PUBLIC SUBMISSION

As of: July 16, 2012
Received: July 13, 2012
Status: Pending_Post
Tracking No. 8109a7ad
Comments Due: July 13, 2012
Submission Type: Web

Docket: NRC-2012-0108
Spent Fuel Transportation Risk Assessment

Comment On: NRC-2012-0108-0001
Spent Fuel Transportation Risk Assessment

Document: NRC-2012-0108-DRAFT-0006
Comment on FR Doc # 2012-11672

5/14/2012
77FR 28406
5

Submitter Information

Name: Robert Halstead

General Comment

Comments plus attachments

Attachments

Comments NUREG-2125 and cover letter

Attachment 1

Attachment 2

Attachment 3

Attachment 4

Attachment 5

SUNSI Review Complete
Template = ADM-013

E-RIDS = ADM-03
Add = J. Cook (JRC1)

BRIAN SANDOVAL
Governor

STATE OF NEVADA

ROBERT J HALSTEAD
Executive Director

OFFICE OF THE GOVERNOR
AGENCY FOR NUCLEAR PROJECTS
1761 E. College Parkway, Suite 118
Carson City, NV 89706-7954
Telephone (775) 687-3744 • Fax (775) 687-5277
E-mail: nwpo@nuc.state.nv.us

July 13, 2012

Chief, Rulemaking Branch
Division of Administrative Services
Office of Administration
Mail Stop: TWB-05-B01 M
US Nuclear Regulatory Commission
Washington, DC 20555-0001
Rulemaking.Comments@nrc.gov

Docket ID: NRC-20212-0108, Spent Fuel Transportation Risk Assessment, NUREG-2125, Draft Report for Comment

The State of Nevada Agency for Nuclear Projects submits the attached preliminary comments on NUREG-2125 in response to the Federal Register notice published May 14, 2012 (77 FR 28406-28407).

We will submit additional comments on NUREG-2125 for consideration by NRC staff as soon as possible.

We will submit written comments for consideration by the Advisory Committee on Reactor Safeguards (ACRS), and will request an opportunity to make an oral statement at the ACRS meeting on September 5, 2012, in accordance with the procedures published in the Federal Register on October 17, 2011 (76 FR 64126-64127).

Sincerely,

Robert J. Halstead
Executive Director

RJH/sja
cc

Nevada Congressional Delegation
Marta Adams, Deputy Attorney General
Affected Units of Local Government and Tribes
Western Interstate Energy Board HLW Committee

State of Nevada
Office of the Governor
Agency for Nuclear Projects
Preliminary Comments
On
Spent Fuel Transportation Risk Assessment,
NUREG-2125,
Draft Report for Comment,
Docket ID: NRC-20212-0108
July 13, 2012

GENERAL COMMENTS

<u>Inadequate Time for Public Review and Comment</u>

The 60-day comment period is inadequate for the following reasons:

- The length of the report (509 pages), the scope of the report, and the technical complexity of the subject matter justify a longer comment period of at least 90 days and, preferably, 120 days.
- Specific technical issues, such as 1) the selection of shipping cask designs for analysis (and the decision not to include two currently licensed casks, the NAC LWT and the IF-300); 2) assumptions about spent fuel burn up history and cooling time; 3) selection of origin-destination pairs, routes, and buffer distances used for routine dose and accident risk analyses; and 4) consequence analyses for transportation accidents resulting in release of radioactive materials, have required that our agency contract with an outside technical reviewer to assist us in preparing our comments.
- The subject report references in its bibliography, but apparently does not actually include in its analyses, a number of recent NRC-sponsored studies of transportation accidents involving long-duration, high-temperature fires. This will require additional time to evaluate possible contradictions between those NRC studies and the findings of NUREG-2125.

The comment period announced in the Federal Register notice, from May 14 to July 13, included two major Federal holidays – Memorial Day on Monday, May 28 and Independence Day on Wednesday, July 4 – which fell on what would otherwise have been normal work days, effectively reducing the time for review by 2-10 days.

The NRC denial of Nevada's request for an extension contrasts with the NRC decision to grant a 14-day extension (to 60 days total) for review of a 138-page draft report, "Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel," (May 2012). In February 2012, the NRC granted a 31-day extension (to 90 days total) for review of a 23-page draft report, "Background and Preliminary Assumptions for an Environmental Impact statement – Long-Term Waste

Confidence Update," (December 2011). (See http://www.nrc.gov/waste/spent-fuel-storage/public-invovement.html) Please explain why extensions were granted for review of these draft reports, which were much shorter and, in our opinion, much less technically complex than NUREG-2125.

In denying Nevada's request for a 60-day extension, NRC cited the scheduling of a review of NUREG-2125 at the Advisory Committee on Reactor Safeguards (ACRS) meeting on September 5, 2012. The ACRS meeting is scheduled to occur 54 days after the July 13 comment deadline. Please explain why NRC did not grant an extension of, at a minimum, 30 days, or even 45 days. Please assist us in understanding how the original 60-day comment period was established by answering the following questions:

- When did the concept for this project originate?
- When did the contractors at Sandia National Laboratories begin work on this project?
- When did the peer review occur, and how long was the peer review period?
- What was the total budget for this project, including peer review?
- What efforts were made by NRC and Sandia to solicit stakeholder comment on this project, prior to publication of the draft report in May 2012?

Potential Implications of NUREG-2125 for NRC Licensing Proceedings

Finalization of Draft Report NUREG-2125 will likely have significant implications for the evaluation of transportation impacts in future NRC licensing proceedings for interim storage facilities and geologic disposal facilities.

NRC administrative law judges have already established the ground rules for evaluation of transportation impacts under the National Environmental Policy Act (NEPA) in the currently suspended licensing proceeding for the proposed Yucca Mountain repository:

> Transportation of nuclear waste is a foreseeable consequence of constructing a nuclear waste repository. As California persuasively argues, "[w]ithout transportation of the waste to it, Yucca Mountain would be just a very large, fancy, and expensive hole in a mountain." The Commission, for example, has stated that there can be "no serious dispute" that the NRC's environmental analysis in connection with licensing nuclear facilities should extend to "related offsite construction projects – such as connecting roads and railroad spurs." Likewise, there can be no serious dispute that the NRC's NEPA responsibilities do not end at the boundaries of the proposed repository, but rather extend to the transportation of nuclear waste to the repository. The two are closely interdependent. Without the repository, waste would not be transported to Yucca Mountain. Without transportation of waste to it, construction of the repository would be irrational. Under NEPA, both must be considered. [1]

[1] NRC, Atomic Safety and Licensing Boards, Memorandum and Order Identifying Participants and Admitted Contentions, Docket NO. 63-001-HLW (May 11, 2009).

As part of the Yucca Mountain licensing process, NRC staff reviewed and adopted the 2008 U.S. Department of Energy (DOE) Final Supplemental Environmental Impact Statement (FSEIS) for Yucca Mountain (DOE/EIS-0250F), including the transportation impact calculations for the mostly rail transportation scenario.[2] The Draft Report makes no reference to the 2008 DOE FSEIS, although it cites DOE's earlier 2002 EIS.

As part of its finalization of Draft Report NUREG-2125, NRC staff must assess the implications of the findings and conclusions of the Draft Report for the FSEIS transportation impact calculations adopted by NRC staff in the Yucca Mountain licensing proceeding. The DOE FSEIS adopted by NRC staff evaluated radiological impacts in three categories related to routine transportation and transportation accidents:

(1) "incident-free" exposures to members of the public residing near transportation routes, cumulative total up to 2,500 person-rem dose and 1.5 latent cancer fatalities, and in certain special circumstances (for example, 0.016 rem to a person in a traffic jam); [FSEIS, Pp.6-20, 6-21, 8-41]

(2) "incident-free" exposures to transportation workers such as escorts, truck drivers, & inspectors, cumulative total up to 13,000 person-rem and 7.6 latent cancer fatalities (by administrative controls, DOE would limit individual doses to 0.5 rem per year; the allowable occupational dose is 5 rem per year); [FSEIS, Pp.6-21, 8-41] and

(3) release of radioactive material as a result of the maximum reasonably foreseeable transportation accident (probability about 5 in one million per year), involving a fully engulfing fire, 34 rem dose to the maximally exposed individual, 16,000 person-rem population dose and 9.4 latent cancer fatalities in an urban area, and cleanup-costs of $300,000 to $10 billion. [FSEIS, Pp.6-15, 6-24, G-56]

Significance of National Transportation Impacts

The Draft Reports fails to adequately assess the national impacts of spent fuel transportation from the current 72 reactor sites to one or more storage and/or disposal facilities. The highway and rail route maps presented in the Draft Report (Pp. 23-26) traverse more than 30 states. A complete routing analysis of all origin-destination pairs would likely demonstrate more widespread impacts similar to those identified in studies prepared for the State of Nevada. These Nevada studies, which are not referenced in the Draft Report, concluded that an extraordinary number of people, communities, and political jurisdictions would have been impacted by shipments to the proposed Yucca Mountain repository. Most of the nation's spent fuel and high-level waste is currently stored at 72 reactor sites and 4 DOE sites in 34 states. The "representative routes" identified by DOE in the FSEIS, from these sites to Yucca Mountain, would have utilized 22,000 miles of railways and 7,000 miles of highways traversing 44 states. (Attachment 1) An updated report, using 2010 census data, found that the representative routes would have traversed 955 counties with a total population of more than 177,000,000. About 56

[2] NRC, U.S. Nuclear Regulatory Commission Staff's Adoption Determination Report for the U.S. Department of Energy's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain, Pp. 3-13, 3-15, 5-1 (September 5, 2008).

percent of the total US population resides in counties that would have been traversed by spent fuel and high-level waste shipments to Yucca Mountain. (Attachment 2)

Sweeping Conclusions Unsupported by the Analyses

The Draft Report contains a number of sweeping conclusions that are not supported by the analyses presented in the document. For example, the Draft Report concludes that the collective radiological doses from spent fuel transportation are "vanishingly small" (Pp. xxii, 128, 139, F-11). This conclusion is based on the analysis of the movement of a single spent fuel cask from four different sites to four different destinations. The report states that its findings are meant to be applied to "a large scale shipping campaign." (Pp.10, 13) From this miniscule sample, the report claims its findings can be extrapolated to future shipping campaigns. This conclusion is not supported by the evidence presented by the report.

Cask Designs Chosen for Analysis

Among the cask designs chosen for analysis in the Draft Report were the GA-4 truck cask, the NAC-STC rail cask, and the HI-STAR 100 rail cask. (Pp.9-13) It is our understanding that these casks have been used for few, or any, spent fuel shipments in the United States. Please answer the following questions about these casks:

- How many GA-4 truck casks are currently being used in the United States? How many shipments of spent fuel in the United States have been made in GA-4 casks?
- How many NAC-STC rail casks are currently being used in the United States? How many shipments of spent fuel in the United States have been made in NAC-STC casks?
- How many HI-STAR 100 rail casks are currently being used in the United States? How many shipments of spent fuel in the United States have been made in HI-STAR 100 casks?
- If the purpose of the report is to assess the adequacy of the existing NRC regulations, why did NRC decide to perform detailed analysis of these three casks, which have been used for few, if any, spent fuel shipments in the United States, under the existing regulations?

Cask Designs Not Chosen for Analysis

Among the cask designs not chosen for analysis in the Draft Report were the NAC LWT truck cask and the IF-300 rail cask. (Pp. 9-13) It is our understanding that these are the two casks that were used for the majority of spent nuclear fuel shipments in the United States over the past two decades. It is also our understanding, based on previous studies, that the performance of these casks in severe accidents involving fires could be significantly different than the casks selected for analysis. It is also our understanding that there have been a number of incidents involving human error in the fabrication and loading of these casks.

Please answer the following questions about these casks:

- How many NAC LWT truck casks are currently being used in the United States? How many shipments of spent fuel in the United States have been made in NAC LWT casks since 1990?
- How many IF-300 rail casks are currently being used in the United States? How many shipments of spent fuel in the United States have been made in IF-300 casks since 1990?

- Have any previous studies known to the NRC evaluated the performance of NAC LWT truck casks in severe accidents involving long-duration, high-temperature fires? How do these studies compare to the findings reported in the Draft Report?
- Have any previous studies known to the NRC evaluated the performance of IF-300 truck casks in severe accidents involving long-duration, high-temperature fires? How do these studies compare to the findings reported in the Draft Report?
- Have any previous studies known to the NRC evaluated human errors involving fabrication and loading of NAC LWT truck casks used for spent fuel shipments in the United States? Did any reported human error incidents result in NRC enforcement actions?
- Have any previous studies known to the NRC evaluated human errors involving fabrication and loading of IF-300 rail casks used for spent fuel shipments in the United States? Did any reported human error incidents result in NRC enforcement actions?
- If the purpose of the report is to assess the adequacy of the existing NRC regulations, why did NRC decide not to perform detailed analysis of the casks which are actually being used for spent fuel shipments at the present time, under the existing regulations?
- Is the NRC aware of any regulation which would prohibit the use of NAC LWT and IF-300 casks for future shipments to an interim storage facility or geologic repository?

Full-Scale Cask Testing

It is our understanding that none of the spent fuel shipping casks currently in use in the United States has been tested full-scale to confirm their performance in regulatory or extra-regulatory accidents. (Attachment 3) Is this correct? Has any of the computer models used for dynamic finite element calculations of the NAC-STC and HI-STAR 100 rail casks in the Draft Report been validated or benchmarked with results from full-scale testing of casks currently in use in the United States?

In 2006, the National Academies (NAS) report, Going the Distance?, endorsed full-scale testing of shipping casks under certain conditions. The Draft Report cites this report, but does not address full-scale cask testing. The NAS finding and recommendation are as follows:

> "FINDING: The committee strongly endorses the use of full-scale testing to determine how packages will perform under both regulatory and credible extra-regulatory conditions. Package testing in the United States and many other countries is carried out using good engineering practices that combine state-of-the-art structural analyses and physical tests to demonstrate containment effectiveness. Full-scale testing is a very effective tool for both guiding and validating analytical engineering models of package performance and for demonstrating the compliance of package designs with performance requirements. However, deliberate full-scale testing of packages to destruction through the application of forces that substantially exceed credible accident conditions would be marginally informative and is not justified given the considerable costs for package acquisitions that such testing would require.
>
> RECOMMENDATION: Full-scale package testing should continue to be used as part of integrated analytical, computer simulation, scale model, and testing programs to validate the performance of package performance. Deliberate full-scale testing of packages to destruction should not be carried out as part of this integrated analysis or for compliance demonstrations."

Why did NRC decide not address full-scale testing as proposed by the NAS in the Draft Report? How might the findings of the Draft Report be used to support full-scale cask testing as proposed by the 2006 NAS report?

In 1999, NRC began the process of developing a cask testing demonstration study as part of the Package Performance Study (PPS). The most recent NRC testing proposal (SECY-05-001), approved by the Commission in June 2005, calls for a demonstration test in which a cask mounted on a railcar is impacted by a speeding locomotive, and then subjected to a 30-minute fire engulfing fire. "The staff's proposed test plan as provided in this SECY is not the final word on this issue, as the project is subject to additional modifications and Commission direction once additional information becomes available."

Nevada believes the test proposed in SRM SECY-05-0051 would not determine if the rail cask meets the accident performance standards set forth in the NRC regulations and would provide little data useful for validating the computer models used in safety evaluations. The demonstration test appears to have the same limits noted by NRC staff regarding the tests proposed in 2004. However, Commission stated that this plan "is not the last word of this issue."

Why did NRC decide not address full-scale testing as proposed in SRM SECY-05-0051 in the Draft Report? How might the findings of the Draft Report be used to support full-scale cask testing as proposed in SECY-05-0051?

Insufficient Detail to Allow Independent Confirmation of Findings

In a number of important instances, the Draft Report does not sufficient data to confirm its findings. For example, regarding the routes evaluated, it provides only national maps of the routes studied, rather than the detailed printouts from the WEBTRAGIS software that would have permitted detailed confirmation of the routes shown in the maps. The WEBTRAGIS outputs for each of the routes evaluated should be included in the final version. Moreover, it is difficult to confirm the population data used in the Draft Report. Nevada submits an alternative approach to assessment of population data along potential shipping routes at the national level (Attachment 4) and at the state and county level (Attachment 5).

Routine Dose Calculations for Truck Shipments Ignore Over-weight Truck Operations and Traffic Gridlock Incidents

The Draft Report routine dose calculations for truck shipments must be completely re-evaluated. The Draft Report assumes that the GA-4 can be shipped as a legal-weight cask. In the 2008 FSEIS, DOE determined that the GA-4 (and GA-9) casks would need to be transported as over-weight truck shipments. As a result, the report's results are incomplete, misleading and tentative at best. The Draft Report completely ignores the potential dose to members of the public resulting transportation gridlock incidents during truck shipments.

Routine Dose Calculations for Rail Shipments Ignore Intermodal Transfers and New Security Regulations

The Draft Report routine dose calculations for rail shipments must be completely re-evaluated. The Draft Report ignores the fact that about one-third of the current 72 reactor sites cannot make

direct rail shipments. Many sites once thought to have rail access, no longer do. Previous examinations of this problem by DOE have found that it will be necessary to use a mix of barge, overweight and heavy trucks to move spent fuel in rail casks to the nearest railhead. The Draft Report ignores past shipping plans which envisioned heavy haul truck, barge, intermodal and overweight truck as all being necessary to ship these materials, and fails to considers potentially lengthy delays due to normal traffic congestion, rail incidents, equipment failure or other causes. Moreover, the Draft Report completely fails to consider the new rail security regulations adopted by the Federal Railroad Administration and the Department of Homeland Security in 2008. These new regulations will dramatically affect routing decisions and create significantly increased stop time for routine rail shipments, even if all shipments are assumed to be made in dedicated trains. These issues regarding rail shipments are addressed in detail in Attachment 1.

Accident Scenarios Underestimate Potential Fire Durations and Temperatures
Nevada believes that the Draft Report underestimates the potential fire durations and fire temperatures to which casks may be exposed in transportation accidents.

Accident Scenarios Underestimate Consequences on Damage to Cask Impact Limiters
Nevada believes that Draft Report underestimates the potential damage to casks in accident fire environments following damage to cask impact limiters.

Yucca Mountain Transportation Planning: Lessons Learned, 1984-2009 - 11256

Robert J. Halstead (bearhalstead@aol.com)
State of Nevada Agency for Nuclear Projects
Carson City, NV 89706
Fred Dilger, PhD (fcd5@cox.net)
Black Mountain Research
Henderson, NV 81012
James D. Ballard, PhD (ballard@csun.edu)
Department of Sociology, California State University, Northridge
Northridge, CA 91330

ABSTRACT

This paper reviews the 25-year-long debate over the transportation program for the now-terminated Yucca Mountain repository project, and identifies lessons learned which might be applied to future spent nuclear fuel and high-level radioactive waste shipments to geologic repositories or centralized storage facilities in the United States.

INTRODUCTION

Over the past two and a half decades, the U.S. Department of Energy (DOE) proposal to construct and operate a geologic repository for spent nuclear fuel (SNF) and high-level radioactive waste (HLW) at Yucca Mountain, Nevada, generated a broad range of transportation controversies. These controversies include the national scope of nuclear waste storage and transportation impacts, the lack of rail access to the Yucca Mountain site, the assessment of transportation impacts as part of the repository licensing process, the widespread concern about transportation safety, the vulnerability of shipments to terrorism and sabotage, the effort to maximize use of rail transportation, and the selection of cross-country rail routes. While the Yucca Mountain project has now been terminated, the same or similar issues and controversies can be expected to arise in the context of any future large-scale SNF and HLW transportation effort.

Yucca Mountain transportation analyses conducted by DOE and the State of Nevada provide a rich source of lessons learned for future SNF and HLW shipments in the United States. [1-22, 30-32] Yucca Mountain transportation lessons learned include the licensing proceeding contentions admitted by the Nuclear Regulatory Commission (NRC) Atomic Safety and Licensing Boards in May 2009; the NRC package performance study cask testing proposal; current NRC proposals for enhanced transportation safeguards regulations, extended at-reactor storage, and integrated regulation of SNF storage and transportation; and the waste confidence final decision. [23-29, 33] The lessons learned also include the findings and recommendations of the National Academy of Sciences (NAS) 2006 report, Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States. [34]

FUTURE SHIPMENTS WILL BE A MATTER OF NATIONAL CONCERN

While important details about the future nuclear waste management system are uncertain, transportation analyses conducted by DOE and Nevada with regard to the now-terminated Yucca Mountain project indicate that SNF and HLW shipments to a future national repository or central storage site would be dramatically different than current shipments. The amount of waste shipped, the number of shipments, and the total shipment miles would greatly increase. Cross-country nuclear waste shipments would occur weekly, or even perhaps daily, for four or five decades, or more. The number of affected congressional districts, States, Indian Tribes, and local governments would create enormous potential for political controversy.

Assuming no new reactors, and license extensions for all operating reactors, the current SNF inventory will grow by about 2,000 MTU (metric tons uranium) per year. Once regular shipments to centralized storage, geologic disposal, and/or reprocessing begin, annual shipments of at least 3,000 MTU seem likely. At that rate, assuming mostly rail (95 percent) transportation of commercial SNF, and all rail transportation of DOE SNF and HLW, there would likely be about 7,000 train shipments (3-5 casks per train) and 5,000 truck shipments (one cask per truck) over about 50 years. That works out to about 100-150 train-load shipments and 100 truck shipments every year in the future, compared to about 10-15 train-loads and 10-15 truck shipments per year currently. Put another way, under a mostly rail scenario, assuming a total SNF and HLW inventory of about 150,000 MTU, there would be about 7-10 times more shipments each year, using larger capacity casks, carrying 50 times more spent fuel annually.

However, the DOE mostly rail scenario may be unrealistic. Even marginally greater reliance on legal-weight truck (LWT) or over-weight truck (OWT) shipments could significantly increase the number of shipments. If 20 percent of the projected inventory were to be shipped by LWT or OWT, an additional 9,000 to 15,000 truck shipments would likely be required, for a total of 14,000 to 20,000 truck shipments. Shipping 35 percent by LWT or OWT could easily bring the total to more than 23,000 truck shipments, an average of more than one truck shipment per day, every day, for 50 years.

Shipments to a national repository or centralized storage facility would impact an extraordinary number of people, communities, and political jurisdictions. There are currently 76 storage sites in 34 states. The "representative routes" identified by DOE, from these sites to Yucca Mountain (see Figure 1), would have traveled 22,000 miles of railways and 7,000 miles of highways, traversing 44 states, the District of Columbia, 33 Indian nations, and about 836 counties with a population of about 161 million. (2005 Census estimates) Between 10 and 12 million people live within one-half mile (800 meters) of these rail and highway routes. And these routes would have affected most of the nation's congressional districts (330 in the 110th Congress). [18, 31, 32]

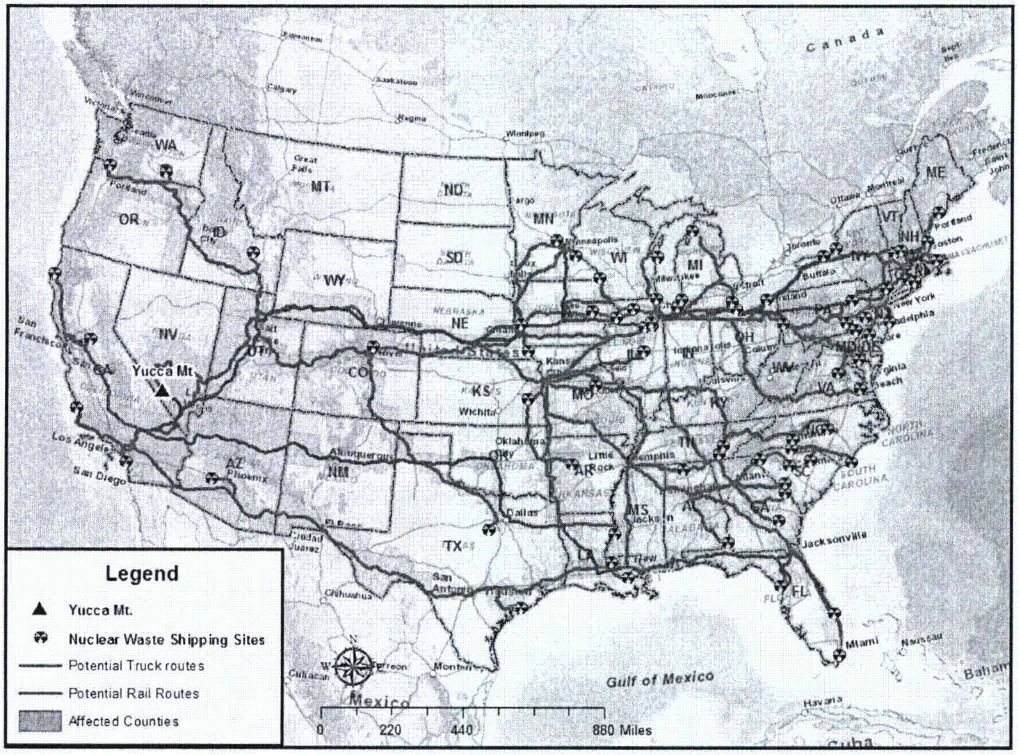

Fig.1. "Representative" Rail and Truck Routes to Yucca Mountain (DOE, 2008)

TRANSPORTATION REQUIREMENTS MUST BE ADDRESSED IN FACILITY SITE SELECTION

One important lesson from the DOE repository program is that critical transportation requirements, such as mainline rail access and interstate highway access, must be addressed in the earliest phases of site selection for storage and disposal facilities. Direct rail access to the national rail network is highly desirable in siting a geologic repository or centralized storage facility. Without direct rail access, delivery of SNF and HLW to a national facility would require either tens of thousands of cross-country over-weight truck (OWT) shipments or many thousands of heavy-haul truck (HHT) shipments from an intermodal transfer facility. Access to the interstate highway system is also highly desirable, for delivery of SNF and HLW and repository construction materials and supplies, and for access by workers and emergency services. In the 2002 Final Environmental Impact Statement (FEIS) for Yucca Mountain, DOE identified rail as the preferred mode of transportation, nationally and in Nevada, based upon the "smaller number of shipments" and "the correspondingly reduced environmental impacts." [8]

But Congressional selection of Yucca Mountain as the only repository candidate site in 1987 ignored known problems with rail access construction and impacts, as well as challenging highway access. DOE's 1986 Environmental Assessments (EAs) for the first repository showed that Yucca Mountain had the most difficult rail access, the most difficult interstate highway access, and most adverse overall transportation system impacts, of the five candidate sites studied (Table I).

Table I. Rail and Highway Access Conditions at Potential Repository Sites

Condition	Davis Canyon, Utah	Deaf Smith, Texas	Hanford, Washington	Richton, Mississippi	Yucca Mountain, Nevada
Nearest Mainline Railroad (miles)	74	25	51	17	100
Nearest Alternative Railroad (miles)	Not Identified	40	101	26	265
Rail Access New Construction (miles)	39	26	3	26	100
Rail Access Cost (Million 1985 Dollars)	142	21	6	16	151
Nearest Interstate Highway (miles)	89	14	28	26	100
Nearest Alternative Interstate (miles)	198	200	72	84	208

Ref. 1, 3

Yucca Mountain lacked the favorable conditions for rail access spelled out in the 1984 repository siting guidelines: short distances; low construction costs; absence of need for Federal condemnation to acquire rights-of-way; absence of need for cuts, fills, tunnels, and bridges; absence of steep grades or sharp curves; and bypass of local cities and towns. Yucca Mountain presented three potentially adverse conditions: relatively high construction costs; relatively difficult terrain; and local conditions (proximity to military facilities and potential military aircraft over-flights) "that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options."[1]

DOE's 1986 Yucca Mountain EA assumed rail access could be attained by constructing a 100-mile railroad, originating in the Las Vegas area, at a cost of $151 million (1985$). By 2008, DOE was proposing construction of the circuitous Caliente rail alignment (Figure 2), a 300-plus-mile railroad, longer than the distance between Washington DC and New York City, crossing 8 mountain ranges, at a cost of $2.7 billion or more. [22] Even if built, the Caliente rail line to Yucca Mountain would not have eliminated rail shipments through downtown Las Vegas, a major concern in Nevada. Additionally, Yucca Mountain had

poor access to the national interstate highway system, which led DOE to propose routing all legal-weight truck shipments to Yucca Mountain through the Las Vegas Valley (Figure 3).

Studies prepared for the State of Nevada estimate that at least 95,000 residents of Clark County live within one-half mile of the Union Pacific rail route DOE would have used for shipments to Yucca Mountain via Caliente, and at least 113,000 residents of Clark County live within one-half mile of the highway routes DOE would have used for truck shipments. A large portion of the world-famous Las Vegas "Strip" and more than 34 hotels with 49,000 hotel rooms are located within what would have been the one-half mile region of influence along the rail route. Nevada estimates at least 40,000 nonresident visitors and workers in Clark County would have been located within one-half mile of the highway and rail routes at any hour of the day. Virtually all of Clark County's 1.8 million residents live within what would have been the 50-mile radiological region of influence for transportation accidents and sabotage.[19] None of this was considered in the early site selection process and failure to do so, contributed significantly to the accumulating problems with Yucca Mountain.

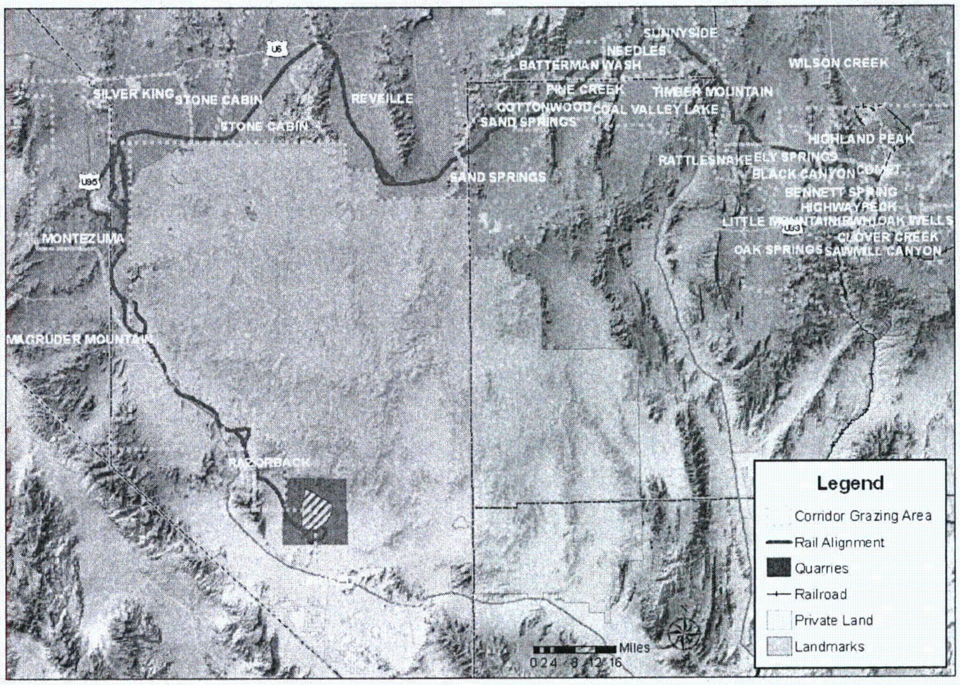

Fig. 2. Caliente Rail Alignment

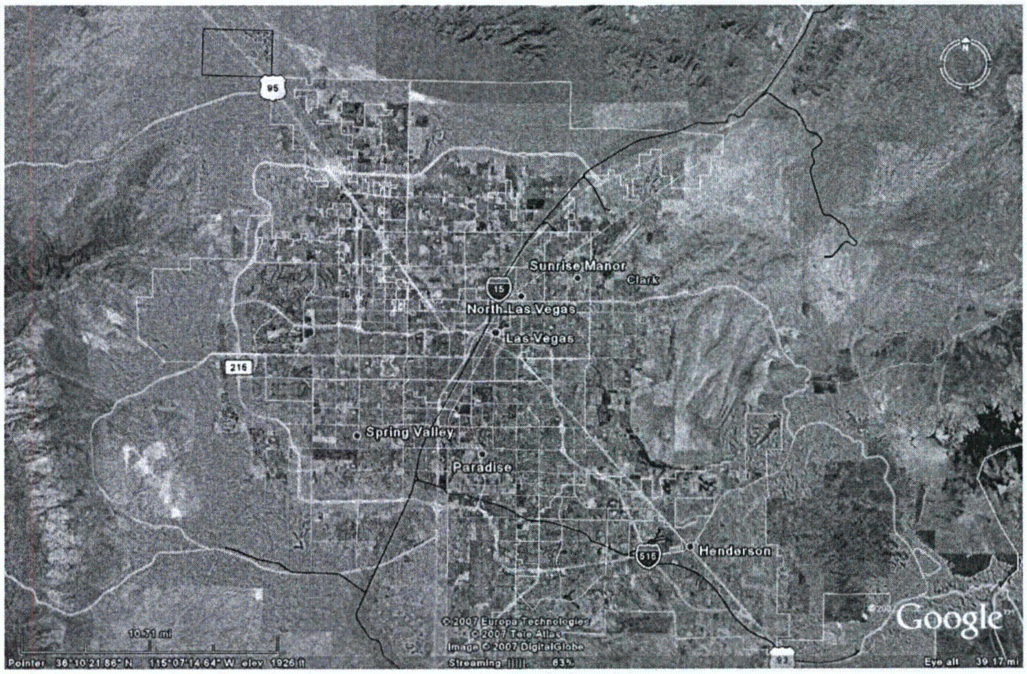

Fig. 3. Potential Rail and Highway Routes through Las Vegas

TRANSPORTATION WILL BE CONSIDERED IN FACILITY LICENSING

The role of transportation in future NRC licensing proceedings for disposal and storage facilities may well have been established by the May 2009 Memorandum and Order issued by the NRC Atomic and Safety Licensing Boards (ASLBs) considering the DOE license application for Yucca Mountain. The key paragraph reads:

> Transportation of nuclear waste is a foreseeable consequence of constructing a nuclear waste repository. As California persuasively argues, "[w]ithout transportation of the waste to it, Yucca Mountain would be just a very large, fancy, and expensive hole in a mountain." The Commission, for example, has stated that there can be "no serious dispute" that the NRC's environmental analysis in connection with licensing nuclear facilities should extend to "related offsite construction projects – such as connecting roads and railroad spurs." Likewise, there can be no serious dispute that the NRC's NEPA responsibilities do not end at the boundaries of the proposed repository, but rather extend to the transportation of nuclear waste to the repository. The two are closely interdependent. Without the repository, waste would not be transported to Yucca Mountain. Without transportation of waste to it, construction of the repository would be irrational. Under NEPA, both must be considered. [24]

Applying this reasoning, the NRC ASLBs admitted 46 NEPA [National Environmental Policy Act] contentions or challenges related to transportation: 17 submitted by the State of California, 16 submitted by the State of Nevada, 8 submitted by California and Nevada Counties, 3 submitted by the Nuclear Energy Institute, and 2 submitted by the Timbisha Shoshone Tribe. These admitted contentions address virtually every aspect of repository transportation, including: selection and design of shipping containers; modal options (rail, legal-weight truck, over-weight truck, heavy-haul truck, and barge); route selection for rail and truck shipments to Nevada, and within Nevada; selection of the Caliente rail alignment to Yucca Mountain; environmental impacts of rail line construction and operation; routine radiation exposures to workers and the public; consequences of severe transportation accidents; consequences of transportation terrorism and sabotage; and emergency response capabilities. [24]

The admitted NEPA contentions regarding transportation safety and security deserve particular attention. The DOE SEIS for Yucca Mountain acknowledged transportation radiological impacts in four categories: (1) routine exposures to members of the public residing near transportation routes, cumulative total up to 2,500 person-rem dose and 1.5 latent cancer fatalities, and in certain special circumstances (for example, 0.016 rem to a person in a traffic jam); (2) routine exposures to transportation workers such as escorts, truck drivers, & inspectors, cumulative total up to 13,000 person-rem and 7.6 latent cancer fatalities (by administrative controls, DOE would limit individual doses to 0.5 rem per year; the allowable occupational dose is 5 rem per year); (3) release of radioactive material as a result of the maximum reasonably foreseeable transportation accident (probability about 5 in one million per year), involving a fully engulfing fire, 34 rem dose to the maximally exposed individual, 16,000 person-rem population dose and 9.4 latent cancer fatalities in an urban area, and cleanup-costs of $300,000 to $10 billion; and (4) release of radioactive material following a successful act of sabotage or terrorism, using a high-energy density device, resulting in 27-43 rem dose to the maximally exposed individual, 32,000-47,000 person-rem population dose and 19-28 latent cancer fatalities in an urban area, and cleanup costs similar to a severe transportation accident. [Ref 12, Pp.6-15 to 6-27, 8-41, G-56, CR-467]

NRC staff reviewed and accepted the DOE SEIS transportation impact analysis in the Yucca Mountain licensing docket. The State of Nevada and other parties have challenged the DOE SEIS consequence estimates for transportation accidents and sabotage. Nevada argued that the consequences of a severe accident could be significantly greater if DOE had considered different radiological characteristics of SNF, different environmental conditions, and exacerbating human errors. Nevada argued that the consequences of a successful act of sabotage could be significantly greater if DOE had considered an attack using two weapons, one to breach the cask and another to disperse the cask contents. [23] The NRC licensing board has accepted Nevada's contentions, and if the licensing proceeding should resume, these matters would be further explored in great detail.

TRANSPORTATION PLAN MUST ADDRESS SAFETY CONCERNS

Spent fuel remains lethally radioactive for at least fifty years after removal from a reactor.[1] Spent fuel transportation involves potential radiological risks to health, safety, and the environment, and social impacts resulting from public perception of radiological risks. In 2009 the DOE Office of Civilian Radioactive Waste Management (OCRWM) published a National Transportation Plan (NTP) for the proposed Yucca Mountain repository that ignored the radiological hazards of spent nuclear fuel, and failed to explain how DOE would manage the safety and security of spent fuel transportation. [20] The NPT contrasted sharply with the approach taken in the 2006 NAS Report on spent fuel transportation safety, and even with the approach taken by DOE in the 2008 SEIS for Yucca Mountain.

The "principal finding" of the NAS report on transportation safety, was that spent fuel transportation "is, from a technical viewpoint, a low-radiological-risk activity with manageable safety, health and environmental consequences when conducted in strict adherence to existing regulations. However, there are a number of social and institutional challenges to the successful initial implementation of large quantity shipping programs that will require expeditious resolution as described in this report. Moreover, the challenges of sustained implementation should not be underestimated."

The NAS report [34] explained further:

> FINDING: There are two potential sources of radiological exposures from transporting spent fuel and high-level waste: (1) radiation shine from spent fuel and high-level waste transport packages under normal conditions; and (2) potential increases in radiation shine and release of radioactive materials from the transport packages under accident conditions that are severe enough to compromise fuel element and package integrity. The radiological risks associated with the transportation of spent fuel and high-level waste are well understood and are generally low, with the possible exception of risks from releases in extreme accidents involving very-long-duration,

[1] Assumes a surface dose rate of 8,640 rem/hour, for 50-year cooled SNF typical of utility discharges in the 1970s, based on US DOE, DOE/NE-0007, 1980, and lethal acute dose of 600 rem. See Ref. 21, p.9.

fully engulfing fires. While the likelihood of such extreme accidents appears to be very small, their occurrence cannot be ruled out based on historical accident data for other types of hazardous material shipments. However the likelihood of occurrence and consequences can be further reduced through relatively simple operational controls and restrictions and route-specific analyses to identify and mitigate hazards that could lead to such accidents.

