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

The Potential Impacts of Recent Transportation Accidents Involving Severe Fires on the Safe Shipment of Spent Nuclear Fuel

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Washington, DC

Outline

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  - Accident Description
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    - Samples Collected
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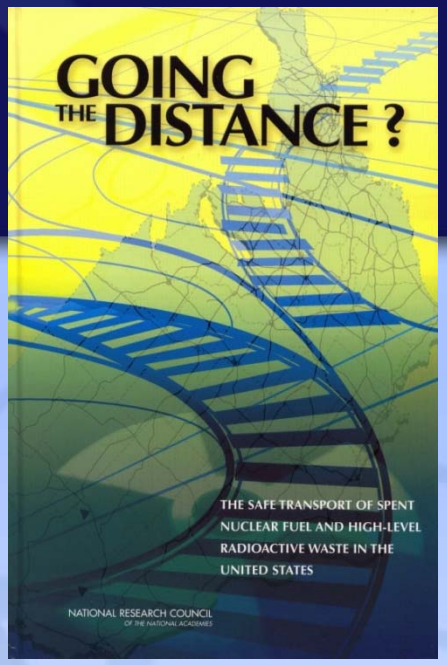
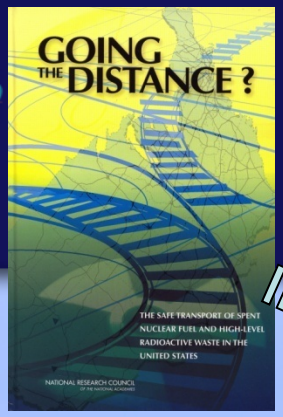
- Newhall Pass
  - Accident Description
  - Samples Collected
  - Materials Analysis Results
  - Conclusions
- Future Work
- Questions

Introduction: NAS Transportation Study



Going The Distance? - The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States

- **Released February 9, 2006**
- **Conclusions:**
  - **NRC safety regulations are adequate to ensure package containment effectiveness over a wide range of transport conditions, including most credible accident conditions.**
  - **The radiological risks are well understood and are generally low, with the possible exception of risks from releases in extreme accidents involving long duration, fully engulfing fires.**



- NRC "*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…shipping programs*."

- These analyses would examine the need for **regulatory** or **operational** changes that could help **prevent** accidents that could lead to such a fire or **mitigate** their consequences.

Road Transportation

Rail Transportation

SFST Actions in Response to NAS Recommendations (VISION)

- Systematic, comprehensive assessments and documentation of the predicted performance of NRC certified spent fuel packages in real life severe accidents
  - Examination and Explanation of Current Regulations
    - 10 CFR Part 71 – Packaging and Transportation of Radioactive Materials
    - Section 73: Hypothetical Accident Conditions
    - 30 Minute fire: Average Temp. 800° C (1475° F)
- Screening of Real Life Accidents
- Case Studies of Most Severe Accidents
- Consequences and Conclusions
- Do the regulations bound recent real-life accidents?

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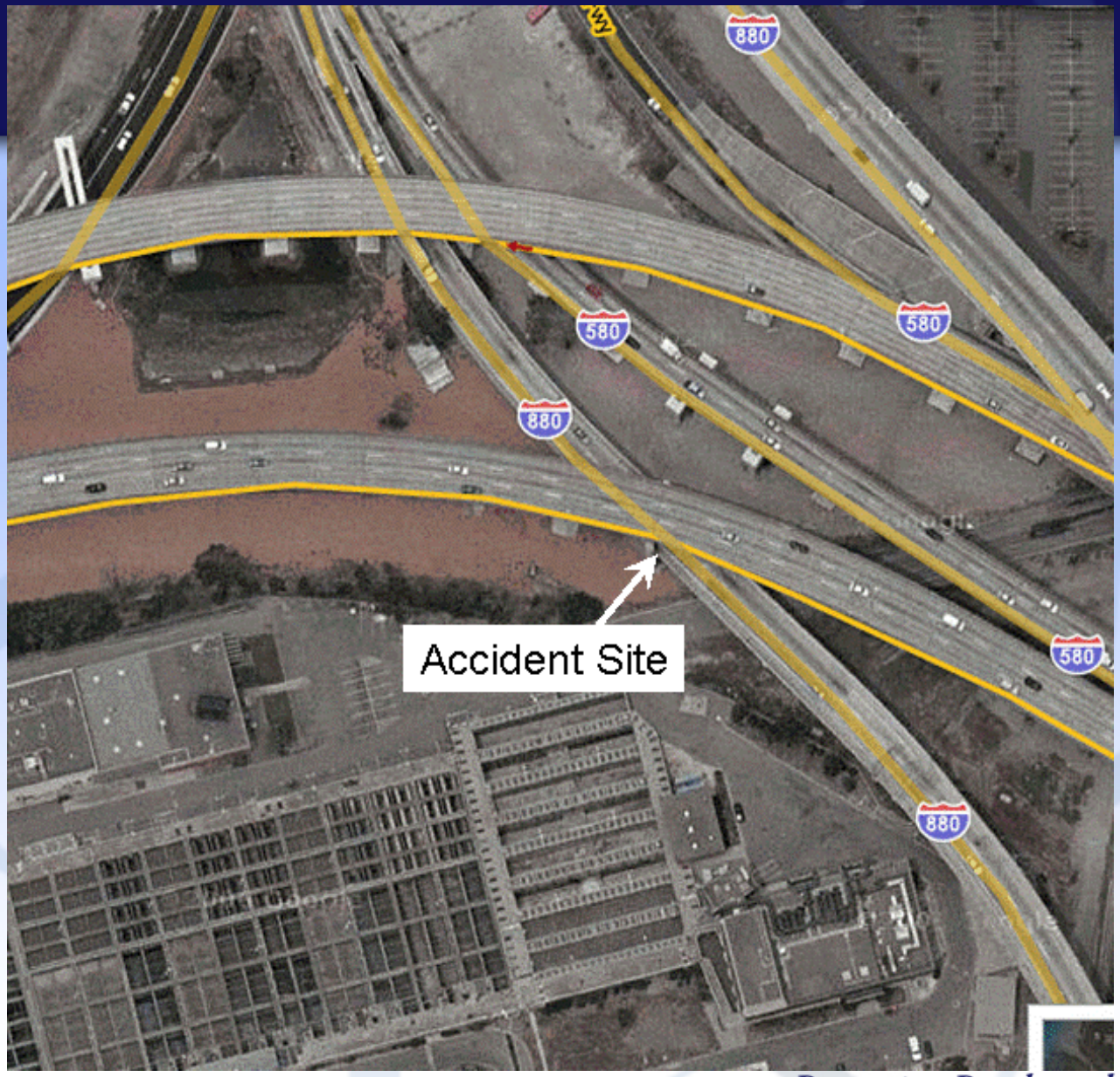
MacArthur Maze Fire

