U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

# RIC 2012

## Office of Nuclear Material Safety and Safeguards

# The MacArthur Maze Fire Study:

## Evaluating the Impacts of Real World Accidents on Spent Nuclear Fuel Transportation

### Division of Spent Fuel Storage and Transportation, Office of Nuclear Material Safety and Safeguards

## The MacArthur Maze Fire, April 2007

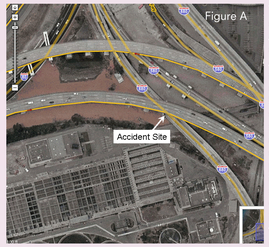


Figure A

The MacArthur Maze fire occurred on Sunday, April 29, 2007, in an area of connector ramps (Figure A) that merge I-80, I-580, and I-880 in Oakland, CA. A dual-tanker truck, carrying 8,600 gallons of gasoline, crashed while heading south along I-880 and caught fire directly below the I-580 overpass. The fire caused two portions of the I-580 overpass to collapse about 17 minutes and 37 minutes after the fire started. A sequence of frames from a surveillance camera video of the fire is shown in figure B below.

Figure B

The fire heated the steel girders of the I-580 overpass to temperatures high enough to reduce the strength of the steel, making the girders unable to support the weight of the elevated roadway. The collapsed roadway is shown in Figure C.

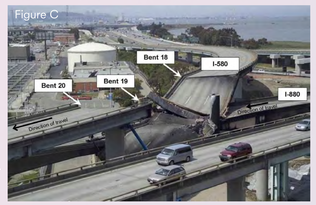


Figure C

## The NRC Worked Collaboratively With other Organizations to Examine the Event

CNWRA — A center of excellence in earth sciences and engineering™
NIST — National Institute of Standards and Technology, U.S. Department of Commerce
CHP
SwRI®
Pacific Northwest National Laboratory
Caltrans

### How Hot Was the MacArthur Maze Fire?

Based on materials analyses conducted at the Center for Nuclear Waste Regulatory Analyses (CNWRA), a division of Southwest Research, Inc., on multiple samples collected (see the adjacent panel), the hottest gas temperatures during the fire approached 1,000°C (1,832°F), and occurred above the I-880 roadway near the steel girders of the I-580 overpass. In the vicinity of the tanker truck on the lower roadway, the maximum fire exposure temperature was estimated to be less than 950°C (1,742°F).

## MacArthur Maze Girder and Truck Sample Collection

Samples of the steel girders were collected from locations in Figure D to determine the effect of the fire temperature on the microstructure of the materials. The NRC focused its metallurgical investigations on samples NRC 3 and NRC 4 because they were taken from areas closest to the fire.

Figure D

### I-580 Girder Material Samples Collected

| Sample Number | Block | Location (bent) | Weld Metal? | Description |
|---|---|---|---|---|
| NRC 3 | Plate #5 | 18–19 | Yes | Plate girder with stiffener—heavy distortion |
| NRC 4 | Plate #5 | 18–19 | Yes | Plate girder with stiffener—medium distortion |

### Results of Girder Sample Materials Analyses

| Sample Number | Block | Location(bent) | Weld Metal? | Description |
|---|---|---|---|---|
| NRC 3 | Plate #5 | 18—19 | Yes | Pearlite and ferrite |
| NRC 4 | Plate #5 | 18–19 | Yes | Pearlite and ferrite |

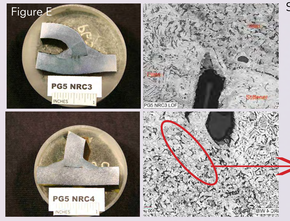


Figure E

Samples NRC 3 & NRC 4

Samples were from plate girder 5 located close to the fire (Figure #E)

The fire caused obvious distortion to the girder

Weld microstructure transformation to ferrite and pearlite (similar to base metal) indicates a fire exposure temperature of 800 to 1000°C.

The base plate and weld microstructures look very similar!