RECOMMENDATION: Transportation planners and managers should undertake detailed surveys of transportation routes to identify potential hazards that could lead to or exacerbate extreme accidents involving very-long-duration, fully engulfing fires. Planners and managers should also take steps to avoid or mitigate such hazards before the commencement of shipments or shipping campaigns."

The NAS further cautioned: "The finding that spent fuel transportation risks are 'generally low' at present does not necessarily mean that such risks will continue to be low in the future. Future risks depend on a number of factors (e.g., the care taken in fabricating transport packages and executing transportation operations). Ongoing vigilance by regulators and shippers will be essential for maintaining low-risk programs in the future, especially during the scale-up and operation of large-quantity shipping programs." And the NAS emphasized the importance of identifying and managing "social risks." "Such risks, which can result in lower property values along transportation routes, reductions in tourism, and increased anxiety, have received substantially less attention than health and safety risks, and some are difficult to characterize." [Ref. 34, Pp. 7-11]

In the National Transportation Plan (NTP), the public face of the DOE transportation program, DOE failed to address these issues in a substantive manner. In the NTP, DOE downplayed the radiological characteristics of spent fuel, was silent about the potentially severe radiological impacts identified by DOE in the SEIS, and ignored national policy on radiation protection, failing to even mention the NRC requirement for maintaining radiation exposures as low as reasonably achievable (ALARA). The NTP made only limited and self-serving references to the NAS report, arguably the most important public document ever published about spent fuel transportation.[2] The NTP seriously damaged the credibility of the DOE OCRWM transportation program, and missed an opportunity to establish a consensus about safety and security among transportation stakeholders.

The NAS report provided separate findings and recommendations on transportation safety and security. Security issues are addressed later in this paper. The NAS divided the safety issues into current concerns and future concerns. Taken together, the NAS current and future safety concerns provide a template for organizing the risk management elements of a national transportation plan for SNF and HLW.

Any future national transportation plan should implement the recommendations of the NAS report, or explain why they should not be implemented:

- **Undertake detailed surveys of transportation routes to identify potential hazards that could lead to or exacerbate extreme accidents involving very-long-duration, fully engulfing fires, and mitigate such hazards before the commencement of shipments; [p.10]**
- **Expand membership and scope of existing DOE advisory group (TEC) to obtain outside advice on social risk, including impact and management; [p.11]**
- **Establish transportation risk advisory group explicitly designed to provide advice on characterizing, communicating, and mitigating the social, security, and health and safety risks of transportation; [p.11]**
- **Undertake additional analyses of very long duration fire scenarios, develop measures to prevent shipments from encountering such fires; [Pp.13-14]**
- **Use full-scale package testing as part of integrated package performance program (testing to destruction should not be required); [Pp.14-15]**

[2] The DOE NTP makes two references to the NAS report, one regarding the general level of risk (p.2) and the other regarding the process for selecting shipment routes (p.25).

- **Continue involvement of states and tribal governments in routing and scheduling of foreign and DOE research reactor spent fuel shipments; [p.15]**
- **Ensure state designation of highway routes are supported by sound risk assessments, and affected states fulfill their regulatory responsibilities; [p.16]**
- **Implement mostly rail option, using intermodal transportation to allow the shipment of rail packages from plants that do not have direct rail access, and avoid extended truck transportation program; [p.17]**
- **Publicly identify DOE suite of preferred highway and rail routes to a federal repository as soon as practicable, with involvement by states and tribes; [p.18]**
- **Fully implement DOE dedicated train decision before commencing the large-quantity shipments to a federal repository (avoid general trains); [Pp.18-19]**
- **Negotiate with commercial spent fuel owners to ship older fuel first, except where storage risks at specific plants dictate otherwise; if negotiations prove to be ineffective, Congress should consider legislative remedies; [p.20]**
- **Immediately begin to execute DOE emergency preparedness responsibilities defined in section 180© of the NWPA, and include emergency responders in program planning and communication with affected communities; [Pp.20-21]**
- **DOE, DHS, DOT, and NRC Develop criteria for protecting sensitive information about transportation, and commit to open sharing of information that does not require such protection, and facilitate timely access to open information; [p.21]**
- **Examine options for changing the organizational structure of the DOE repository transportation program. [p.21]**

Even though the potential for new rail construction particular to Yucca Mountain has been rendered moot, by DOE's decision to terminate the project, the authors of this paper disagree with the NAS recommendation that "DOE should fully implement its mostly rail decision by completing construction of the Nevada rail spur." [Pp. 17, 217] Rather, what the failed Yucca Mountain experience teaches us is that selecting a future disposal, storage or waste treatment site without fully considering transportation requirements, and then trying to correct the lack of rail access later, can have disastrous consequences for the waste program.

The NEPA issues raised in Nevada's 2005 legal challenge to DOE's selection of the Caliente rail corridor have not yet been finally decided. Nevada's challenges to the DOE Caliente rail line proposal are still pending before the NRC and the U.S. Surface Transportation Board (STB). Further legal actions are expected by affected landowners and land users in the affected Nevada counties. The potential adverse impacts within and outside Nevada, and the massive cost uncertainties associated with new rail construction, threaten to undermine any future "mostly rail" transportation option, and should serve as a cautionary reminder for any future facility siting effort

PHYSICAL PROTECTION OF SHIPMENTS WILL BE A MAJOR CONCERN

Potential threats to spent nuclear fuel shipments include theft, diversion, sabotage, terrorism, induced accidents, and violent protest demonstrations. Over the past decade, concern has focused on acts of sabotage or terrorism intended to release and disperse radioactive material, including attacks using military explosives and anti-tank missiles. The frequency, predictability, and symbolic value of repository shipments would be dramatically different from current shipments. Operation of a national repository or centralized storage facility would result in frequent (perhaps daily), highly-visible, long-distance shipments of SNF, to a single destination.

The State of Nevada brought its concerns about physical protection of current and future SNF shipments to the NRC in a 1999 petition for rulemaking (PRM-73-10). [25] DOE addressed the vulnerability of repository shipments in the1999 Draft EIS for Yucca Mountain. NRC delayed its response to Nevada's petition after the September 11, 2001 terrorist attacks. DOE acknowledged the vulnerability of shipping casks to terrorism and sabotage in the 2002 Final EIS for Yucca Mountain. [8] The NRC commissioned a

series of classified threat and consequence assessments in response to the 9/11 attacks and Nevada's petition, and in response to congressional direction. [25]

The NAS report also addressed this issue:

> PRINCIPAL FINDING ON TRANSPORTATION SECURITY: Malevolent acts against spent fuel and high-level waste shipments are a major technical and societal concern, especially following the September 11, 2001, terrorist attacks on the United States.
> RECOMMENDATION: An independent examination of the security of spent fuel and high-level waste transportation should be carried out prior to the commencement of large-quantity shipments to a federal repository or to interim storage. This examination should provide an integrated evaluation of the threat environment, the response of packages to credible malevolent acts, and operational security requirements for protecting spent fuel ad high-level waste while in transport. This examination should be carried out by a technically knowledgeable group that is independent of the government and is free from institutional and financial conflicts of interest. This group should be given full access to the necessary classified documents and Safeguards Information to carry out this task. The findings and recommendations from this examination should be made available to the public to the fullest extent possible. [Ref. 34, Pp. 8-9]

In its petition to the NRC, and in comments to the DOE and the NAS, Nevada cited more than 20 years of tests and analyses, reported in unclassified literature, indicating that SNF shipping casks could be breached by a range of weapons, including Korean War-era military demolition charges, and Vietnam War-era anti-tank weapons. In 2008, in its SEIS for Yucca Mountain, DOE revised its earlier assessment of impacts of an act of sabotage, increasing its estimate of health and economic consequences. [12] However, DOE continued to assume that an attack would utilize a single weapon, which would deeply penetrate, but not fully perforate, the shipping cask.

The SEIS estimated that a single-weapon attack, penetrating one wall of the cask, could result in a 32,000-47,000 person-rem population dose and 19-28 latent cancer fatalities in an urban area, and cleanup costs similar to a severe transportation accident, in the range of $300,000 to $10 billion. [12] A DOE-sponsored study estimated that a single-weapon attack that fully penetrated the cask, creating an exit hole, could increase the amount of radioactive material released as an aerosol by about 10 times, compared to the one-hole penetration. [35] A Nevada-sponsored study estimated that a multiple weapon attack, which created an exit hole, would increase the release of radioactive cesium by 100 times or more. The resulting population dose was estimated to be 55-202 times greater than the SEIS estimate; the dose to the maximally exposed individual was estimated to be 555-1,615 times greater; and cleanup costs were estimated to be hundreds of billions of dollars(2008$) in an urban area. [36]

As of January 2011, the NRC has extended the comment period for its 2010 proposed rule, which would significantly strengthen physical protection of SNF in transit. The proposed rule incorporates regulatory clarifications and security enhancements requested in Nevada's 1999 petition for rulemaking, findings of NRC and DOE consequence analyses, and agency and licensee experience gained since the terrorist attacks of September 11, 2001. However, DOE SNF shipments would continue to be exempt from the NRC physical protection regulations. [26]

The State of Nevada recommends the following measures to enhance physical protection of future spent fuel shipments and mitigate the consequences of potential sabotage events: ship the oldest fuel first; minimize number of shipments and shipment-miles; maximize use of rail, requiring dedicated trains; adopt NRC proposed amendments to 10 CFR 73.37 for all shipments; assess implications of federal regulations for cross-country rail shipments; require full-scale testing of shipping casks; adopt DOE-SRG WIPP transportation protocols for accident prevention and emergency response; and implement a comprehensive human factors management program.

MAXIMUM USE OF RAIL MAY NOT BE FEASIBLE GIVEN EXISTING WASTE STORAGE AND TRANSPORTATION SYSTEM CONDITIONS

There is virtually unanimous agreement among nuclear waste transportation planners that rail is the preferred mode for repository shipments. The NAS report summarizes the major reasons that favor the "mostly rail" option:

- It reduces the total number of shipments to the federal repository by roughly a factor of five, which reduces the potential for routine radiological exposures, conventional traffic accidents, and severe accidents.
- Rail shipments have a greater physical separation from other vehicular traffic and reduced interactions with people along transportation routes, which also contributes to safety.
- Operational logistics are simpler and more efficient.
- There is a clear public preference for this option. [34]

An additional development favoring rail transport is the growing number of at-reactor SNF dry storage systems utilizing large dual-purpose (transportable storage) canisters, which would be shipped off-site in loaded transport packages weighing more than 110 short tons. This trend is expected to continue.

Transportation planners confront three questions: What is the maximum share of SNF shipments that can reasonably use rail transport to a repository? What would it cost to maximize the rail share of SNF shipments? What are the larger national implications, particularly in terms of impacts on highly populated areas, and compliance with new rail security regulations, of maximizing use of rail for repository shipments?

Studies for the now-terminated Yucca Mountain project identified a significant challenge to future plans for rail shipments to storage, disposal or waste processing facilities at regardless of location. The DOE 2008 assessment of reactor shipping capabilities determined that 44 commercial sites could ship SNF directly by rail; 7 sites could ship truck casks only; 21 commercial sites could ship rail casks by heavy haul truck (HHT) to the nearest rail line; and 15 of the 21 HHT sites could also ship rail casks by barge. [12]

The DOE "mostly rail" transportation option for Yucca Mountain assumed that about 93 percent of the commercial SNF destined for the repository could be shipped in rail casks. Nevada analyses, based on current shipping site capabilities, found that the maximum share of SNF shipped in rail casks, could be in the range of 65-75 percent. The 7 sites that would ship by truck, and the 21 sites that would require intermodal transport of rail casks, account for about 35 percent of commercial SNF that would be shipped to a repository. [11] The NRC licensing boards accepted Nevada's contention [NEV-NEPA-015] challenging the provision in DOE's license application that at least 90 percent of SNF would be shipped to Yucca Mountain annually by rail in TAD canisters. The NAS report discussed this issue at length, but did not specify the percentage of rail shipments that would constitute the "mostly rail" option it recommended. [34] There no is evidence that the 93 percent "mostly rail" option projected by DOE for Yucca Mountain would be any more feasible for shipments to other future disposal or storage facilities.

The cost of maximizing rail transportation of SNF is uncertain, regardless of the destination, because of uncertainty about the cost of upgrading infrastructure at and near the originating sites. In 2008, DOE estimated the future life cycle cost of the repository transportation program at $19.5 billion (in 2007$), about 24 percent of the projected future total cost of the waste management system over the next seven decades. The three largest transportation cost items were cask systems acquisition ($10.9 billion), operations execution ($3.1 billion), and construction of the now-terminated Nevada railroad ($2.7 billion). [22] The operations execution item presumably included the cost of using HHTs to move more than 2,100 rail casks from the 21 sites that lack rail connections. Two other potentially significant costs of maximizing rail use were not included: the cost of infrastructure upgrades necessary for use of HHTs at 21 sites, and the cost of upgrading short lines that connect 23 reactor sites with mainline railroads.

DOE plans did not provide a cost estimate for infrastructure upgrades necessary to use HHTs. These heavy haul trucks would be up to 220 feet (67.1 meters) in length, with gross vehicle weights of as much as 500,000 pounds (227,000 kilograms). The 21 HHT routes DOE proposed to use are a combination of local,

state, and federals highways, ranging in length from 2.1 miles to 150 miles, with a total distance of about 565 miles (915 kilometers). DOE provided no information on the likely cost of upgrading roads, bridges, traffic controls, and emergency response capabilities necessary to allow safe and secure HHT shipments from reactor sites to nearby railroads. [11] The DOE life cycle cost study estimates for the national transportation system did not include infrastructure upgrades. In its 2009 National Transportation Plan (NTP), DOE stated needed upgrades "within their gates" would be made by the utilities, and off-site track, highway and bridge upgrades would be made "by States, counties, and railroads."[20]

Nor did DOE plans provide a cost estimate regarding use of short lines (Class II or III railroads) to originate shipments from 23 reactor sites, 14 of which DOE classified as rail-capable. DOE assumed it could use at least 17 short line railroads, totaling more than 1,360 route miles, without assessing their financial status, infrastructure conditions, current traffic, or traffic capabilities. The Federal Railroad Administration (FRA) informed DOE of conditions that might require significant upgrading before such routes could be safely used for SNF shipments, including: class of track, rail weight, track restrictions, signals, hazardous materials registration and training, grade crossings, track conditions, sharp curves, tunnels and bridges. [11] In the NTP, DOE said it planned to "consult with" FRA about "short-line railroad track capability near reactors." [20]

RAIL SHIPMENTS MUST COMPLY WITH NEW SECURITY REGULATIONS

The "mostly rail" option for cross-country SNF shipments requires a safety and security trade-off that generally goes unrecognized in repository impact assessments: fewer opportunities, compared with truck shipments, to route rail shipments away from highly populated areas. "The mainline rail network was designed to link, not avoid, major urban areas, and therefore traverses suburban and urban population zones. Cross-country rail routes to Yucca Mountain must traverse suburban and urban areas to access carrier interchanges. There are no Federal (USDOT) routing regulations for Yucca Mountain shipments that require rail routes to avoid highly populated areas. The Interstate highway system is constructed to allow truck shipments to either access or bypass major urban areas, and bypasses typically affect both suburban and rural population zones. Cross-country interstate truck routes to Yucca Mountain can access route interchanges at a variety of urban, suburban, and rural locations. Federal (USDOT) routing regulations (HM-164) require Yucca Mountain shipments to use interstate routes generally, and to use interstate bypass routes, where available, to avoid highly populated areas." [30]

In late 2008, after publication of the Yucca Mountain SEIS, new Federal regulations were promulgated that would restrict rail shipments of certain hazardous materials, including SNF and HLW, through highly populated areas. The new regulations were intended to prevent "catastrophic release or explosion in proximity to densely populated areas, including urban areas and events or venues with large numbers of people in attendance. Also of major concern is the release or explosion of rail cars in close proximity to iconic buildings, landmarks, or environmentally significant areas." [19] "Although the number of rail shipments carrying explosives and radioactive materials is relatively low, a release of these materials could cause serious and devastating harm. If terrorists detonated certain explosives at critical points in the transportation cycle, they could cause significant loss of life and damage to infrastructure, and harm the national economy through the accompanying disruption to commerce. Likewise, if terrorists perpetrated an attack against a rail car transporting certain radioactive materials, they could endanger a significant number of people as well as disrupt the supply chain as a result of contamination. " [19]

Future cross-country rail shipments of SNF and HLW will have to comply with these new security regulations adopted by the Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) in conjunction with the FRA and the Department of Homeland Security's Transportation Security Administration (TSA). The new rules became effective December 26, 2008, after issuance of the DOE SEIS for Yucca Mountain. [19] As a result, the "representative" rail routes to Yucca Mountain would have to be reexamined, along with the larger assumptions about the "mostly rail" scenario, for future cross-country SNF and HLW shipments.

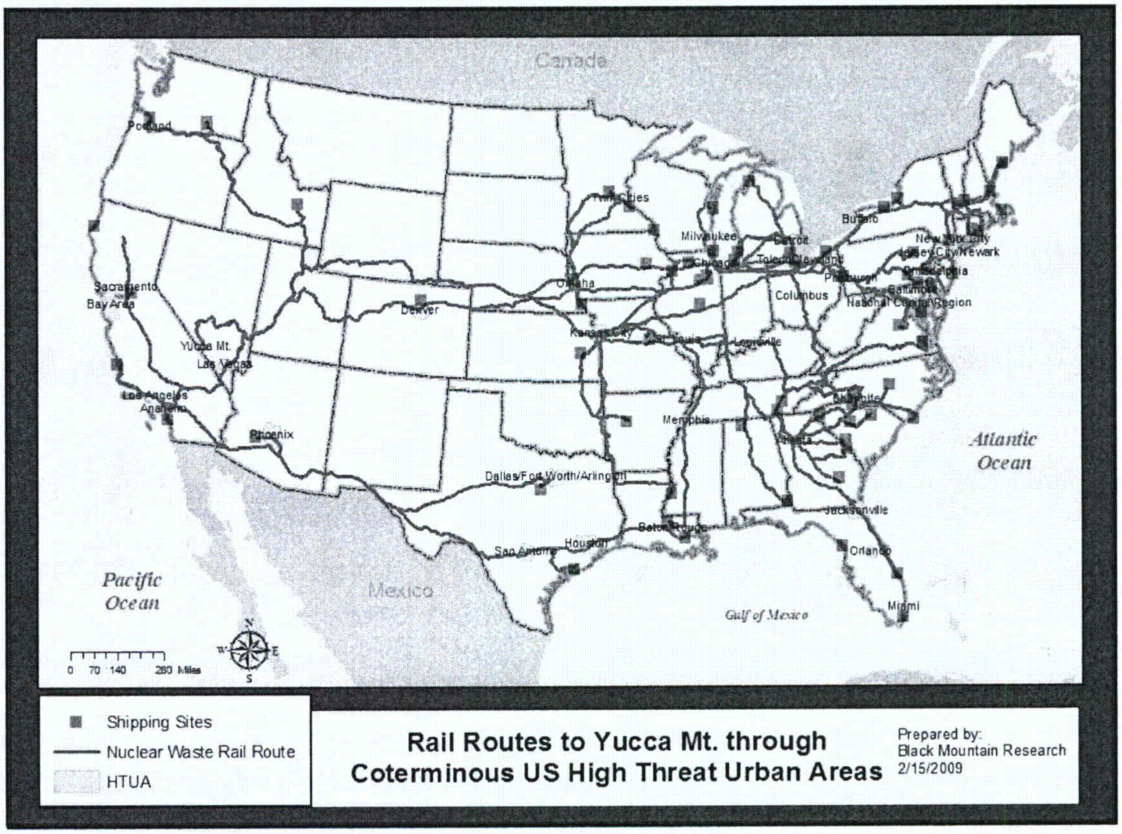

Fig.4. HTUAs Traversed by DOE Rail Routes to Caliente

By way of example, DOE's representative rail routes to Yucca Mountain would have traversed most of the "high threat urban areas" identified by TSA. The TSA Final Rule designated 46 high threat urban areas (HTUAs) in 28 states and the District of Columbia [49 CFR Part 1580, Appendix A]. Rail shipments of spent nuclear fuel and high-level radioactive waste through these HTUAs would be subject to new chain of custody and control and other procedures, such as designation of rail security coordinators and monitoring plans, established by the TSA Final Rule [49 CFR Part 1580, Appendix B]. [19]

Figure 4 shows the HTUAs traversed by DOE representative rail routes to Yucca Mountain via the now-terminated Caliente rail line. Thirty HTUAs in 25 states and the District of Columbia would have been traversed by at least one DOE rail route to Caliente. Several HTUAs, including Atlanta, Chicago, Kansas City, and St. Louis are traversed by two or more rail routes. Major carrier interchanges would have occurred in HTUAs, including Chicago, Kansas City, and St. Louis. Of DOE's 72 rail routes to Yucca Mountain, 63 would have traversed at least one HTUA, 49 would have traversed two or more HTUAs, and 28 would have traversed 3 or more HTUAs. [19]

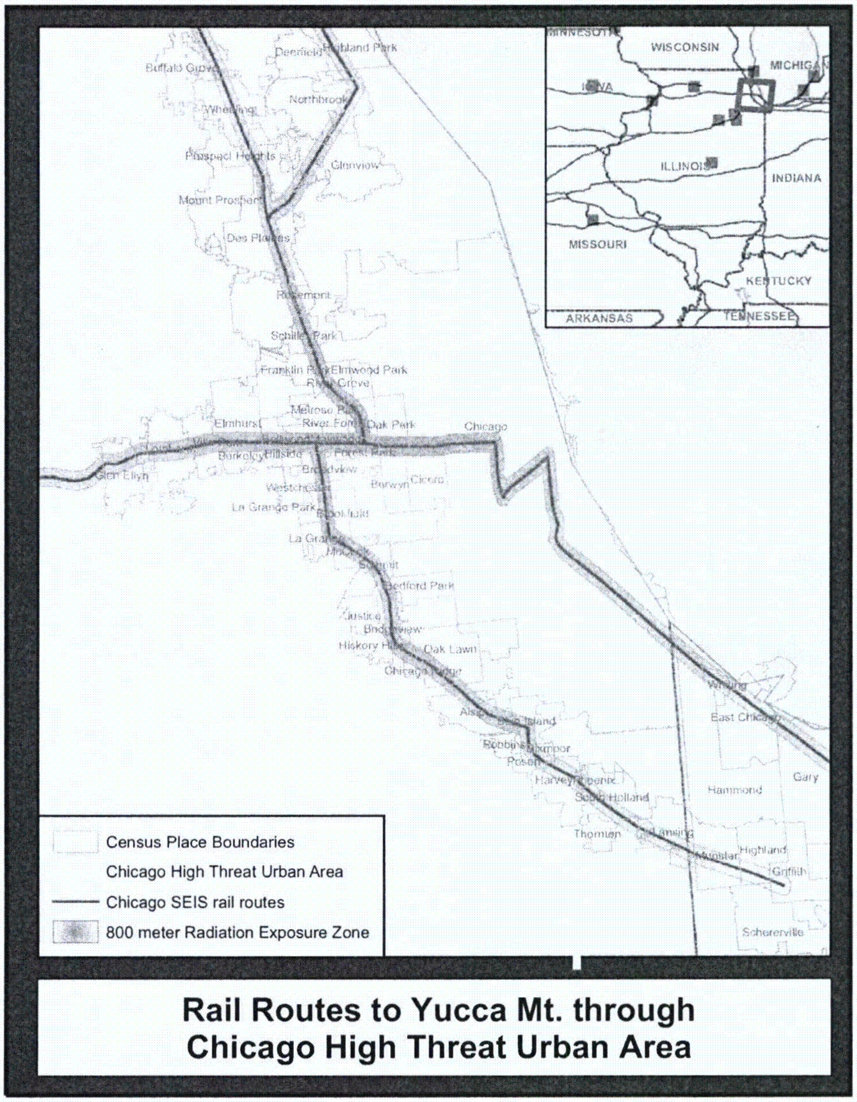

Fig.5. DOE Representative Rail Routes Through Chicago

Chicago illustrates the potentially heavy impact that cross-country shipments might have on HTUAs (Figure 5). About 25 percent of the DOE rail shipments to Yucca Mountain would have traveled through the Chicago area. According to the 2000 census, about 4.4 million people live in the HTUA in and around Chicago. About 585,000 people in the Chicago HTUA live within 800 meters (one-half mile) of the rail lines that would have been used for Yucca Mountain shipments. [19] Because of its role as major national rail hub, and because of its proximity to reactor sites in the Midwest, the Chicago area would likely be impacted by future SNF shipments to other destinations.

Salt Lake City represents another aspect of how the new TSA and PMSHA security regulations might impact selection of cross-country routes for SNF and HLW shipments. Salt Lake City is not a designated HTUA, but the rail routes through Salt Lake City (Figure 6) exhibit precisely the conditions of concern identified in the PHMSA routing regulations, which are designed to protect highly populated areas and iconic locations. If the 27 routing risk analysis factors [49 CFR Part 172, Appendix D] had been applied, DOE's representative routes through Salt Lake City might not have been permissible.

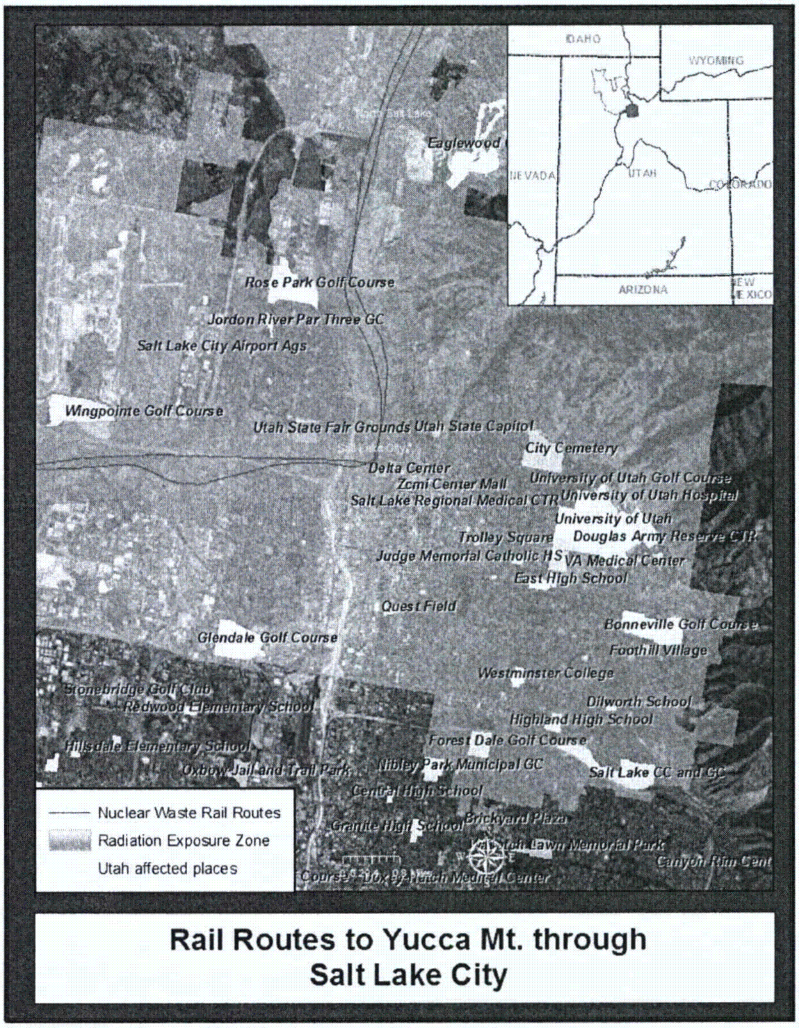

Fig.6. DOE Representative Rail Route Through Salt Lake City

The Union Pacific mainline through Salt Lake City would have carried about 87 percent of the rail shipments of SNF and HLW to Yucca Mountain. According to the 2000 census, about 660,000 people live in the affected area in and around Salt Lake City, and about 136,000 people in the Salt Lake City area live within 800 meters (one-half mile) of the rail route. The area has a large population of day-time business and government employees, visitors and tourists. Nearby iconic buildings and landmarks include Temple Square, the State Capitol, the State Fairgrounds, and the Delta Center/Energy Solutions Arena. The Temple Square area reportedly draws up to 5 million tourists and visitors per year. The 20,000-seat Energy Solutions Arena is located within 800 meters of the Union Pacific rail line. [19] Because of its role in east-west transportation, because of its location relative to DOE HLW storage sites in Washington and Idaho, and because of its proximity to the PFS storage site in Utah, the safety and security issues associated with SNF and HLW shipments through Salt Lake City might well be revisited.

One more uncertain aspect of the new TSA and PHMSA security regulations regards potential impacts on the nation's railroads. As many as 18 rail carriers transporting DOE SNF and HLW shipments to Yucca Mountain would have been required to prepare rail transportation route analyses under the PHMSA Final Rule. The Union Pacific Railroad would likely have been required to prepare route analyses involving at least 13 designated HTUAs and at least 23 other major urban areas. The Norfolk Southern Railroad and

CSX Transportation would each likely have been required to prepare rail transportation route analyses involving at least 10 designated HTUAs and at least 11 other major urban areas. The NS and CSXT route analyses would have required coordination with those prepared by the UP for routes involving carrier interchanges, especially the large number of route interchanges in Chicago, St. Louis, and Kansas City. Dozens of other interchanges with originating and connecting carriers would also have required coordination with the analyses prepared by CSXT, NS, and UP. [19]

In addition to the HTUAs designated by TSA, the DOE representative rail routes to Yucca Mountain would have traversed 39 urban areas with 2000 census population greater than 100,000, and 12 state capitol cities. [19] Application of all 27 PHMSA route analysis risk factors could have significantly increased the number (and complexity) of the route analyses required for DOE rail shipments to Yucca Mountain.

Future planning for SNF and HLW shipments to storage, disposal or waste processing facilities at other locations around the country would likely present comparable challenges to DOE, the nuclear utilities, the national rail system, and the rail carriers that make up the national system. Considering these uncertainties, it would be prudent to reexamine all aspects of the mostly rail scenario for repository shipments.

CONCLUSION

The Yucca Mountain repository project has now been terminated. Between 1983 and 2006, DOE expended $780 million (in 2007$) on transportation planning activities. [22] Between 1995 and 2008, DOE prepared three major environmental impact statements for the Yucca Mountain repository that together devoted more than 4,600 pages to transportation. [8, 12, 16]

But the Nevada component of the DOE transportation program was never able to overcome the reality that Yucca Mountain had the most difficult rail access, the most difficult interstate highway access, and most adverse overall transportation system impacts, of all the sites studied for the first repository. And even after the National Academy of Sciences provided a template for resolving public concerns about safety and security, the national component of the DOE program was unable to address the radiological risks of spent fuel transportation in a manner that could achieve stakeholder confidence. Transportation became the Achilles Heel of the DOE civilian nuclear waste repository program.

The principal lesson to be learned from the history of DOE's failed effort at Yucca Mountain is that transportation must be given equal consideration with storage and disposal, at every stage, in planning and implementing a successful national nuclear waste management program. Critical transportation requirements, such as mainline rail access and interstate highway access, must be addressed at the very beginning of site selection for storage and disposal facilities. The National Academy of Sciences recommendations on safety and security are waiting to be implemented in a national transportation plan. Risk assessment, risk management, and risk communication will be required over the entire life of operations - for storage, transportation, and disposal.

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Counties Potentially Affected by High-level Nuclear Waste Shipments to Yucca Mountain, NV

Fred Dilger PhD.
Black Mountain Research
4/12/2012

Background

On June 16, 2008 the Department of Energy (DOE) released the *Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (SEIS). The SEIS identified and evaluated what DOE called "representative routes" that "it could use" for rail and highway shipments of spent nuclear fuel and high-level radioactive waste to the now-terminated repository at Yucca Mountain, Nevada. DOE included state maps showing these representative routes and tables estimating the number of rail and highway shipments through each state in Appendix G of the SEIS.

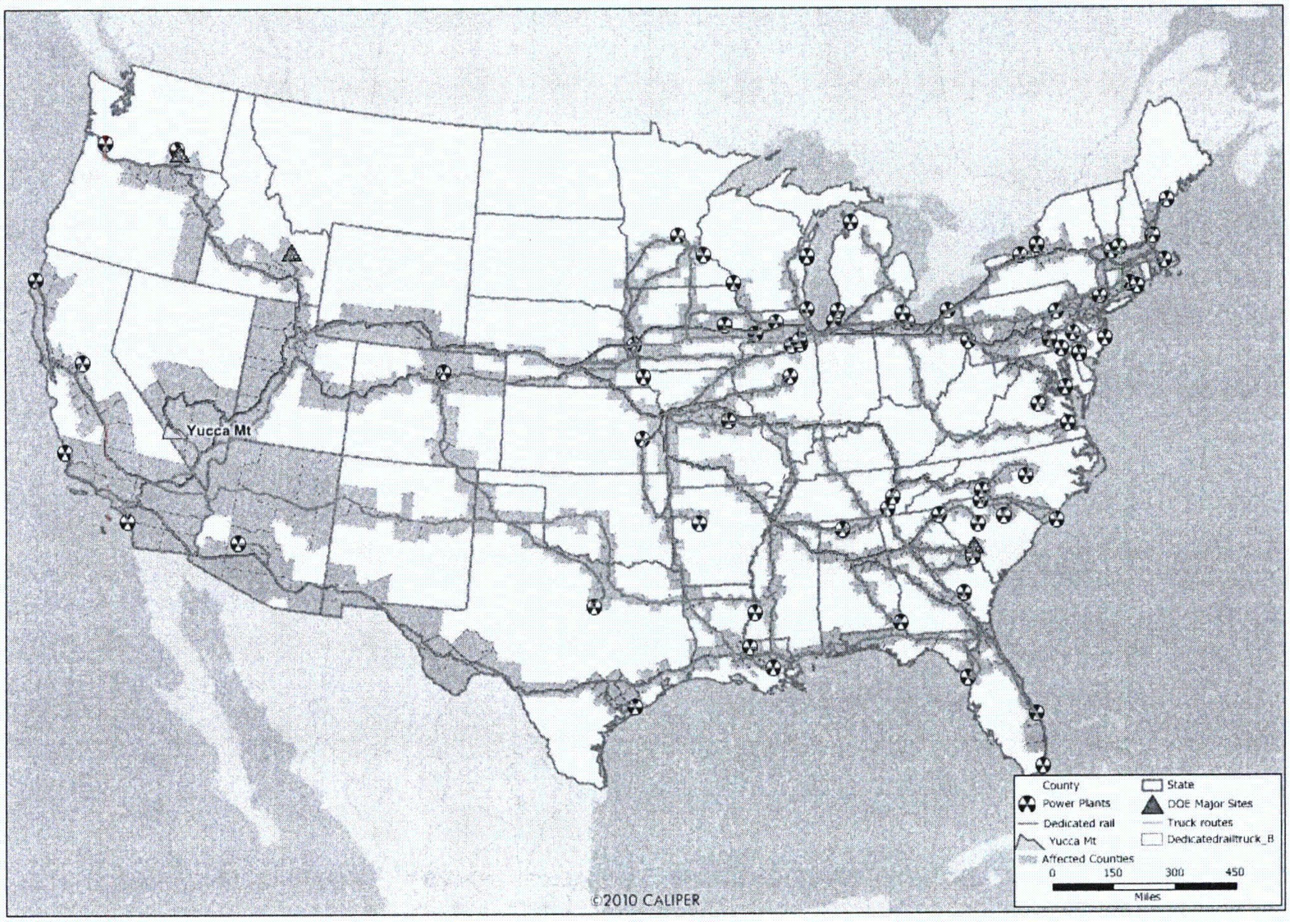
In order to assess the potential impacts on counties, the author of this report converted the representative routes into a format used by the Maptitude Geographic Information System software developed by Caliper Corporation. County data was downloaded from the Bureau of Transportation Statistics (BTS) National Transportation Atlas Database. http://www.bts.gov/publications/national_transportation_atlas_database/2010/

The routes were overlaid onto the counties and subdivisions that are traversed by SEIS routes. Those counties/subdivisions that would be traversed by the SEIS rail and/or highway routes are identified in this report. About 56% of the total US population live in counties that would be traversed by SEIS routes. The total 2010 Census population of the 955 counties that would be affected by these shipments is 177,055,299 persons. The 2005 estimate of population was 161,016,352 persons. The 2010 data is an 9.96 percent increase from the 2005 estimate.

This report was prepared for the State of Nevada Agency for Nuclear Projects.