- **Accident and fire occurred April 29, 2007 at about 3:45 AM**
- **Gasoline double tanker truck**
  - **32,500 liters [8,600 gallons] of gasoline**
- **Traveling south along Interstate 880 in Oakland, California**
- **Accident occurred in the MacArthur Maze, an interchange connecting I-80, I-580, and I-880**
- **The I-580 overpass directly above I-880 collapsed approximately 17 minutes after the fire started**

Accident Location



The MacArthur Maze Fire Scene--

6m 48s (03:44:32 PDT)

16m 41s (03:54:25 PDT)

19m 55s (03:57:33 PDT)

37m 16s (04:15:00 PDT)

72m 16s (04:50:00 PDT)

107m 13s (05:25:57 PDT)

Estimates of Material Temperatures in MacArthur Maze Fire

- NRC and SwRI staff collected samples to determine temperatures experienced by girders and truck during the fire
- Performed isothermal exposures of unaltered specimen (Sample NRC 9) to 900ºC (1652ºF) to determine weld transformation temperatures
- Performed metallurgical analysis of girder and truck structures, including microstructure evaluation of weld regions

Overpass Demolition

Girder cutting after concrete removal

Remnants of tanker truck

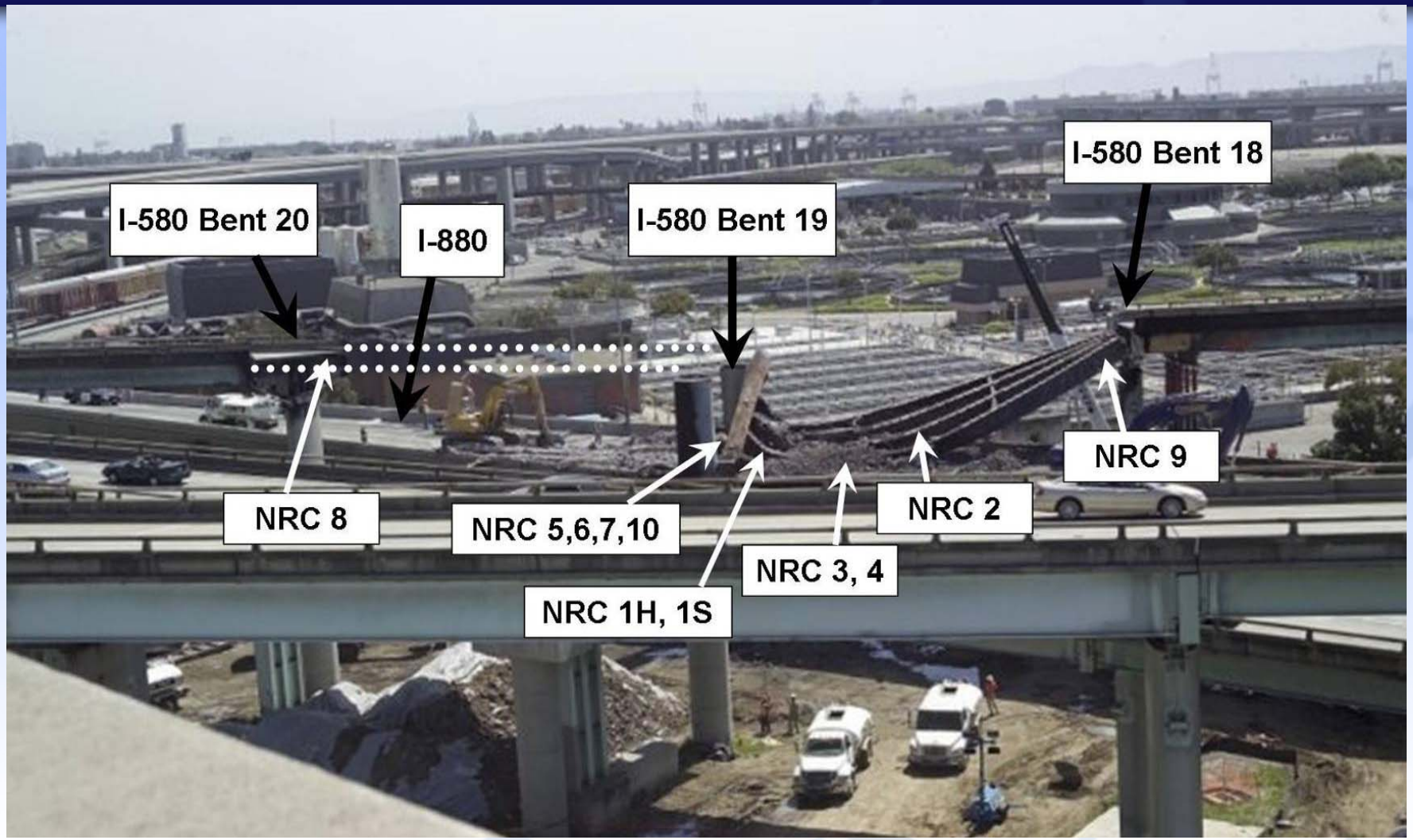
Fire Damaged Girders

JOURNAL
PG 12
MB 18

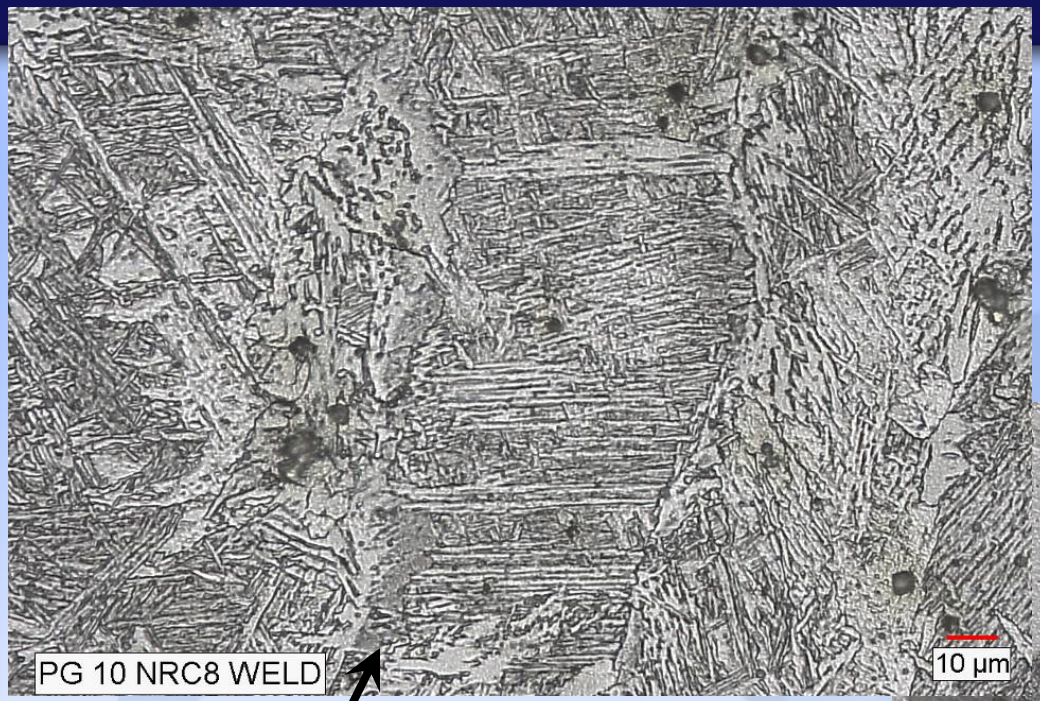
Samples Collected

Sample Number	Girder	Location (Bent)	Weld Metal?	Description
NRC 1H	Plate # 3	19	No	Plate Girder with rivet holes
NRC 1S	Plate # 3	19	Yes	Plate Girder with stiffener
NRC 2	Plate # 4	18 – 19	Yes	Plate Girder with butt weld
NRC 3	Plate # 5	18 – 19	Yes	Plate Girder with stiffener - heavy distortion
NRC 4	Plate # 5	18 – 19	Yes	Plate Girder stiffener - medium distortion
NRC 5	Box # 7	19	Yes	Box Girder lower plate with side and weld
NRC 6	Box # 8	19	No	Plate Girder segment attached to Box Girder
NRC 7	Box # 8	19	No	Rivet head
NRC 8	Plate # 10	20	Yes	Plate Girder Web and plate with weld
NRC 9	Plate # 12	18	Yes	Plate Girder with stiffener
NRC 10	Box # 8	19	No	Paint Flakes

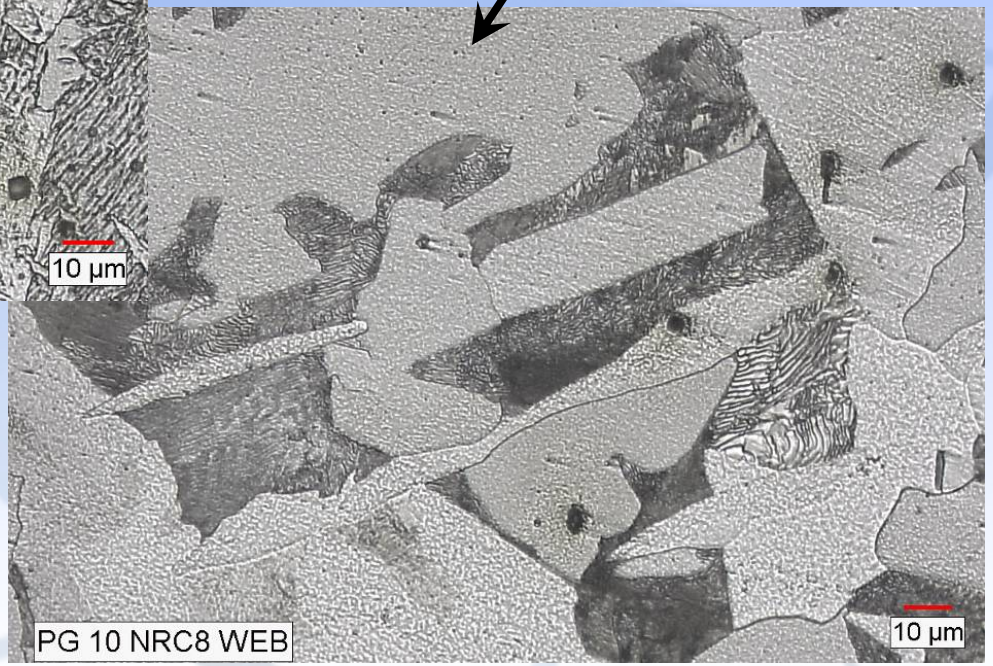
Sample Locations



Possible Microstructures



Equilibrium microstructure – ferrite (light gray) and pearlite (dark gray)