## Tanker Truck Material Samples

Figure F

In March 2008, the NRC inspected the tanker truck involved in the accident and collected samples for analysis.

Figure F shows the remains of what was a 2001 Freightliner 3-axle tank truck with a 2,000 Weld-It 2-axle pull tank trailer.

The NRC collected a variety of materials, including glass, aluminum alloys, steel, copper, brass, and stainless steel.

Near the truck, the maximum exposure temperature was estimated to be:

**720°C [1,328°F] and to 930°C [1,706°F]**

## MacArthur Maze Fire Model and Analysis

Experts at the Building and Fire Research Laboratory of the National Institute of Standards and Technology refined a model of the MacArthur Maze fire developed by the CNWRA using the Fire Dynamics Simulator (FDS) code to assess the thermal environment during the fire.

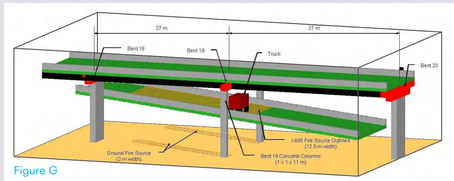


Figure G

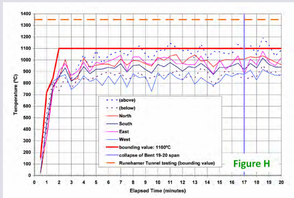


Figure H

Figure G shows a diagram of the FDS computational domain modeling the accident site. The fire was assumed to span the full width of the roadway and extend more than 20 meters along its length. Figure H shows that the peak temperatures predicted during the first phase of the fire are bounded by 1,100°C (2,012°F), as shown by the plot in Figure H.

The collapse of the overhead spans greatly reduced the size of the fire, effectively extinguishing large portions of it and reducing the extent of the fire "pool" to the distance between the fallen roadway spans. This portion of the fire is bounded by a peak fire temperature of 900°C (1652°F).

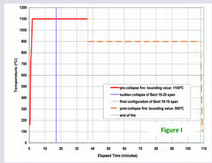


Figure I

As a conservative simplification, the MacArthur Maze fire is defined as a fully engulfing fire for the entire 108 minutes, with a bounding fire temperature of 1,100°C (2012°F) for the first 37 minutes, and 900°C (1,652°F) for the remainder of the fire duration. (See Figure I)

Title 10 of the *Code of Federal Regulations* (CFR) Part 71, Packaging and Transportation of Nuclear Material, specifies that transportation packages must survive an accident sequence that includes a fully engulfing fire of at least 800°C (1,472°F) for 30 minutes, with only minimal releases.

The MacArthur Maze fire provided an environment with a higher maximum temperature for a longer period of time than what the regulations specify.

## Spent Nuclear Fuel Transportation Package

The General Atomics GA-4 Legal Weight Truck (LWT) package (Figure J) was selected to investigate how this accident might affect an NRC-certified transportation package.

The GA-4 carries up to four intact PWR SNF assemblies, and is designed for a maximum decay heat load of 0.617 kW per assembly, for a total package decay heat load of 2.468 kW.

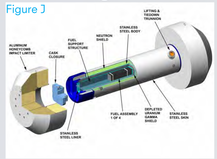


Figure J

## Thermal Response of the GA-4 Transportation Package

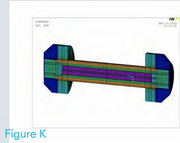


Figure K

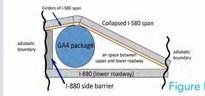


Figure L

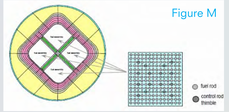


Figure M

The model of the GA-4 package constructed for analysis using the ANSYS® finite element code includes a detailed three-dimensional representation of the package (Figure K). Fuel assemblies are represented as homogeneous regions with an effective radial conductivity. To evaluate the effect on the cooldown rate of the package after the end of the fire, the postfire analysis includes elements representing the lower roadway beneath the package and the collapsed upper roadway covering it (Figure L).