Fred C. Dilger Ph.D.
4/12/2012
Blackmountainresearch@gmail.com

Cover photo: Convergence of rail routes on the west side of Chicago, Ill. Source: Nevada Agency for Nuclear Projects


Yucca Mt
County
State
Power Plants
DOE Major Sites
Dedicated rail
Truck routes
Yucca Mt
Dedicatedrailtruck_B
Affected Counties
0
150
300
450
Miles
©2010 CALIPER

Impacted Counties

State	Name	Population
Alabama		
	Autauga AL	54571
	Baldwin AL	182265
	Calhoun AL	118572
	Chambers AL	34215
	Chilton AL	43643
	Clay AL	13932
	Cleburne AL	14972
	Colbert AL	54428
	Dale AL	50251
	Elmore AL	79303
	Fayette AL	17241
	Henry AL	17302
	Houston AL	101547
	Jackson AL	53227
	Jefferson AL	658466
	Lamar AL	14564
	Lawrence AL	34339
	Limestone AL	82782
	Madison AL	334811
	Marion AL	30776
	Mobile AL	412992
	Montgomery AL	229363
	Morgan AL	119490
	Pike AL	32899
	Randolph AL	22913
	Shelby AL	195085
	St. Clair AL	83593
	Talladega AL	82291
	Walker AL	67023
Arizona		
	Apache AZ	71518
	Cochise AZ	131346

State	Name	Population
	Coconino AZ	134421
	Maricopa AZ	3817117
	Mohave AZ	200186
	Navajo AZ	107449
	Pima AZ	980263
	Pinal AZ	375770
	Yavapai AZ	211033
	Yuma AZ	195751
Arkansas		
	Benton AR	221339
	Craighead AR	96443
	Crawford AR	61948
	Crittenden AR	50902
	Franklin AR	18125
	Fulton AR	12245
	Greene AR	42090
	Johnson AR	25540
	Lawrence AR	17415
	Little River AR	13171
	Miller AR	43462
	Poinsett AR	24583
	Polk AR	20662
	Pope AR	61754
	Randolph AR	17969
	Sevier AR	17058
	Sharp AR	17264
California		
	Contra Costa CA	1049025
	Fresno CA	930450
	Humboldt CA	134623
	Imperial CA	174528
	Kern CA	839631
	Los Angeles CA	9818605
	Madera CA	150865
	Marin CA	252409
	Mendocino CA	87841

State	Name	Population
	Merced CA	255793
	Napa CA	136484
	Orange CA	3010232
	Riverside CA	2189641
	Sacramento CA	1418788
	San Bernardino CA	2035210
	San Diego CA	3095313
	San Joaquin CA	685306
	San Luis Obispo CA	269637
	Santa Barbara CA	423895
	Solano CA	413344
	Sonoma CA	483878
	Stanislaus CA	514453
	Trinity CA	13786
	Tulare CA	442179
	Ventura CA	823318
Colorado		
	Adams CO	441603
	Arapahoe CO	572003
	Boulder CO	294567
	Broomfield CO	55889
	Denver CO	600158
	Douglas CO	285465
	Eagle CO	52197
	El Paso CO	622263
	Garfield CO	56389
	Gilpin CO	5441
	Grand CO	14843
	Huerfano CO	6711
	Jefferson CO	534543
	Larimer CO	299630
	Las Animas CO	15507
	Mesa CO	146723
	Morgan CO	28159
	Pueblo CO	159063
	Sedgwick CO	2379

State	Name	Population
	Washington CO	4814
	Weld CO	252825
	Yuma CO	10043
Connecticut		
	Fairfield CT	916829
	Hartford CT	894014
	Middlesex CT	165676
	New Haven CT	862477
	New London CT	274055
	Tolland CT	152691
	Windham CT	118428
District of Columbia		
	District of Columbia DC	601723
Florida		
	Alachua FL	247336
	Baker FL	27115
	Bradford FL	28520
	Brevard FL	543376
	Broward FL	1748066
	Citrus FL	141236
	Clay FL	190865
	Columbia FL	67531
	Duval FL	864263
	Escambia FL	297619
	Flagler FL	95696
	Gadsden FL	46389
	Holmes FL	19927
	Indian River FL	138028
	Jackson FL	49746
	Jefferson FL	14761
	Leon FL	275487
	Levy FL	40801
	Madison FL	19224
	Marion FL	331298
	Martin FL	146318
	Nassau FL	73314

State	Name	Population
	Okaloosa FL	180822
	Palm Beach FL	1320134
	Santa Rosa FL	151372
	St. Johns FL	190039
	St. Lucie FL	277789
	Suwannee FL	41551
	Volusia FL	494593
	Walton FL	55043
	Washington FL	24896
Georgia		
	Appling GA	18236
	Bacon GA	11096
	Banks GA	18395
	Bartow GA	100157
	Ben Hill GA	17634
	Bibb GA	155547
	Bleckley GA	13063
	Burke GA	23316
	Butts GA	23655
	Carroll GA	110527
	Catoosa GA	63942
	Charlton GA	12171
	Clayton GA	259424
	Cobb GA	688078
	Coffee GA	42356
	Columbia GA	124053
	Crisp GA	23439
	Dade GA	16633
	DeKalb GA	691893
	Dodge GA	21796
	Dooly GA	14918
	Douglas GA	132403
	Fulton GA	920581
	Gordon GA	55186
	Greene GA	15994
	Gwinnett GA	805321

State	Name	Population
	Habersham GA	43041
	Hall GA	179684
	Haralson GA	28780
	Henry GA	203922
	Irwin GA	9538
	Jeff Davis GA	15068
	Jefferson GA	16930
	Jenkins GA	8340
	Jones GA	28669
	Macon GA	14740
	McDuffie GA	21875
	Meriwether GA	21992
	Monroe GA	26424
	Morgan GA	17868
	Newton GA	99958
	Pierce GA	18758
	Richmond GA	200549
	Rockdale GA	85215
	Stephens GA	26175
	Talbot GA	6865
	Taliaferro GA	1717
	Taylor GA	8906
	Telfair GA	16500
	Troup GA	67044
	Turner GA	8930
	Twiggs GA	9023
	Walton GA	83768
	Ware GA	36312
	Warren GA	5834
	Washington GA	21187
	Whitfield GA	102599
	Wilcox GA	9255
	Wilkinson GA	9563
Idaho		
	Ada ID	392365
	Bannock ID	82839

State	Name	Population
	Bingham ID	45607
	Blaine ID	21376
	Butte ID	2891
	Canyon ID	188923
	Elmore ID	27038
	Franklin ID	12786
	Gooding ID	15464
	Lincoln ID	5208
	Minidoka ID	20069
	Payette ID	22623
	Power ID	7817
	Washington ID	10198
Illinois		
	Alexander IL	8238
	Bureau IL	34978
	Carroll IL	15387
	Clinton IL	37762
	Cook IL	5194675
	DeKalb IL	105160
	DeWitt IL	16561
	DuPage IL	916924
	Edwards IL	6721
	Grundy IL	50063
	Hancock IL	19104
	Henderson IL	7331
	Henry IL	50486
	Jackson IL	60218
	Jefferson IL	38827
	Jo Daviess IL	22678
	Kane IL	515269
	Kendall IL	114736
	Knox IL	52919
	Lake IL	703462
	LaSalle IL	113924
	Lee IL	36031
	Livingston IL	38950

State	Name	Population
	Logan IL	30305
	Macon IL	110768
	Madison IL	269282
	Marion IL	39437
	Marshall IL	12640
	Morgan IL	35547
	Ogle IL	53497
	Peoria IL	186494
	Perry IL	22350
	Pike IL	16430
	Pulaski IL	6161
	Randolph IL	33476
	Rock Island IL	147546
	Sangamon IL	197465
	Scott IL	5355
	St. Clair IL	270056
	Union IL	17808
	Wabash IL	11947
	Warren IL	17707
	Washington IL	14716
	Wayne IL	16760
	Whiteside IL	58498
	Will IL	677560
Indiana		
	Crawford IN	10713
	DeKalb IN	42223
	Dubois IN	41889
	Elkhart IN	197559
	Floyd IN	74578
	Gibson IN	33503
	Harrison IN	39364
	Kosciusko IN	77358
	LaGrange IN	37128
	Lake IN	496005
	LaPorte IN	111467
	Marshall IN	47051

State	Name	Population
	Noble IN	47536
	Pike IN	12845
	Porter IN	164343
	St. Joseph IN	266931
	Steuben IN	34185
	Vanderburgh IN	179703
Iowa		
	Adair IA	7682
	Adams IA	4029
	Benton IA	26076
	Black Hawk IA	131090
	Boone IA	26306
	Buchanan IA	20958
	Butler IA	14867
	Carroll IA	20816
	Cass IA	13956
	Cedar IA	18499
	Cerro Gordo IA	44151
	Clarke IA	9286
	Clinton IA	49116
	Crawford IA	17096
	Dallas IA	66135
	Delaware IA	17764
	Des Moines IA	40325
	Dubuque IA	93653
	Franklin IA	10680
	Greene IA	9336
	Hamilton IA	15673
	Hardin IA	17534
	Harrison IA	14928
	Henry IA	20145
	Iowa IA	16355
	Jackson IA	19848
	Jasper IA	36842
	Jefferson IA	16843
	Johnson IA	130882

State	Name	Population
	Lee IA	35862
	Linn IA	211226
	Lucas IA	8898
	Lyon IA	11581
	Madison IA	15679
	Marshall IA	40648
	Mills IA	15059
	Monona IA	9243
	Monroe IA	7970
	Montgomery IA	10740
	O'Brien IA	14398
	Osceola IA	6462
	Plymouth IA	24986
	Polk IA	430640
	Pottawattamie IA	93158
	Poweshiek IA	18914
	Scott IA	165224
	Sioux IA	33704
	Story IA	89542
	Tama IA	17767
	Union IA	12534
	Wapello IA	35625
	Woodbury IA	102172
	Worth IA	7598
	Wright IA	13229
Kansas		
	Anderson KS	8102
	Bourbon KS	15173
	Cherokee KS	21603
	Coffey KS	8601
	Crawford KS	39134
	Douglas KS	110826
	Franklin KS	25992
	Jackson KS	13462
	Jefferson KS	19126
	Johnson KS	544179

State	Name	Population
	Leavenworth KS	76227
	Linn KS	9656
	Marshall KS	10117
	Miami KS	32787
	Montgomery KS	35471
	Pottawatomie KS	21604
	Shawnee KS	177934
	Washington KS	5799
	Wilson KS	9409
	Woodson KS	3309
	Wyandotte KS	157505
Kentucky		
	Anderson KY	21421
	Ballard KY	8249
	Boyle KY	28432
	Carlisle KY	5104
	Christian KY	73955
	Fulton KY	6813
	Henderson KY	46250
	Hickman KY	4902
	Hopkins KY	46920
	Jefferson KY	741096
	Lincoln KY	24742
	McCreary KY	18306
	Mercer KY	21331
	Pike KY	65024
	Pulaski KY	63063
	Shelby KY	42074
	Todd KY	12460
	Webster KY	13621
Louisiana		
	Allen LA	25764
	Ascension LA	107215
	Avoyelles LA	42073
	Beauregard LA	35654
	Bienville LA	14353

State	Name	Population
	Bossier LA	116979
	Caddo LA	254969
	Calcasieu LA	192768
	DeSoto LA	26656
	East Baton Rouge LA	440171
	East Feliciana LA	20267
	Evangeline LA	33984
	Iberville LA	33387
	Jefferson Davis LA	31594
	Lafayette LA	221578
	Lincoln LA	46735
	Livingston LA	128026
	Madison LA	12093
	Natchitoches LA	39566
	Ouachita LA	153720
	Pointe Coupee LA	22802
	Rapides LA	131613
	Richland LA	20725
	St. Charles LA	52780
	St. James LA	22102
	St. John the Baptist LA	45924
	St. Landry LA	83384
	St. Martin LA	52160
	St. Tammany LA	233740
	Tangipahoa LA	121097
	Webster LA	41207
	West Baton Rouge LA	23788
	West Feliciana LA	15625
Maine		
	Cumberland ME	281674
	Lincoln ME	34457
	Sagadahoc ME	35293
	York ME	197131
Maryland		
	Allegany MD	75087
	Charles MD	146551

State	Name	Population
	Frederick MD	233385
	Montgomery MD	971777
	Prince George's MD	863420
	Washington MD	147430
Masschusetts		
	Berkshire MA	131219
	Bristol MA	548285
	Essex MA	743159
	Franklin MA	71372
	Hampden MA	463490
	Hampshire MA	158080
	Middlesex MA	1503085
	Norfolk MA	670850
	Plymouth MA	494919
	Suffolk MA	722023
	Worcester MA	798552
Michigan		
	Arenac MI	15899
	Bay MI	107771
	Berrien MI	156813
	Calhoun MI	136146
	Cass MI	52293
	Crawford MI	14074
	Eaton MI	107759
	Genesee MI	425790
	Ingham MI	280895
	Kalamazoo MI	250331
	Monroe MI	152021
	Oakland MI	1202362
	Ogemaw MI	21699
	Otsego MI	24164
	Roscommon MI	24449
	Saginaw MI	200169
	Shiawassee MI	70648
	St. Joseph MI	61295
	Van Buren MI	76258

State	Name	Population
	Wayne MI	1820584
Minnesota		
	Blue Earth MN	64013
	Chippewa MN	12441
	Cottonwood MN	11687
	Dakota MN	398552
	Freeborn MN	31255
	Goodhue MN	46183
	Hennepin MN	1152425
	Jackson MN	10266
	Kandiyohi MN	42239
	Le Sueur MN	27703
	Lincoln MN	5896
	Lyon MN	25857
	Meeker MN	23300
	Nobles MN	21378
	Pipestone MN	9596
	Ramsey MN	508640
	Rice MN	64142
	Rock MN	9687
	Scott MN	129928
	Steele MN	36576
	Washington MN	238136
	Watonwan MN	11211
	Wright MN	124700
	Yellow Medicine MN	10438
Mississippi		
	Alcorn MS	37057
	Benton MS	8729
	Copiah MS	29449
	DeSoto MS	161252
	Hancock MS	43929
	Harrison MS	187105
	Hinds MS	245285
	Holmes MS	19198
	Jackson MS	139668

State	Name	Population
	Lee MS	82910
	Leflore MS	32317
	Lincoln MS	34869
	Madison MS	95203
	Marshall MS	37144
	Monroe MS	36989
	Panola MS	34707
	Pike MS	40404
	Pontotoc MS	29957
	Quitman MS	8223
	Tallahatchie MS	15378
	Tate MS	28886
	Tishomingo MS	19593
	Tunica MS	10778
	Union MS	27134
	Warren MS	48773
	Yazoo MS	28065
Missouri		
	Adair MO	25607
	Audrain MO	25529
	Barton MO	12402
	Bates MO	17049
	Boone MO	162642
	Callaway MO	44332
	Carroll MO	9295
	Cass MO	99478
	Chariton MO	7831
	Clark MO	7139
	Clay MO	221939
	Cole MO	75990
	Cooper MO	17601
	Dade MO	7883
	Franklin MO	101492
	Gasconade MO	15222
	Greene MO	275174
	Howard MO	10144

State	Name	Population
	Howell MO	40400
	Jackson MO	674158
	Jasper MO	117404
	Johnson MO	52595
	Knox MO	4131
	Lafayette MO	33381
	Linn MO	12761
	Macon MO	15566
	Marion MO	28781
	McDonald MO	23083
	Moniteau MO	15607
	Monroe MO	8840
	Montgomery MO	12236
	Morgan MO	20565
	Newton MO	58114
	Oregon MO	10881
	Osage MO	13878
	Pettis MO	42201
	Ralls MO	10167
	Randolph MO	25414
	Ray MO	23494
	Saline MO	23370
	Scotland MO	4843
	St. Charles MO	360485
	St. Louis City MO	319294
	St. Louis MO	998954
	Texas MO	26008
	Vernon MO	21159
	Warren MO	32513
	Webster MO	36202
	Wright MO	18815
Nebraska		
	Adams NE	31364
	Buffalo NE	46102
	Burt NE	6858
	Cass NE	25241

State	Name	Population
	Cheyenne NE	9998
	Clay NE	6542
	Colfax NE	10515
	Dakota NE	21006
	Dawson NE	24326
	Deuel NE	1941
	Dodge NE	36691
	Douglas NE	517110
	Dundy NE	2008
	Fillmore NE	5890
	Furnas NE	4959
	Hall NE	58607
	Hamilton NE	9124
	Harlan NE	3423
	Hitchcock NE	2908
	Jefferson NE	7547
	Kearney NE	6489
	Keith NE	8368
	Kimball NE	3821
	Lancaster NE	285407
	Lincoln NE	36288
	Merrick NE	7845
	Nuckolls NE	4500
	Otoe NE	15740
	Phelps NE	9188
	Platte NE	32237
	Red Willow NE	11055
	Saline NE	14200
	Sarpy NE	158840
	Saunders NE	20780
	Seward NE	16750
	Thayer NE	5228
	Thurston NE	6940
	Washington NE	20234
	York NE	13665
Nevada		

State	Name	Population
	Clark NV	1951269
	Esmeralda NV	783
	Lincoln NV	5345
	Nye NV	43946
New Hampshire		
	Rockingham NH	295223
	Strafford NH	123143
New Jersey		
	Bergen NJ	905116
	Camden NJ	513657
	Essex NJ	783969
	Gloucester NJ	288288
	Hunterdon NJ	128349
	Middlesex NJ	809858
	Monmouth NJ	630380
	Morris NJ	492276
	Ocean NJ	576567
	Passaic NJ	501226
	Salem NJ	66083
	Somerset NJ	323444
	Sussex NJ	149265
	Union NJ	536499
	Warren NJ	108692
New Mexico		
	Bernalillo NM	662564
	Cibola NM	27213
	Doña Ana NM	209233
	Grant NM	29514
	Guadalupe NM	4687
	Hidalgo NM	4894
	Luna NM	25095
	McKinley NM	71492
	Quay NM	9041
	Santa Fe NM	144170
	Torrance NM	16383
	Union NM	4549

State	Name	Population
New York		
	Albany NY	304204
	Cayuga NY	80026
	Chautauqua NY	134905
	Columbia NY	63096
	Dutchess NY	297488
	Erie NY	919040
	Genesee NY	60079
	Herkimer NY	64519
	Madison NY	73442
	Monroe NY	744344
	Montgomery NY	50219
	Oneida NY	234878
	Onondaga NY	467026
	Orange NY	372813
	Oswego NY	122109
	Putnam NY	99710
	Rensselaer NY	159429
	Rockland NY	311687
	Saratoga NY	219607
	Schenectady NY	154727
	Wayne NY	93772
	Westchester NY	949113
North Carolina		
	Alamance NC	151131
	Anson NC	26948
	Bladen NC	35190
	Brunswick NC	107431
	Buncombe NC	238318
	Burke NC	90912
	Cabarrus NC	178011
	Catawba NC	154358
	Columbus NC	58098
	Davidson NC	162878
	Durham NC	267587
	Gaston NC	206086

State	Name	Population
	Guilford NC	488406
	Iredell NC	159437
	Lincoln NC	78265
	Madison NC	20764
	McDowell NC	44996
	Mecklenburg NC	919628
	Orange NC	133801
	Randolph NC	141752
	Richmond NC	46639
	Robeson NC	134168
	Rowan NC	138428
	Scotland NC	36157
	Union NC	201292
	Wake NC	900993
Ohio		
	Ashland OH	53139
	Ashtabula OH	101497
	Columbiana OH	107841
	Cuyahoga OH	1280122
	Defiance OH	39037
	Delaware OH	174214
	Erie OH	77079
	Franklin OH	1163414
	Fulton OH	42698
	Hancock OH	74782
	Henry OH	28215
	Huron OH	59626
	Lake OH	230041
	Lawrence OH	62450
	Lorain OH	301356
	Lucas OH	441815
	Mahoning OH	238823
	Marion OH	66501
	Medina OH	172332
	Ottawa OH	41428
	Pickaway OH	55698

State	Name	Population
	Pike OH	28709
	Portage OH	161419
	Ross OH	78064
	Sandusky OH	60944
	Scioto OH	79499
	Seneca OH	56745
	Stark OH	375586
	Summit OH	541781
	Trumbull OH	210312
	Wayne OH	114520
	Williams OH	37642
	Wood OH	125488
	Wyandot OH	22615
Oklahoma		
	Adair OK	22683
	Beckham OK	22119
	Caddo OK	29600
	Canadian OK	115541
	Carter OK	47557
	Cleveland OK	255755
	Custer OK	27469
	Garvin OK	27576
	Le Flore OK	50384
	Love OK	9423
	McClain OK	34506
	Murray OK	13488
	Muskogee OK	70990
	Nowata OK	10536
	Oklahoma OK	718633
	Rogers OK	86905
	Sequoyah OK	42391
	Wagoner OK	73085
	Washita OK	11629
Oregon		
	Baker OR	16134
	Columbia OR	49351

State	Name	Population
	Gilliam OR	1871
	Hood River OR	22346
	Malheur OR	31313
	Morrow OR	11173
	Multnomah OR	735334
	Sherman OR	1765
	Umatilla OR	75889
	Union OR	25748
	Wasco OR	25213
Pennsylvania		
	Allegheny PA	1223348
	Beaver PA	170539
	Bedford PA	49762
	Berks PA	411442
	Blair PA	127089
	Butler PA	183862
	Cambria PA	143679
	Carbon PA	65249
	Centre PA	153990
	Chester PA	498886
	Clarion PA	39988
	Clearfield PA	81642
	Clinton PA	39238
	Columbia PA	67295
	Cumberland PA	235406
	Dauphin PA	268100
	Erie PA	280566
	Fayette PA	136606
	Huntingdon PA	45913
	Indiana PA	88880
	Jefferson PA	45200
	Juniata PA	24636
	Lackawanna PA	214437
	Lawrence PA	91108
	Lebanon PA	133568
	Lehigh PA	349497

State	Name	Population
	Luzerne PA	320918
	Mercer PA	116638
	Mifflin PA	46682
	Monroe PA	169842
	Montgomery PA	799874
	Montour PA	18267
	Northampton PA	297735
	Northumberland PA	94528
	Perry PA	45969
	Philadelphia PA	1526006
	Pike PA	57369
	Somerset PA	77742
	Union PA	44947
	Venango PA	54984
	Wayne PA	52822
	Westmoreland PA	365169
	York PA	434972
South Carolina		
	Aiken SC	160099
	Barnwell SC	22621
	Chesterfield SC	46734
	Darlington SC	68681
	Fairfield SC	23956
	Greenville SC	451225
	Lancaster SC	76652
	Marlboro SC	28933
	Oconee SC	74273
	Pickens SC	119224
	Spartanburg SC	284307
	Union SC	28961
	York SC	226073
South Dakota		
	Minnehaha SD	169468
Tennessee		
	Anderson TN	75129
	Bedford TN	45058

State	Name	Population
	Cocke TN	35662
	Coffee TN	52796
	Davidson TN	626681
	Dyer TN	38335
	Fayette TN	38413
	Franklin TN	41052
	Hamblen TN	62544
	Hamilton TN	336463
	Hardeman TN	27253
	Jefferson TN	51407
	Knox TN	432226
	Lauderdale TN	27815
	Marion TN	28237
	McNairy TN	26075
	Montgomery TN	172331
	Morgan TN	21987
	Obion TN	31807
	Rhea TN	31809
	Roane TN	54181
	Robertson TN	66283
	Rutherford TN	262604
	Scott TN	22228
	Shelby TN	927644
	Tipton TN	61081
Texas		
	Armstrong TX	1901
	Bexar TX	1714773
	Bowie TX	92565
	Brewster TX	9232
	Caldwell TX	38066
	Carson TX	6182
	Cass TX	30464
	Childress TX	7041
	Clay TX	10752
	Colorado TX	20874
	Cooke TX	38437

State	Name	Population
	Culberson TX	2398
	Dallam TX	6703
	Dallas TX	2368139
	Deaf Smith TX	19372
	Denton TX	662614
	DeWitt TX	20097
	Donley TX	3677
	El Paso TX	800647
	Fayette TX	24554
	Fort Bend TX	585375
	Gonzales TX	19807
	Gray TX	22535
	Gregg TX	121730
	Guadalupe TX	131533
	Hall TX	3353
	Hardeman TX	4139
	Harris TX	4092459
	Harrison TX	65631
	Hartley TX	6062
	Hood TX	51182
	Hudspeth TX	3476
	Jackson TX	14075
	Jeff Davis TX	2342
	Jefferson TX	252273
	Johnson TX	150934
	Kaufman TX	103350
	Kinney TX	3598
	Lavaca TX	19263
	Liberty TX	75643
	Matagorda TX	36702
	Medina TX	46006
	Montague TX	19719
	Newton TX	14445
	Oldham TX	2052
	Orange TX	81837
	Parker TX	116927

State	Name	Population
	Pecos TX	15507
	Potter TX	121073
	Presidio TX	7818
	Smith TX	209714
	Somervell TX	8490
	Tarrant TX	1809034
	Terrell TX	984
	Uvalde TX	26405
	Val Verde TX	48879
	Van Zandt TX	52579
	Victoria TX	86793
	Wharton TX	41280
	Wheeler TX	5410
	Wichita TX	131500
	Wilbarger TX	13535
	Wise TX	59127
Utah		
	Beaver UT	6629
	Box Elder UT	49975
	Cache UT	112656
	Carbon UT	21403
	Davis UT	306479
	Emery UT	10976
	Grand UT	9225
	Iron UT	46163
	Juab UT	10246
	Millard UT	12503
	Morgan UT	9469
	Salt Lake UT	1029655
	Summit UT	36324
	Tooele UT	58218
	Utah UT	516564
	Wasatch UT	23530
	Washington UT	138115
	Weber UT	231236
Vermont		

State	Name	Population
	Bennington VT	37125
	Windham VT	44513
Virginia		
	Alexandria VA	139966
	Appomattox VA	14973
	Arlington VA	207627
	Bedford City VA	6222
	Bedford VA	68676
	Botetourt VA	33148
	Campbell VA	54842
	Caroline VA	28545
	Charlotte VA	12586
	Dinwiddie VA	28001
	Fairfax VA	1081726
	Fredericksburg VA	24286
	Giles VA	17286
	Hanover VA	99863
	Louisa VA	33153
	Lynchburg VA	75568
	Montgomery VA	94392
	Nottoway VA	15853
	Petersburg VA	32420
	Prince Edward VA	23368
	Prince George VA	35725
	Prince William VA	402002
	Pulaski VA	34872
	Roanoke City VA	97032
	Roanoke VA	92376
	Salem VA	24802
	Southampton VA	18570
	Spotsylvania VA	122397
	Stafford VA	128961
	Sussex VA	12087
	Tazewell VA	45078
Washington		
	Benton WA	175177

State	Name	Population
	Walla Walla WA	58781
West Virginia		
	Berkeley WV	104169
	Hampshire WV	23964
	Jefferson WV	53498
	McDowell WV	22113
	Mercer WV	62264
	Mineral WV	28212
	Mingo WV	26839
	Morgan WV	17541
	Wayne WV	42481
Wisconsin		
	Brown WI	248007
	Crawford WI	16644
	Dodge WI	88759
	Fond du Lac WI	101633
	Grant WI	51208
	Kenosha WI	166426
	Outagamie WI	176695
	Racine WI	195408
	Vernon WI	29773
	Walworth WI	102228
	Washington WI	131887
	Waukesha WI	389891
	Winnebago WI	166994
Wyoming		
	Albany WY	36299
	Carbon WY	15885
	Laramie WY	91738
	Sweetwater WY	43806
	Uinta WY	21118

FULL-SCALE CASK TESTING AND PUBLIC ACCEPTANCE OF SPENT NUCLEAR FUEL SHIPMENTS-12254

Fred Dilger, PhD (fcd5@cox.net)
Black Mountain Research
Henderson, NV 81012

Robert J. Halstead (bearhalstead@aol.com)
State of Nevada Agency for Nuclear Projects
Carson City, NV 80906

James D. Ballard, PhD (ballard@csun.edu)
Department of Sociology, California State University, Northridge
Northridge, CA 91330

ABSTRACT

Full-scale physical testing of spent fuel shipping casks has been proposed by the National Academy of Sciences (NAS) 2006 report on spent nuclear fuel transportation, and by the Presidential Blue Ribbon Commission (BRC) on America's Nuclear Future 2011 draft report. The U.S. Nuclear Regulatory Commission (NRC) in 2005 proposed full-scale testing of a rail cask, and considered "regulatory limits" testing of both rail and truck casks (SRM SECY-05-0051). The recent U.S. Department of Energy (DOE) cancellation of the Yucca Mountain project, NRC evaluation of extended spent fuel storage (possibly beyond 60-120 years) before transportation, nuclear industry adoption of very large dual-purpose canisters for spent fuel storage and transport, and the deliberations of the BRC, will fundamentally change assumptions about the future spent fuel transportation system, and reopen the debate over shipping cask performance in severe accidents and acts of sabotage. This paper examines possible approaches to full-scale testing for enhancing public confidence in risk analyses, perception of risk, and acceptance of spent fuel shipments.

The paper reviews the literature on public perception of spent nuclear fuel and nuclear waste transportation risks. We review and summarize opinion surveys sponsored by the State of Nevada over the past two decades, which show consistent patterns of concern among Nevada residents about health and safety impacts, and socioeconomic impacts such as reduced property values along likely transportation routes. We also review and summarize the large body of public opinion survey research on transportation concerns at regional and national levels.

The paper reviews three past cask testing programs, the way in which these cask testing program results were portrayed in films and videos, and examines public and official responses to these three programs: the 1970s impact and fire testing of spent fuel truck casks at Sandia National Laboratories, the 1980s regulatory and demonstration testing of MAGNOX fuel flasks in the United Kingdom (the CEGB "Operation Smash Hit" tests), and the 1980s regulatory drop and fire tests conducted on the TRUPACT II containers used for transuranic waste shipments to the Waste Isolation Pilot Plant in New Mexico.

The primary focus of the paper is a detailed evaluation of the cask testing programs proposed by the NRC in its decision implementing staff recommendations based on the Package Performance Study, and by the State of Nevada recommendations based on previous work by Audin, Resnikoff, Dilger, Halstead, and Greiner. The NRC approach is based on demonstration impact testing (locomotive strike) of a large rail cask, either the TAD cask proposed by DOE for spent fuel shipments to Yucca Mountain, or a similar currently licensed dual-purpose cask. The NRC program might also be expanded to include fire testing of a legal-weight truck cask. The Nevada approach calls for a minimum of two tests: regulatory testing (impact, fire, puncture, immersion) of a rail cask, and extra-regulatory fire testing of a legal-weight truck cask, based on the cask performance modeling work by Greiner.

The paper concludes with a discussion of key procedural elements – test costs and funding sources, development of testing protocols, selection of testing facilities, and test peer review – and various methods of communicating the test results to a broad range of stakeholder audiences.

INTRODUCTION

The paper reviews the literature on public perception of spent nuclear fuel and nuclear waste transportation risks. We review and summarize opinion surveys sponsored by the State of Nevada over the past two decades, which show consistent patterns of concern among Nevada residents about health and safety impacts, and socioeconomic impacts such as reduced property values along likely transportation routes. We also review and summarize the large body of public opinion survey research on transportation concerns at regional and national levels, including research conducted by H. Jenkins-Smith and P. Slovic.

Under the Nuclear Waste Policy Act (NWPA), shipments of spent nuclear fuel to a repository by the Department of Energy (DOE) would be largely self-regulated by the DOE(1). However, the NWPA requires that the packages used to transport the spent nuclear fuel to NWPA facilities would have to be licensed by the NRC. Prior to the closure of the Yucca Mountain Project, the DOE did not express an intention to independently conduct full-scale testing of the casks that would be used for shipments of spent nuclear fuel to Yucca Mountain. The Final Environmental Impact Statement (FEIS) for Yucca Mountain, strongly suggests that the DOE did not intend to perform such testing: "The NWPA [Nuclear Waste Policy Act] requires DOE to use casks certified by the NRC when transporting spent nuclear fuel and high-level radioactive waste to a repository. A cask's ability to survive the tests prescribed by the regulations (10 CFR Part 71) can be demonstrated either through component analysis or through scale-model and full-scale testing to demonstrate and confirm the performance of the casks. The NRC would decide which level of physical testing or analysis was appropriate for each cask design submitted (2)."

Full scale cask testing is not a requirement for NRC certification for spent fuel shipping casks. Of the currently licensed shipping casks, none have been tested full-scale. In place of full-scale testing, the NRC relies on scale model testing and computer simulation. These techniques are used to assess the ability of the cask design to meet regulatory standards. The regulatory standards require casks demonstrate the ability to meet NRC requirements as they relate to containment of material, radiation control, and criticality control under normal conditions (3 described in 10CFR 71.71) and hypothetical

accident conditions (described in 10CFR 71.73). The testing for accident conditions require that the conditions be sequentially applied to the transportation package. This is done to ensure damage to the package is cumulative. The accident conditions are described in 10CFR 71.73. These conditions must be applied in sequence:

Free Drop: A 30-foot (9 meter) free drop of the cask onto a flat, unyielding, horizontal surface. The cask must strike the surface in a position for which maximum damage is expected.

Puncture: A 40-inch (1 meter) free drop of the cask onto a vertical steel bar, six inches (15 centimeters) in diameter, mounted on an unyielding, horizontal surface.
The cask must strike the steel bar in a position for which maximum damage is expected.

Thermal: Exposure of the cask in a fully-engulfing, hydrocarbon fuel/air fire with an average flame temperature of at least 1475 °F (800 °C) for a period of 30 minutes. The regulations specify the physical conditions of the fire, including the dimensions of the hydrocarbon fuel source around the cask and the position of the
cask relative to the surface of the fuel source.

Immersion: Immersion under at least 3 feet (0.9 meters) of water. 10CFR 71.61 requires a deep immersion test for SNF packages with activity greater than 1 million Curies (37 PBq). The regulations require that the package's containment system withstand external water pressure of 290 psi (2 MPa) for a period of not less than one hour without collapse, buckling, or in-leakage of water.

As of 2011, seven truck and nine rail cask designs have been certified for use in the United States(4). The primary method for determining cask performance has been through the use of computer modeling. In some cases, half scale models were used to simulate compliance with the drop (impact) tests. Four other casks used 1/3 or 1/4 scale models to simulate the drop test portion of the regulation.

PUBLIC CONCERNS ABOUT TRANSPORTATION SAFETY

In the aftermath of the March 2011 Fukushima Daiichi nuclear disaster in Japan several implications for SNF transportation in the United States were noted by observers. The state of Nevada's Nuclear Waste Project Office initiated a meta-analysis of public opinion and perception research on the transportation of spent nuclear fuel (SNF) and other high level radioactive wastes.

Risk perception research relative to nuclear waste has a long history in the social sciences. One of the first examples was produced by three of the pioneers of risk perception research (5). This research used a combination of national level and localized Nevada public opinion polls to focus on risk perceptions of nuclear waste. While transportation was not a primary focus of these particular studies, they were the first national level risk studies related to nuclear wastes and the research findings, format and methodology informed many of the risk perception work that followed.

Near the same timeframe as the 1992 study, a significant text on risk perception research was released (6). This text's focus on citizen's perceptions was a change from past practice wherein technical experts were the primary focus of risk perception work. Rather, these researchers looked at the public that would be exposed to the risk at the fixed sites, proposed sites like Yucca Mountain and the transport routes between these facilities. The anthology of public perception research herein remains the single most comprehensive examination of public perceptions in nuclear waste policy issues. Again the issue of transportation was not the singular focus of this collection of research, rather the text focused on the multiplicity of public risk perception issues facing any program that would ship these radioactive materials.

Risk perceptions are hotly debated when radioactive materials are concerned. Local communities have addressed the issue of transport risk perception as the result of significant shipment campaigns that may affect their jurisdictions, albeit with opinion leaders and not necessarily focused on the general public. For example, Binney, Mason, and Martsolf (7) conducted a research project "to examine attitudes among community leaders to the transport of radioactive waste through local communities. Data were gathered from a survey of 28 community leaders who reside beside a planned route in Oregon along which nuclear waste from Hanford, Washington." These shipments "would be trucked to a disposal site under consideration in New Mexico" (WIPP). "Findings reveal that problems of credibility regarding the U.S. Department of Energy as a message source and public distrust of the agency's performance are grounded in the risk communication of waste transport. It is concluded that a full alliance between the agency and local citizens could be an initial step in restoring lost credibility and trust on transport issues" (p. 283).

Such studies informed research projects on transportation risk perceptions (8). As part of the University of Maryland Omnibus Survey project, the authors investigated the perceived risks of transportation of highly radioactive nuclear wastes. This survey research found four significant transportation related public perception risks:

- Approximately 2/3 of the respondents felt that property values would be lowered as a result of transportation.
- Approximately 70% of respondents expressed concern for terrorist attacks against shipments.
- The majority of respondents were unwilling to live near SNF transportation routes.
- The majority of respondents always felt that the transportation of SNF was riskier than the transportation of industrial chemicals and volatiles like gasoline.

In summary, these publicly expressed fears of transportation issues– terrorism, loss of property values, unwillingness to live near transportation routes and perception of the risks for SNF all point to the need for policy makers to address the public's concerns in their transportation planning.

Nevada has addressed these concerns in a series of state sponsored public opinion surveys (Nevada 2002, 2003, 2004, 2006, 2010) (9). The most recent public opinion poll summarized the risk perception concerns of the public:

"Respondents were asked to rank risks potentially associated with the Yucca Mountain project as being little or no risk, slight risk, moderate risk, or high risk. Table I summarizes results from these questions".

Table I Ranking of risks people associate with the Yucca Mountain project and related activities

		High/Moderate Risk	Low/No Risk
1	Rail and truck shipments of radioactive waste	75.8%	23.4%
2	Radioactive contamination of the environment	69.8%	27.4%
3	Losses to property values for homes and businesses near shipping routes	69.4%	29.6%
4	Adverse health effects	64.2%	43%
5	Damage to Nevada's reputation as a place to live or visit	56.8%	34.6%
6	Loss of public revenues due to reduced numbers of visitors/tourists	54.0%	45.4%
7	Economic damage to Nevada's major industries	51.8%	45.6%

"Risks associated with the transport of spent nuclear fuel and high-level radioactive waste by rail and highway ranked first, with almost seventy-six percent (75.8%) of respondents considering such risks to be of moderate to high risk. Of those, almost 59% considered waste transportation to be in the high risk category.

Radioactive contamination of the air and water ranked second (almost 70%), followed by the risk of loss to property values along nuclear waste shipping routes (over 69%), the risk of adverse health effects from the repository itself or from transportation operations (over 64%), the risk of damage to Nevada's reputation as a place to live or visit (almost 57%), the risk that public revenues would be lost due to decreased numbers of visitors and tourists (54%); and the risk of serious economic damage to Nevada's major tourism and gaming industries (almost 52%)."

The Nevada surveys also document the range of perceptions and risks the public may consider in their thinking about the potential of any shipment campaign. These were categorized as:

- Risks associated with transportation (documented in table 2 above).
- The public's perceptions of deal making v. continued opposition to shipments.
- Actions that states and local governments could undertake to oppose federal shipment programs.
- Impacts on local economies, industries, tourist choices and relevant issues for many local governments.
- Trust in DOE and government regarding the highly radioactive shipments and the repository siting process.

The research on transportation risks and public perceptions is clear, the public does not trust government agencies and in particular the DOE. The public fears economic, social, and stigma related impacts from shipments and these fears will not be easily overcome given the mistrust of the DOE.

CASK TESTING PROGRAMS

Although none of the spent fuel shipping casks currently in service in the US have been tested full-scale, there have been several full-scale cask -testing programs. Each of these programs offers insight into how a cask testing program can proceed. In 1977, three obsolete spent fuel shipping casks were subjected to crash and fire tests at Sandia National Laboratories (SNL). An obsolete spent fuel shipping cask was subjected to a sabotage test at SNL in 1981.

The State of Nevada sponsored contractor studies of the Sandia cask tests. Other U.S. Type B package full-scale testing programs were also studied. These include: the TRUPACT II container for transuranic waste shipments, the NUPAC 125B internal canister for the Three Mile Island core debris shipments, and private sabotage testing of a German storage-transport cask at the US Army Aberdeen Test Center. The State of Nevada also evaluated the "Operation Smash Hit" testing program for the Magnox reactor fuel cask, conducted in 1984 by the Central Electricity Generating Board (CEGB) in the United Kingdom.

SANDIA

Films of Sandia cask tests were produced by DOE. These films became a matter of heated dispute because of their use to influence the public during debates over nuclear waste policy. Increased attention of the issue of spent nuclear fuel transportation led to stakeholder demands for full-scale testing of cask designs that would be used to move waste to a repository. These demands were driven in part by the films of the Sandia crash tests. Although the cask designs used in the tests were adequate for the investigators' primary purpose, benchmarking computer programs and validating scale model tests, the tests were not appropriate for evaluating NRC accident performance standards, or the safety performance of casks currently in use (10).

The DOE used these films in a public relations campaign in an effort to assure the public that current spent nuclear fuel shipments were "safe." (9) In so doing, the DOE misrepresented the Sandia test program and its findings, Some critics of the Sandia tests and test films later endorsed the CEGB approach, which combined regulatory confirmation testing and public demonstration testing, and the TRUPACT II testing program, which involved a high-degree of stakeholder participation.

There were significant problems with the Sandia tests which limited their public influence. First, the test program was forced to use obsolete casks due to budget constraints. The casks used were different from currently licensed casks. The casks were not subjected to regulatory tests. The tests were spectacular, but did not show regulatory compliance. The written reports about the tests were objective and accurate, the films portraying the tests were less accurate, and some versions were sensational. The debate over the tests and their portrayal in the films increased stakeholder skepticism about cask performance in severe accidents (11).

SMASH HIT

"Operation Smash Hit" involved full-scale regulatory tests of a cask design currently in use, similar to the tests proposed by NANP. The tests were performed by the Central Electricity Generating Board (CEGB) in 1984. These tests consisted of rigorous full-scale regulatory tests which included impact and fire tests. The tests culminated in a public demonstration of a crash when a locomotive was driven into a cask on a derailed train car at 100 miles per hour. The cask sustained only minimal superficial damage and its integrity was not compromised. The railcar and the locomotive were destroyed by the test. Post-event analysis of the "Operation Smash Hit" demonstration test concluded that the locomotive impact at 100 miles per hour actually applied less force to the cask lid, than did the regulatory drop test conducted earlier.