As deposited weld metal – dendritic and equiaxed ferrite with some carbides

Girder Sample Analysis Results

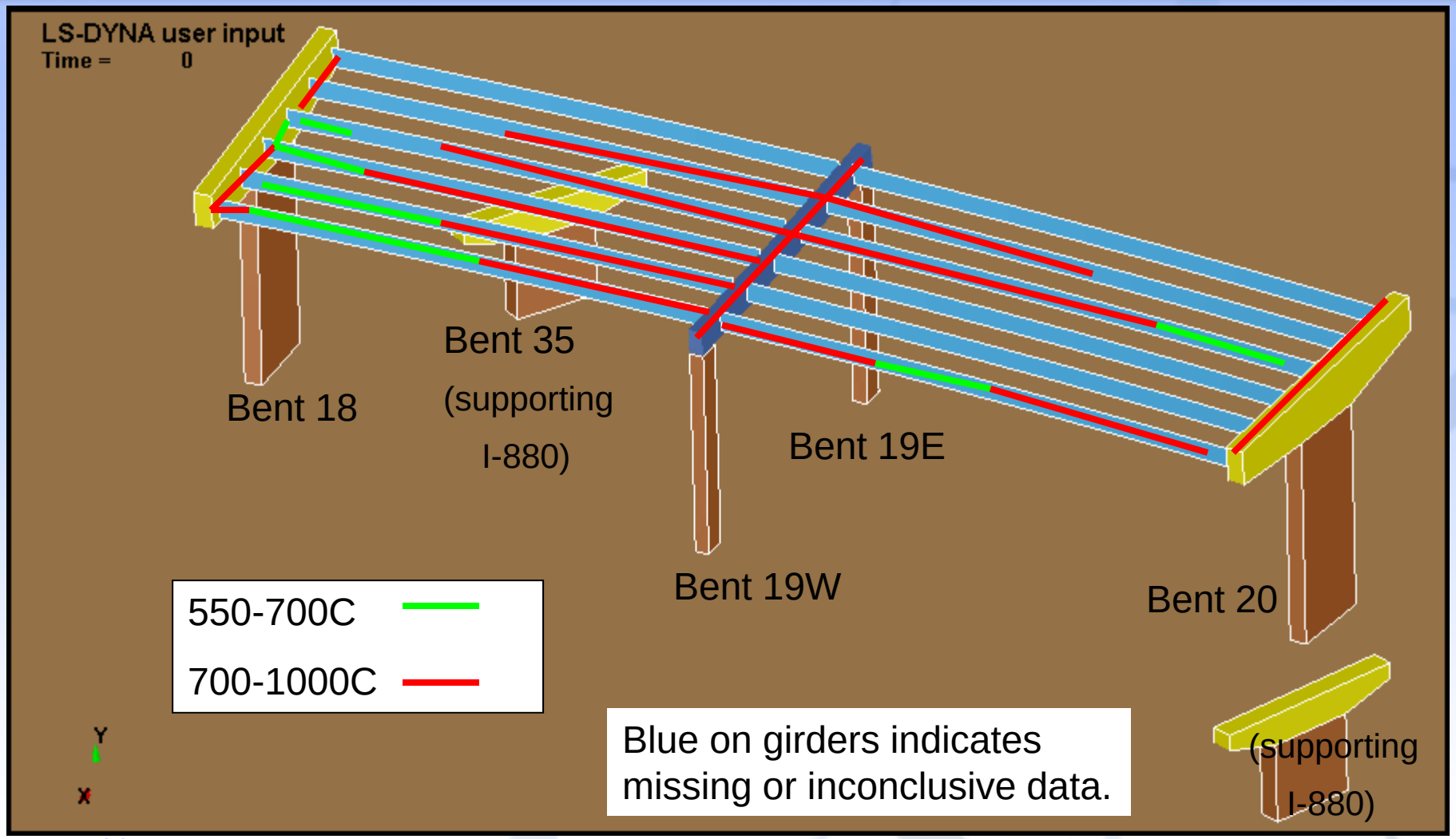
Sample Number	Girder	Location (Bent)	Weld Metal?	Weld Microstructure
NRC 1S	Plate # 3	19	Yes	Dendritic Ferrite (as-deposited weld metal)
NRC 2	Plate # 4	18 – 19	Yes	Pearlite and Ferrite
NRC 3	Plate # 5	18 – 19	Yes	Pearlite and Ferrite
NRC 4	Plate # 5	18 – 19	Yes	Pearlite and Ferrite
NRC 5	Box # 7	19	Yes	Dendritic Ferrite with some Pearlite (partial transformation)
NRC 8	Plate # 10	20	Yes	Dendritic Ferrite (As-deposited weld metal)
NRC 9	Plate # 12	18	Yes	Dendritic Ferrite (as-deposited weld metal)

Girder Material Temperature Estimates

Sample Number	Girder	Location (Bent)	Estimated maximum temperature (ºC)	Description
NRC 1H	Plate # 3	19		Plate Girder with rivet holes
NRC 1S	Plate # 3	19	800	Plate Girder with stiffener
NRC 2	Plate # 4	18 – 19		Plate Girder with butt weld
NRC 3	Plate # 5	18 – 19	900	Plate Girder with stiffener - heavy distortion
NRC 4	Plate # 5	18 – 19	850	Plate Girder stiffener - medium distortion
NRC 5	Box # 7	19	300	Box Girder lower plate with side and weld
NRC 6	Box # 8	19		Plate Girder segment attached to Box Girder
NRC 7	Box # 8	19	400	Rivet head
NRC 8	Plate # 10	20		Plate Girder Web and plate with weld
NRC 9	Plate # 12	18	200	Plate Girder with stiffener (no evidence of overheating)
NRC 10	Box # 8	19	400	Paint Flakes

Remaining Girder Paint at Bent 18

I-580 Overpass Peak Temperature Zones (Approximations from Paint Photos)



Girder Sample Thermal Exposure Tests

- Isothermal exposures of unaltered girder specimens (from Sample NRC 9) to determine weld transformation temperature
  - 550 to 900 C [1,022 to 1,652° F]
  - 3 hours and allowed to cool in laboratory air (i.e. the samples were not quenched)
- Metallurgical analysis conducted after isothermal exposure

