a 2 metric tonne rock block). However, assigning an upward velocity to the WP equal to the peak vertical ground velocity (i.e., 1 m/s) when the impacting rock block makes contact significantly contributes to the total kinetic energy associated with the impact event. Specifically, a loaded 21 PWR WP having a mass of approximately 47.8 metric tonnes[4] moving at 1 m/s represents 23.9 kJ of kinetic energy.

The rock block material was represented as an elastic-perfectly plastic material whose yield strength is equal to its compressive strength. The uniaxial compressive strength used in the FE model of the rock (42.8 MPa) is considerably smaller than that of an average intact rock block (166 MPa) expected to be encountered at YM[7]. This was done in an attempt to account for the lower strength that can be expected for a rock block containing some minor fractures.

Preliminary Rock Block and Waste Package Impact Analysis Results

Preliminary FE analysis results were obtained for six different rock block and WP impact scenarios (see table 2). Each rock block mass, regardless of shape, was 2 metric tonnes. The rock block and WP velocities at the moment of impact were 8 and 1 m/s, respectively, for all six scenarios investigated.

One method for characterizing the response of an elastic-perfectly plastic material, once it has been subjected to a stress level beyond its yield strength, is the amount of plastic distortion or strain that occurs. Consequently, the displacement results obtained from the analyses will be used to convey the amount of plastic distortion that the WP has incurred. In particular, table 2 summarizes the maximum displacements and concomitant residual values for the inner and outer barriers of the WP. Care must be taken when interpreting the significance of the results, however, because displacements reflect rigid body translations and rotations in addition to strain. Of all the scenarios investigated, case 5 clearly represents the most severe condition. In this scenario, the rock block strikes the WP immediately above one of the pedestal supports, causing residual displacements of 5.9 mm for the inner barrier and 6.2 mm for the outer barrier. This is to be expected because a smaller amount of the kinetic energy associated with the impact can be dissipated by way of gross flexural deformation of the WP. For example, case 1 demonstrated relatively large flexural displacements for the inner and outer barriers of the WP with very little residual deformation.

For the cubical rock block scenarios, the face impact was the most critical. This result is somewhat unexpected because the edge and corner impact scenarios would intuitively produce higher stresses at the impact point because of their stress concentration potential. It has been postulated that the edge and corner scenarios did not cause more severe localized residual damage to the WPs because the rock block mass was modeled as a relatively soft elastic-perfectly plastic material to account for minor fractures in its structure.

The results of the study appear to indicate that a spherical rock block shape will cause more damage to the WP than the cubic shape. However, the yield strength for the rock block has been assumed to be much lower than the average compressive strength of an intact rock to account for potential minor fractures within the rock block. As a result, if the rock block is

Table 2. Maximum and residual displacements incurred by the inner and outer barriers of the waste package

Case	Description	Inner Barrier		Outer Barrier	
		Maximum Displacement (mm)	Residual Displacement (mm)	Maximum Displacement (mm)	Residual Displacement (mm)
1	Spherical rock block impact at the midspan and top of the waste package	12.4	1.07	14.8	2.38
2	Cubical rock block corner impact at the midspan and top of the waste package	2.99	0.0531	3.56	0.0916
3	Cubical rock block edge impact at the midspan and top of the waste package	5.30	0.58	5.60	0.180
4	Cubical rock block face impact at the midspan and top of the waste package	6.66	1.02	6.87	0.390
5	Spherical rock block impact over a support and top of the waste package	14.7	5.90	16.5	6.20
6	Spherical rock block impact over an edge and top of the waste package	NA	NA	6.38	0.828

modeled as an intact rock mass, then the localized damage to the WP caused by a cubic rock block shape impact may be more severe than what has been presented here.

Conclusions and Discussion

Six different impact scenarios using spherical and cubical rock block shapes were evaluated. The different scenarios were assessed using maximum residual displacements of the WP as the basis for comparison. It was determined that a spherical rock block impacting the WP directly above one of its pedestal supports (i.e., Case 5) was the most critical scenario of the six analyzed. This is expected because less of the kinetic energy associated with the impact is dissipated by the gross flexural deformation of the WP. Consequently, more energy is available to cause localized damage in the immediate area of the rock block and WP impact zone.

The results presented in this report are based on FE analyses that employ various modeling assumptions, approximations, and simplifications. In particular, the materials were characterized as behaving in an elastic-perfectly plastic manner with properties determined at temperatures significantly lower than those expected within the WP. Higher material temperatures typically lead to overall weaker structures because the yield stress, ultimate strength, and Young's modulus of the materials are reduced. Moreover, the residual stresses within the WP caused by shrink fits and welding procedures during the fabrication process have not been considered. These residual stresses may have a significant influence on the amount of plastic strain that can be incurred by the WP materials before rupturing will occur. Additional effects that may play a role in the ability of the WP to perform its confinement function without disruption from rock block impacts are corrosion degradation, material embrittlement, and initial manufacturing defects.

Acknowledgment

This work was performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Material Safety and Safeguards, Division of Waste Management under Contract No. NRC-02-97-009. The work is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

References

[1] U.S. Department of Energy. *Viability Assessment of a Repository at Yucca Mountain, Overview*. DOE/RW–0508. Las Vegas, NV: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. 1998.

[2] U.S. Department of Energy. *Viability Assessment of a Repository at Yucca Mountain, Preliminary Design Concept for the Repository*. DOE/RW–0508. Las Vegas, NV: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. 1998.

[3] Civilian Radioactive Waste Management System Management and Operating Contractor. *License Application Design Selection Report*. B00000000–01717–4600–00123.

Revision 01. Las Vegas, NV: Civilian Radioactive Waste Management System Management and Operating Contractor. 1999.

[4] Civilian Radioactive Waste Management System Management and Operating Contractor. *Mined Geologic Disposal System Advanced Conceptual Design Report.* B00000000–01717–5705–00027. Revision 00. Volume III of IV: Engineered Barrier Segment/Waste Package. Las Vegas, NV: Civilian Radioactive Waste Management System Management and Operating Contractor. 1996.

[5] American Society for Testing and Materials. *Specification for Structural Steel.* A36–88C. Philadelphia, PA: American Society for Testing and Materials. 1988.

[6] American Society for Testing and Materials. *Specification for High-Strength Low-Alloy Columbium-Vanadium Steels of Structural Quality.* A572–88C. Philadelphia, PA: American Society for Testing and Materials. 1988.

[7] U.S. Department of Energy. *Consultation Draft Site Characterization Plan.* Yucca Mountain Site, Nevada Research and Development Area, Nevada. Washington, DC: U.S. Department of Energy. 1988.