Central Electric Generating Board (CEGB) tests of MAGNOX flasks in the United Kingdom in the 1980s appear to have succeeded in enhancing public confidence and acceptance.. The test program used shipping containers that were actually to be used for rail shipments of SNF. The test program began with tests designed to replicate the regulatory requirements (drop test, fire test). Testing identified a design deficiency – lid seal leak of coolant – which was corrected, although the amount released did not exceed regulatory limits. The cask was subsequently used in a public demonstration test – impact by a 140-ton locomotive and 3 freight cars, travelling at 100 mph – which did not represent the same actual impact as the drop test, but demonstrated a real world accident environment. The tests were recorded on high-speed film/video. The test results were accurately portrayed in public information materials (especially the film entitled "Operation Smash Hit"). The testing program and the test results were endorsed by key stakeholders - British local and central government officials. (10)

TRUPACT II

The Trupact II testing program in the 1980's was designed to examine the strength of casks destined for disposal in the Waste Isolation Pilot plant in Carlsbad, New Mexico. These tests succeeded in enhancing stakeholder confidence and acceptance.. The shipping containers tested used shipping containers that were actually to be used for transuranic waste shipments to WIPP. The tests conducted were the regulatory tests specified in the NRC regulations. The tests identified a design deficiency – O-ring performance – which was corrected.

The test results were reported in great detail in the Safety Analysis Report required for NRC certification. The tests were recorded on high-speed film/video. The test results were accurately portrayed in public information materials and emergency response training materials, materials in some cases produced by the states . The testing program and the test results were endorsed by key stakeholders in the affected states along the shipping routes to WIPP – tests allowed officials to assure the public that reasonable precautions had been taken coupled with extra-regulatory safety protocols for the ensuing shipments. (10)

NEVADA CONCLUSIONS ABOUT FULL-SCALE TESTING PROGRAMS

Nevada contractor studies documented results of the tests (including test program costs) and lessons learned (10). These lessons were used to inform the NANP

recommendations to cask testing as they related to the DOE repository cask development program. These studies were key inputs to the full-scale cask testing approach that Nevada recommended to DOE in 1990 (14). The lessons learned are summarized below:

- Full-scale testing should be a supplement to regulatory analysis, not a substitute for regulatory analysis.
- Full-scale tests should be performed on casks used for current and future shipments.
- Full-scale tests should be designed to challenge cask integrity.
- Demonstration testing is acceptable only in conjunction with regulatory testing.
- Stakeholders should be involved in the testing program.
- Safety claims should not be exaggerated in test reports, films, and videos.

DOE YUCCA MOUNTAIN TRANSPORTATION PROGRAM

As part of it's work on the now-defunct Yucca Mountain Program, DOE examined the problem of the necessary cask fleet size and design. DOE stated that even if rail access is constructed, all repository shipments for the first six years or so could be made directly by truck, or Legal Weight Truck (LWT) casks on railcars. DOE expected more than a thousand LWT shipments would be expected over 24 years even if the railroad was completed by the time the repository opened.

In 2005, new uncertainties about the shipping cask designs that DOE might use for Yucca Mountain transportation arose. In April 2005, DOE announced that it would adopt a transport system that would make maximum use of available cask designs. This system would seek to achieve the maximum flexibility in terms of facility and fuel compatibility. In April and August 2005, DOE stated that it had no plans to accept spent fuel shipped in welded canisters, such as those used in utility dry storage systems, and designed for shipment using the currently licensed HI-STAR 100 rail cask. In October 2005, DOE again revised its program approach to include the use of Transport, Aging, and Disposal (TAD) canisters, for the acceptance of spent fuel from utilities. In the 2008 Supplemental EIS for Yucca Mountain, DOE proposed a base case transportation system that assumed that about 95 percent of the projected disposal inventory could be delivered to the repository by rail.

The issue of truck casks and rail access has gone largely unremarked. Rail access is a critical issue influencing the type and number of transportation casks. The number of nuclear power plants that can be accessed by rail is declining. The only currently feasible modes of transportation from all reactor sites are either 1) direct shipment by legal-weight truck (LWT), or 2) shipment of LWT casks to an intermodal transfer facility with final delivery by LWT. The cost and difficulty of establishing rail access to all of the nation's nuclear power plants is so great that there will inevitably be thousands of truck or truck to intermodal shipments of spent nuclear fuel. Any full-scale cask

BALTIMORE TUNNEL FIRE STUDIES

In July 2001, a freight train moving a railcar containing tripropylene in the Howard Street Tunnel, Baltimore, Maryland derailed and caught fire. This fire resulted in one of the most severe transportation accidents in recent U.S. history. A decade after studies by the National Transportation Safety Board, the Federal Emergency Management Agency Fire Division, the Nuclear Regulatory Commission, and the Nevada Agency for Nuclear Projects, important facts about the fire are still in dispute, and the implications for nuclear waste transportation are unresolved.

Analyses of that accident by Nevada consultants and by the NRC seem to agree that fire temperatures in the hottest region of the fire burned 2-3 hours at 1500-2000°F or 800-1,000°C, burned another 3-4 hours at lower temperatures, and cooled down over several days. They also agree that this was not the worst case rail fire, because its duration and temperature were limited by a water main break, tunnel oxygen supply, and other factors. The burning tank car contained enough fuel for a 6-7 hour fire.

In 2005, the NRC commissioned a draft contractor report NUREG/CR-6886. The final version was released in 2006(15) that evaluated three different cask designs subjected to a hypothetical accident based on the conditions estimated to have occurred in the July 2001 Baltimore tunnel fire. NUREG/CR-6886 concluded that there would have been no release of radioactive material from one of the casks (HI-STAR 100), and only minor releases from two other casks (TN-68 and NAC-LWT). This report evaluated the performance of The NRC report assumed that the casks could be no closer than 20 meters (66 feet) to the hottest region of the fire because of FRA regulations governing placement of spent fuel casks in mixed freight trains

Nevada's evaluation of NUREG/CR-6886 argues that it significantly underestimates the potential radiological consequences of the fire by assuming the casks would be located at least 20 meters from the hottest region of the fire. Even at 20 meters distance, NUREG/CR-6886 significantly underestimated consequences for NAC-LWT by assuming enclosure in ISO shipping container. Even at 20 meters distance, NUREG/CR-6886 may have significantly underestimated potential radiological consequences for all three casks because of uncertainties in NIST fire model, assumptions about SNF cladding performance, assumptions about release pathways from casks, and other factors.

The Baltimore Tunnel fire is an important waypoint in policy discussion about full-scale cask testing. The fire was much more severe fire than the hypothetical accident fire assumed in 10CFR 71.73. If subjected to the hottest region of the Baltimore fire for its full duration, most, if not all, NRC certified shipping casks could experience failure of lid seals, neutron and gamma shielding, and fuel cladding failure, resulting in a potentially significant release and dispersion of fission products. A possible exception, the HI-STAR 100 with welded canister, requires more analysis.

NRC PROPOSALS FOR FULL-SCALE TESTING

In 1999, NRC began the process of developing a cask testing demonstration study as part of the Package Performance Study (PPS). Laudably, the NRC engaged the public and stakeholders with an innovative public participation program. NRC held public meetings in throughout the country and invited a wide range of participants to engage in detailed discussions of technical and institutional issues. NRC and its contractor SNL provided detailed technical proposals for public discussion, and provided timely access to information and transcripts of the meetings on the SNL PPS website. Many

stakeholders, including the State of Nevada, commended the NRC and SNL for an exemplary public participation program.

In April, 2003, the NRC issued its proposed cask testing plan, NUREG-1768, for public comment. Many non-industry stakeholders, including the State of Nevada, concluded that the proposed testing protocols were unacceptable, and called upon the NRC to reissue new draft test protocols for public comment. Instead, the NRC made no further commitment to public input. Between February 2004 and March 2005, NRC staff presented the Commission with three additional testing options (SECY-04-0029, SECY-04-0135, and SECY-05-0051). (12, 13, 14)
Sometime in 2004, the NRC apparently decided that full-scale tests conducted under the PPS would not involve drop tests or fire tests severe enough to challenge cask containment integrity. The Commission directed staff to prepare a plan for demonstration testing of a rail cask impacted by a locomotive in May 2004.

NRC staff prepared such a plan and presented it the Advisory Committee on Nuclear Waste (ACNW) in July 2004. The ACNW then advised the NRC: "The ACNW has not seen any compelling science-based justification for the proposed test. In the Committee's opinion the proposed demonstration will add little new information of technical value. If a full-scale demonstration is deemed necessary, it should be justified on grounds other than technical needs (15)." The ACNW instead recommended use of scale model testing and computer analyses for demonstrating package compliance with regulations.

The most recent NRC testing proposal (SECY-05-001), approved by the Commission in June 2005, calls for a demonstration test in which a cask mounted on a railcar is impacted by a speeding locomotive, and then subjected to a 30-minute fire engulfing fire. "The staff's proposed test plan as provided in this SECY is not the final word on this issue, as the project is subject to additional modifications and Commission direction once additional information becomes available (16)."

Based on review of the available documents, Nevada consultants believe the test proposed in SRM SECY-05-0051 would not determine if the rail cask meets the accident performance standards set forth in the NRC regulations and would provide little data useful for validating the computer models used in safety evaluations. The demonstration test appears to have the same limits noted by NRC staff regarding the tests proposed in 2004. However, Commission stated that this plan "is not the last word of this issue." Nevada urges the Commission to consider the following concerns before proceeding further:

NAS TRANSPORTATION STUDY
The National Academies' (NAS) Committee on Transportation of Radioactive Waste released a report In February 2006 entitled Going The Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States (17). The committee found:

> "the radiological risks associated with the transportation of spent fuel and high-level waste are well understood and are generally low, with the possible exception of risks from releases in extreme accidents involving very-long-duration, fully engulfing fires. While the likelihood of such extreme accidents appears to be very small, their occurrence cannot be ruled out based on

> historical accident data for other types of hazardous material shipments. However, the likelihood of occurrence and consequences can be further reduced through relatively simple operational controls and restrictions and route-specific analyses to identify and mitigate hazards that could lead to such accidents."

The committee examined in detail previous accident consequence analyses, and previous full-scale cask testing programs, including the SNL testing program in the United States in the 1970s, and the "Operation Smash Hit" testing program. The committee directly addressed the issue of full-scale cask testing

> "FINDING: The committee strongly endorses the use of full-scale testing to determine how packages will perform under both regulatory and credible extra-regulatory conditions. Package testing in the United States and many other countries is carried out using good engineering practices that combine state-of-the-art structural analyses and physical tests to demonstrate containment effectiveness. Full-scale testing is a very effective tool for both guiding and validating analytical engineering models of package performance and for demonstrating the compliance of package designs with performance requirements. However, deliberate full-scale testing of packages to destruction through the application of forces that substantially exceed credible accident conditions would be marginally informative and is not justified given the considerable costs for package acquisitions that such testing would require.
>
> RECOMMENDATION: Full-scale package testing should continue to be used as part of integrated analytical, computer simulation, scale model, and testing programs to validate the performance of package performance. Deliberate full-scale testing of packages to destruction should not be carried out as part of this integrated analysis or for compliance demonstrations."

REVISED NEVADA PROPOSAL FOR FULL-SCALE CASK TESTING

The Nevada Agency for Nuclear Projects (NANP) has advocated full-scale cask testing since 1990. (22) The original Nevada proposal called for a five-part approach to full-scale cask testing: 1) meaningful stakeholder participation in development of testing protocols and selection of test facilities and personnel; 2) full-scale physical testing (sequential drop, puncture, fire, and immersion) of each cask design prior to NRC certification or DOE procurement; 3) additional testing (casks, components, models) and computer simulations to determine performance in extra-regulatory accidents and to determine failure thresholds; 4) reevaluation of previous risk study findings, and if appropriate, revision of NRC cask performance standards; and 5) evaluation of costs and benefits of destructive testing of a randomly-selected production model cask.

A comprehensive full-scale testing program would not only demonstrate compliance with NRC performance standards. It would improve the overall safety of the cask and vehicle system, and generally enhance confidence in both qualitative and probabilistic risk analysis techniques. It could potentially increase acceptance of shipments by state and local officials and the general public by demonstrating performance and reliability of a cask system.

The authors of this paper recommend that NRC adopt Nevada's revised proposal for full-scale testing. These revisions are based primarily on the authors' review of the recommendations presented by the National Academies Committee on Radioactive Waste Transportation in its 2006 study. These revisions also reflect review of all stakeholder comments submitted to the NRC through the PPS public hearings and comment letters, the most recent NRC cask testing plan, the NRC draft contractor report on the Baltimore tunnel fire, recent developments in the DOE Yucca Mountain transportation program, and recent Yucca Mountain routing studies. These revised recommendations are summarized below, and discussed in greater detail in the below.

Stakeholders should have a meaningful role in development of testing protocols & selection of test facilities and personnel

The federal agency responsible for testing (DOE or NRC) must provide a meaningful and substantive role for stakeholders in specifying the objectives of the tests, developing the testing protocols, selecting the testing contractors, and overseeing the implementation of the test program. The only way to assure that the testing program is accepted by stakeholders is to include the stakeholders in all phases of program development and implementation. Moreover, past experience with the TRUPACT-II testing program demonstrates that involvement of a broad range of stakeholders can make the tests more relevant to real world conditions (10).

Stakeholder involvement in selection of testing facilities is especially important. Before a final selection of test facilities, all relevant issues and options should be discussed with stakeholders. The accessibility of the test facilities to stakeholders, and the willingness of facility personnel to facilitate stakeholder participation in testing, may be as important as technical testing capabilities and previous experience. Even the best-equipped and most-experienced facilities have known limitations regarding capabilities to perform drop tests on large rail casks, and to perform long-duration fire tests. These factors, plus the potential tens-of-millions dollar value of the testing program, create the potential for real or perceived conflict of interest if the testing facility is selected without a formal competitive evaluation.

The approach used for testing of the TRUPACT shipping container is a model for effective stakeholder involvement. The TRUPACT-II shipping container is used for transporting transuranic waste to the Waste Isolation Pilot Plant (WIPP) in New Mexico. In that case,

Full-scale regulatory tests (drop, puncture, fire, and immersion, in sequence) should be performed on each cask design to be used for repository shipments, either prior to NRC certification, or prior to DOE procurement.

The heart of Nevada's cask testing proposal is to subject full-scale casks to the four hypothetical accident conditions specified in the NRC regulations (3).

Full-scale regulatory testing could be implemented either as the final step in NRC certification, or as a preliminary step in the DOE procurement of casks already certified by NRC but not previously tested. Considering the political controversy associated with cask testing, Federal legislation would probably be required. Absent congressional action to require full-scale testing by statute, DOE might be able to require full-scale regulatory testing as part of its procurement process for Yucca Mountain transportation

hardware. NRC action, independent of congressional direction, would almost certainly require formal rulemaking.

The number of casks which would need to be tested full-scale under Nevada's proposal, and the resulting costs, depend upon the final repository system design adopted by DOE. If the DOE were to adopt an approach based on standardization of transportation hardware designs, the number of regulatory tests could be as low as two, one truck and one rail. If, on the other hand, DOE decides to use all of the currently certified casks which the NRC has identified as potential casks for repository shipments, as many as seven or eight regulatory tests would be needed.

A cost analysis prepared in 2003 estimated that the regulatory testing program proposed by Nevada (drop, puncture, fire, and immersion) for a truck cask weighing up to 30 tons, would likely cost $7.8-8.4 million. Regulatory testing of a large rail cask would cost $9.1-12.0 million for each rail cask tested. In addition, a onetime cost of about $10 million would be incurred upgrading the testing facility to lift and drop rail casks weighing up to 170 tons (18). Table I summarizes the basis of these cost estimates.

The authors estimated test cost components based on contractor reports prepared for Nevada and DOE, and personal communications. Cost of cask acquisition assumes full compliance with NRC quality assurance and quality control procedures, and includes delivery to the test facility. Stakeholder participation costs assume intensive oversight of all planning, testing, and reporting activities; two major public meetings for each cask testing program; and large-scale stakeholder observation at the testing facilities. The relatively large contingency costs reflect uncertainty about instrumentation requirements, extent to which cask would be loaded with fresh fuel and heater elements, disposal of casks after testing, and compliance with environmental regulations.

The cost of physical testing assumes use of existing facilities in the United States or the United Kingdom. Test facility upgrading costs assume use of existing drop test facilities at SNL. Construction of a new cask testing facility would likely cost $15 million, compared to the $10 million upgrade cost. The NAS study (2006) found that a new drop test facility would probably be needed for truck as well as rail cask tests. However, a 1993 SNL report identified 12 facilities in United States with various capabilities for testing 40-ton and 100-ton containers, and a 1991 report prepared for Nevada identified 5 potential testing facilities in the United States, 2 in the United Kingdom, and 1 in Canada (11).

Table II. Estimated Cost of Full-Scale Cask Regulatory Testing (2003 Dollars)

Cost Component	Legal-Weight Truck Cask	Large Rail Cask (Up to 150 tons)
Cask	$2,750,000-3,250,000	$3,000,000-5,250,000
Physical Testing	530,000	1,190,000
Computer Analysis	800,000	800,000
Test Documentation	100,000	100,000
Technical Peer Review	600,000	600,000
Stakeholder Participation	775,000	775,000
Administration	425,000	525,000
Contingency (30%)	1,794,000-1,944,000	2,097,000-2,772,000

Subtotal for Testing	7,774,000-8,424,000	9,087,000-12,012,000
Facility Upgrade for Large Rail Cask Drop Tests (One-time)	0	10,000,000
Total for Testing First Cask	7,774,000-8,424,000	19,087,000-22,012,000

A comprehensive regulatory testing program (drop, puncture, fire, and immersion as proposed for the first truck cask), would likely cost about $8-9 million. Comprehensive regulatory testing for the first large rail cask would cost about $20-22 million, including the onetime cost of about $10 million for upgrading the testing facility to lift and drop rail casks weighing up to 170 tons. The authors estimate that it would cost about $30 million to complete the regulatory testing program for one truck cask and one rail cask (an additional $5 million in the event that a completely new cask testing facility would be needed). Subsequent tests, for additional cask designs, would likely cost considerably less per cask. The authors estimate that it would cost $50-80 million to conduct a comprehensive testing program, if five to eight truck and rail cask designs are used for repository shipments.

A truck cask, and possibly a rail cask, should be subjected to an extra-regulatory fire test based on the Baltimore Tunnel Fire conditions (an engulfing fire for 3 hours @ 1475°F-1800°F or 800°C-1000°C, followed by appropriate cool-down).

NANP staff and contractors have re-evaluated Nevada's previous position on extra-regulatory testing of full-scale shipping casks, including testing to failure and destructive testing. Based on re-examination of previous analyses of cask testing issues, on studies of the 2001 Baltimore rail tunnel fire, on review of stakeholder comments to NRC under the PPS program, and on consideration of the recent NAS report, Nevada contractors recommend that the highest priority should be the thermal testing of a legal weight truck cask subjected to the conditions created by the 2001 Baltimore rail tunnel fire.

A legal weight truck cask design that DOE plans to use for Yucca Mountain shipments should be subjected to an extra-regulatory fire test. Based on the DOE FEIS and other program documents, the GA-4 truck cask would be an appropriate choice. The fire temperature and duration should be similar to the conditions of the Baltimore tunnel fire – a fully engulfing, hydrocarbon-fuel fire with a temperature of 1475°F-1800°F (800°C-1000°C) for three hours, followed by a cool down period of at least five hours.

Nevada contractors have evaluated various aspects of regulatory and extra-regulatory fire tests. (26, 27, 28) The minimum cost for regulatory thermal testing of a legal-weight truck cask would likely be $3.3-3.8 million. Based on previous studies, the estimated cost of a 3-hour fire test, including cask purchase, would be approximately $4-5 million for a truck cask, and $6-7 million for a rail cask.

Shipping cask and spent fuel failure thresholds should be determined by computer simulations, scale model testing and component testing (<u>not</u> by full-scale cask testing)

Full-scale cask testing is not necessary to determine failure thresholds of shipping casks and their contents. A combination of computer simulations, component tests, and scale model tests would be sufficient to determine the impact and fire conditions under which

failure would occur. Failure of lid seals, shielding, and fuel cladding deserve thorough analysis. Failure in this sense means that one or more components fail, and the cask therefore fails to maintain its containment and shielding integrity as required under NRC regulations (10 CFR 71.51, 71.71, and Table A-2).

Further definition of failure may be needed regarding release of fission products, particularly release of the key radionuclide Cs-137, but even a release of less than one percent of the Cs-137 inventory could be considered a catastrophic failure. In this regard, cask designs with and without internal welded canisters could perform differently in severe fire environments, and both types of rail casks (with and without internal canisters) should be analyzed.

Nevada consultants agree with the NAS study finding "that extreme accident scenarios involving very-long-duration, fully engulfing fires might produce thermal loading conditions sufficient to compromise containment effectiveness."

Nevada consultants agree with the NAS recommendation that the NRC "should undertake additional analyses of very-long-duration fire scenarios that bound expected real-world accident conditions for a representative set of package designs that are likely to be used in future large-quantity shipping programs." The objectives of these analyses should be to: "Understand the performance of package barriers (spent fuel cladding and package seals). Estimate the potential quantities and consequences of any releases of radioactive material. Examine the need for regulatory changes (e.g., package testing requirements) or operational changes (e.g., restrictions on trains carrying spent fuel) to help prevent accidents that can lead to such fire conditions or to mitigate their consequences."

There is no need at this time to evaluate costs and benefits of destructive testing of a randomly-selected, production model cask.

In previous reports, Nevada has recommended that NRC undertake an evaluation of the costs and benefits of destructive testing of a randomly selected production model cask. The basis for this recommendation was that casks submitted for certification testing would of necessity be prototypes, and that prototypes might be constructed more carefully than production models, and might perform differently than production models, when tested. This concern was buttressed by documentation of a case in the 1970s, where a significant safety-related error had occurred in cask fabrication, and the error was only discovered, and the cask withdrawn from service, after the cask had been used for many shipments. (23)

After reviewing cask performance issues as part of Nevada's participation in the NRC PPS program, Nevada consultants have advised the State that this concern should be directly addressed through cask fabrication quality assurance requirements, and not through cask testing proposals. The State has therefore been advised to drop the recommendation for evaluation of destructive testing of a production model cask.

Moreover, the term "destructive testing" is imprecise, and open to misinterpretation. The NAS and the NRC seem to have interpreted Nevada's recommendation as a request that casks be tested "to destruction". This is not the case. The regulatory and extra-regulatory testing that Nevada has recommended would be destructive tests, in the

sense that the casks would not only be rendered useless for their original purpose, but would also likely be permanently disassembled for post-test examination.

Nevada consultants agree with the NAS study that "the failure of a package, in the sense that it can no longer perform its intended containment function, will generally occur under conditions that are much less severe than needed for destruction," and that "testing to destruction would provide little or no insight into the conditions that would cause a loss of package containment under real service conditions."

CONCLUSION: THE COST OF FULL-SCALE TESTING

The most compelling argument against full-scale cask testing is the cost. However, the cost of the cask itself is the main component. Cost was a major factor in the Sandia test design and in cask selection. "Financial constraints affected both test definition and equipment procurement. Because current generation spent fuel shipping casks cost from $500,000 for truck casks to $3,500,000 for rail casks, it was necessary to utilize used or retired equipment."

In developing a full-scale cask testing program for future shipments, investigators must balance the same three conflicting considerations as they have for every other cask testing program: "exposing the cask to very severe accident environments, amenability of the tests to analyses and scale model testing, and test costs."

The cost argument against full-scale testing is not compelling when the test costs are compared to the overall cost of a waste disposal program. A comprehensive regulatory testing program as proposed by Nevada would likely cost $8-9 million for the first truck cask. Comprehensive regulatory testing for the first large rail cask would cost $20-22 million, including a onetime cost of about $10-15 million for upgrading an existing testing facility, or building a new one, to lift and drop rail casks weighing up to 170 tons. Subsequent tests would likely cost considerably less per cask.

The authors estimate that a comprehensive testing program for spent fuel shipping casks would cost $60-80 million, including regulatory tests for 4 or 5 rail casks and 1 or 2 truck casks, an extra-regulatory fire test of a full-scale truck cask, and cask and fuel failure analyses. If DOE were to adopt a standardized approach to transportation hardware, for example using a single rail cask design based on the TAD concept, and a single truck cask design such as the General Atomics GA-4/9, then a comprehensive regulatory and extra-regulatory testing program might cost less than $50 million.

Testing costs are small when compared to the projected costs of the waste transportation system. Independent analyses by the State of Nevada (1998) and by DOE (2002) concluded that the projected life-cycle cost of the repository transportation system would be in the range of $7.5 billion to $9.5 billion. From this perspective, cask testing-done properly- is a bargain.

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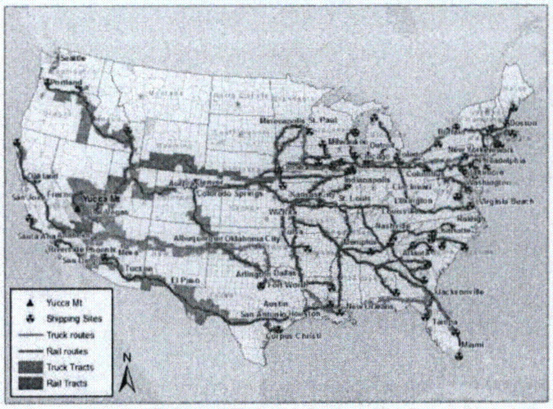
YUCCA MOUNTAIN TRANSPORTATION IMPACTS ACROSS THE UNITED STATES



7/13/2012

Population trends along US transportation routes to Yucca Mountain

This document reports calculations of the population living within the 800-meter radiological region of influence (ROI) along potential shipping routes to Yucca Mountain. The report uses 1990, 2000, and 2010 census data.

Prepared by Fred C. Dilger, PhD.
Black Mountain Research
Henderson, NV

INTRODUCTION

This report uses US census data from 1990, 2000 and 2010 to examine the national population that would have been affected by shipments of spent nuclear fuel and high-level radioactive waste to the now-terminated Yucca Mountain repository.

METHODOLOGY

The analysis was performed using geographic information systems (GIS) software to overlay the proposed routes contained in the 2008 US Department of Energy (DOE) Final Supplemental Environmental Impact Statement (FSEIS) onto census tract data from 1990, 2000, and 2010. The areas assessed were the representative rail and truck routes identified by DOE from shipping sites to the potential repository site.

The analysis method used in the report overlays and clips a portion of the affected census tracts. The results of the clipped census tracts reveal the characteristics of the affected census tracts. The routes are shown below in Figure 1.

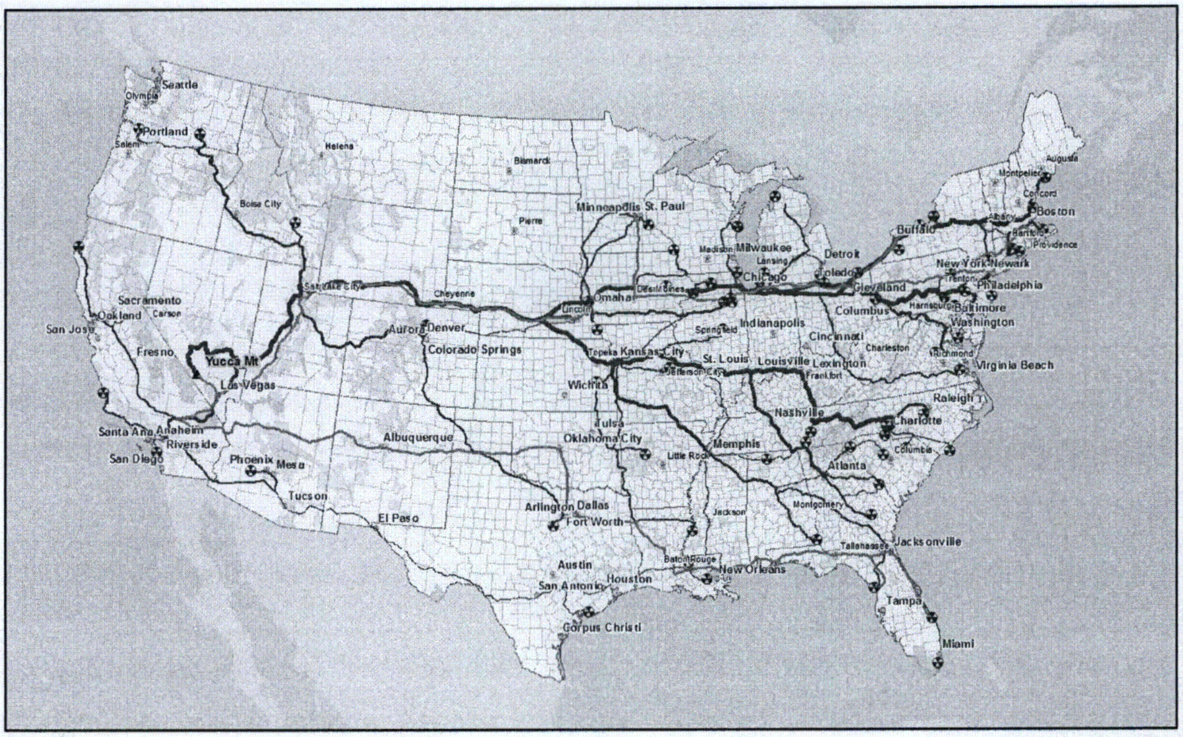


FIGURE 1. FSEIS RAIL AND TRUCK ROUTES

Process

The steps to implement the study were:

1. Define national rail and truck representative routes across the US as identified in the FSEIS.

2. Create buffers around the centerline of the route that are 800 meters on either side. This represents the radiological region of influence (ROI) as defined by the FSEIS (FSEIS, Page 6-12). The ROI is created as a new buffer layer.

3. Overlay the ROI buffer layer onto the census tracts for each US census from 1990, 2000, and 2010. The TIGER line file from 1990 had to be converted into an acceptable format prior to use.

4. Calculate statistics from the results of the overlay. The GIS operation-overlay was performed using two GIS software packages: Maptitude 6 and ArcGIS 9.3.1. The census tracts traversed by the rail and truck routes are depicted below in Figure 2.

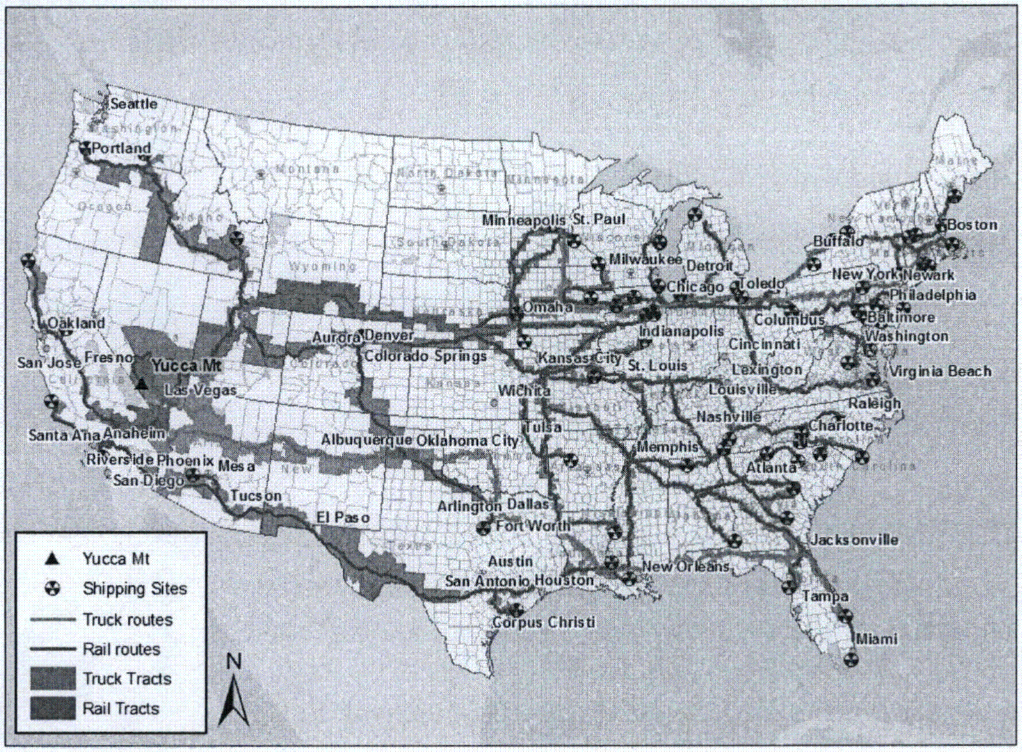


FIGURE 2. CENSUS TRACTS TRAVERSED BY RAIL AND TRUCK ROUTES TO YUCCA MOUNTAIN

The operation was repeated for each area analyzed and the results were compared. No substantial differences were identified by repeating the results.

ASSUMPTIONS

The 800-meter radiological ROI is the standard used to define the affected environment for normal shipments of spent nuclear fuel and high-level radioactive waste. In this case, the impacted area consists of the resident population within the radiological ROI of 800 meters on either side *of the centerline of the transportation routes.*

Census data was used for this analysis. There are different levels at which the census data is aggregated. The relevant possibilities for use in this report are: (1) census block, covers the smallest areas and is the most detailed; (2) census block group, covers a larger area and is comprised of several census blocks; and (3) census tract, collects block groups. The census tract level of data was used in this report because smaller sized areas require longer to compute. The larger areas are faster.

The potential transportation routes used were those identified by the DOE in the FSEIS (FSEIS 6-18). This includes the Caliente rail corridor.

This report presents the residential population. The buffer overlay was applied to the census tracts for EACH of the census years. That is, the same ROI boundaries were overlaid onto the 1990 TIGER census tracts, the 2000 census tracts and the 2010 census tracts. This was done to provide a consistent comparison over the years. It should be noted that the census tract boundaries changed slightly for each of the census years because of rapid changes in population.

ANALYSIS

The national population living within the radiological ROI is shown in Table 1.

	1990	2000	2010
Number of US Residents living within the Radiological ROI	7,368,639	7,912,208	8,495,068

TABLE 1. NUMBER OF US RESIDENTS LIVING WITHIN THE RADIOLOGICAL ROI

The results of the analysis also indicate the proportion of US residents living within the radiological ROI, as shown in Table 2.

	1990	2000	2010
Percentage of US residents living with the Radiological ROI	2.99 %	2.81 %	2.75 %

TABLE 1. PERCENTAGE OF US RESIDENTS LIVING WITHIN THE RADIOLOGICAL ROI

Characteristics of the Transportation Corridors Across the US

The US Census data for 2010 indicate the following land uses, institutions, and areas of special concern within the radiological ROI. The individual names and characteristics of each category within the transportation corridors to Yucca Mountain are available on a state-by-state basis.

- 954 Counties
- 3302 Parks
- 6110 Landmarks
- 8164 Schools
- 776 Recreation areas
- 4181 Public buildings
- 11419 Institutions
- 1025 Hospitals
- 10768 Churches

Characteristics of the US Population within the Radiological ROI

Selected demographic characteristics of the US population within the radiological ROI for 1990, 2000, and 2010 are shown in Table 3.

	1990		2000		2010	
	Within ROI	US	Within ROI	US	Within ROI	US
Households	2,611,306	91,947,410	3,006,860	105.480,101	3,265,239	114,825,428
Median Household Income	$28,553	$30,056	$39,791	$40,382	$47,209	$49,445
Median Age	34.28	32.9	36.39	35.3	39	37.2

TABLE 3. CHARACTERISTICS OF US POPULATION WITHIN AND OUTSIDE THE ROI

SOURCES

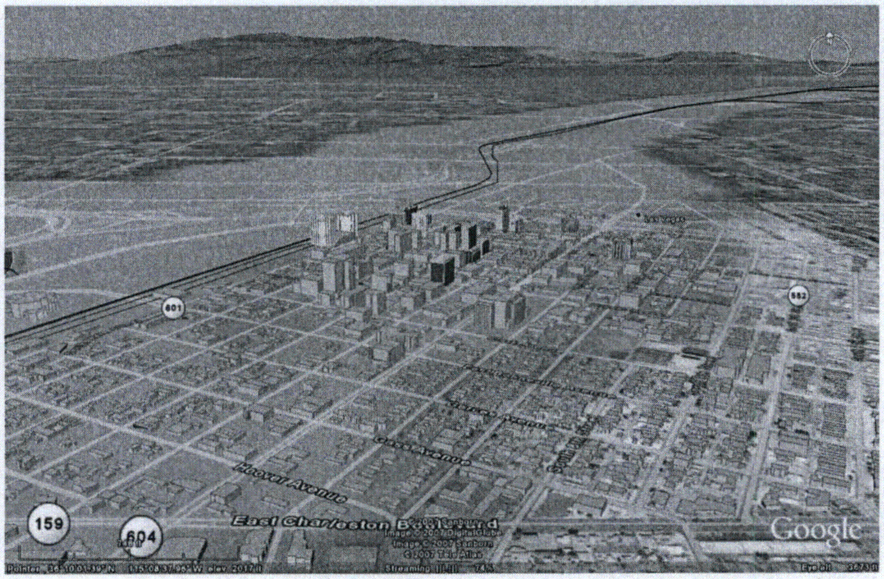
Caliper. Web. 11 June 2012. <http://www.caliper.com/>.

ESRI. Web. 11 June 2012. <http://www.esri.com/>

"US Census Bureau." Guide to State and Local Census Geography. Web. 30 Mar. 2012. <http://www.census.gov/geo/www/guidestloc/st32_nv.html>. http://www.census.gov/geo/www/guidestloc/st32_nv.html

"Energy.gov." Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada Rail Transportation Corridor DOE/EIS-0250F-S2 and Final Envir. Web. 30 Mar. 2012. http://energy.gov/downloads/final-supplemental-environmental-impact-statement-geologic-repository-disposal-spent-2

YUCCA MOUNTAIN TRANSPORTATION IMPACTS IN NEVADA



The picture above depicts the 800-meter radiological region of influence along the Union Pacific railroad through Las Vegas, NV

6/22/2012

Population trends along transportation routes to Yucca Mountain in Nevada (Revised Final Version)

This document reports calculations of the number of Nevadans living within the 800-meter radiological region of influence (ROI) along potential transportation routes to Yucca Mountain. The report uses 1990, 2000, and 2010 US census data.

Prepared by: Fred C. Dilger, PhD.
Black Mountain Research
Henderson, NV

INTRODUCTION

This report uses US census data from 1990, 2000 and 2010 to examine the changes in the population of Nevadans that would have been affected by the shipment of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) to the now-terminated Yucca Mountain repository site. The report describes the procedures used to perform the analysis and concludes by describing the very substantial increases in the number of Nevadans that would have been affected.

METHODOLOGY

The analysis was performed using geographic information systems (GIS) software to overlay the proposed routes contained in the 2008 Department of Energy (DOE) Final Supplemental Environmental Impact Statement (FSEIS) onto census tract data from 1990, 2000, and 2010. The areas assessed were: 1) the routes through the State of Nevada; and 2) routes through Clark County. The representative routes in the FSEIS traversed Nevada in a way that most heavily affected southern Nevada. The routes travel through Clark, Nye, Esmeralda, and Lincoln counties. The analysis method used in the report overlays and clips a portion of the affected population. The results of the clipped census tracts reveal the characteristics of the affected population.