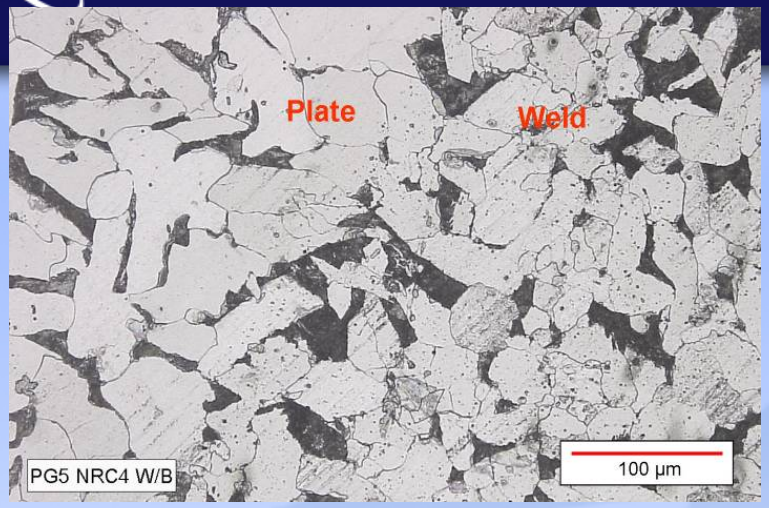
Specimens From NRC 9

- Specimens contain material from the plate girder, stiffener and plate-stiffener weld
- Thermal exposure according to prescribed matrix
- Large specimen collected for this purpose

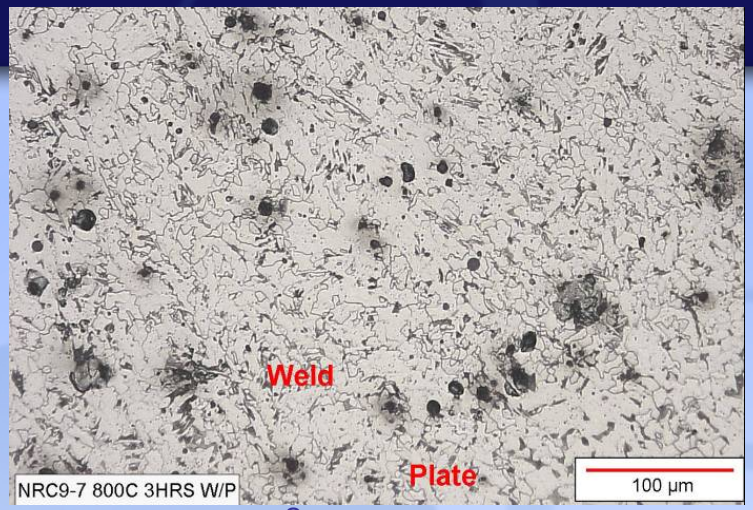
Thermally Treated Sample Results

Sample Number	Thermal Exposure Temperature	Microstructure
NRC 9-1	None	Dendritic Ferrite (as-deposited weld metal)
NRC 9-2	550° C [1,022° F]	Dendritic Ferrite (as-deposited weld metal)
NRC 9-3	600° C [1,112° F]	Dendritic Ferrite (as-deposited weld metal)
NRC 9-4	650° C [1,202° F]	Dendritic Ferrite (as-deposited weld metal)
NRC 9-5	700° C [1,292° F]	Dendritic Ferrite (as-deposited weld metal)
NRC 9-6	750° C [1,382° F]	Dendritic Ferrite (as-deposited weld metal)
NRC 9-7	800° C [1,472° F]	Dendritic Ferrite with small regions of pearlite
NRC 9-8	850° C [1,562° F]	Ferrite and Pearlite with some dendritic Microstructure
NRC 9-9	900° C [1,652° F]	Ferrite and Pearlite (complete transformation)