A second model of the GA-4 package, assembled in the COBRA-SFS code (Figure M), was developed to obtain precise fuel rod temperatures by utilizing a detailed rod-and-subchannel representation that fully captures radiation, conduction, and convection heat transfer within the rod array. For this model, the impact limiters were removed, as part of a conservative estimate of the damage due to the fire and overpass collapse onto the package.

## Thermal Analysis Results

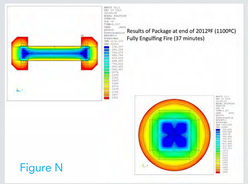
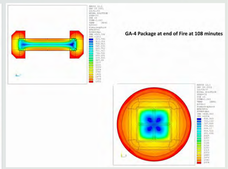


Figure N



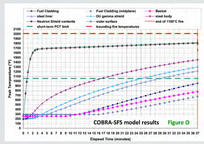



Figure O

As shown in the COBRA-SFS (Figure O) and ANSYS results above (Figure N) and in the table below, vital components of this package, such as the fuel cladding and containment boundary seals, exceed their rated service temperatures, and therefore, could degrade. The potential consequences of fuel cladding or seal degradation are currently being evaluated.

| Component | | NCT (Start of fire) | | 37 minutes (end of 1,100°C fire) | |
|---|---|---|---|---|---|
| | | ANSYS | COBRA | ANSYS | COBRA |
| Fuel Cladding | | 306 (152) | 293 (145) | 551 (1023) | 513 (955) |
| Seals | lid closure | 131 (55) | 144 (62) | 136 (277) | 983 (1802) |
| | gas sample port | 129 (54) | 145 (63) | 87 (188) | 895 (1643) |
| | drain valve | 134 (57) | 150 (66) | 87 (189) | 909 (1668) |
| Component | | 108 minutes (end of fire) | | 4 hours (2.2 hrs after end of fire) | |
| | | ANSYS | COBRA | ANSYS | COBRA |
| Fuel Cladding | | 779 (1,433) | 753 (1,388) | 732 (1,349) | 730 (1,347) |
| Seals | lid closure | 408 (766) | 870 (1,598) | 575 (1,068) | 414 (776) |
| | gas sample port | 274 (526) | 850 (1,563) | 515 (960) | 466 (871) |
| | drain valve | 388 (730) | 854 (1,569) | 589 (,1092) | 462 (863) |

## Structural Evaluation of Overpass Collapse onto Package

The NRC evaluated various impact orientations to find the greatest potential for damage to the package.

The response of the package body is dominated by the amount of girder deformation. The girders deform readily around the comparatively rigid package body, imparting plastic strains on the surface of the package wall, the magnitudes of which are within material ductility limits for all cases, with the worst case identified in Figure P.

Lid closure bolts and impact limiter bolts were evaluated for thermal expansion stresses in separate calculations, which determined that these components would remain in place.

Overpass girders (ASTM A7 structural grade steel) exceeded 900°C (1,652°F), and deformed upon impact.

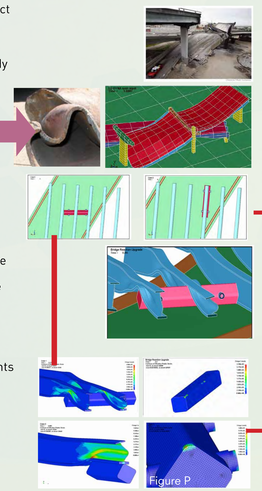


Figure P

## Conclusions

The MacArthur Maze fire and overpass collapse was a severe transportation accident involving a fire of long duration that had the ability to fully engulf a SNF transportation package if one had been involved. While the potential for an SNF shipment to be involved in this type of accident is extremely low,[1] the NRC is currently studying the possible consequences of this scenario. The NRC remains confident that the current transportation regulations in 10 CFR Part 71 provide adequate protection to the health and safety of the public.

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## For Further Information:

The MacArthur Maze Materials Analysis
http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6987
[1]The Frequency of Severe Roadway Accidents
http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr7035


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