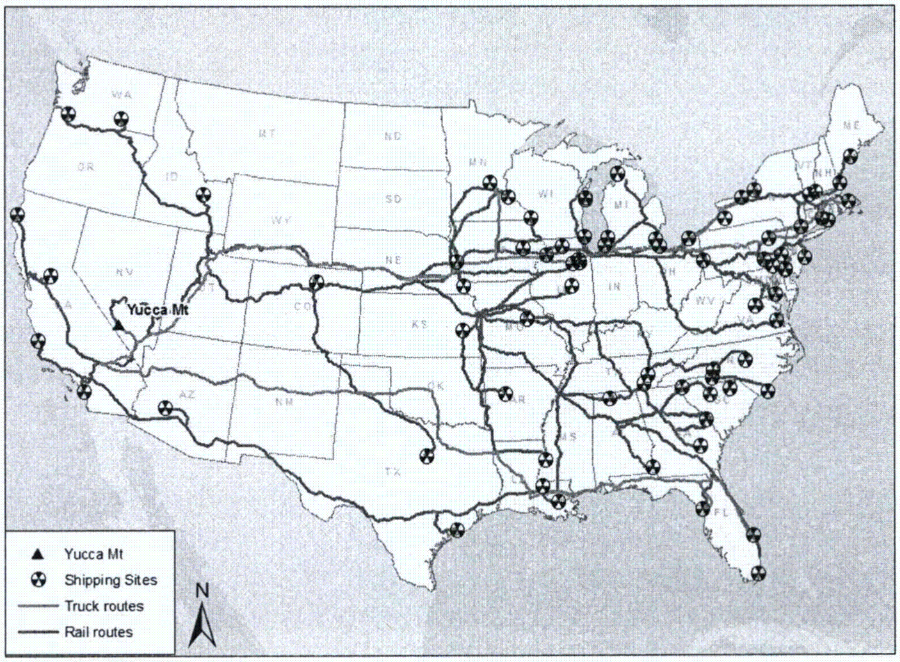


FIGURE 1. FSEIS NATIONAL RAIL AND TRUCK ROUTES TO YUCCA MOUNTAIN

Process

The steps to implement the study were:

1. Define national rail and truck representative routes across the US as identified in the FSEIS.

2. Create buffers around the centerline of the route that are 800 meters on either side. This represents the radiological region of influence as defined by the FSEIS (FSEIS, Page 6-12). The ROI is created as a new buffer layer.

3. Overlay the ROI buffer layer onto the census tracts for each census from 1990, 2000, and 2010. The TIGER line file from 1990 had to be converted into an acceptable format prior to use.

4. Calculate statistics from the results of the overlay. The GIS operation overlay was performed using two GIS software packages: Maptitude 6 and ArcGIS 9.3.1 . The operation was repeated for each area analyzed and the results were compared. No substantial differences were identified by repeating the results.

ASSUMPTIONS

The 800-meter ROI is the standard used to define the affected environment for normal shipments of spent nuclear fuel and high-level radiological waste. The impacted area consists of the population within the radiological ROI of 800 meters on either side of the centerline of the potential transportation routes.

Census data was used for this analysis. There are different levels at which the census data is aggregated. The relevant possibilities for use in this report: (1) census block, covers the smallest areas and is the most detailed; (2) census block group, covers a larger area and is comprised of several census blocks; and (3) census tract, collects block groups. The census tract level of data was used in this report because smaller sized areas require longer to compute. The larger areas are faster. The county level census data used in the report is enclosed in Appendix 1.

The potential transportation routes used were those identified by the DOE in the FSEIS (FSEIS 6-18). This includes the Caliente rail corridor.

This memo reports the residential population. The buffer overlay was applied to the census tracts for EACH of the census years. That is, the same ROI boundaries were overlaid onto the 1990 TIGER census tracts, the 2000 census tracts and the 2010 census tracts. This was done to provide a consistent comparison over the years. It should be noted that the census tract boundaries changed slightly for each of the census years because of rapid changes in population.

FINDINGS

The analysis reveals substantial increases in the numbers of people who would have been affected by transportation of SNF and HLW to Yucca Mountain. The analysis divides the results between Nevada and Clark County. The Clark County results are included within the Nevada numbers. The population impacts can also be divided for each individual county. There are an increasing number of Nevadans living within the ROI. The characteristics of the people living within the ROI are shown in the tables below.

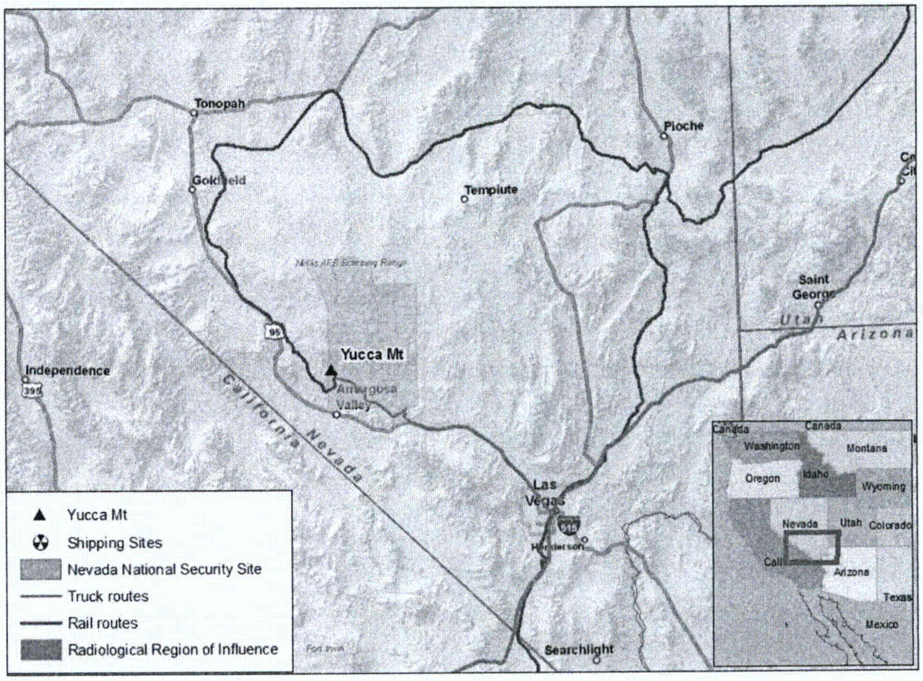


FIGURE 2. RAIL AND TRUCK ROUTES IN NEVADA TO YUCCA MOUNTAIN

	1990	2000	2010
Number of Nevada Residents living within the radiological ROI	40,872	91,394	222,517
Percentage of Nevada residents living within the radiological ROI	3.4%	4.5%	8.1%

TABLE 1. NUMBER OF NEVADA RESIDENTS LIVING WITHIN THE RADIOLOGICAL ROI

The results of the assessment indicate that the number of Nevadans living within the radiological ROI increased substantially between 1990 and 2010. The proportion of the state's residents living within the ROI is larger than ever before as well.

The increase in the number and proportion of people within the radiological ROI is almost entirely due to the increased residential population along the northern and western beltway in Clark County.

	1990		2000		2010	
	Within ROI	Nevada	Within ROI	Nevada	Within ROI	Nevada
Households	12,313	466,297	34,554	751,165	81,394	1,006,250
Median Age	34.6	34.6	36.7	35	35.2	36.3
Housing Units	26,019	518,858	39,055	827,457	102,257	1,173,814

TABLE 2. CHARACTERISTICS OF NEVADA POPULATION

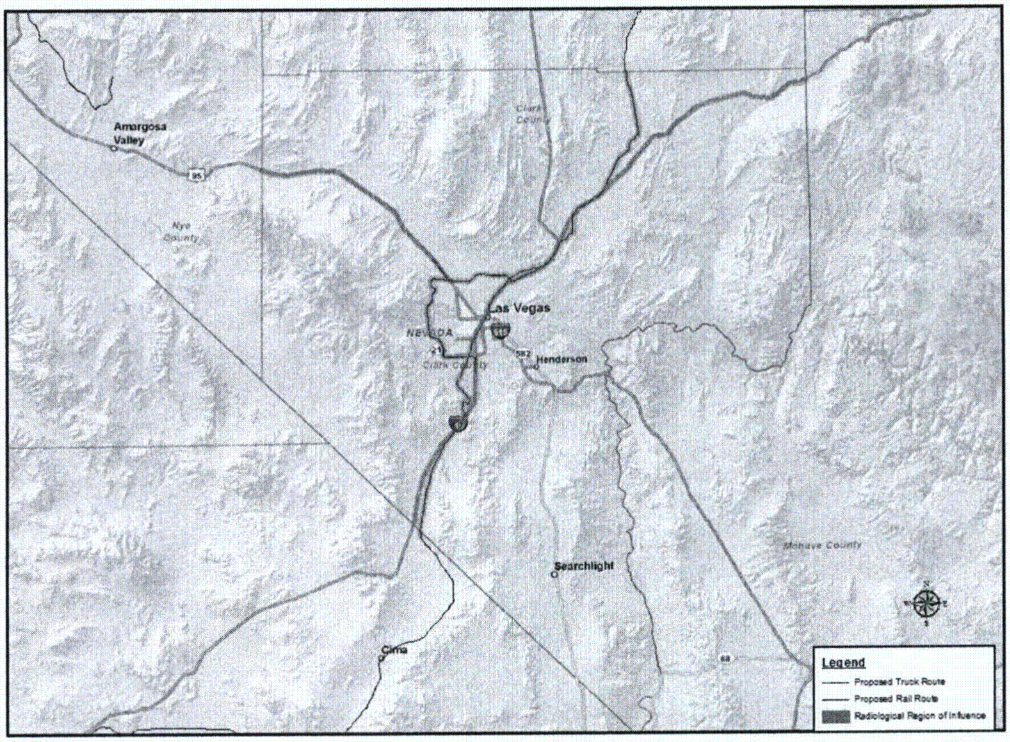


FIGURE 3. FSEIS RAIL AND TRUCK ROUTES THROUGH CLARK COUNTY, NEVADA

The number and proportion of Clark County residents living within the radiological ROI is shown in Table 3.

	1990	2000	2010
Number of Clark County Residents living within the radiological ROI	40,039	91,394	220,225
Percentage of Clark County residents living within the radiological ROI	5.4%	6.6%	11.28%

TABLE 3. CLARK COUNTY RESIDENT LIVING WITHIN THE ROI

The Clark County census tracts within the radiological ROI are shown in Figure 4. Selected demographic characteristics of the Clark County population are shown in Table 4.

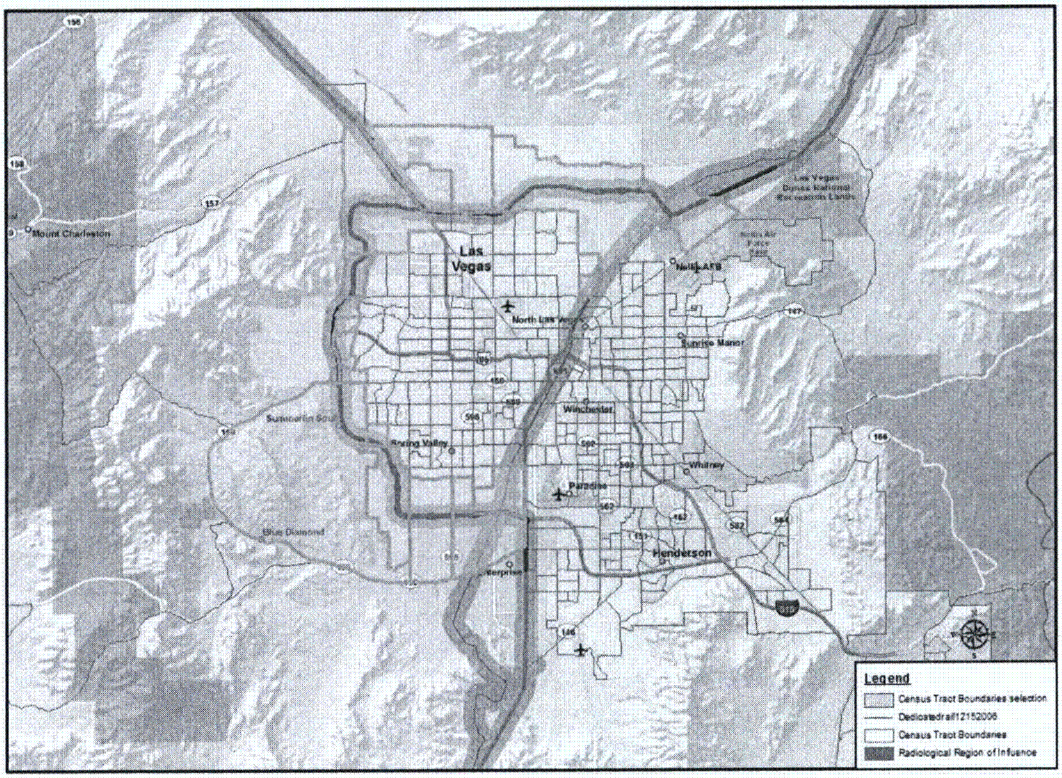


FIGURE 4. CLARK COUNTY CENSUS TRACTS WITHIN THE ROI WITH THE GREATEST POPULATION CHANGES

	1990		2000		2010	
	Within ROI	Clark County	Within ROI	Clark County	Within ROI	Clark County
Households	12,055	287,025	34,446	512,253	81,272	715,365
Median Age	34.4	34.6	34.6	34.8	35.4	35.5
Housing Units	25,743	357,045	38,905	559,799	101,884	840,343

TABLE 4. CLARK COUNTY POPULATION CHARACTERISTICS

SOURCES

Caliper. Web. 11 June 2012. <http://www.caliper.com/>.

ESRI. Web. 11 June 2012. <http://www.esri.com/>

"US Census Bureau." *Guide to State and Local Census Geography*. Web. 30 Mar. 2012. <http://www.census.gov/geo/www/guidestloc/st32_nv.html>.
http://www.census.gov/geo/www/guidestloc/st32_nv.html

"Energy.gov." *Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada Rail Transportation Corridor DOE/EIS-0250F-S2 and Final Envir*. Web. 30 Mar. 2012.

http://energy.gov/downloads/final-supplemental-environmental-impact-statement-geologic-repository-disposal-spent-2

http://censtats.census.gov/cgi-bin/pl94/pl94data.pl

Appendix 1
Census Data Sources

BRIAN SANDOVAL
Governor

STATE OF NEVADA

ROBERT J HALSTEAD
Executive Director

OFFICE OF THE GOVERNOR
AGENCY FOR NUCLEAR PROJECTS
1761 E. College Parkway, Suite 118
Carson City, NV 89706-7954
Telephone (775) 687-3744 • Fax (775) 687-5277
E-mail: nwpo@nuc.state.nv.us

State of Nevada
Office of the Governor
Agency for Nuclear Projects
Additional General Comments
On
Spent Fuel Transportation Risk Assessment,
NUREG-2125,
Draft Report for Comment,
Docket ID: NRC-20212-0108
July 15, 2012

ADDITIONAL GENERAL COMMENTS

Accident Scenarios Underestimate Potential Fire Durations and Temperatures

Nevada believes that the Draft Report underestimates the potential fire durations and fire temperatures to which casks may be exposed in transportation accidents.

The NAS 2006 report underscored the importance of assessing and managing the radiological risks from "releases in extreme accidents involving very long duration, fully engulfing fires. While the likelihood of such extreme accidents appears to be very small, their occurrence cannot be ruled out based on historical accident data for other types of hazardous material shipments." The NAS recommended a combination of administrative controls, route-specific risk analyses, studies of real-world accident conditions, computer analyses of cask performance, and full-scale testing to address these risks. (Pp. 10-15) The NRC has prepared a number of studies since 2006 that implement some of the NAS recommendations, particularly studies of specific accidents such as the 2001 Baltimore Tunnel rail fire and the 2007 MacArthur Maze highway fire.

The Draft Report specification of accident fire scenarios raises questions about how the authors considered and incorporated the findings of other NRC reports, particularly regarding the Baltimore Tunnel rail fire and the MacArthur Maze highway fire.

Underestimation of fire durations and temperatures challenge the Draft Report conclusion: "Probable worst-case fire accident scenarios for a rail cask transported by railway and for a truck cask transported by roadway were represented within the cases analyzed." (p. 107)

Underestimation of fire durations and temperatures also challenge the Draft Report conclusion: "If there were an accident during a spent fuel shipment, there is only about a one in a billion chance that the accident would result in a release of radioactive material." (p. 139)

Moreover, since the Draft Report did not evaluate the NAC LWT truck cask and the IF-300 rail cask, which are currently used for most spent fuel shipments in the United States, there is no basis for the far-reaching claim in the Draft Report that "the results demonstrate that SNF casks designed to meet current regulations will prevent the loss of radioactive material in realistic severe fire accidents." (p. 107)

The cask designs chosen for analysis in the Draft Report were the GA-4 truck cask, the NAC-STC rail cask, and the HI-STAR 100 rail cask. The Draft Report evaluated the responses of the two rail casks to the hypothetical accident fire specified in 10CFR71 (engulfing 30-minute fire at 800°C, 1472°F) and to three variations of an extra-regulatory fire (3 hours at 800°C, 1472°F). The Draft Report evaluated the response of the truck cask to an extra-regulatory fire (1 hour at 800°C, 1472°F). The Draft Report characterizes these combinations of fire conditions and cask damage assumptions as representing "worst-case" scenarios. "The neutron shield material of each cask analyzed was assumed to melt and flow out of the cask instantly at the beginning of the fire." (p. 107) Impact limiters were however "modeled as undamaged (not deformed)." (p. 77)

The Draft Report cites the primary NRC study of the Baltimore Tunnel rail fire, NUREG/CR-6886, Revision 2, but it is not clear exactly how the authors used NUREG/CR-6886 in designing their analyses. NUREG/CR-6886, Revision 2, carefully avoided categorizing the Baltimore Tunnel rail fire as a "worst case" tunnel fire accident, describing it as a "a 'beyond design-basis' scenario." (p. 1.9) Building upon previous NRC studies, including a fire study prepared by the National Institute of Standards and Technology (NIST), NUREG/CR-6886, Revision 2, evaluated the performance of three different cask designs subjected to a hypothetical accident based on the conditions estimated to have occurred in the Baltimore tunnel fire, and concluded that there would have been no release of radioactive material from one of the casks (HI-STAR 100), and only minor releases from two other casks (TN-68, and NAC-LWT shipped inside an ISO container). A critical assumption in NUREG/CR-6886, Revision 2, was that the casks could be no closer than 20 meters (66 feet) to the hottest region of the fire, because of FRA regulations governing placement of spent fuel casks in mixed freight trains and because of the geometry of the single track tunnel.

Based on the Baltimore Tunnel rail fire, Nevada believes that a credible maximum accident fire scenario for a rail cask would be an engulfing fire for 2-3 hours at 800-1,000°C, followed by 3-4 hours at 600-800°C , and at least 24 hours of cool-down. While respectful of the methodology and findings of NUREG/CR-6886, Revision 2, there are numerous uncertainties about the calculated fire conditions and possible rail tunnel, track, and train configurations. The Baltimore Tunnel fire was clearly not a "worst case" rail fire, because its duration and temperature were limited by a water main break, tunnel oxygen supply, and other factors. The burning tank car contained enough fuel for a 6-7 hour fire. NUREG/CR-6886, Revision 2, significantly underestimated the potential radiological consequences of the fire by assuming the casks would be located at least 20 meters from the hottest region of the fire. Even at 20 meters distance, the NRC analysis may have underestimated potential radiological consequences for all three casks because of uncertainties in the NIST fire model, assumptions about impact limiter damage, assumptions about SNF cladding performance, and assumptions about release pathways from casks. Administrative controls, in the form of AAR operating protocols for trains carrying spent fuel, are intended to prevent a spent fuel fire accident involving two trains in a single-bore, double-track tunnel.

The MacArthur Maze highway fire is still being studied by NRC. However, the fire conditions appear to have been significantly greater than those specified in 10CFR71 or those assumed in the Draft Report for a fire accident involving a truck cask. NRC has estimated that the fire burned for about 17 minutes at 1,100°C (2012°F), followed by 71 minutes at 900°C (1,652°F), followed by a cool-down period. Preliminary results reported by NRC in February 2012, for a spent fuel truck accident assuming a similar fire, suggest that "fuel rods are expected to rupture before the end of the fire." The peak fuel cladding temperature "would almost certainly exceed the short-term limit of 570°C (1058°F), and would likely exceed the zircaloy burst temperature limit of 750°C (1382°F) assumed in previous transportation studies." The NRC analysis assumed that the impact limiters remained intact. (Attachment 6) In finalizing the Draft Report, the results of the MacArthur Maze fire studies must be considered.

<u>Accident Scenarios Underestimate Consequences on Damage to Cask Impact Limiters</u>

Nevada believes that Draft Report underestimates the potential damage to casks in accident fire environments following damage to cask impact limiters.

The Draft Report evaluates rail and truck cask performance in accident severe fires assuming that the impact limiters are intact. The NRC studies of the Baltimore Tunnel rail fire and the MacArthur Maze highway fire make similar assumptions, although those reports correctly point out the significance of the impact limiter on the lid end of the cask as an important source of thermal insulation for the lid bolts and seals. The attached report by Dr. Miles Greiner uses the CAFÉ-3D fire model to measure the significance of the impact limiter, intact and damaged in different scenarios, relative to the temperatures of concern for the containment seal, for a legal-weight truck cask modeled on the NAC LWT. (Attachment 7) In future efforts to model the performance of both rail and truck casks in long-duration, high-temperature fires, Nevada suggests that the accident fire scenarios include impact limiter damage and/or loss.

The MacArthur Maze Fire and Roadway Collapse:

Consequences for SNF Transportation - 12476

Christopher S. Bajwa*, Earl P. Easton*, Harold Adkins**, Judith Cuta**,
Nicholas Klymyshyn**, and Sarah Suffield**
*U.S. Nuclear Regulatory Commission, Washington, DC 20005
**Pacific Northwest National Laboratory, Richland, Washington 99352

ABSTRACT

In 2007, a severe transportation accident occurred near Oakland, California, on a section of Interstate 880 known as the "MacArthur Maze," involving a tractor trailer carrying gasoline which impacted an overpass support column and burst into flames. The subsequent fire caused the collapse of portions of the Interstate 580 overpass onto the remains of the tractor-trailer in less than 20 minutes, due to a reduction of strength in the structural steel exposed to the fire. The US Nuclear Regulatory Commission is in the process of examining the impacts of this accident on the performance of a spent nuclear fuel transportation package, using detailed analysis models, in order to determine the potential regulatory implications related to the safe transport of spent nuclear fuel in the United States. This paper will provide a summary of this effort and present results and conclusions.

NOMENCLATURE

Caltrans – California Department of Transportation
CHP – California Highway Patrol
FDS – Fire Dynamics Simulator
HAC – Hypothetical Accident Condition
LWT SNF – Legal Weight Truck Spent Nuclear Fuel (package)
NIST – National Institute of Standards and Technology
NRC – United States Nuclear Regulatory Commission
SwRI® – Southwest Research Institute®

BACKGROUND

The primary objective of the work described in this paper was to assess the potential impact of this type of accident on a spent nuclear fuel transportation package, and, secondarily, to evaluate the accident in comparison to the hypothetical accident condition (HAC) fire exposure defined in Title 10 of the Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material." [1]

The MacArthur Maze Accident and Fire

The accident occurred on Sunday morning, April 29, 2007, in an area commonly known as the "MacArthur Maze", a network of connector ramps that merge highways I-80, I-580, and I-880 in Oakland, California. The fire that eventually led to collapses of the overpass started at about 3:38 a.m. when a gasoline tanker truck carrying 32,500 liters [8,600 gallons] of gasoline crashed and caught fire. The tanker truck was heading south along I-880 at the time of the accident. While nearing the I-580 overpass, the vehicle rolled onto its side and slid to a stop on the 21-foot-high ramp connecting westbound I-80 to southbound I-880.

The main portion of the fire, fueled by gasoline leaking from the tanker, spread along a section of the I-880 roadway, and encompassed an area of roughly 30 m [100 ft] in length by 10 m [33 ft] in width. Some of the gasoline went through the scupper drain on I-880 and burned on the ground around an I-880 roadway support pillar. The fire on the I-880 roadway heated the steel

girders on the underside of the I-580 overpass to temperatures at which the steel strength was reduced and was insufficient to support the weight of the elevated roadway. A portion of the I-580 overpass (between Bents 19 and 20) completely collapsed onto the I-880 roadway about 17 minutes after the fire started, based on surveillance video taken from a water treatment plant adjacent to the highway interchange. A second portion of the I-580 overpass (between Bents 18 and 19) began to sag heavily and eventually partially collapsed approximately 40 minutes after the fire began. The fire was determined to have burned intensely for about 40 minutes, but for the remaining 60 minutes of the fire, it was significantly reduced in size, due to the collapse of the two I-580 spans. An image captured from the video at 16.7 minutes, just before the collapse of the first overhead span, is shown in Figure 1. A photograph of the scene after the fire was extinguished (from later that day) is shown in Figure 2[1] [2].

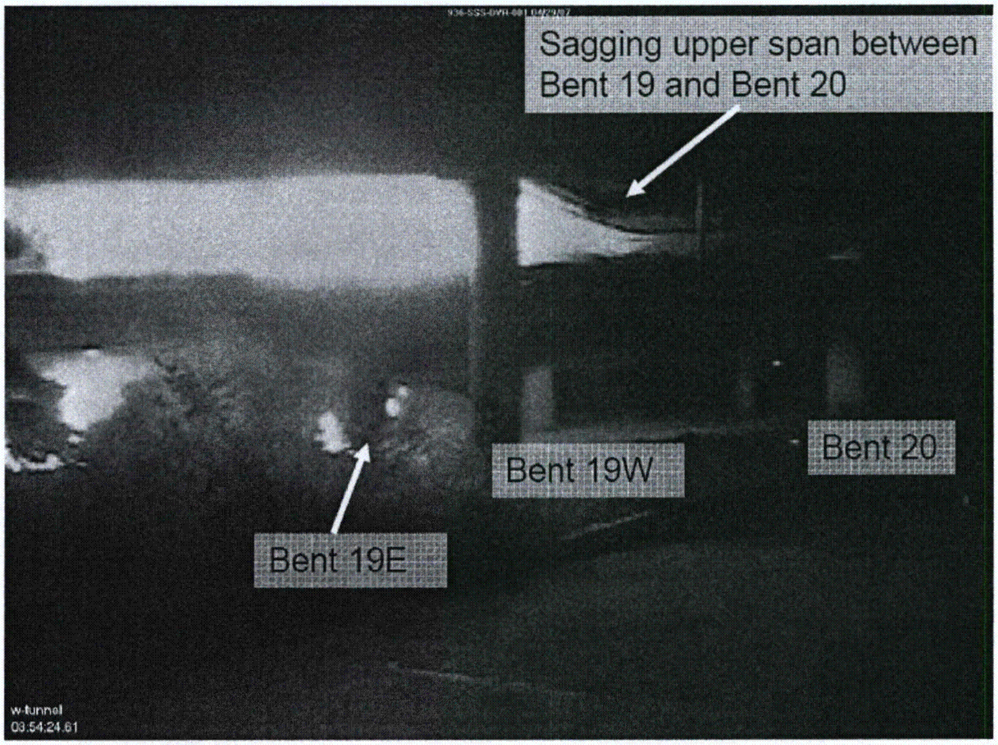


Fig. 1. MacArthur Maze fire at +16.7 minutes (video image at 03:54:24.61 PDT)

[1] The transverse support locations for the elevated roadway are referred to as "Bents" in Figures 1 and 2.

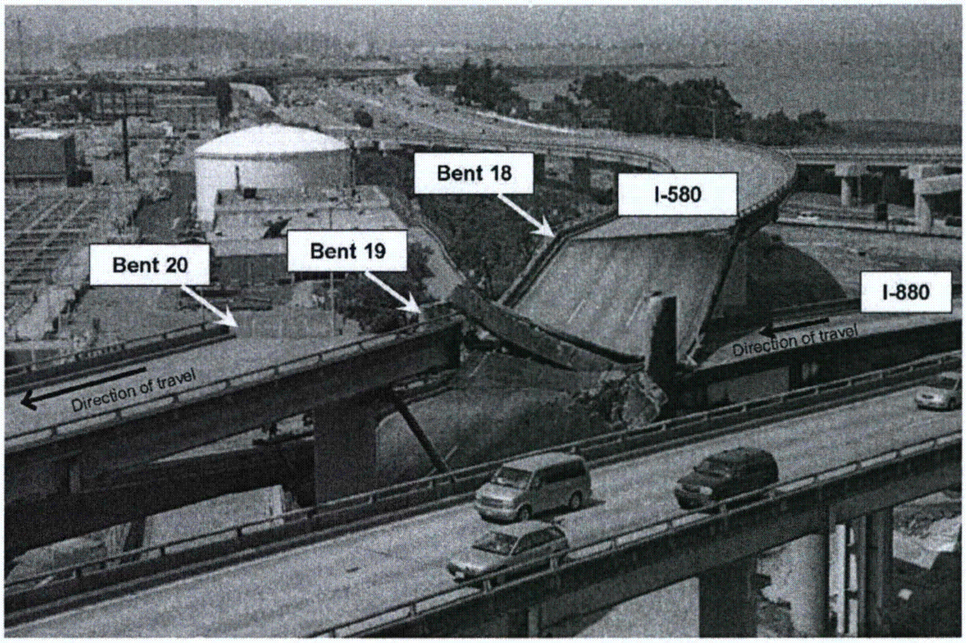


Fig. 2. Post-fire aerial view of the collapsed section of I-580 looking west. Picture from Caltrans http://www.dot.ca.gov/dist4/photography/images/070429.

DETERMINING FIRE TEMPERATURES: THE MACARTHUR MAZE FIRE

Examining Physical Evidence

Initial media reports of the MacArthur Maze accident suggested that the fire could have reached temperatures as high as 1,650°C [3,000°F]. However, no direct temperature measurements were taken of the fire, and this estimate fails to take into account two crucial factors; the maximum temperatures achievable in an open hydrocarbon fueled pool fire, and the temperature-dependent nature of the strength of structural steel. Based on experimental and analytical evaluations of large pool fires [3], a consistent estimate of the bounding flame temperature for these types of fires is approximately 1000ºC (1832ºF). Higher temperatures may be achievable if the fire is confined in a manner that does not restrict the flow of oxygen to the fire or remove significant heat from the fire by means of conduction, evaporation, or ablation (spalling). However, the upper limit is only about 1350ºC (2462ºF), based on tunnel fire testing [4, 5].

Review of the documentation compiled by Caltrans during the demolition and repair of the overpass, as well as examination of the I-580 overpass girders after the demolition, revealed no indications that any of the steel girders were exposed to temperatures where melting would be expected. Other items that aided in determining the fire temperature included melting of alloys used on the tanker truck, spalling of concrete, damage to paint, and solid-state phase transformations in the steel girders. Spalling of the concrete was observed on the surface of the I-880 roadbed, the physical extent of which was measured by Caltrans. Damage to the paint of the steel girders also served as a useful indication of temperature especially with the extensive photographic documentation available from Caltrans. NRC and SwRI® staff collected and analyzed material samples from the steel girders and the tanker truck to estimate exposure temperatures.

The MacArthur Maze Fire: Materials Analysis Conclusions

Based on the samples collected and the results of thermal exposures, the temperature of the fire below the I-580 overpass is estimated to have ranged from 850°C [1,562°F] to approximately 1,000°C [1,832°F]. Near the truck, the maximum exposure temperature is estimated to be at least 720°C [1,328°F] and less than 930°C [1,706°F]. Results obtained from the analysis of the overpass and truck samples are consistent with modeling results (discussed below), indicating the hottest gas temperatures during the fire were located above the I-880 roadway near the steel girders of the I-580 overpass. An extensive discussion of the materials analyses completed for the samples collected are provided in previous papers [6], as well as a NRC NUREG/CR series report [7].

The insights gained from the materials analyses from the MacArthur Maze fire have been used to verify computer models of the fire and roadway collapse. This has allowed for further investigation of the potential effects that a fire of this magnitude and duration, followed by a roadway collapse, could have had on an NRC certified over-the-road radioactive material transportation package. Preliminary results of these investigations are discussed below.

CFD MODELING OF THE MACARTHUR MAZE FIRE

A preliminary model of the MacArthur Maze fire was developed using the FDS code [8, 9] for NRC at the Center for Nuclear Waste Regulatory Analyses, SwRI®, San Antonio, Texas under contract NRC-02-07-006, and provided an initial scoping analysis of the fire. The model was then refined and final calculations were performed at NIST. A diagram of the structural elements and roadways as represented in the FDS model is shown in Figure 3.

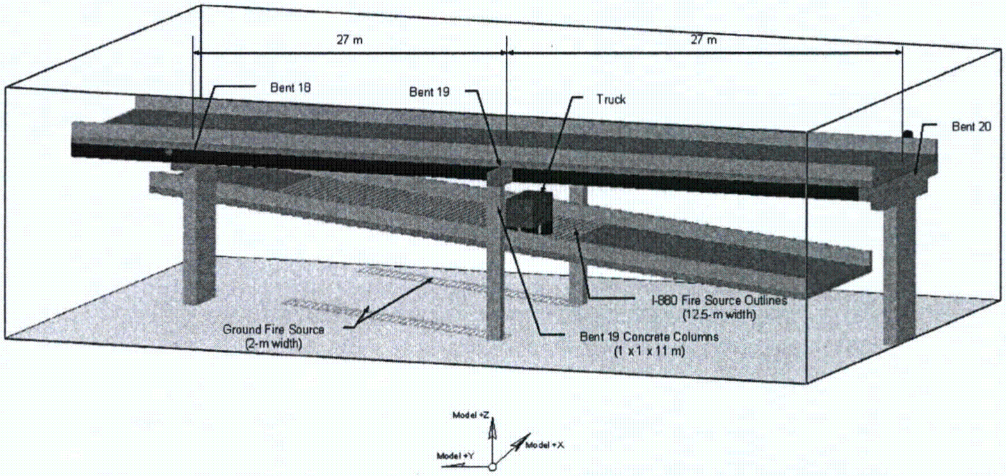
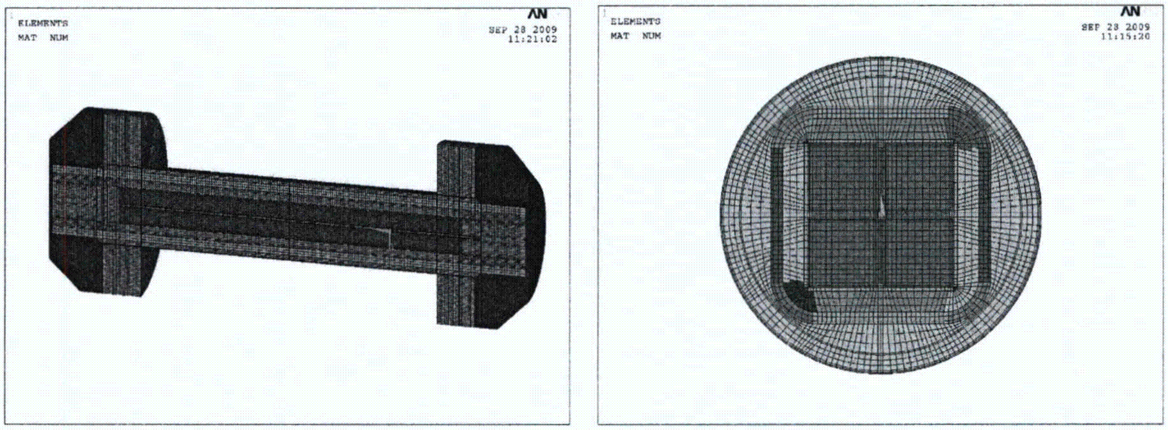


Fig. 3. Diagram of FDS model of MacArthur Maze Geometry for Fire Simulation

The FDS analysis was limited to the pre-collapse phase of the fire (17 minutes). The upper bound on the peak fire temperature during this first phase of the fire is 1100ºC (2012ºF), based on predicted Adiabatic Surface Temperatures (ASTs) at points in the fire near the final position of the tanker truck, at elevations of 1 m above the roadway and 1 m below the girders of the overhead I-580 span. The results of the FDS analysis were used to determine appropriate boundary conditions for the analyses presented below of the thermal effects of the fire on a typical legal weight truck (LWT) SNF package, and the structural effects of the lower roadway dropping onto the package. For these analyses, the GA-4 LWT SNF package was selected, based primarily on its ability to carry up to 4 spent PWR fuel assemblies.

MODELING OF THERMAL EFFECTS OF THE MACARTHUR MAZE FIRE

Simulation of the GA-4 package in the MacArthur Maze fire consisted of imposing in sequence a series of three sets of boundary conditions representing a large (pre-collapse) fully engulfing fire at 1100°C (2012°F), a smaller (post-collapse) fully engulfing fire at 900°C (1652°F), and the post-fire cooldown with the package beneath the fallen upper roadway. Two independent models were developed for this analysis, one using the ANSYS finite element code [10] and one using the COBRA-SFS thermal-hydraulics finite difference code [11]. These models were developed in parallel to expedite cross-checking and verification between the codes. Figure 4 shows a cross-section of the model geometry developed for the simulation with ANSYS. Figure 5 shows a cross-section of the model developed for the COBRA-SFS simulation.



(A) Axial Cross-Section (B) Mid-Plane Cross-section

Fig. 4. Diagram of ANSYS model of GA-4 Package

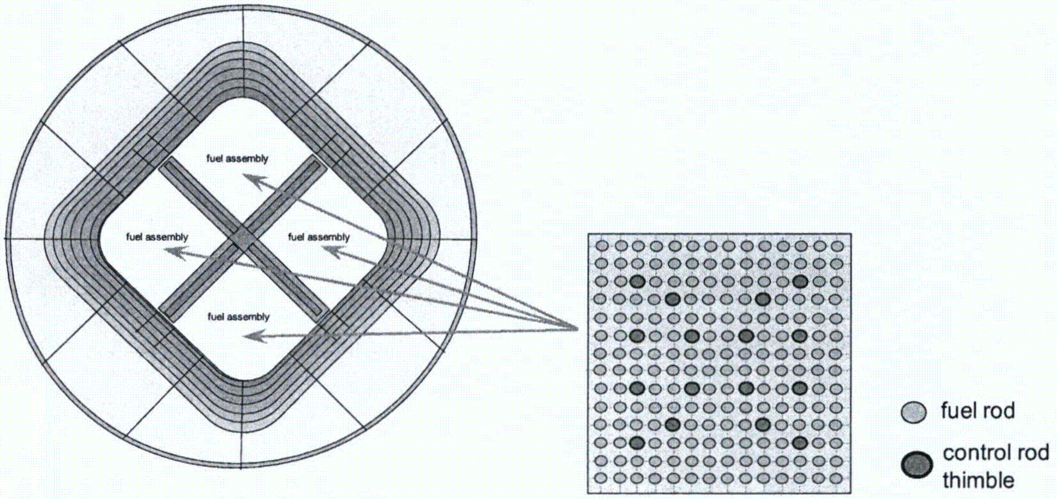


Fig. 5. Diagram of COBRA-SFS model of GA-4 Package

To simulate the pre-collapse fire, the package model was subjected to an ambient boundary temperature of 1100°C (2012°F) for 37 minutes, to conservatively represent the fire conditions before and during the collapse of the two overhead spans. To simulate the smaller post-collapse fire, the fire boundary temperature was reduced to 900°C (1652°F) for the remaining

71 minutes of the transient, for a total fire duration of 108 minutes. Figure 6 shows the bounding fire temperatures assumed for the MacArthur Maze fire, compared to the prescribed fire boundary temperature for the HAC fire described in 10CFR71. The figure clearly illustrates that the MacArthur Maze fire is larger in intensity and duration than the HAC fire in 10CFR71, therefore, it is considered an extra-regulatory fire.