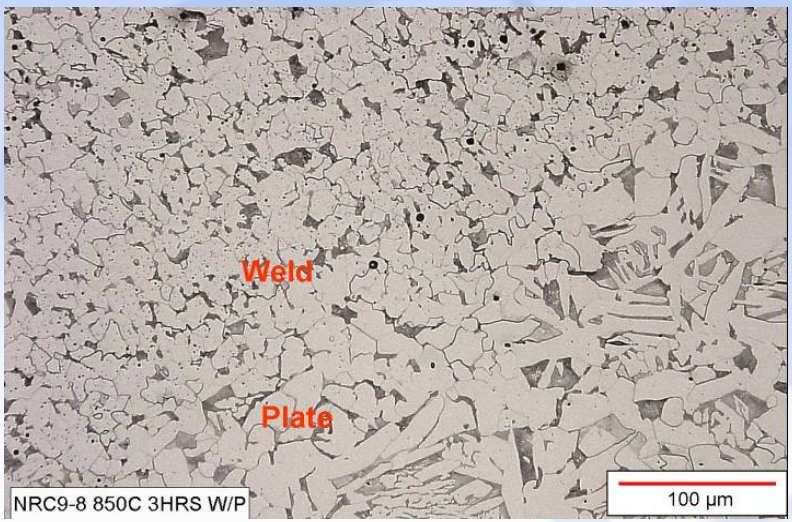
Sample Microstructures



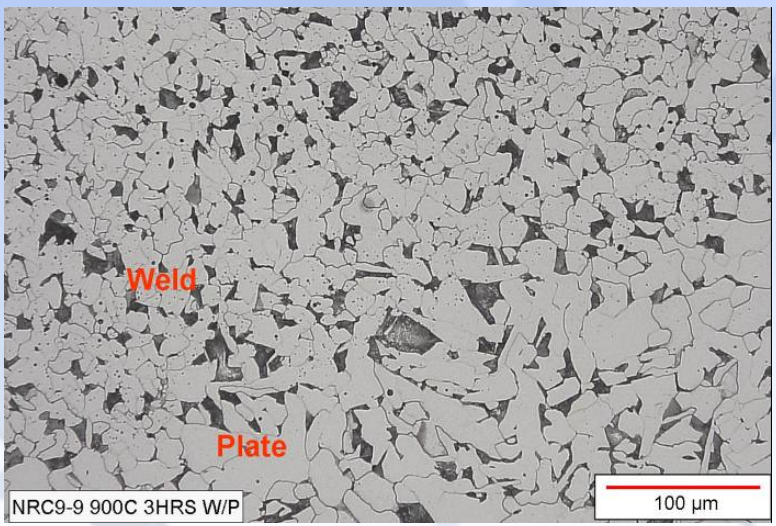
NRC 4



800° C – 3hrs

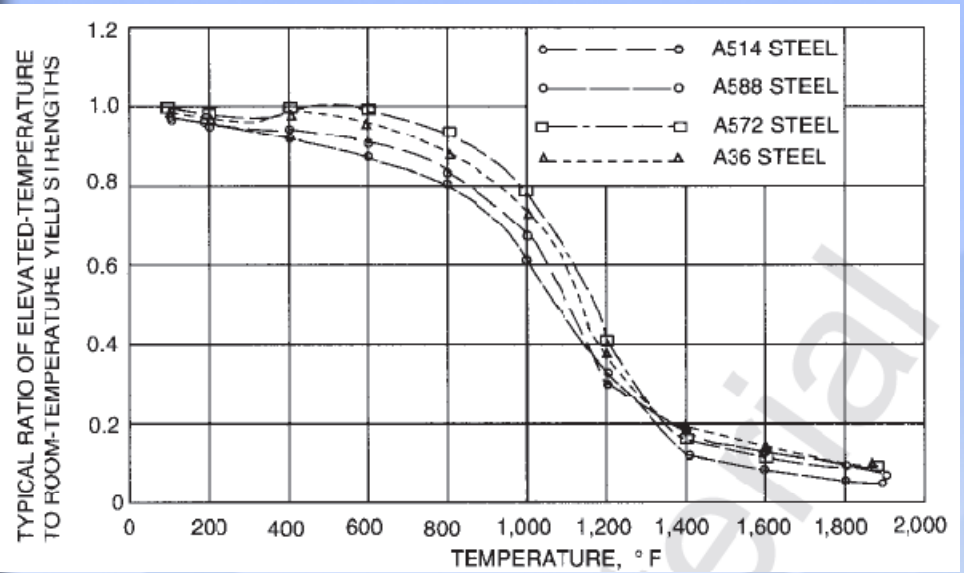


850° C – 3hrs



900° C – 3hrs

Effect of Temperature on Girders



Structural steel yield strength variation with temperature (from ***Structural Steel Designer's Handbook***, Figure 1.9(a)

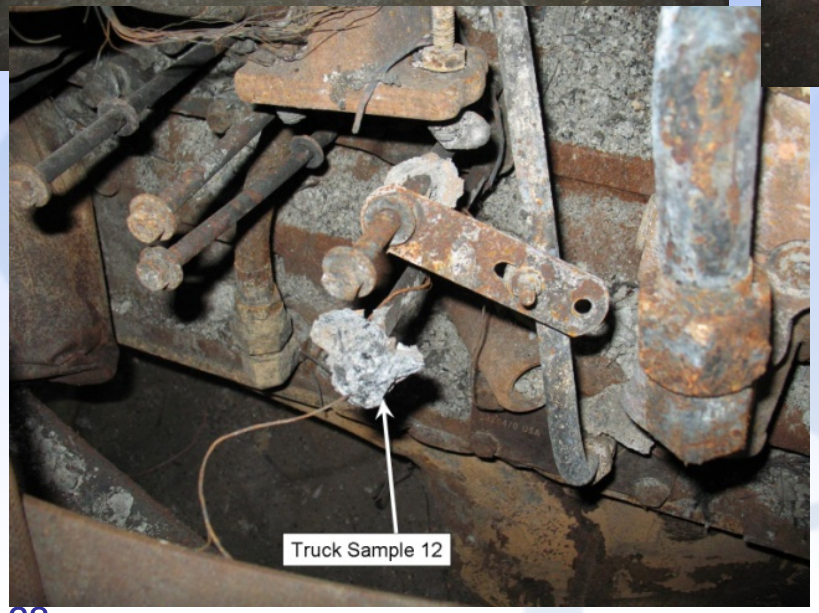
- **Material evaluations indicate that the steel girders experienced maximum temperatures in the range of 800-900ºC (1472-1652ºF)**
- **Yield strength of structural steels drops rapidly with temperature above about 427ºC (800ºF)**
- **For A36 steel (the grade of steel in the girders supporting the I-580 roadway) at the estimated maximum temperatures experienced during the fire, the yield strength is less than 20% of its normal room-temperature value**

Tanker Truck Materials

Truck Samples Collected

Sample Identification	Description
Truck Sample 1	Front tire cord from left side of vehicle
Truck Sample 2	Tire cord from #5 axle on right side of vehicle
Truck Sample 3	Brake pad located near rear of vehicle
Truck Sample 4	Rim component sample from #5 axle
Truck Sample 5	Spring located near rear of truck
Truck Sample 6	Large bolts (3) located on frame and near engine
Truck Sample 7	Grade 5 bolt located on frame
Truck Sample 8	Copper wire ground strap located on frame
Truck Sample 9	Copper wire battery cable
Truck Sample 10	Copper wire electrical system wiring located on frame and melted aluminum
Truck Sample 11	Fitting with brass located on engine
Truck Sample 12	Bolt from engine passenger side with steel wire and melted aluminum
Truck Sample 13	Aluminum screen from radiator
Truck Sample 14	Aluminum rim from dual wheel axle
Truck Sample 15	Aluminum tank section
Truck Sample 16	Glass mirror from passenger side
Truck Sample 17	Stainless steel mirror support bracket