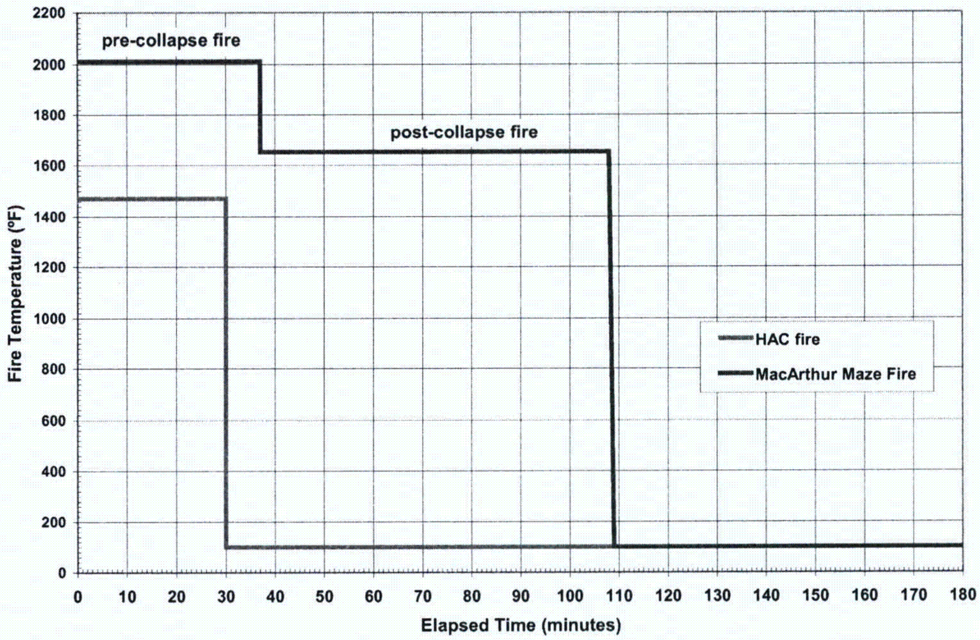


Fig. 6. Diagram of COBRA-SFS model of GA-4 Package

Preliminary Results of Thermal Analysis with ANSYS Model

The temperatures predicted with the ANSYS model simulation of the MacArthur Maze pre-collapse fire scenario at 1100°C (2012°F) are shown in Figure 7. This color thermograph shows the temperature distribution in the package cross-section at 37 minutes (end of the pre-collapse portion of the fire scenario.) Figure 8 shows the temperature distribution predicted at the end of the fire, at 108 minutes, after the additional 71 minutes of the post-collapse fire at 900°C (1652°F).

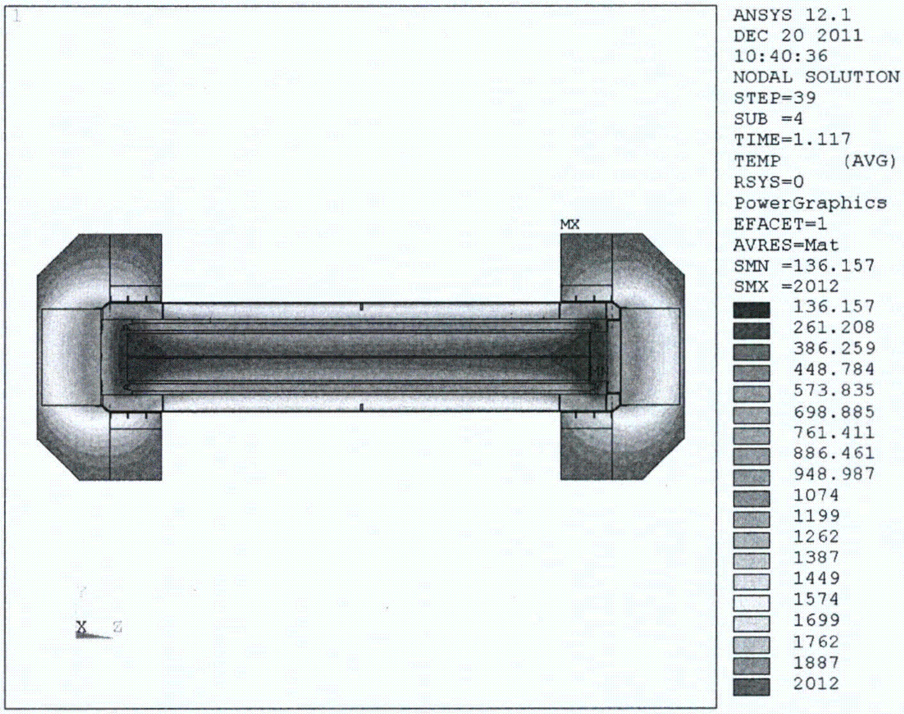


Fig. 7. Temperature distribution Predicted with ANSYS model for the GA-4 Package at end of Pre-collapse 1100°C (2012°F) Fully Engulfing Fire (37 minutes)

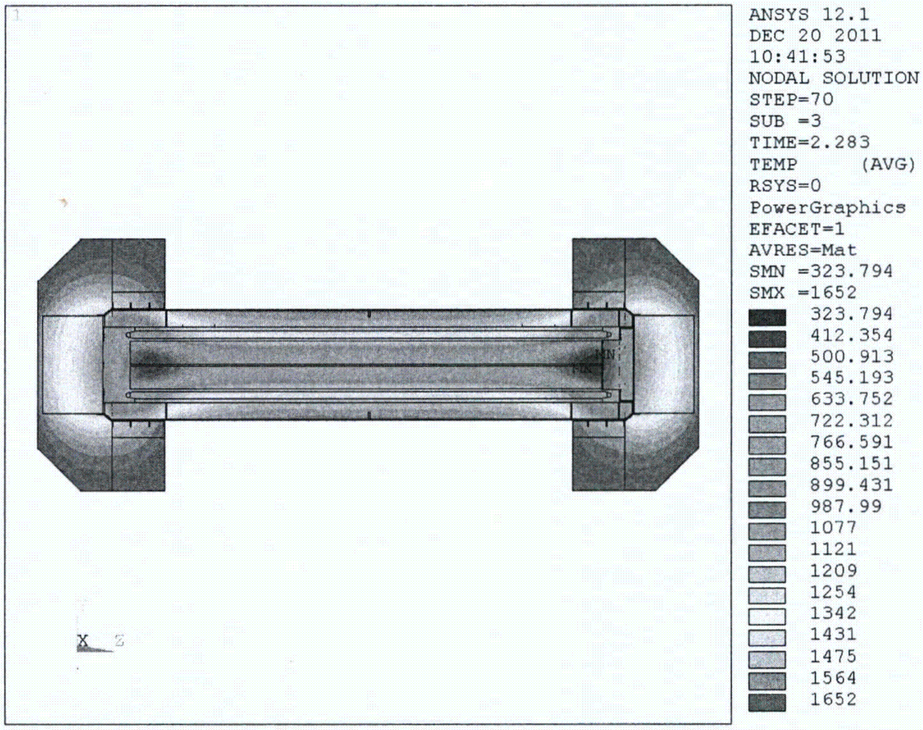


Fig. 8. Temperature distribution Predicted with ANSYS model for the GA-4 Package at end of fire (108 minutes), after Post-collapse 900°C (1652°F) Fully Engulfing Fire

The peak clad temperature predictions obtained with the COBRA-SFS model in the MacArthur Maze fire are shown in Figure 9. The peak cladding temperature predicted with the ANSYS model slightly exceeds the maximum temperature curve predicted with the COBRA-SFS model, due to the more conservative homogeneous k-effective model for the fuel region used in the ANSYS model. The maximum peak cladding temperature predicted with the COBRA-SFS model occurs at the end of the rod, where the steel base of the package is exposed directly to the fire. Without the thermal insulation provided by the impact limiter, the fuel cladding temperature is predicted to exceed the short-term limit of 570°C (1058°F) by about 58 minutes. By the end of the fire, the maximum peak fuel cladding temperature predicted with both models is approaching 750°C (1382°F), the assumed Zircaloy burst temperature in previous transportation studies [12]. The mid-plane peak fuel cladding temperature predicted with the COBRA-SFS model is not far behind, at 675°C (1248°F).

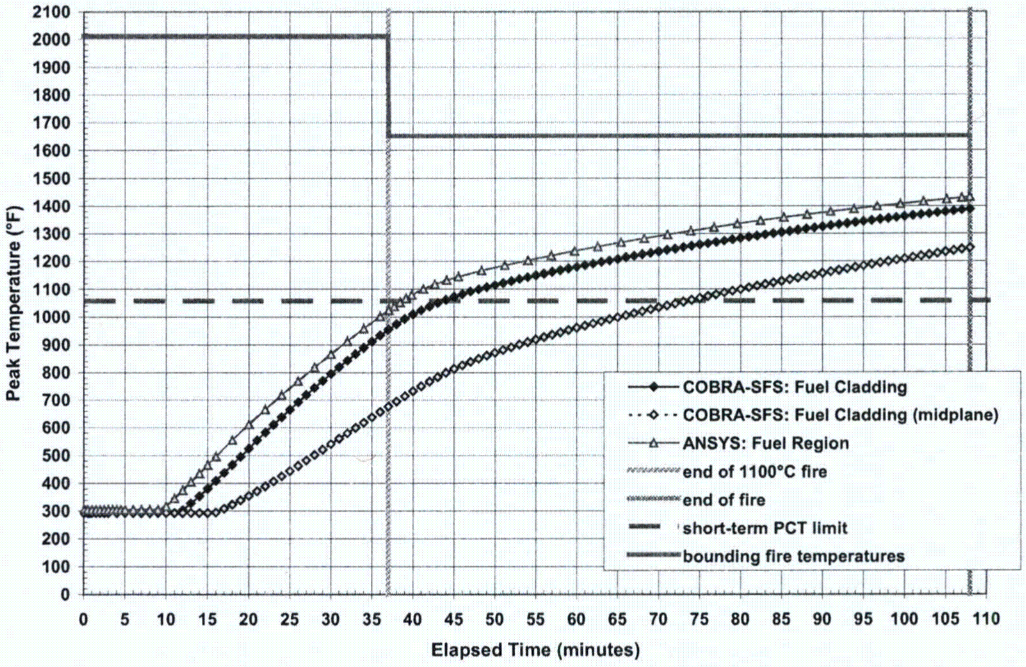


Fig. 9. Peak clad temperature predictions with ANSYS and COBRA-SFS models for the complete MacArthur Maze fire scenario

The effect of the impact limiters on the thermal response of the package is to restrict the most severe temperature rise in the fuel region to the middle section of the package. After the fire, the impact limiters insulate the ends of the package and the fuel rod ends continue to increase in temperature for several hours after the end of the fire. Preliminary results show that the peak fuel cladding temperatures predicted with both models continue to rise for several hours after the end of the fire, due to the decay heat load within the package that is not removed during the fire and is removed only at a rate much below the required design rate during the post-fire cooldown. In the MacArthur Maze fire scenario, the cooldown rate is further slowed by the assumption that the SNF package is buried under the fallen span of the upper roadway. The peak clad temperature predictions for the cooldown portion of the transient are illustrated in Figure 10.

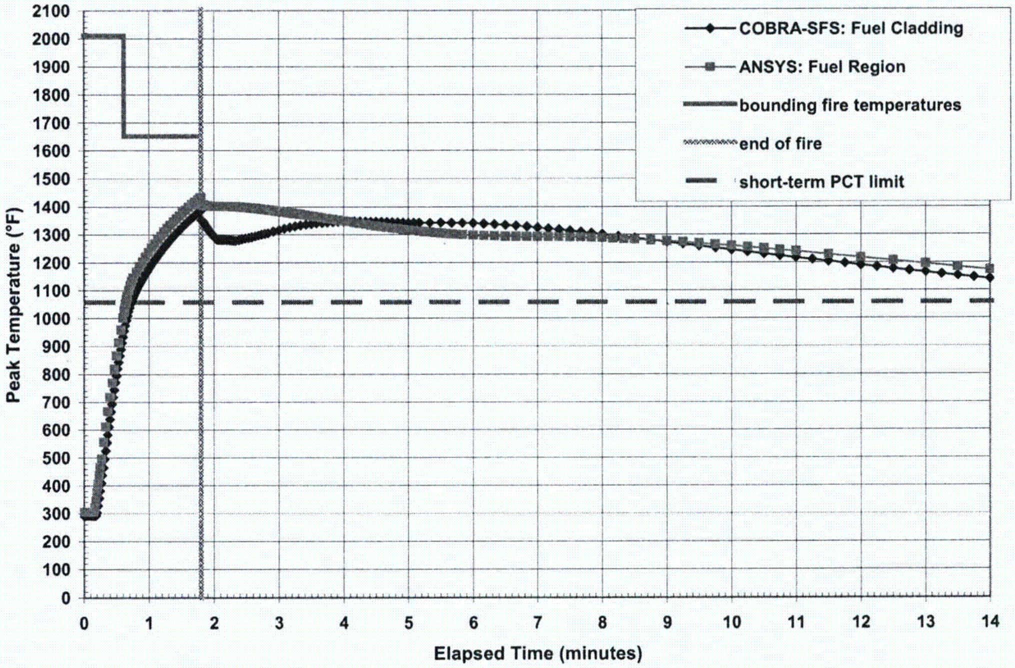


Fig. 10. Peak clad temperature predictions with ANSYS and COBRA-SFS models for the MacArthur Maze fire scenario to 14 hours

To evaluate the potential for fuel rod failure at the temperatures predicted in this fire scenario, a detailed analysis was performed with FRAPTRAN1.4 [13], a fuel performance code for calculating LWR fuel rod behavior in severe transient conditions. FRAPTRAN evaluates burst rupture using a burst stress/strain model developed from test data obtained for LOCA analyses. Spent fuel rods can fail by burst rupture, but creep rupture is considered a possible alternative mechanism of failure. To evaluate this possibility, an additional analysis was performed using the FRAPCON code [14] in conjunction with the DATING code [15], to apply a creep rupture model using the temperatures predicted for the MacArthur Maze fire scenario.

Based on the burst strain model, the fuel rods are expected to rupture before the end of the fire. The FRAPTRAN1.4 model predicts that rod ballooning initiates at 558°C (1037°F), with rod burst rupture at 592°C (1097°F). The creep rupture model also predicts that the fuel rods would begin rupturing before the end of the fire, when the clad temperature reaches 665°C (1229°F). Furthermore, the thermal models predict that the peak cladding temperature remains significantly above these rupture temperatures for more than ten hours, due to thermal inertia and build-up of decay heat that is not removed from the package during and immediately following the fire. By 4.2 hours (2.37 hours after the end of the fire), the peak temperature on every rod in the package exceeds the highest temperature predicted for cladding rupture (665°C (1229°F)).

Evaluation of the potential consequences of the hypothetical involvement of the GA-4 package in this severe accident scenario is in progress. This work involves evaluation of package integrity during the fire, and the potential for release of radioactive material from the package.

Preliminary Results of Structural Analysis with LS-Dyna

The I-580 roadway is modeled in LS-Dyna [16] as a deformable impact object for the analyses of the potential effects of the upper roadway dropping onto the GA-4 package. The model of the span between Bent 19 and Bent 20 was constructed using the original plate girder design drawings. The plate girders are the most important components of the overpass system for the impact modeling because under the most damaging assumptions they are expected to contact the package body directly. The concrete and rebar structure of the I-580 roadway is simply modeled as a homogenized elastic material with a low modulus of elasticity. The falling span was subjected to a constant gravity acceleration and an initial velocity based on the maximum vertical clearance between the cask body and the underside of the overpass girders at a given location. A number of cask locations and orientations were analyzed in an effort to cover the worst-case drop scenario, so each case had a slightly different impact velocity. The cask was always placed at a point on the I-880 road surface and the I-580 overpass section always fell straight down.

The sequence of events in this accident scenario is the reverse of the postulated order of a package drop followed by a fully engulfing fire, as specified in 10CFR71 (see Ref. 1). In contrast to the prescribed package drop scenario, which occurs at normal ambient temperatures, the temperature distribution on the I-580 overpass in the MacArthur Maze fire scenario is a key factor in determining the potential severity of the impact with the package. The stiffness of the girders, and therefore the magnitude of the force that can be imparted to the SNF package by the drop impact, is primarily a function of the girder temperatures. A conservative estimate of 982°C (1800°F) was obtained for the girder temperatures in the drop scenario, based on the material data analyses discussed above, and thermal modeling of the effect of the fire on the girder temperatures at the time of the complete collapse of the first overhead span at 17 minutes into the fire. This value was applied uniformly along the axial length of the steel girders for the drop calculation.

The position assumed for the SNF package beneath the falling upper roadway has a significant influence on the potential damage to the package, and a range of possible orientations of the package on the lower roadway was investigated. These included (1) orienting the package perpendicular to the axis of the girders so that the main impact was across the center of the package, (2) orienting the package parallel to the axis of the girders so that one girder would strike the cask along its full axial length, (3) orienting the package such that the main impact would be localized on the package closure, and (4) orienting the package such that the girder impact is localized on one of the trunnions. The structural model of the package excluded the impact limiters and the thin neutron shield shell on the outer surface of the package, as these components were considered superficial to the overall structural integrity of the package containment boundary. The bolted lid and flange end was represented as continuous material instead of modeling the lid and bolts as separate components. After the preliminary set of impact evaluations, it was determined that a more realistic representation of the bolted flange area was not necessary for the purposes of this study.

The results of these analyses showed that the steel plate girders of the overhead roadway would undergo significant plastic strains and therefore tend to deform under the impact, while the SNF package would be relatively unaffected by the impact force. Limited plastic strains are predicted in the package wall and the depleted uranium (DU) gamma shield; however, these strains are substantially less than those predicted for the girders. Figure 11 shows the geometry of the perpendicular impact scenario, and the deformation of the girders is clearly visible in the graphic (the overpass concrete has been removed from this image, for clarity).

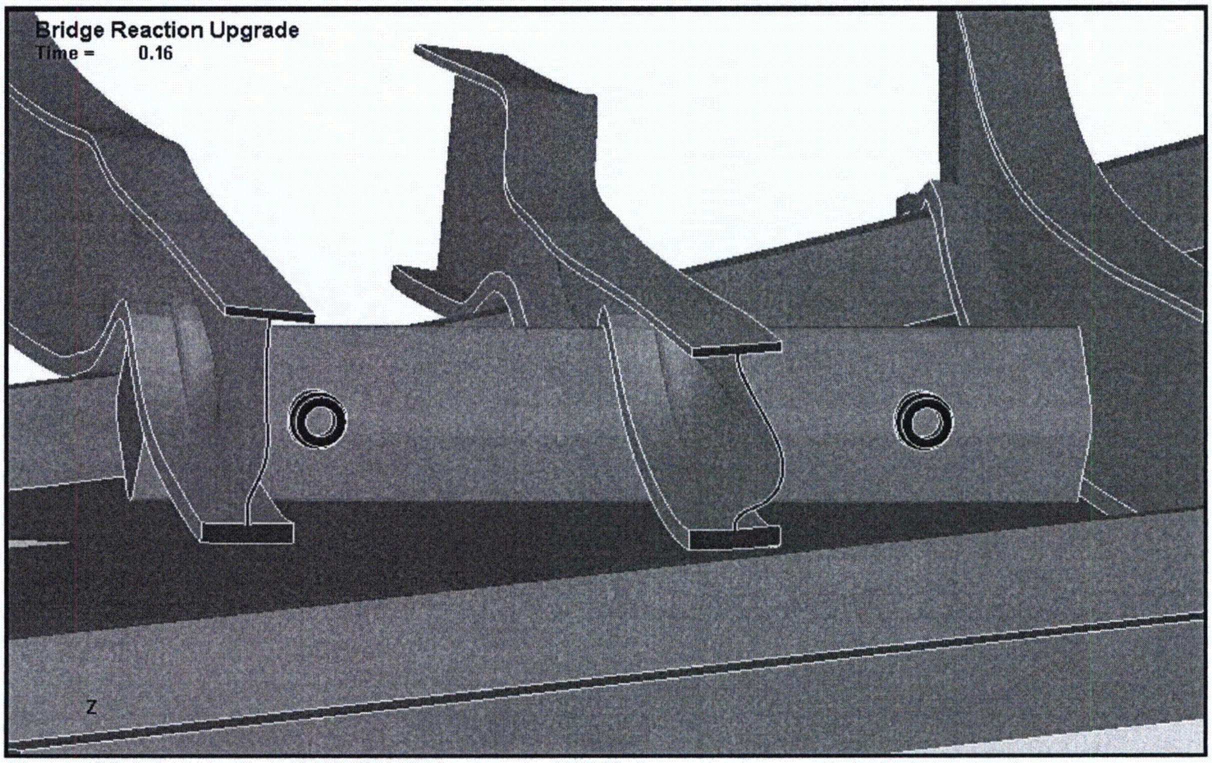


Fig. 11. Predicted Deformation of I-580 Span after Impact; Package Oriented Perpendicular to Girders

Of the cases evaluated, the most severe effects on the package were obtained with the package oriented parallel to the axis of the girders. Figure 12 shows contours of effective plastic strain on the package body (local mesh and girder deformation images added to the standard LS-DYNA contour plot, as supplemental information.) One location at the bottom end of the cask experiences localized plastic strains of about 10%. At this combination of temperature and strain rate, the expected plastic strain limit is beyond 30%. This level of localized plastic strain is not expected to be a challenge to the structural integrity of the containment boundary, but the location of the plastic deformation near the bolted closure lid requires additional consideration. The closure end is represented as solid material which envelopes a region that includes a lid, bolts, and two O-ring seals. The impact model results suggest that, when actual cask geometry is considered, local deformation of the flange lip could potentially contact the side of the lid and transfer a transverse mechanical shock load to the lid. This shock load is not expected to cause structural damage, but is considered in the ongoing assessment of the potential consequences of this accident scenario.

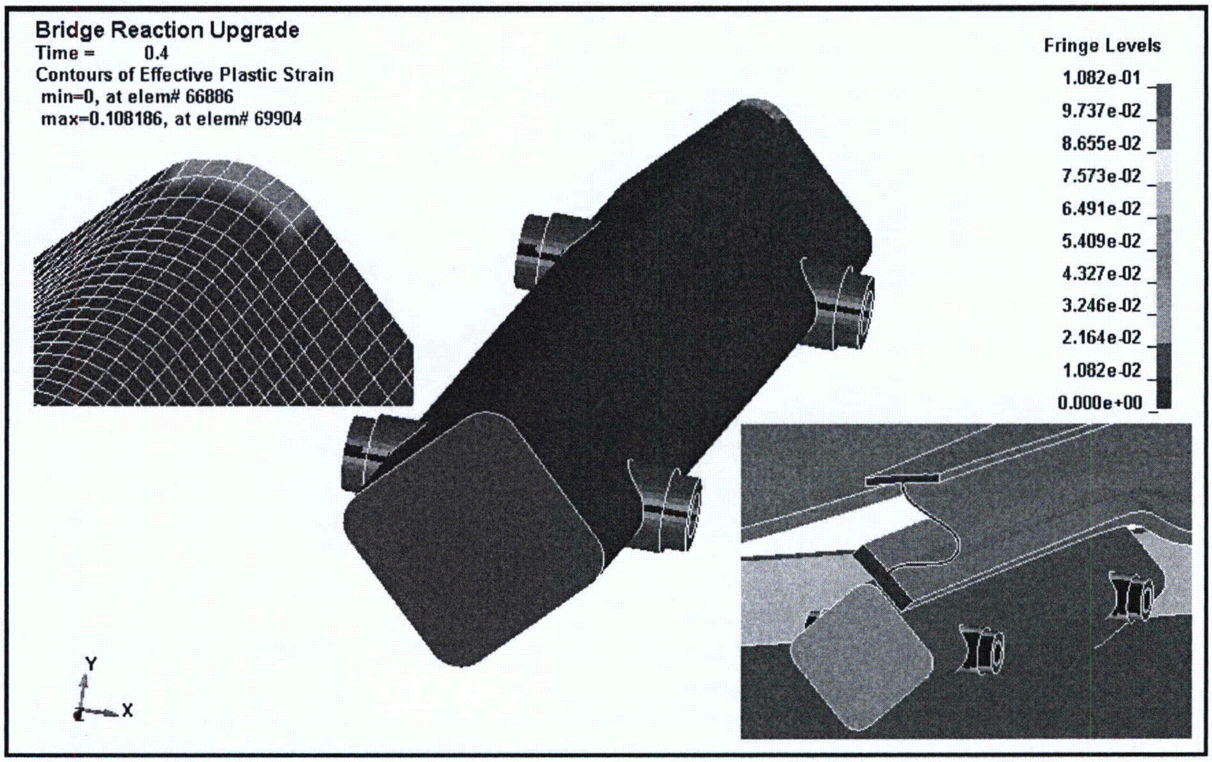


Fig. 12. Plastic Strain in SNF Package Body after I-580 Span Impact in Parallel Orientation. (Local mesh and girder deformation superimposed on contour plot.)

Preliminary Results of Bolt Evaluation

Thermal expansion stresses in the closure bolts and impact limiter bolts were both evaluated at the predicted extra-regulatory temperatures. The GA-4 design uses stainless steel threaded inserts in both bolt types to protect against thread galling. At these predicted extra-regulatory fire temperatures, the threaded inserts tended to be the weakest link in the connection between the nickel alloy bolts and the XM-19 stainless steel of the cask. It was determined that the thermal expansion in the impact limiter bolts is expected to cause yielding in the threaded inserts, but the bolt shank would begin to yield and release tension before failure of the insert could occur. At worst, this would allow some release of bolt tension and loosen the connection of the impact limiter to the cask, but it is not credible to assume that the impact limiter attachment could be lost. This finding is critical to the closure bolts, which are expected to maintain their attachment throughout the fire when the impact limiters are present, but could reach compromising temperatures in the closure region if the thermal protection of the impact limiters was lost. With impact limiters attached, the closure bolt threaded inserts are expected to remain in the elastic shear stress region throughout the collapse of the overpass until the end of the 108 minute fire, by which time they are expected to exceed the insert yield strength and release some amount of the increased bolt tension. This response at the closure is being considered in the ongoing assessment of the potential consequences of this hypothetical accident scenario.

The MacArthur Maze Fire: Thermal and Structural Analysis Conclusions

The detailed thermal models of the MacArthur Maze fire scenario with ANSYS and COBRA-SFS have produced preliminary results indicating that in a fire of this severity, the peak fuel cladding temperature would almost certainly exceed the short-term limit of 570°C (1058°F), and

would likely exceed the Zircaloy burst temperature limit of 750°C (1382°F) assumed in previous transportation studies [12]. Additional work is needed to refine and verify some of the details of these complex models, but the overall results are consistent with previous fire analyses with similar models, and with the results obtained for the HAC fire evaluations with these models. These results as well as future results produced by these models can therefore be considered as reliable estimates of the temperatures that would be experienced in fire conditions of the severity of the MacArthur Maze fire scenario.

The structural analyses show that the GA-4 package is robust enough to withstand the impact of the overhead span without suffering major damage or deformation to the containment boundary. The greatest potential for local package damage in this scenario appears to be at the bolted closure end.. The thermal expansion response of the closure bolts and impact limiter attachment bolts were evaluated in a separate analysis, and it was determined that both the lid and impact limiters are expected to remain in place. The response of the closure seal is currently being evaluated separately in the context of the accident's overall potential to release radioactive material in the environment.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance provided by Dr. Kevin McGrattan of the National Institute of Standards and Technology on the fire models described in this paper.

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ANALYSES OF ACCIDENT CONSEQUENCES AND TERRORISM AGAINST SPENT FUEL SHIPMENTS

Fire Durations of Concern for Legal Weight Truck Packages with Different Placements Relative to a 7.2-m-diameter Pool Fire

Miles Greiner, Professor, greiner@unr.edu
Narayana Rao Chalasani, Graduate Research Assistant
Mechanical Engineering Department
University of Nevada, Reno
Reno, NV 89557

Background

Large packages that transport significant (Type B) quantities of radioactive materials must be qualified to withstand a 30-minute fully engulfing pool fire without significant release of their contents. Regulations describing these tests are contained in Title 10, Part 71 of the Code of Federal Regulations, known as 10CFR71 [U.S. Nuclear Regulatory Commission, 2000]. The regulations specify that a transport package under test must be suspended one meter above a hydrocarbon fuel pool, and that the pool must extend horizontally between 1 and 3 m beyond the object. Moreover, the wind conditions must be sufficiently calm so that the object is engulfed in a fire environment characterized by a temperature of at least 800°C and emissivity of at least 0.9 for 30 minutes.

The regulatory conditions are more severe than 99.4% of all transportation accidents [Fischer et al. 1987]. However risk assessment studies must consider both larger and smaller fires since a wide variety of accidents are possible during a transportation campaign [Sprung et al. 2000].

The results of package response simulations are somewhat dependent on the fire model employed in the calculations. The 10CRF71 regulations describe a simple fire model that employs an 800^0C fire temperature and an effective thermal radiation emissivity of 0.9. This model does not include effects that winds or the package itself has on the fire.

The three-dimensional Container Analysis Fire Environment (CAFE-3D) computer code was developed at Sandia National Laboratories to estimate the response of massive nuclear waste transport packages to large fires [Lopez et al. 2003]. CAFE-3D links the Isis-3D computational fluid dynamics/radiation heat transfer fire model to commercial finite element (FE) computer codes such as PATRAN or Ansys. Isis-3D calculates the fire behavior and heat transfer from a fire to the package. The FE code calculates the response of the package to the heat transfer.

Isis-3D uses a number of reaction chemistry, fuel evaporation and radiation heat transfer models. These models are physics based but are semi-empiric because they employ parameters whose

values are based on experimental data. Are, Greiner and Suo-Anttila [2004] recently determined the values of some of these parameters by comparing CAFE-3D results with experimental data acquired in a large-scale fire test performed by Kramer et al. [2003]. In that experiment, a pipe calorimeter, which was roughly the same size as a legal weight truck package, was suspended in a 7.2-m-diameter, 30-minute hydrocarbon pool fire. The configuration of that test was similar to the 10CFR71 regulatory conditions.

Recent CAFE-3D simulations estimated the time for a fire to bring the temperatures of the containment seal, gamma shield and fuel within a generic truck package to their respective temperatures of concern [Greiner et al. 2004a]. That study considered sub-regulatory-sized fires and a package placed at ground level.

The radiation heat transfer model within CAFE-3D was improved after the Are et al. [2004] work was completed. The effect of that change on the predicted response of an object in a fire had not been investigated before the current work.

The current work has two phases. In the first simulations are performed using the new version of CAFE-3D. Those calculations simulate the conditions of the large-scale calorimeter fire test performed by Kramer et al. [2003]. These simulations employ some of the model parameter values determined by Are et al. [2004]. The new-CAFE simulation results are compared to the experimental data, the results of the earlier simulation that used the old version of CAFE-3D, and to simulations that used the simplified fire model specified in 10CFR71.

In the second phase the new version of CAFE-3D is used to simulate the response of a generic legal weight truck package to three-hour fires from a 7.2-m-diameter hydrocarbon fuel pool. First, a finite element model of the package is constructed. Simulations are performed with the package suspended 1.07 m over the center of the fuel pool, and for the package offset horizontally from that location by 1 and 2.5 m. Simulations are performed for normal conditions of transport, fire, and post-fire conditions for an intact package. For each configuration, the fire duration of concern for the seal, which is the minimum duration that causes the containment seal to reach its temperature of concern, is estimated. Pre-fire damage in severe accidents may limit the thermal protection provided by the impact limiter to the seal. The simulations are repeated for a package whose impact limiters are completely removed. These no-impact-limiter simulations are intended to represent the most severe loss of protection provided by the impact limiter that can result from a severe pre-fire accident.

CAFE-3D Benchmark

Large Scale Calorimeter Fire Tests Two fire tests were performed at Sandia National Laboratories in August 2000 (Fig. 1) [Kramer et al. 2003]. These tests were designed to acquire data to adjust and benchmark CAFE-3D. This section describes the conditions of the second of those tests and the ambient wind conditions.

Figure 1b shows a carbon steel pipe calorimeter suspended 1-m above the center of a 7.2-m-diameter pool of JP8 fuel before the test (the fuel was floating on a 1-m deep water pool, and it was contained to form a circle by a sheet metal dam). The calorimeter diameter, length and wall thickness were 4 ft, 15 ft and 1 inch, respectively, and it had 1 inch thick caps on each end. It

was roughly the size of a legal weight truck package. The fuel pool size and location of the calorimeter were designed to comply with the conditions specified in the 10CFR71 regulations.

Figure 2 shows plan views of the test facility. The calorimeter interior temperature was measured at 47 locations on four rings, shown in Fig. 2b. The test facility was surrounded by a series of wind fences. There were gaps between these fences to allow the natural indraft of air toward the fire, but reduce the effect of wind. The wind speed and direction was measured outside the barriers. Figures 3a and 3b show the wind speed and direction measured during the test at the location shown in Fig. 2a. During the first 17 minutes of the test the wind blew toward the northwest with an average speed of 1 m/s (2.2 mi/hr). The wind speed was low between t = 17 and 27 min. After that time it blew toward the east with increasing speed.

Benchmark Simulations Figure 4 shows a finite element thermal model of the pipe calorimeter. It has the same dimensions and material properties as those measured for the experiment calorimeter. It was created using the PATRAN commercial finite element package.

Figure 5 shows the Isis-3D computational domain used to model the benchmark fire experiment. The measured wind conditions presented in Figure 3 were applied to the side boundaries of this domain. The calorimeter outer surface, the fuel pool and a wind fence model are included within the Isis-3D domain. CAFE-3D links the calorimeter exterior surface in the Isis-3D domain (Fig. 5) to the outer surface of the finite element model in Fig. 4. The finite element model calculates the response of the calorimeter to the fire heat flux.

A large fraction of the heat transfer from a fire to an object takes place at locations where the package surface is in direct contact with the fire volume. This fire volume moves with time due to ambient winds and fire puffing motion. The fire volume is characterized by large volume fractions of hot, thermally radiating soot particles.

Isis-3D defines the fire volume as regions of the computational domain where the soot volume fraction f_{Soot} is greater than a user specified value, $f_{Soot,Min}$. While this is a physical model, it is semi-empirical since an appropriate value of $f_{Soot,Min}$ must be determined. In order to do this, several simulations of a 7.2-m diameter pool fire were performed using the old version of CAFE-3D and different values of $f_{Soot,Min}$ [Are et al. 2004]. The fire volumes calculated in these simulations decreased as $f_{Soot,Min}$ increased. Figure 6 shows the average fire surface temperature versus time from these simulations. These temperatures remained fairly steady 6 seconds after the fires were initiated. We see that the steady state surface temperature increases with $f_{Soot,Min}$. A dashed line in Fig. 6 show the expected surface temperature of a 7.2-m diameter fire based on data presented in the Society of Fire Protection Engineering Handbook [1995]. Are et al. [2004] used the value $f_{Soot,Min} = 0.4$ ppm (0.4×10^{-6}) to calculate fire behavior.

The total heat transfer to the calorimeter is dependent on amount of its surface engulfed in flames. This portion is dependent on the winds present during the fire and the resistance to the wind (drag) supplied by the wind fences. Simulations were performed using the old version of CAFE-3D and several values of the fence drag coefficient C_d [Are et al. 2004]. The average temperature at the location of all 47 thermocouples was calculated as a function of time from these simulations.

Figure 7 shows the average temperature rise (the difference between the average temperature at a given time and that at the start of the fire) versus time. Results are presented for the experimental measurement, a simulation using the old version of CAFE-3D with $C_d = 1.55$ and $f_{Soot,Min} = 0.4$ ppm, a simulation using the new version with $C_d = 1.55$ and $f_{Soot,Min} = 0.5$ ppm, and a simulation using the simplified fire model specified in 10CFR71. The simulation results from the old version of CAFE-3D agree with the experiment. The results from the new version and from the 10CFR71 fire model exhibit a smaller average temperature rise (less energy transfer from the fire to the calorimeter). Figure 8 shows a snapshot of the CAFE-3D fire engulfing the pipe calorimeter. In the next section the parameter values $f_{Soot,Min} = 0.5$ ppm and $C_d = 1.55$ are used with the *new* version of CAFE-3D to simulate the response of a generic truck package to 7.2-m diameter fires.

Package Response Simulations

Package Model Figure 9 shows three-dimensional views of the finite element (FE) models of intact and no-impact-limiter versions of a generic legal weight truck package. The intact package dimensions and material properties are similar but not identical to those of a currently licensed package [NAC International 2000].

Figures 10 and 11 show axial and cross sectional slices through the package models. The exterior dimensions are indicated in centimeters. The locations of the cross section slices are shown in Figs. 10a and 11a as section AA. Regions in these figures are colored according to their material.

The innermost cylinder with outer radius 8.5 cm and length 3.66 m represents the spent fuel payload. Its sides are surrounded by an aluminum basket with inner radius 12.7 cm and thickness of 4.1 cm. The gap on the sides and ends of the fuel are filled with air. A stainless steel containment vessel surrounds these components. The side wall thickness of this vessel is 1.9 cm. The vessel sides are surrounded by a 14.5 cm thick lead gamma shield. A 4.8 cm thick stainless steel cask body surrounds this shield. A 12.7 cm thick neutron shield tank surrounds the outer shell. This tank does not cover a 22.9 cm region on the left-hand-side of the containment vessel. The outer skin of the neutron shield is constructed of 0.7-cm-thick stainless steel.

The neutron shield tank contains a 56% ethylene glycol/water solution during normal conditions of transport before the fire. This tank is assumed to contain air during the fire and post-fire simulations. This is a standard practice for package analysis. We assume that this practice is based on an effort to conservatively over predict the maximum temperatures experience by the package components. However, we have not checked the validity of this assumption for the current work. The outermost region of the main package body is an expansion tank for the neutron shield fluid. The tank is 5.7 cm thick, and its outer skin is constructed of 0.6 cm thick stainless steel.

A spent nuclear fuel assembly is loaded into the package by removing the impact limiter and bolted closure on the left-hand side of Figs. 10a and 11a. The massive stainless steel cylinder on this "closure" end consists of two parts. The first is a circular flange that is permanently attached to the package body. The second is a closure that is bolted to the flange. The axial location of a 45.2-cm-diameter elastomer gasket that seals the interface between the flange and this closure is

shown in Fig. 10a using a dotted line. The cylindrical steel-lead-steel sandwich structure on the right-hand-side of Figs. 10a and 11a is permanently attached to the package body. This structure has a 7.6 cm thick, 52.8 cm diameter cylinder of lead encapsulated in a 26.7 cm thick, 72.6 cm diameter stainless steel cylinder.

Conduction heat transfer within the solid steel, lead and aluminum components and the air employ standard computational methods and material properties [Incropera and DeWitt 1996]. Thermal effects of phase change (heat of fusion) are modeled for the lead gamma shield and the aluminum basket. The possible effects of flowing molten metal are not included. The impact limiters are made of aluminum honeycomb. Honeycomb properties vary significantly depending upon its density and cell configuration. We implemented the honeycomb material properties used in the safety analysis report of a transport package [Westinghouse Electric Company 2000].

The spent fuel region properties are based on one pressurized water reactor (PWR) fuel assembly. This fuel type is chosen because its maximum heat generation rate is 2.5 kW, which is the greatest of any payload considered in the NAC LWT transport package Safety Analysis Report [NAC International 2000].

Under steady and quasi-steady state conditions, heat generated within the spent fuel assembly elevates its cladding temperature above that of the surrounding basket structure. This temperature rise is dependent on the rate at which heat is generated, and the thermal transport properties of the fuel assembly and backfill gas region. The transport properties are affected by both thermal radiation and natural convection. The radiative properties depend on the emissivity of the fuel cladding and basket walls, and the geometric configuration of the fuel pins. The backfill gas thermal properties and pressure as well as the fuel pin geometric configuration affect natural convection.

A highly simplified method for evaluating the temperature within the fuel/backfill gas region is employed in this work. The fuel region is modeled as a homogenous cylinder whose dimensions are similar to that of a pressurized water reactor (PWR) fuel assembly. The volume fractions of fuel, cladding and air within the fuel/backfill gas region were calculated. The effective density, specific heat and thermal conductivity for the cylinder are volume fraction averages of these three components. The total fuel heat generation rate is applied uniformly throughout the cylindrical volume.

The volume-averaged properties model some aspects of conduction heat transfer in the fuel/backfill-gas region. It is not currently known if this approach under- or over-predicts the conduction heat transfer rates. However, this analysis completely neglects the effect of natural convection and thermal radiation. Development of an accurate thermal model for spent nuclear fuel is outside the scope of this work. Future analysis is needed to more accurately understand and model heat transfer in this region [Manteufel and Todreas 1994, Bahney and Lotz 1996].

Under normal transport conditions, natural convection heat transfer in the liquid filled neutron shield tank is modeled as conduction using an effective thermal conductivity of 16.17 W/mK [NAC International 2000]. Air fills the gap between the fuel and the aluminum basket. Air also fills the interior of the neutron shield tank during the fire. Heat transfer across these air gaps is modeled as a combination of conduction through stagnant air and view factor radiation from

surface to surface. The emissivity of the fuel region is 0.8, while the emissivity of the metal surfaces is 0.36 [NAC International 2000].

Package Temperatures of Concern In this work the temperature of concern for spent fuel cladding is 866 K (593°C, 1100°F) [Office of Civilian Radioactive Waste Management, 1993] and for the elastomer seal is 664 K (391°C, 735°F) [NAC International 2000]. The temperatures of concern for the lead gamma shield and aluminum basket were 601 K (328°C, 662°F) and 855 K (582°C, 1080°F), respectively. These temperatures are the melting points of the component materials [Incropera and DeWitt, 1996]. The properties of the gamma shield, basket, fuel cladding and seal are known to change at their temperatures of concern. This paper does not evaluate whether or not these property changes affect the performance of a component. Moreover, packages generally employ multiple components for containment, criticality and shielding safety. This paper does not evaluate whether or not malfunction of a single component affects the performance of the entire package system.

Pre-Fire/Fire/Post-Fire Simulation Sequence Steady state simulations of the normal conditions of transport are performed first to determine the package temperature distribution before the fire. The 10CFR71 regulations specify that under these conditions, the package receives 193.8 W/m^2 of insolation, and transfers heat to a 38°C surrounding by radiation and natural convection. The package outer surface emissivity is assumed to be 0.36 [NAC International 2000]. Under these conditions heat generated within the spent fuel causes the interior components to be hotter than the exterior ones.

The pre-fire simulations for the intact version of the package included the impact limiter. The calculations the no-impact limiter version did not. These simulations therefore model situations where the impact limiter was removed long before the fire begins.

The pre-fire simulations were used as initial conditions for the fire simulations. CAFE-3D was used to simulate the response of the package to a 7.2-m-diameter pool fire for fire durations of D = 3 hr = 180 min (six times the regulatory duration). The package temperature distribution at the end of the fire is used as the initial condition for post-fire simulations, which use the normal conditions of transportation environment.

Isis-3D Computational Domain Figure 12 shows portions of the Isis-3D computational domains used for fire simulations. It shows plan views of the package and fuel pool for the six different configurations considered in this work. In all four configures the outer surface of the neutron shield expansion tank is 1.07 m above the fuel pool. Configurations 1, 2 and 3 are for an intact package. In Configuration 1 the package is centered over the fuel pool. In that case, the horizontal offset distance between the center of the package and pool center was Y_{Off} = 0. In Configuration 3 the containment seal is centered over the fire. The center of the package is offset axially from the center of the pool by a distance Y_{Off} = 2.5 m. In Configuration 2 Y_{Off} = 1 m. Configurations 4, 5 and 6 examine the no-impact-limiter version of the package with Y_{Off} = 0, 1 and 2.5 m, respectively.

The same ambient wind conditions and wind fences model (with C_d = 1.55) used in the calorimeter benchmark simulations (Figs. 3 and 5) are employed in the package response simulations. The wind condition time scale is modified so that the 30-minutes of wind data are

applied during the entire 180-minute package response simulation. (Another option would be to re-run the measured wind conditions six times to cover the 180-minute fire simulations. We do not currently know how this would affect the simulation results, but may be considered in future work.)

Fire Surface Figure 13 shows snapshots of the fire surface from simulations of all six configurations. It shows the fire outer surfaces, which are the locations where $f_{Soot} = f_{Soot,Min} =$ 0.5 ppm. These surfaces are colored according to their local temperature. The un-engulfed portions of the package are also visible. The fire surface moved with time during each simulation. However, these surfaces are representative of the fire shape throughout each simulation. When the package is centered over the fuel pool (Configurations 1 and 4) it is almost entirely engulfed in the fire.

Temperature Response Temperatures at several discrete locations within the package are monitored as functions of time during and after the simulated fire. The dots in Figs. 10a and 11a show the locations where the temperature of the fuel center, fuel edge, fuel basket inner surface, gamma shield centerline and the neutron shield cover are reported. All of these temperatures were determined at the mid-plane of the package, roughly halfway between the two ends. In addition to these locations, the temperatures at both sides and the top and bottom of the containment seal are also monitored.

Figures 14 and 15 show the fuel, fuel basket, gamma shield and the neutron shield cover temperatures versus time for a fire of duration D = 3 hours. The intact package results are shown in Fig. 14 while the no-impact-limiter data is in Fig. 15. The temperature of each component is determined at multiple locations. The data presented in Figs. 14 and 15 are the maximum component temperature at any time. Vertical lines show the end of the 3-hr fire.

In Figs. 14 and 15, the neutron shield outer shell temperature rises very rapidly at the beginning of the fire, oscillates with fire motion, and decreases rapidly when the fire is extinguished. The interior components are more thermally massive and further away from the outer surface of the package. They respond more slowly to changes in the fire. The gamma shield and basket temperatures versus time exhibit discontinuities in their slopes during the fire. These discontinuities occur at times when the solid lead gamma shield experiences phase change (melts). Possible effects of flowing lead are not included in these simulations.

The gamma shield, basket, and fuel temperatures reach their maximum temperatures after the fire is extinguished. This is because heat continues to diffuse to the interior components from the hotter exterior regions of the package after the fire is extinguished.

For the intact package (Fig. 14) the interior component temperatures are fairly insensitive to the package offset position, Y_{Off}. This may be because the midplane of the package was mostly engulfed in the fire for all the values of Y_{Off} considered in this work. However, the midplane temperatures were much more sensitive to position for the no-impact-limiter version of the package (Fig. 15). This is particularly evident for Configuration 5. The different behavior of the intact and no-impact-limiter packages is somewhat surprising since the impact limiters do not cover the package midsection. This suggests that the impact limiters affected the simulated fire behavior. We do not know if the difference in fire behavior is physically significant because

CAFE-3D has not been benchmarked against data for dumbbell-shaped objects similar to the intact package.

In Figs. 14 and 15 horizontal line segments show the gamma shield temperature of concern near the time when the shield temperature crosses that threshold. Neither the fuel nor the basket reaches it temperature of concern at the locations where these component temperatures are monitored. However, these results may be somewhat misleading since the temperatures of these components were only monitored at the midplane of the package. We cannot determine if or when these components reach their limit temperatures at other locations. Moreover, we cannot determine what fraction of these components exceeds their temperatures of concern.

Figures 16 and 17 show the predicted maximum seal temperature versus time. The intact package results are shown in Fig. 16 while the no-impact-limiter data is in Fig. 17. The data presented in Figs. 16 and 17 are the maximum seal temperature at any time. The horizontal lines marked $T_{C,Seal} = 391^0C$ show the seal temperature of concern.

The lines marked CAFE-3D, D = 3 hr shows result for a three-hour fire. This fire duration causes the seal to exceed its temperature of concern for all six configurations. The time after the fire begins when the seal temperature first reaches its temperature of concern is defined as the seal time of concern, t_C. This time is shown in the plots with vertical dashed lines. The seal temperatures continue to increase after $t = t_C$, and do not begin to decrease until after the fire is extinguished.

For each configuration the maximum seal temperature is denoted $T_{S,Max}$, and this value is included in the plots. The total time the seal temperature exceeds it temperature of concern is defined as its excess time, Δt_E. The values of $T_{S,Max}$ are significantly larger for the no-impact-limiter package (Fig. 15) than they were for the intact one (Fig. 16). This is not surprising since the impact limiter insulates the seal end of the package and protects it from the fire.

As discussed earlier, the predicted seal response is dependent on the fire model used in the simulation. The seal response was recalculated for the intact and no-impact-limiter packages centered over the fuel pool (Configurations 1 and 4) using the simplified radiation heat transfer fire model specified in 10CFR71. The lines marked 10CFR71, D = 3 hr in Figs. 16a and 17a show these results. For both configurations the maximum seal temperature $T_{S,Max}$ and the excess time Δt_E predicted by 10CFR71 calculations were smaller than they were for the CAFE-3D simulation. This difference was more significant for the no-impact-limiter package than for the intact one. The differences between the seal temperature versus time traces indicate that the CAFE-3D fire transferred more heat to the package than the 10CFR71 fire model.

The fire duration of concern for the seal D_C is defined as the minimum duration that causes the seal to reach its temperature of concern. Fire durations of D = 3 hr causes the seal to exceed its temperature of concern for all six configurations studied in this work. The seal durations of concern for these configurations are therefore less than 3 hrs. In the current work we determine the seal duration of concern using an iterative approach. The lines in Fig. 16 and 17 marked CAFE-3D, $D = D_C$ show the seal temperature versus time for fires with durations equal to the duration of concern. The value of the duration of concern is included in each figure. The

duration of concern is shorter than the time of concern, t_C. This is because the seal temperature continues to rise even after the fire is extinguished.

Seal Performance Versus Location Figure 18a show the maximum seal temperature excess $\Delta T_E = T_{S,Max} - T_{C,Seal}$ versus package offset distance. This value quantifies the maximum amount the seal temperature exceeds it temperature of concern. Figure 18b show the excess time Δt_E versus package offset distance. It quantifies the amount of time the seal spends above its temperature of concern. Solid symbols represent results based on CAFE-3D simulations. The temperature excess and excess time are also calculated for $Y_{Off} = 0$ based on the simplified fire model specified in 10CFR71. These data are presented using open symbols.

For the intact package centered over the pool ($Y_{off} = 0$) the maximum seal temperature exceeds its temperature of concern by $\Delta T_E = 106^0$C, and the seal spends a total of $\Delta t_E = 5.5$ hrs above its temperature of concern. The 10CFR71 calculation gives smaller values of ΔT_E and Δt_E, but they are very close. When the package is offset by $Y_{off} = 1$ and 2.5 m, the temperature excess and excess time both decrease by roughly half to $\Delta T_E = 46^0$C and $\Delta t_E = 3$ hrs. For the intact package heat reaches the seal by conduction through the package body. As Y_{Off} increases the portion of the body engulfed in flames decreases. This decreases the heat transfer to the seal and reduces its temperature response compared to $Y_{off} = 0$.

The temperature excess for the no-impact-limiter package was much larger than it is for the intact package. The excess time for the intact and no-impact-limiter packages is nearly the same when the packages are center over the pool ($Y_{off} = 0$). However, the no-impact limiter package value is larger for $Y_{off} > 0$. These results indicate that the heat transfer to the seal is much larger for the no-impact-limiter package than it is for the intact package. This is because the impact limiter insulates the seal end of the package from the fire.

For the intact package, ΔT_E and Δt_E decrease as Y_{Off} increases. However, we observed the opposite trend for the no-impact-limiter package. When the impact limiter is removed heat is able to conduct directly from the end of the package to the seal. The seal end may be in a hotter region of the fire for $Y_{Off} = 1$ and 2.5 m than for $Y_{Off} = 0$.

Figure 19 shows the fire duration of concern versus offset distance calculated by CAFE-3D for both the intact and no-impact-limiter version of the package. Results from the 10CFR71 fire model are presented for $Y_{Off} = 0$. The results from the CAFE-3D and 10CFR71 models are in fairly good agreement for $Y_{Off} = 0$.

For the intact package the duration of concern is 2.1 hours when it is centered over the fuel pool, and it is higher for $Y_{Off} = 1$ abd 2.5 m. For the no-impact-limiter package centered over the pool, the duration of concern is 0.65 hours. It decreases as Y_{Off} increases. This may be because the seal end moves to hotter locations of the fire. The duration of concern is 3 to 7 times longer for the intact package than it is for the no-impact-limiter version. This difference quantifies the level of thermal protection provided by the impact limiter to the seal end of the package.

For both the intact and the no-impact-limiter packages, we expect D_C to increase with Y_{Off} once Y_{Off} is sufficiently large. This is because the heat transfer from the fire to the package decreases once the package is no longer engulfed in the flames.

Summary

A version of the CAFE-3D computer code with an improved radiation heat transfer model is benchmarked against data from a large fire experiment. A finite element model of an intact legal-weight-truck package is then linked to the CAFE-3D fire model. Simulations of the package response to 7.2-m-diameter, 3-hr hydrocarbon pool fires are performed with the package centered over the pool, and offset axially from that location by 1 and 2.5 m. The containment seal within the package exceeds its temperature of concern for all three package locations. Simulations of a no-impact-limiter version of the package are performed and compared to those for the intact package. This comparison quantifies the level of thermal protection the impact limiter provides to the seal end of the package.

Future Work

A new version of CAFE-3D with an improved fuel evaporation model is currently under development. Improved fuel/backfill gas region heat transfer models are also being developed. Future work may employ these new models to determine the response of the current generic legal weight package.

The current work considers three values of package offset displacement, Y_{Off}. Future work may determine the package response for more values of Y_{Off}. This work may help determine the placement that gives the shortest duration of concern, $D_{C,Min}$. Simulations in which the package is not completely engulfed in the fire may help determine the minimum "safe" distance, $Y_{Off,Safe}$, which is the minimum value of Y_{Off} for which an infinitely long fire would not cause the seal to reach its temperature of concern.

Additional package models may be developed to perform the same analysis for (a) a modern truck package that is capable of transporting four PWR fuel assemblies (based on the GA-4), and (b) a rail package (however, the benchmark fire experiment was performed for a truck package sized object).

Future work should also consider more accurate measurement of the wind conditions and the application of those conditions to the CAFE model.

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(a)

(b)

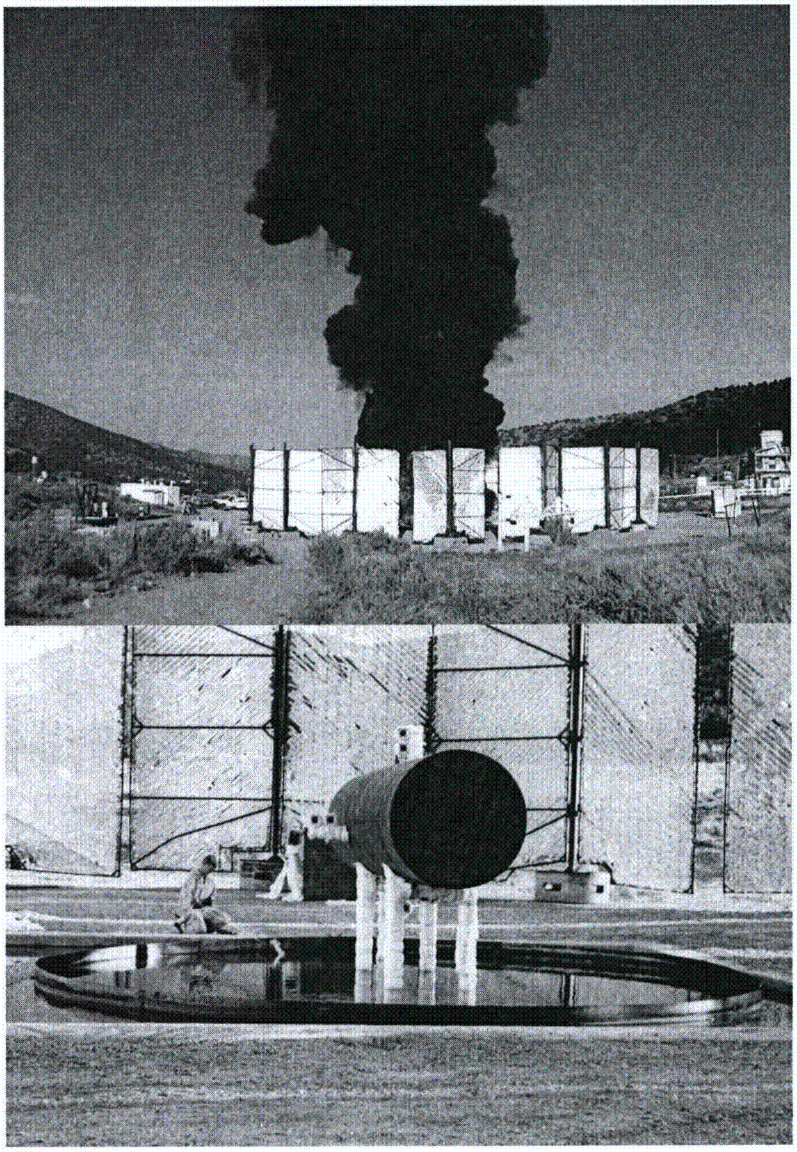
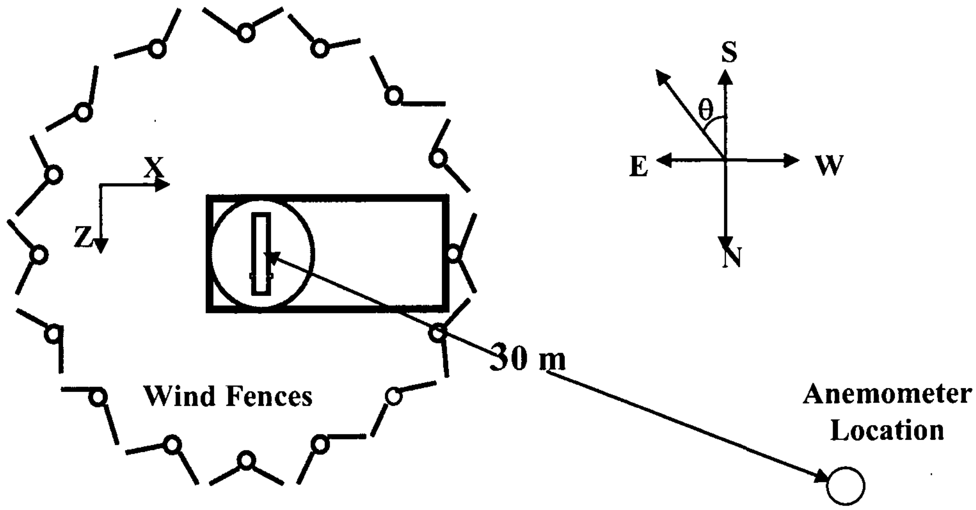


Figure 1 Sandia facility used to acquire fire test data used in the current work to benchmark and adjust the CAFE-3D fire simulation code. (a) Fire test surrounded by wind fences, August 25, 2000. (b) Pipe calorimeter before fire test. During the test, water filled a 1-m-deep basin. A 7.2-m-diameter fuel dam allowed jet fuel that floated on the water to be contained within a circle. Thermocouples inside the calorimeter measured it temperature during the 30-minute fire test.

(a)



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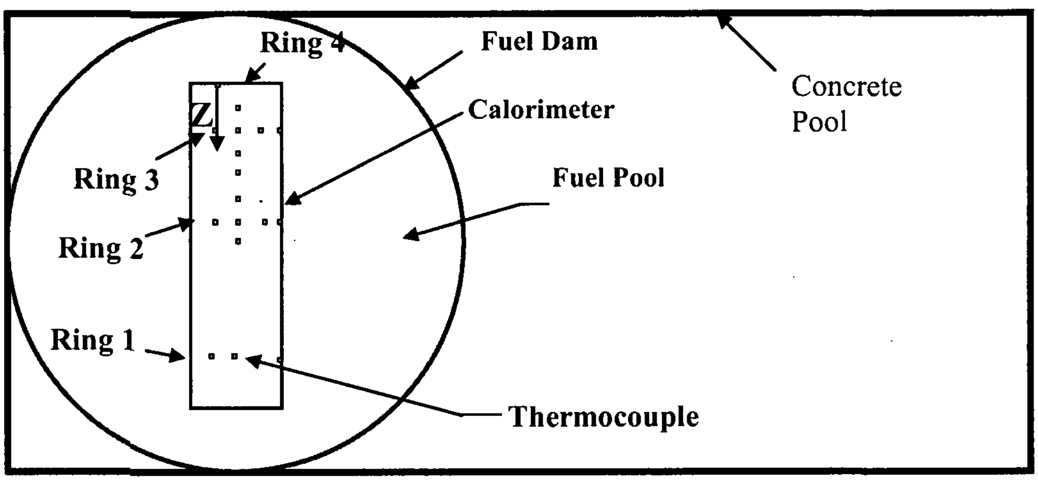


Figure 2 Plan-view of test facility **(a)** wind fences, anemometer location, campus direction, and coordinate system **(b)** pool, calorimeter and thermocouples

(a)

(b)

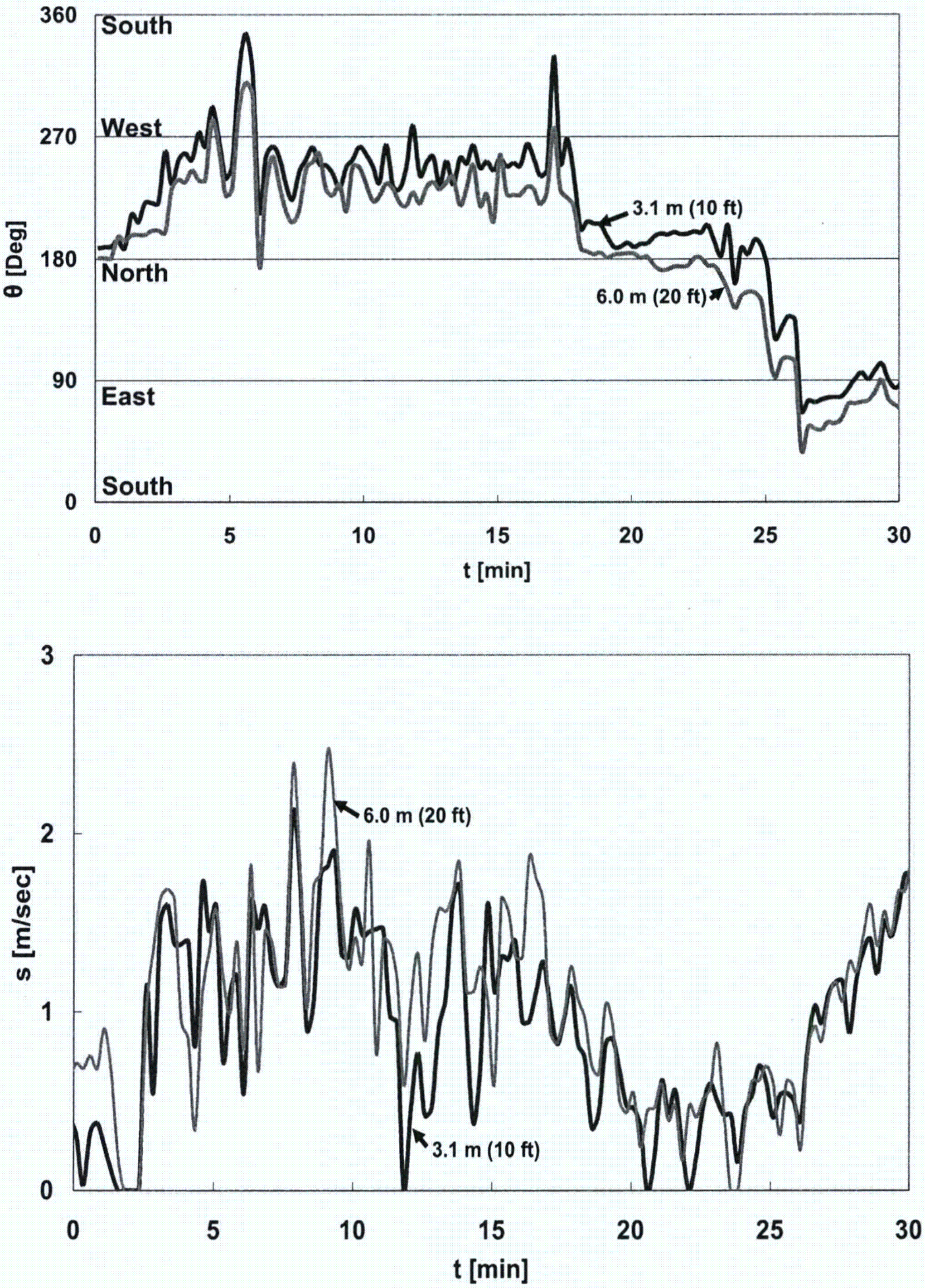


Figure 3 Wind conditions versus time measured by two anemometers during the 30-minute burn period of the experiment. (a) Wind direction (indicates direction to which the wind blew, see Fig. 2a). (b) Wind speed

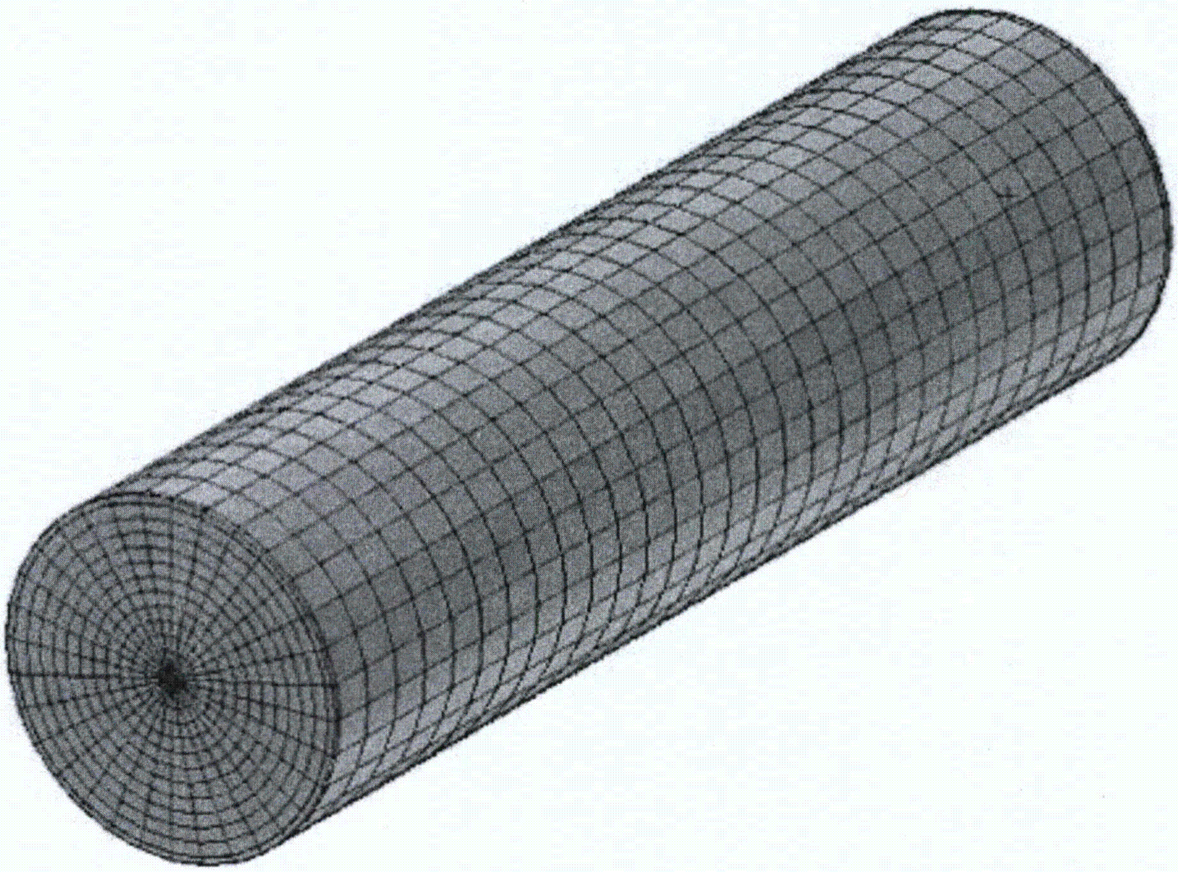


Figure 4 Calorimeter finite element model used for benchmark simulations

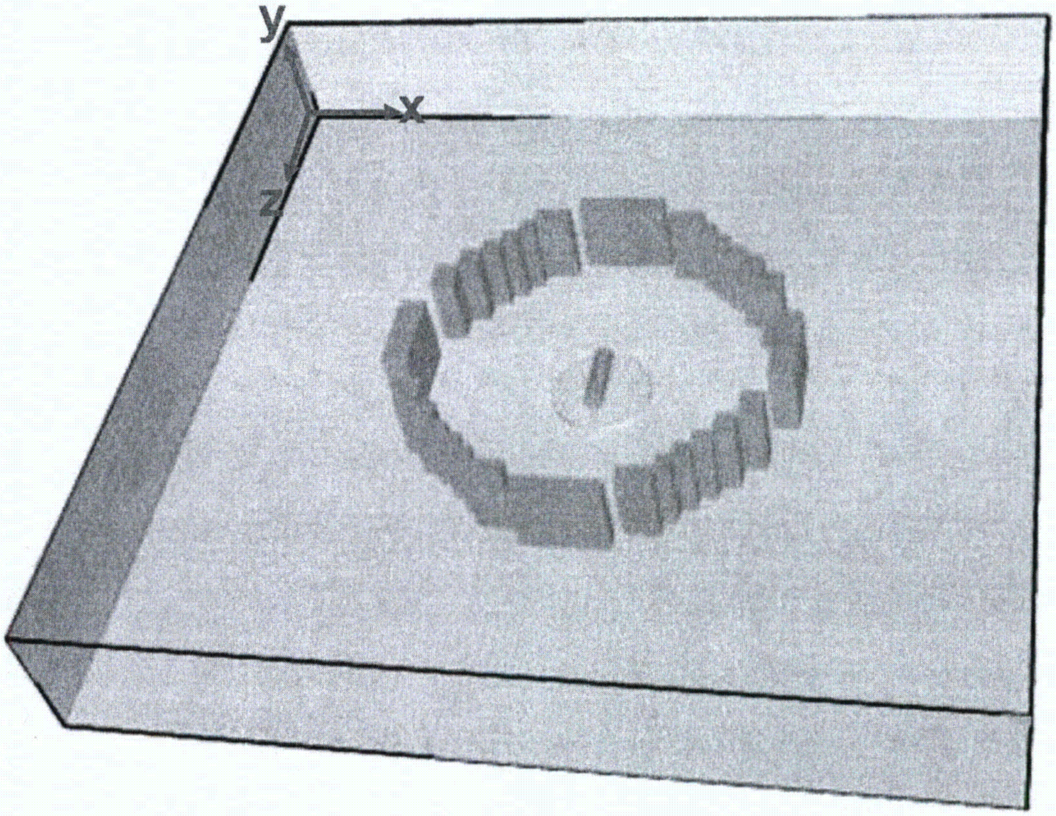


Figure 5 CAFE-3D computational domain used for the benchmark simulations

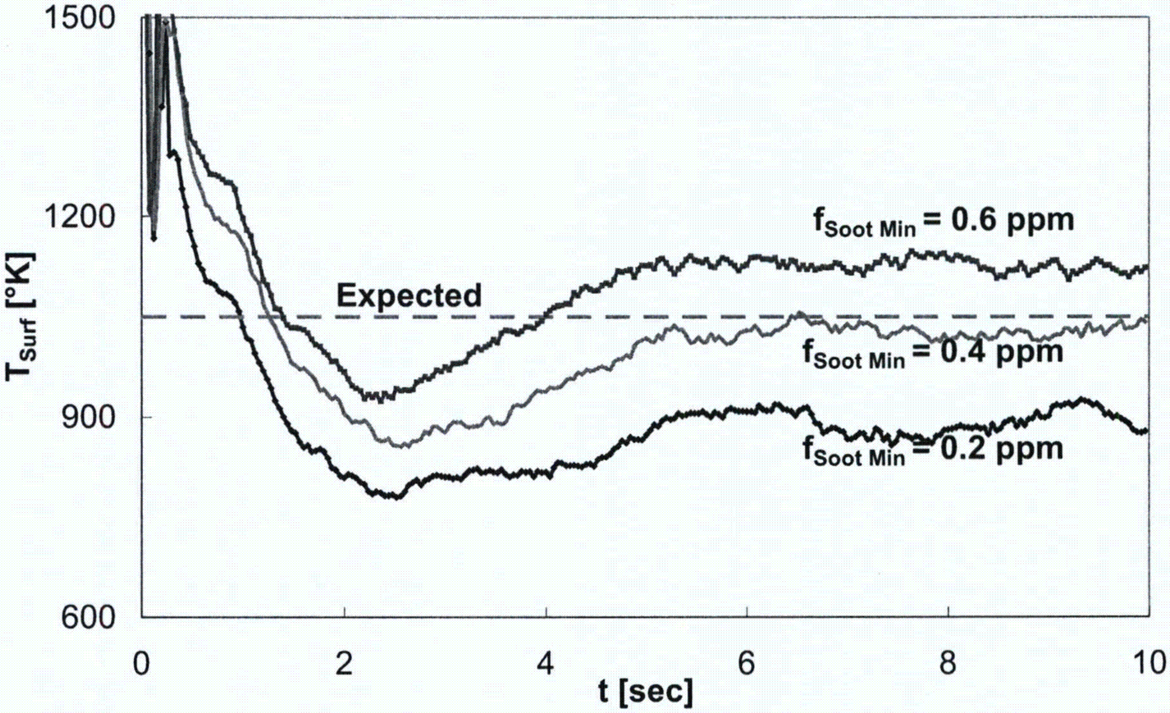


Figure 6 Solid lines: Average fire surface temperature versus time as simulated by the old version of CAFE-3D for different values of the soot volume fraction used to define the edge of the fire zone, $f_{soot,min}$. Dashed line: the expected surface temperature of a 7.2 m diameter fire [Society of Fire protection Engineers 1995]. The value $f_{soot,min}$ = 0.4 ppm was used in the newer version of CAFE-3D to predict the response of a transport package.

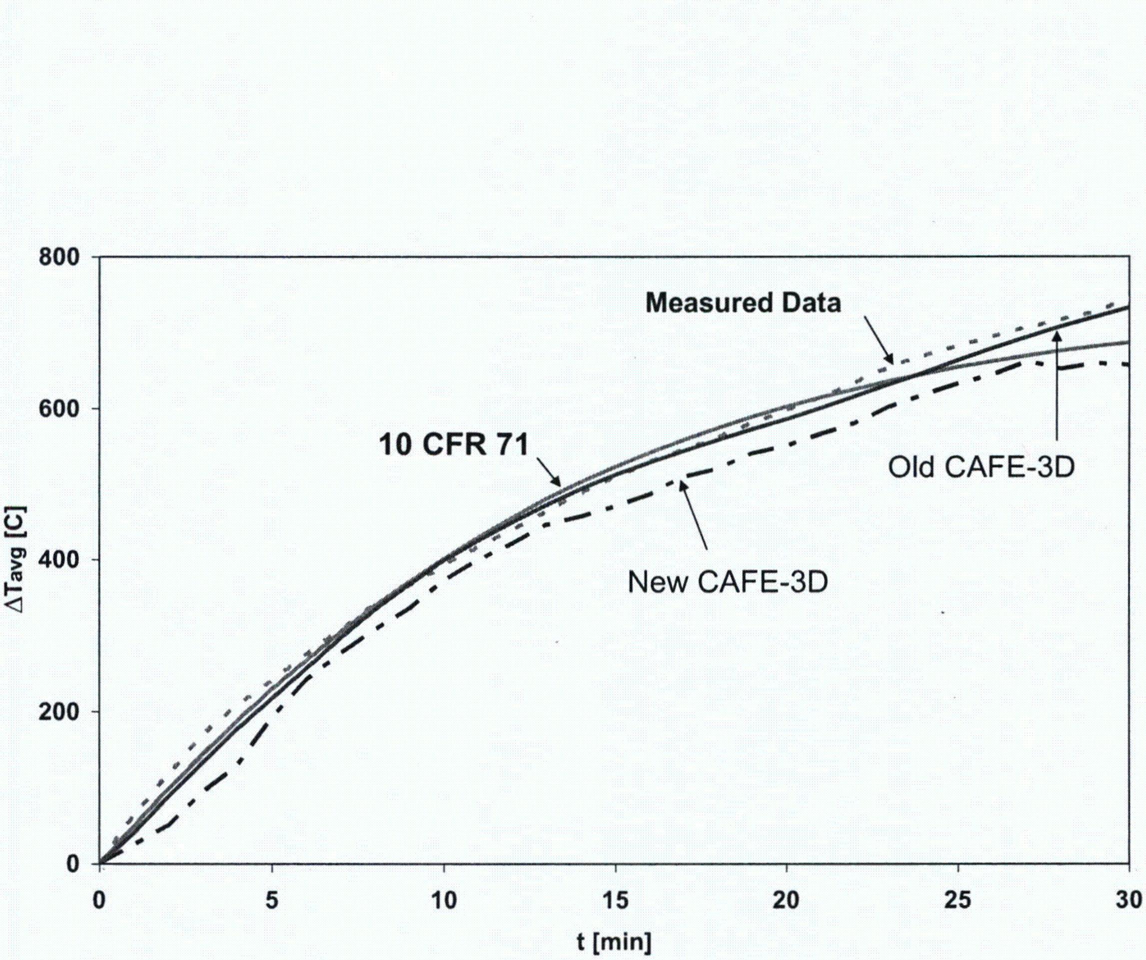


Figure 7 Average thermocouple temperature rise versus time. Results are presented based on experimental data, simulations using the simplified 10CFR71 fire model, and simulations using the new and old version of CAFE-3D. The old version of CAFE-3D accurately reproduced the experimental results. 10CFR71 and the new version of CAFE-3D under predicted the average temperature rise. Ideally, the values of $f_{Soot,Min}$ and C_d used in the new version of CAFE-3D should be adjusted so that it accurately reproduces the expected surface fire surface temperature presented in Fig. 6 and the measured average temperature rise presented in the current figure. This may be done in future work.