Sample Photos



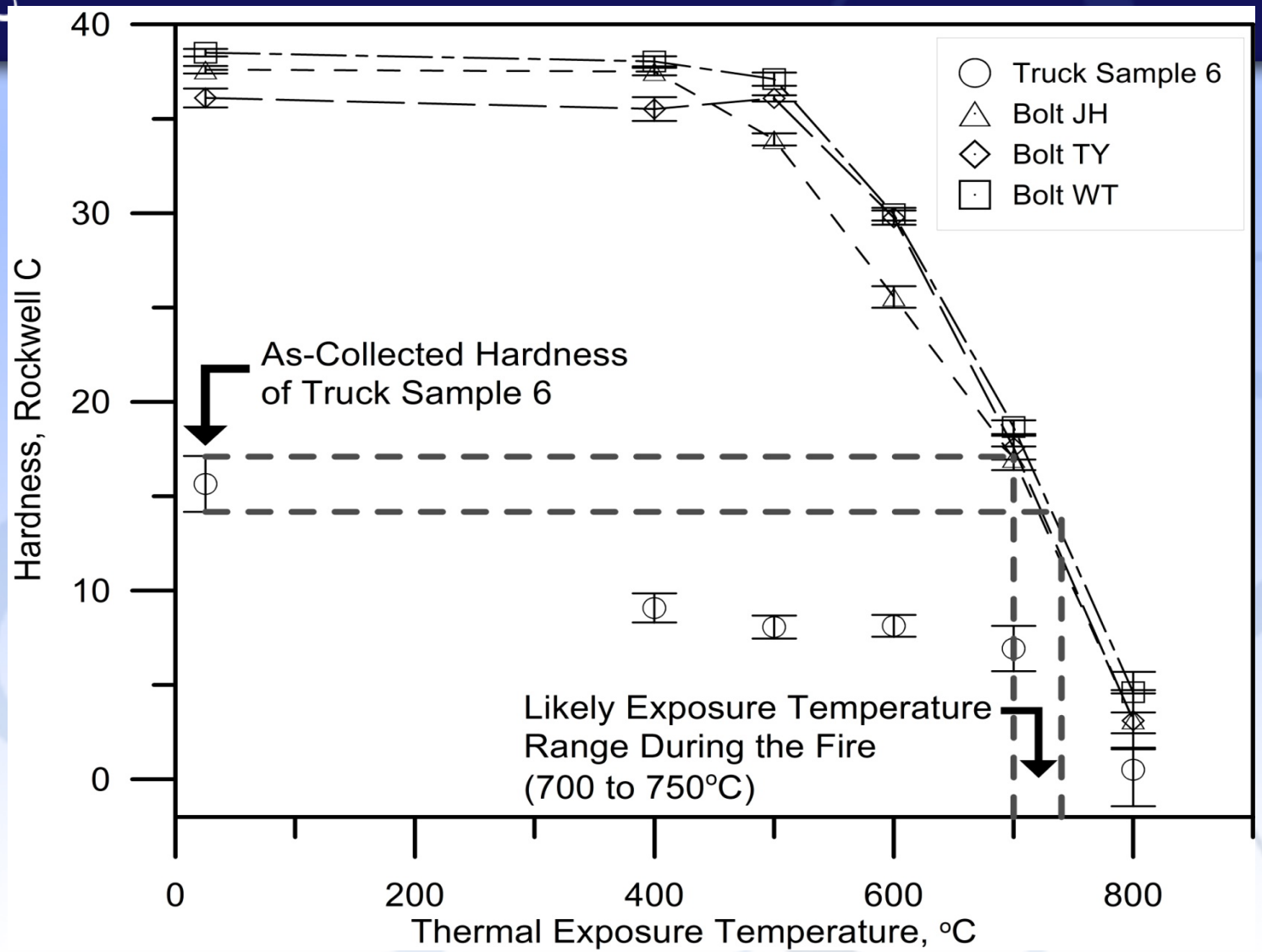
Tanker Truck Samples Analyses Description

- Aluminum Alloys (Partial Melting)
  - Tank sections, wheel rim, radiator screen
    - Analyzed to determine composition and melting points
- Copper Alloys (No Melting)
  - Electrical wiring, battery cables
    - Analyzed to determine composition
- Iron Based Alloys (No Melting)
  - Vehicle frame, stainless steel brackets, bolts
    - Frame exhibited scaling
    - Rearview mirror bracket was not sensitized
    - Fasteners tested for yield and tensile strength

Steel Fastener Analysis

- **Grade 8 Hardware (new)**
  - **Minimum 130,000 psi yield**
  - **Minimum 150,000 psi tensile**
  - **Rockwell hardness C33 to C39**
- **Truck Sample 6 (as exposed)**
  - **98,000 psi tensile**
  - **Rockwell C16**
- **Testing indicated a exposure of 700 to 750°C**