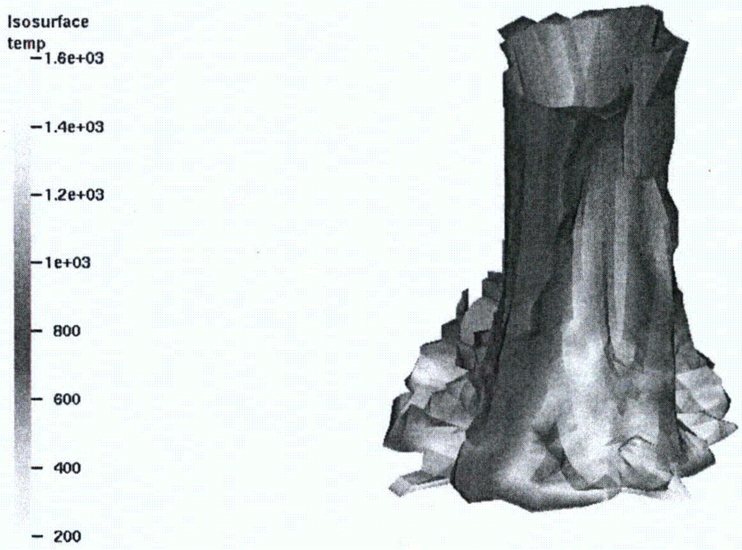
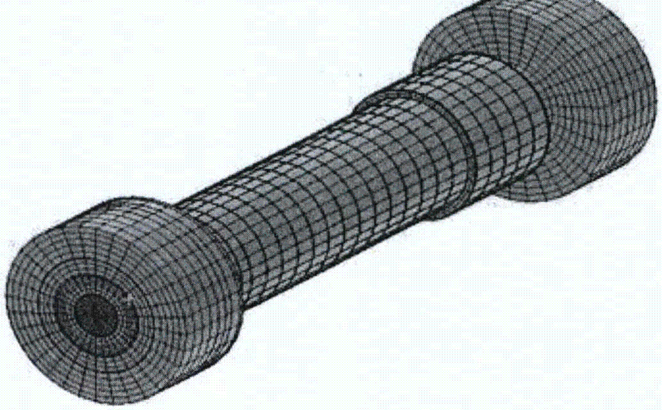


Figure 8 Simulated fire surface ($f_{Soot} = f_{Soot,min} = 0.4$ ppm) at time t = 15 minutes based on the old version of CAFE-3D and a fence discharge coefficient of $C_d = 1.55$. The surface is colored according to its local surface temperature in Kelvin degrees.

(a)



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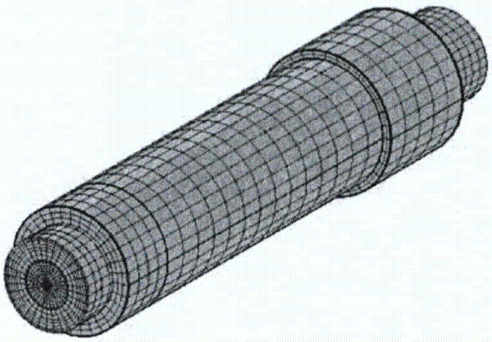

Figure 9 Three dimensional view of package finite element model (a) With Impact Limiters (b) Without Impact Limiters.

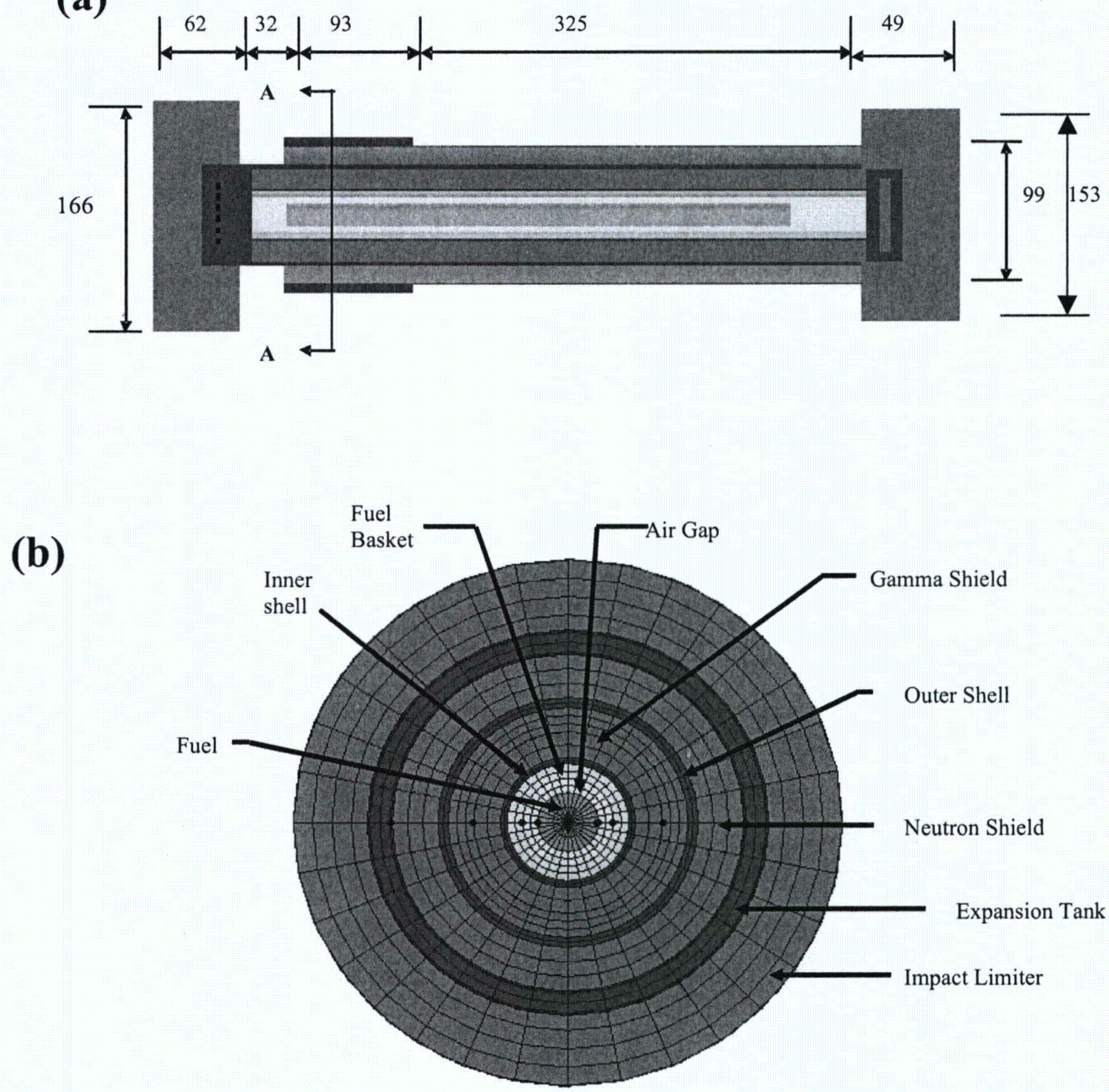

Figure 10 (a) Axial and (b) Cross-sectional slice views of the generic package model with Impact Limiters: All dimensions are in centimeters. Material color code: blue = stainless steel, red = lead, green = glycol/water mixture or air, yellow = air, Cyan = Fuel, Dusty pink = Aluminum, Magenta = Honeycomb-Aluminum.

(a)

(b)

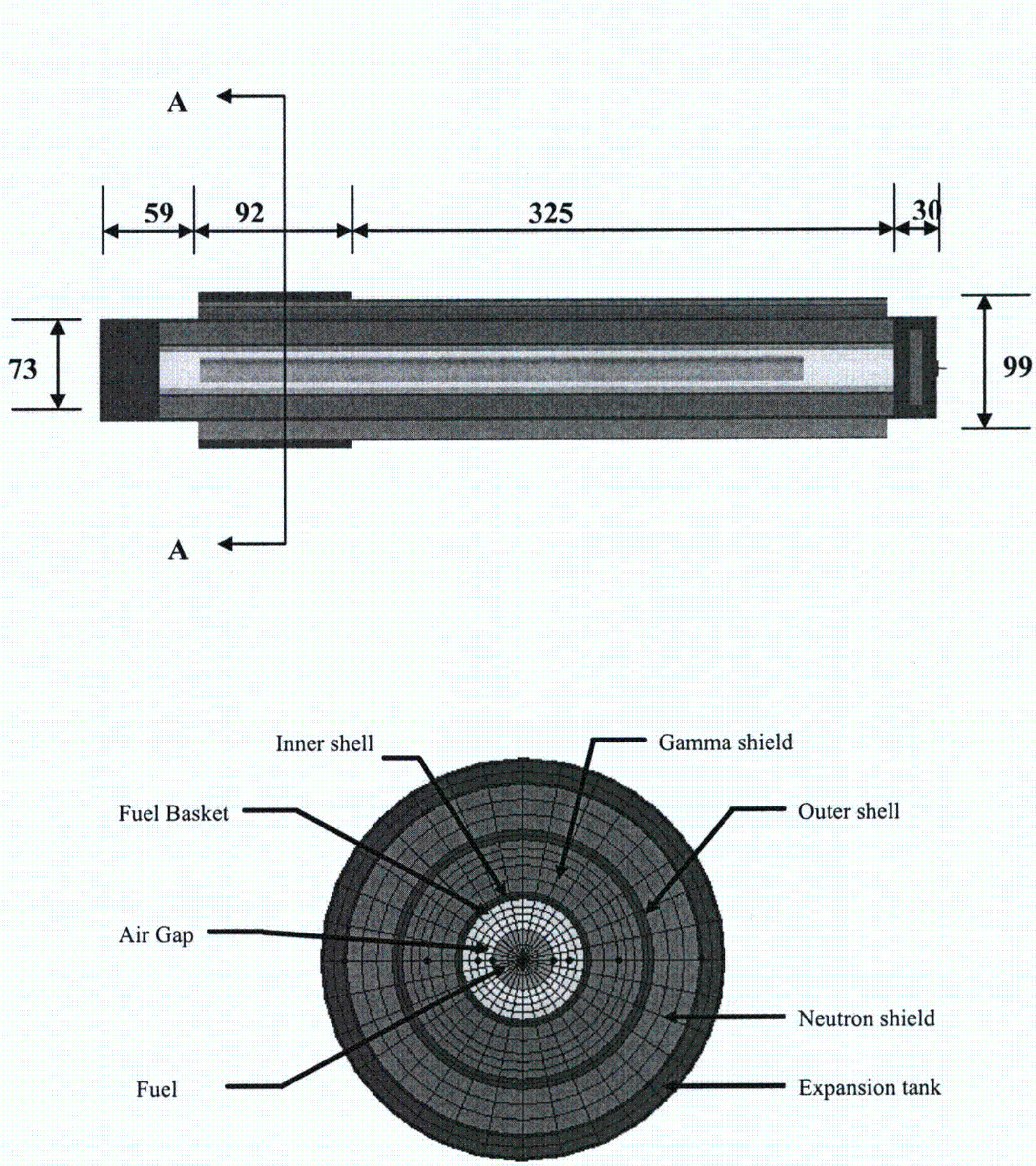

Figure 11 (a) Axial and (b) Cross-sectional slice views of the generic package model without Impact Limiters: All dimensions are in centimeters. Material color code: blue = stainless steel, red = lead, green = glycol/water mixture or air, yellow = air, Cyan = Fuel, Dusty pink = Aluminum.

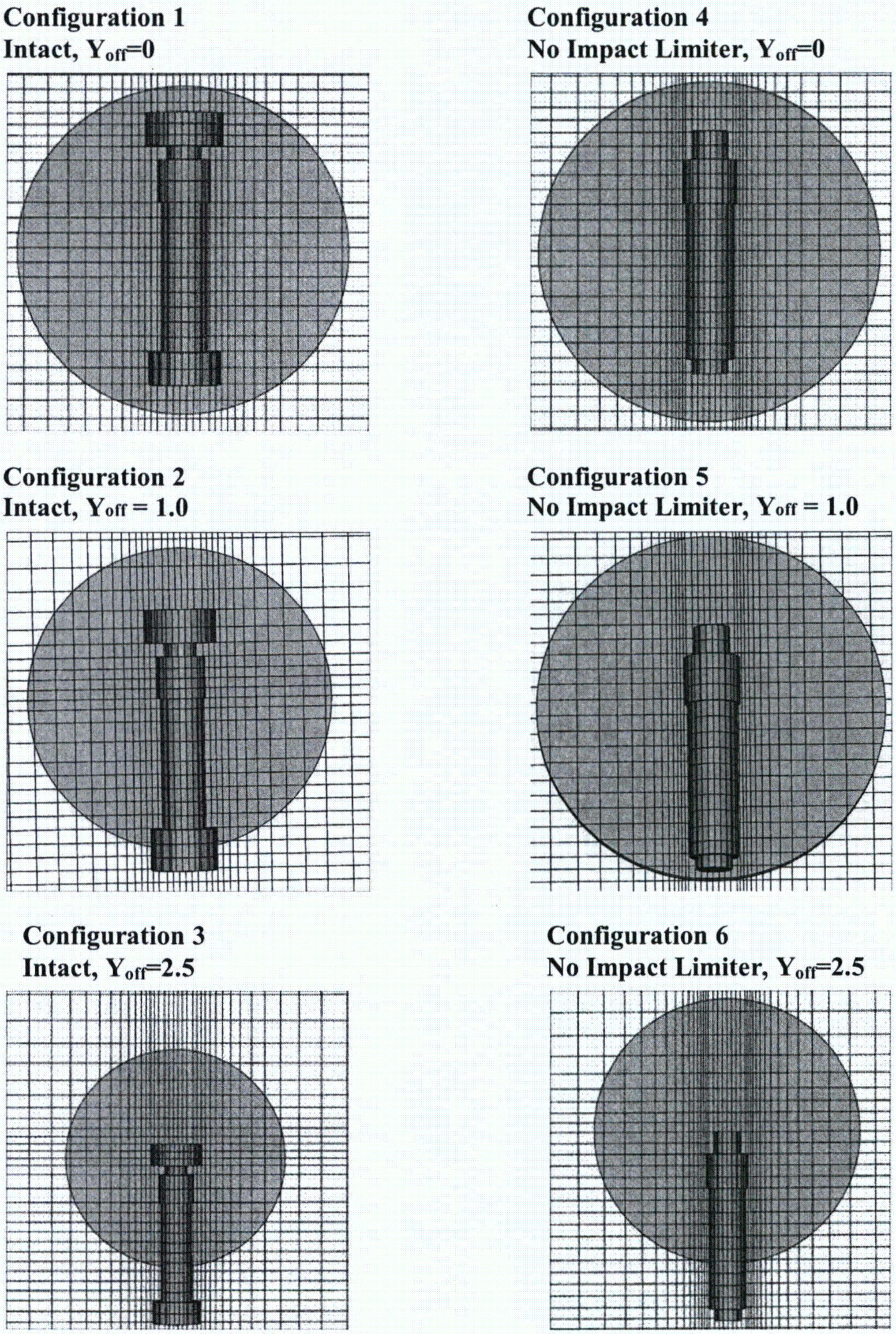

Figure 12 Plan views of package model and position with respect to fuel pool for Configurations 1 to 6.

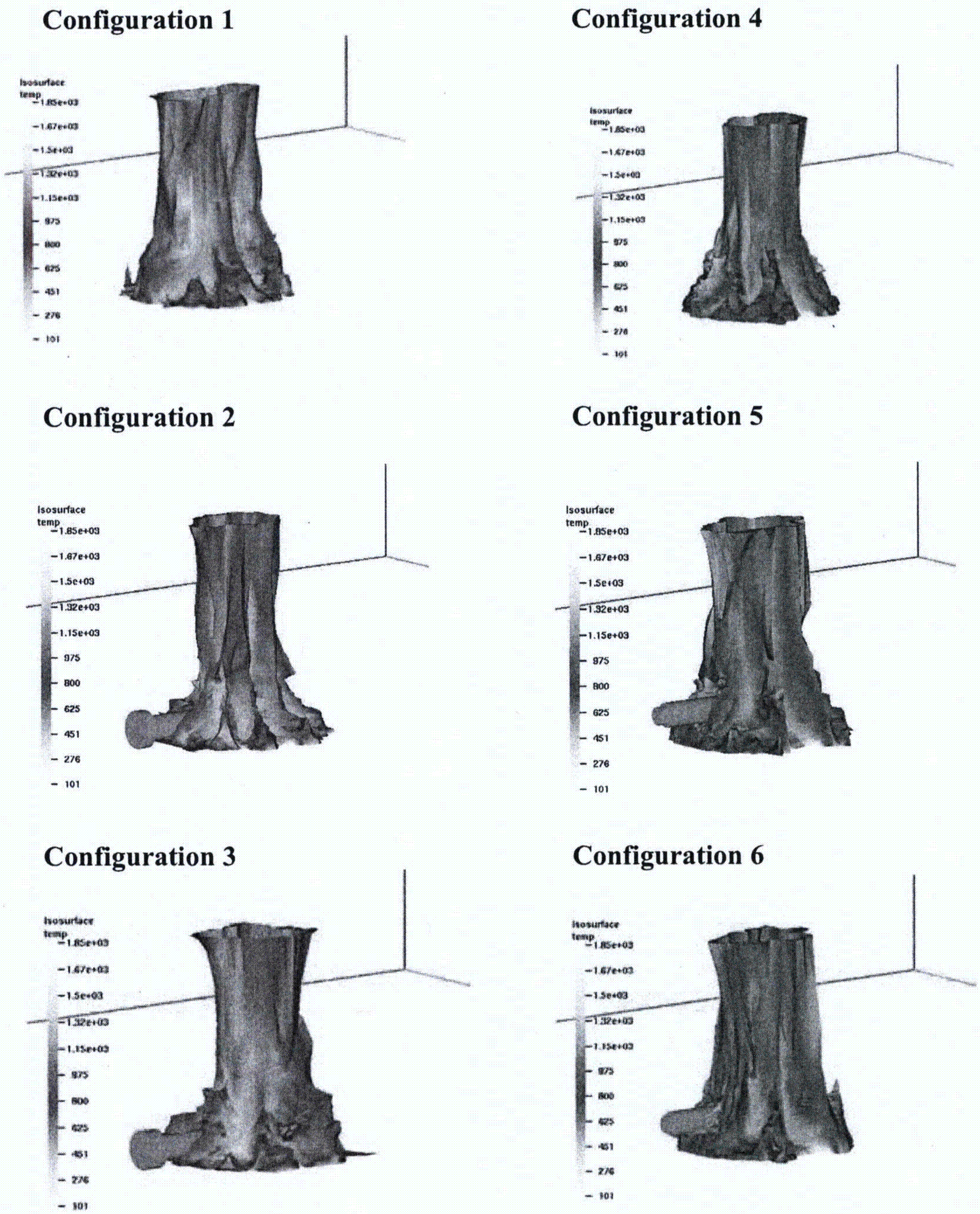

Figure 13 Typical Isis-3D simulated fire surface snapshots for Configurations 1 to 6.

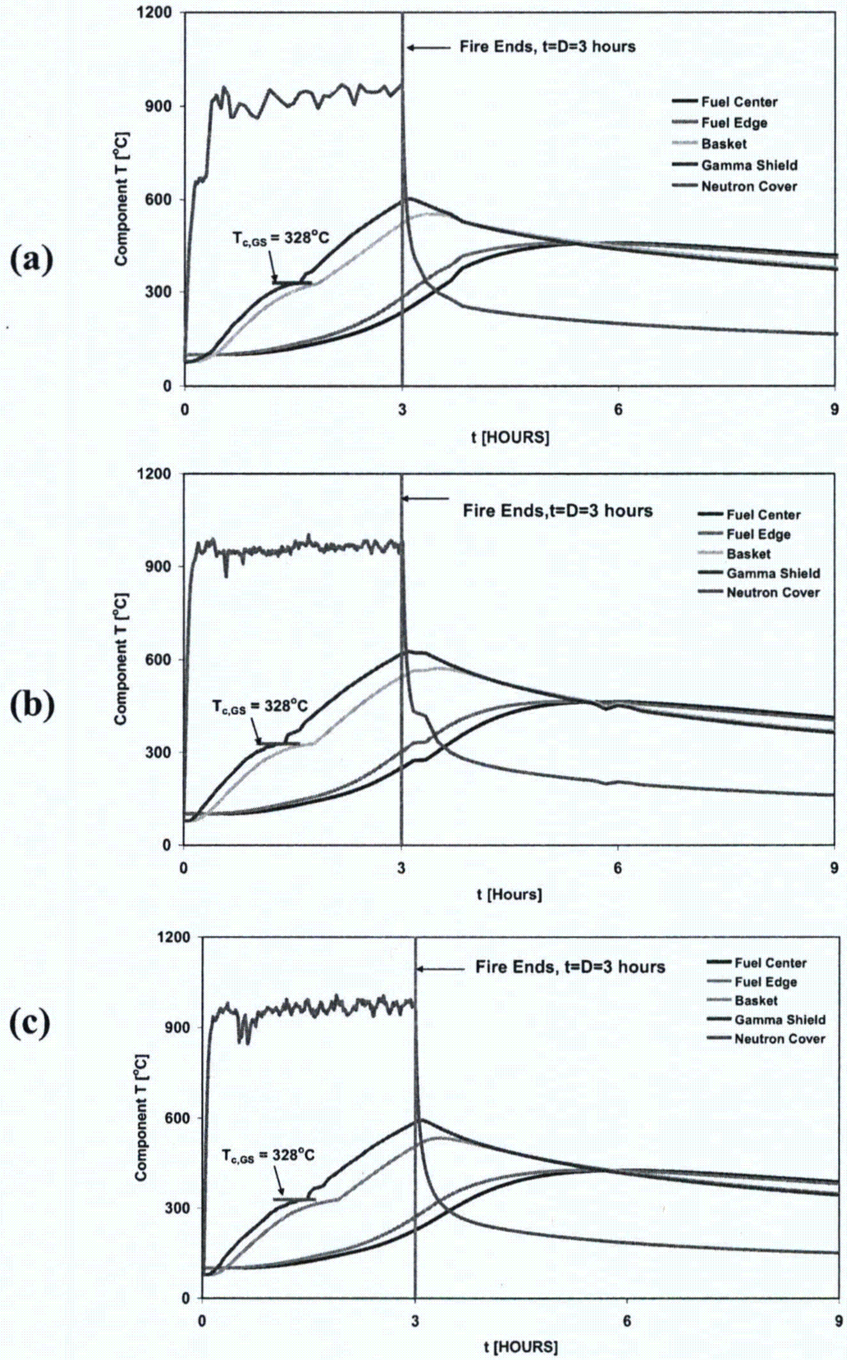

Figure 14 Component temperatures for an intact package in a plane roughly halfway between the package ends. (a) Configuration 1, $Y_{Off} = 0$, (b) Configuration 2, $Y_{Off} = 1$ m, (c) Configuration 3, $Y_{Off} = 2.5$ m.

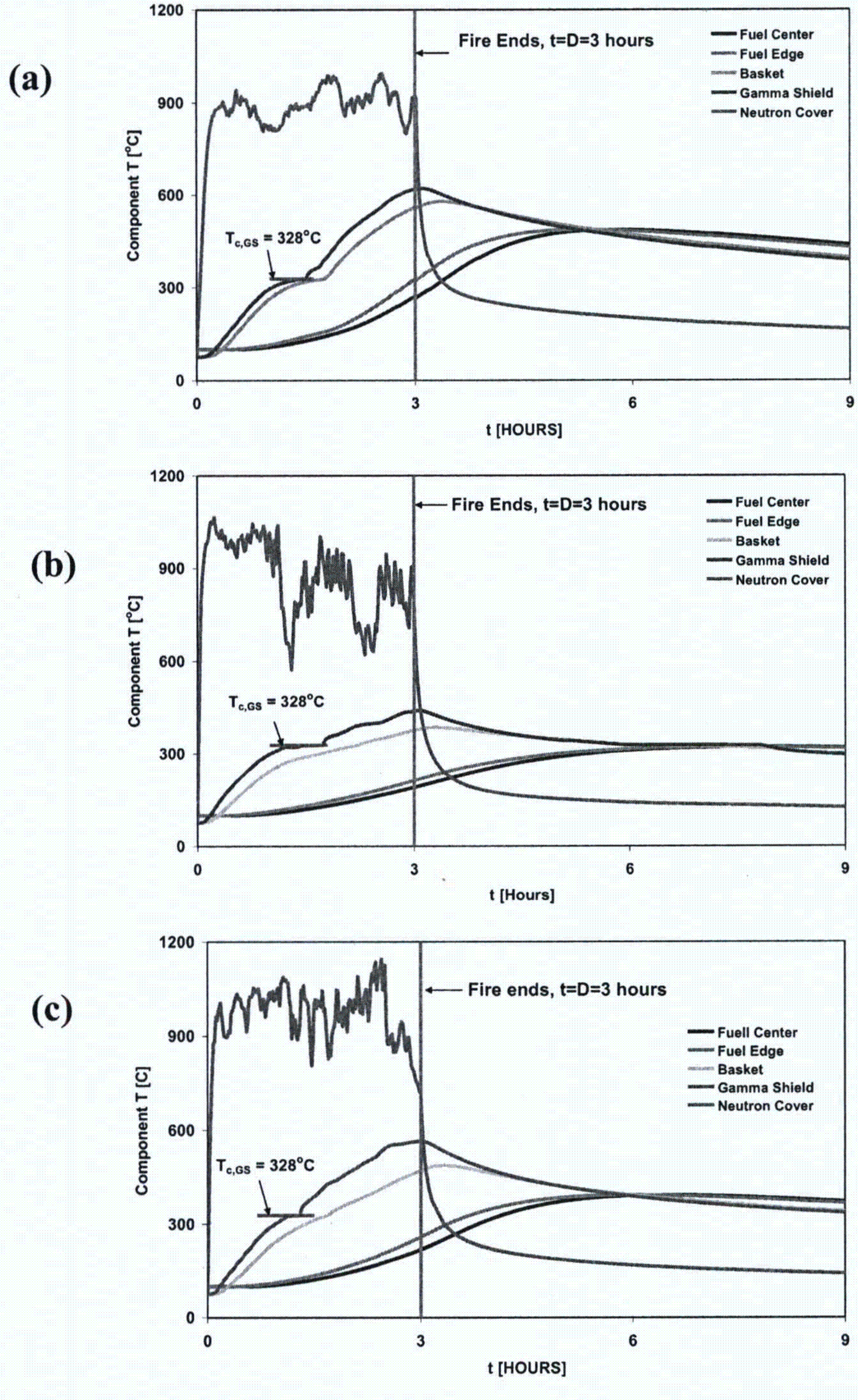

Figure 15 Component temperatures for a no-impact-limiter package in a plane roughly halfway between the package ends. (a) Configuration 4, $Y_{Off} = 0$, (b) Configuration 5, $Y_{Off} = 1$ m, (c) Configuration 6, $Y_{Off} = 2.5$ m.

(a)

(b)

(c)

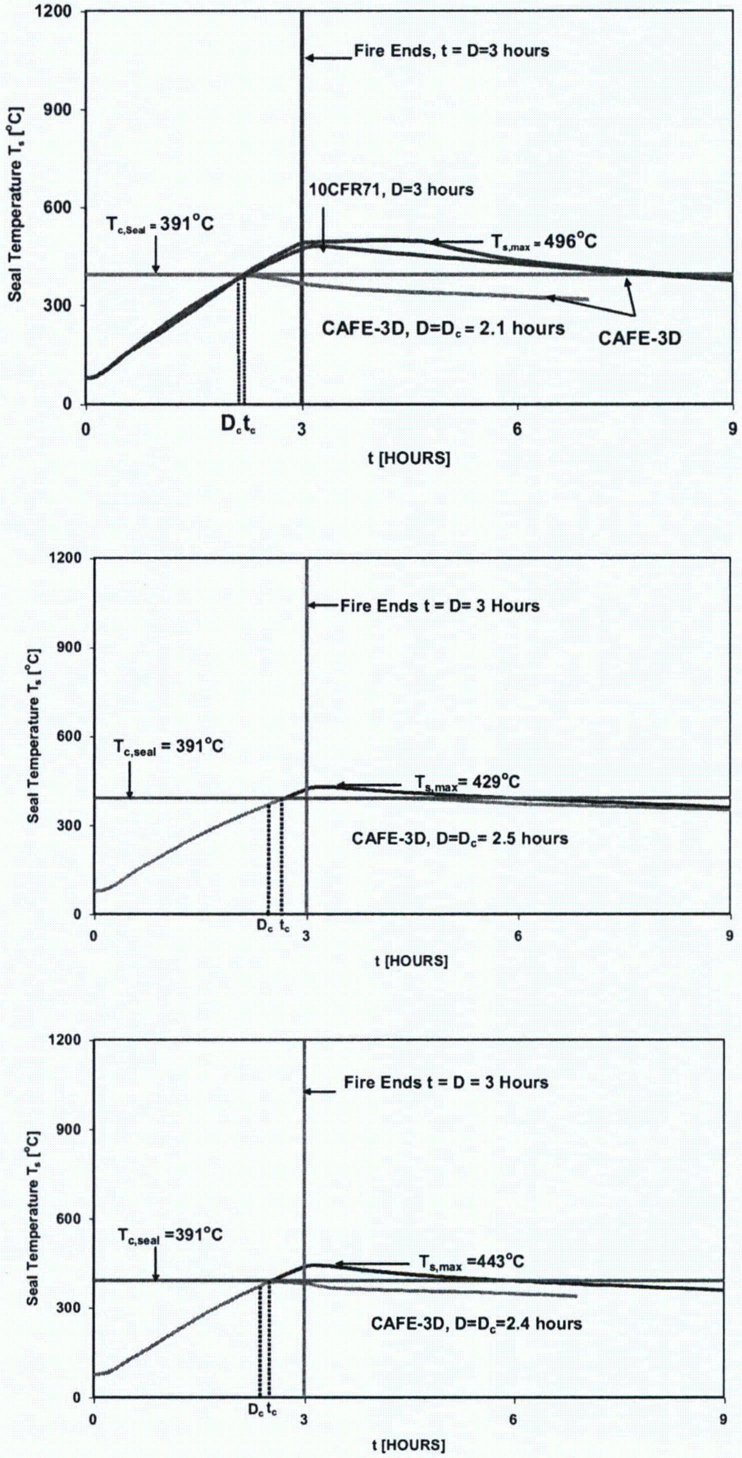

Figure 16 Maximum Seal temperature for an intact package. (a) Configuration 1, Y_{Off} = 0, (b) Configuration 2, Y_{Off} = 1 m, (c) Configuration 3, Y_{Off} = 2.5 m.

(a)

(b)

(c)

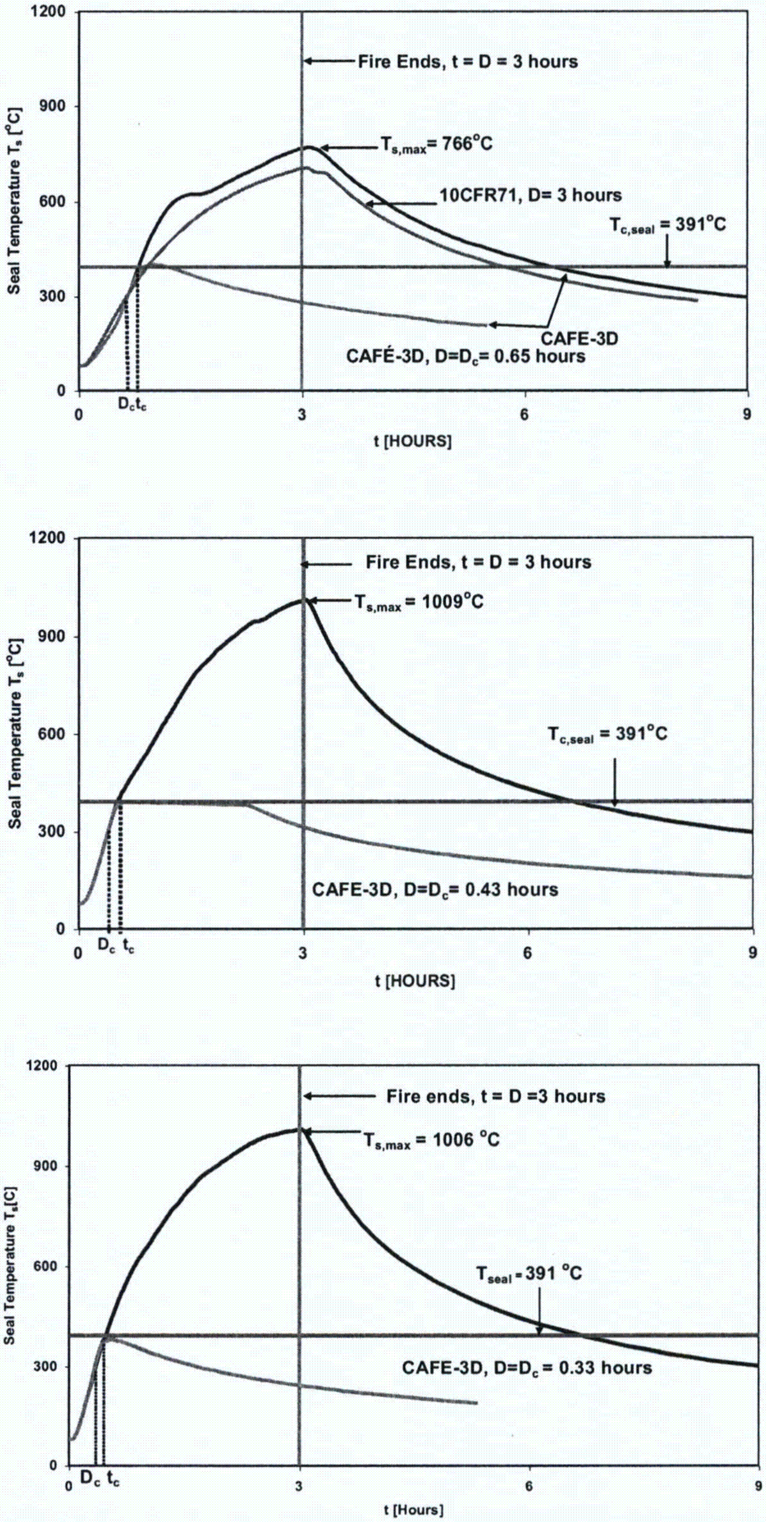

Figure 17 Maximum Seal temperature for a no-impact-limiter package. (a) Configuration 4, Y_{Off} = 0, (b) Configuration 5, Y_{Off} = 1 m, (c) Configuration 6, Y_{Off} = 2.5 m.

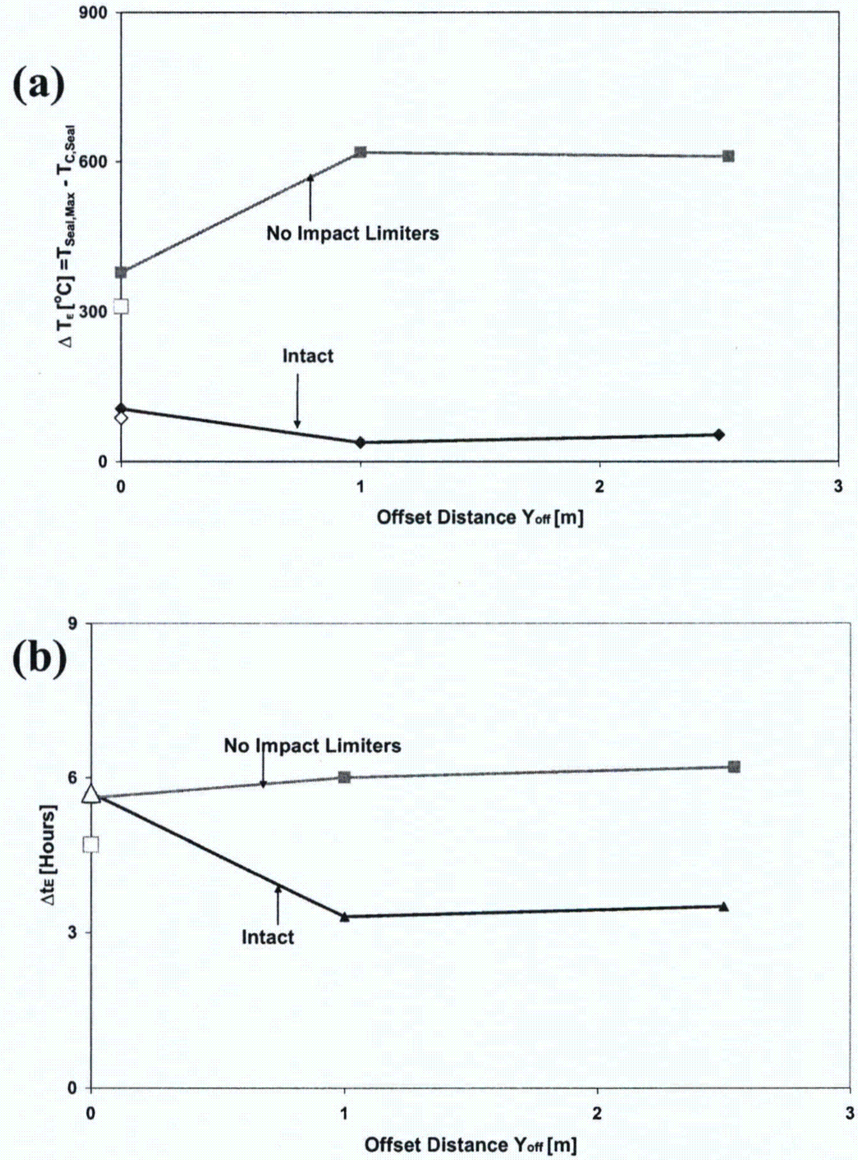

Figure 18 Seal response to a three-hour fire/post fire simulation. CAFE-3D results are presented with solid symbols, 10CFR71 results are reported with open symbols. (a) Maximum Temperature excess $\Delta T_E = T_{MaxSeal} - T_{C,Seal}$. (b) Excess time (total time the seal spends above it temperature of concern during and after the three-hour fire).

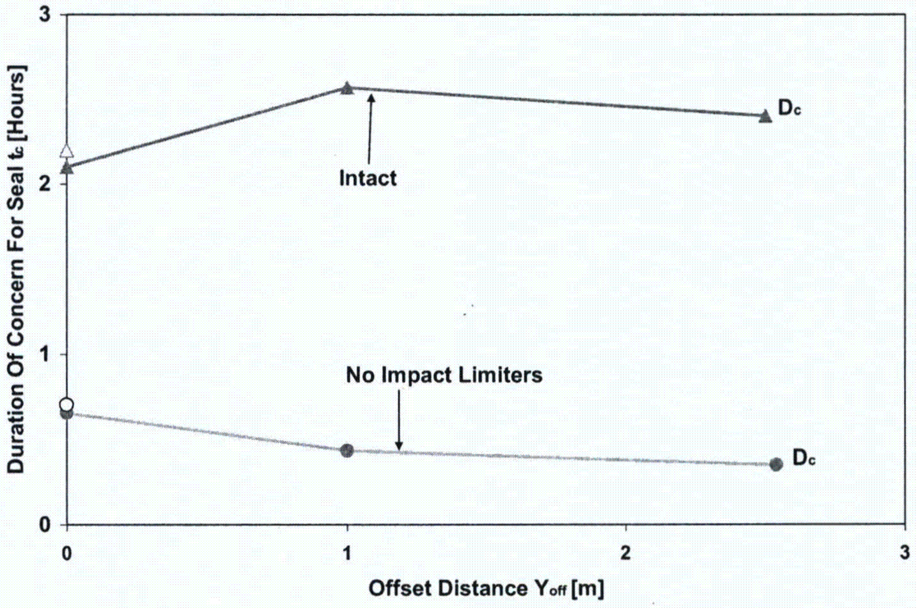

Figure 19 Duration of concern for seal versus offset distance for intact and no-impact-limiter packages. CAFE-3D results are presented with solid symbols, 10CFR71 results are reported with open symbols.