Exposure Temperature vs. Hardness



Truck Material Temperature Estimates--

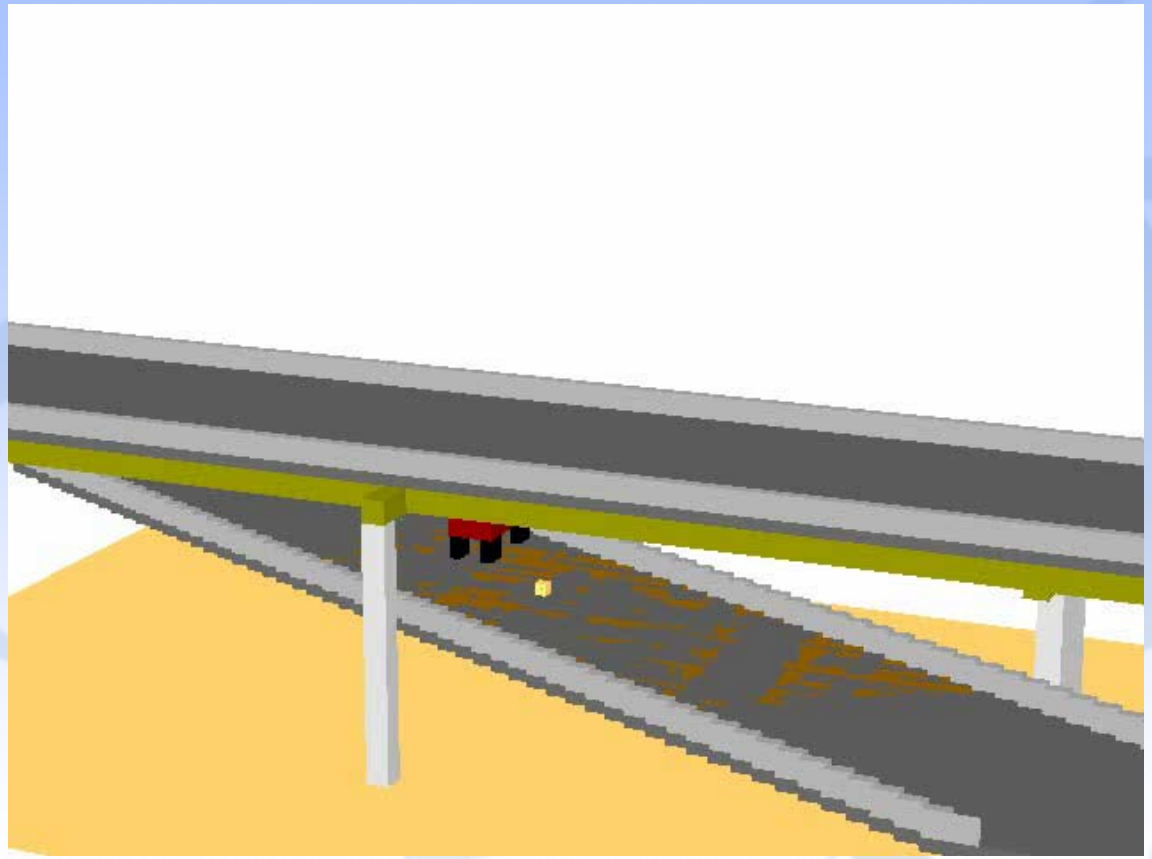
Sample Identification	Estimated maximum temperature (ºC)	Description
Truck Sample 1		Front tire cord from left side of vehicle
Truck Sample 2		Tire cord from #5 axle on right side of vehicle
Truck Sample 3		Brake pad located near rear of vehicle
Truck Sample 4		Rim component sample from #5 axle
Truck Sample 5		Spring located near rear of truck
Truck Sample 6	750	Large bolts (3) located on frame and near engine
Truck Sample 7	500	Grade 5 bolt located on frame
Truck Sample 8	590	Copper wire ground strap located on frame
Truck Sample 9	590	Copper wire battery cable
Truck Sample 10	590	Copper wire electrical system wiring located on frame and melted aluminum
Truck Sample 11	700	Fitting with brass located on engine
Truck Sample 12	900	Bolt from engine passenger side with steel wire and melted aluminum
Truck Sample 13	720	Aluminum screen from radiator
Truck Sample 14		Aluminum rim from dual wheel axle
Truck Sample 15	720	Aluminum tank section
Truck Sample 16		Glass mirror from passenger side
Truck Sample 17	540	Stainless steel mirror support bracket

MacArthur Maze Fire: Materials Analyses Conclusions

- **Based on the samples collected and the results of thermal exposures, the temperature of the I-580 overpass is estimated to range 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].**
- **The hottest gas temperatures during the fire were located above the I-880 roadway near the steel girders of the I-580 overpass.**

MacArthur Maze Fire Model

- Modeling the MacArthur Maze Fire
  - Fire Dynamics Simulator (FDS) code



Newhall Pass (I-5) Fire October 12, 2007

- 24 Tractor trailer rigs and 1 car involved
- Severe fire lasting several hours
- 3 deaths
- 1/10 mile (550 ft) tunnel (truck bypass)

- **NRC Actions**
  - Met with CHP MAIT team to review accident information and data
  - Retrieved and analyzed material samples to determine temperature exposures
  - Developing fire model to characterize the fire

Newhall Pass Fire: Tunnel Exit

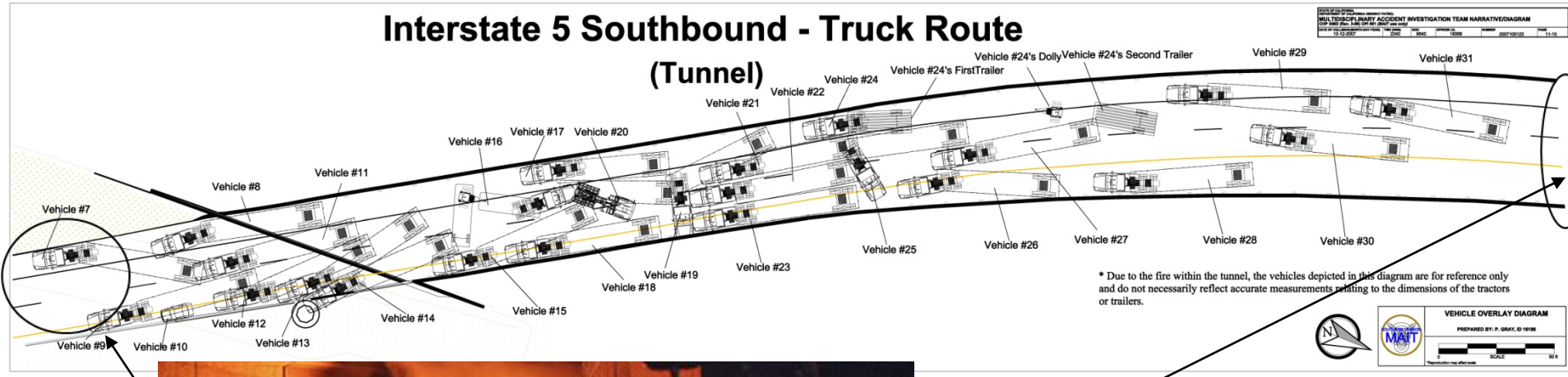
Photo by Gene Blevins/LACOFD/Photo

Newhall Pass Fire: Tunnel Exit

Newhall Pass Tunnel: Post-Fire

NHP Tunnel: Post-Fire Damage

Newhall Pass Accident



Photos by Gene Blevins/LACOFD/Photo; Diagram Courtesy of CHP

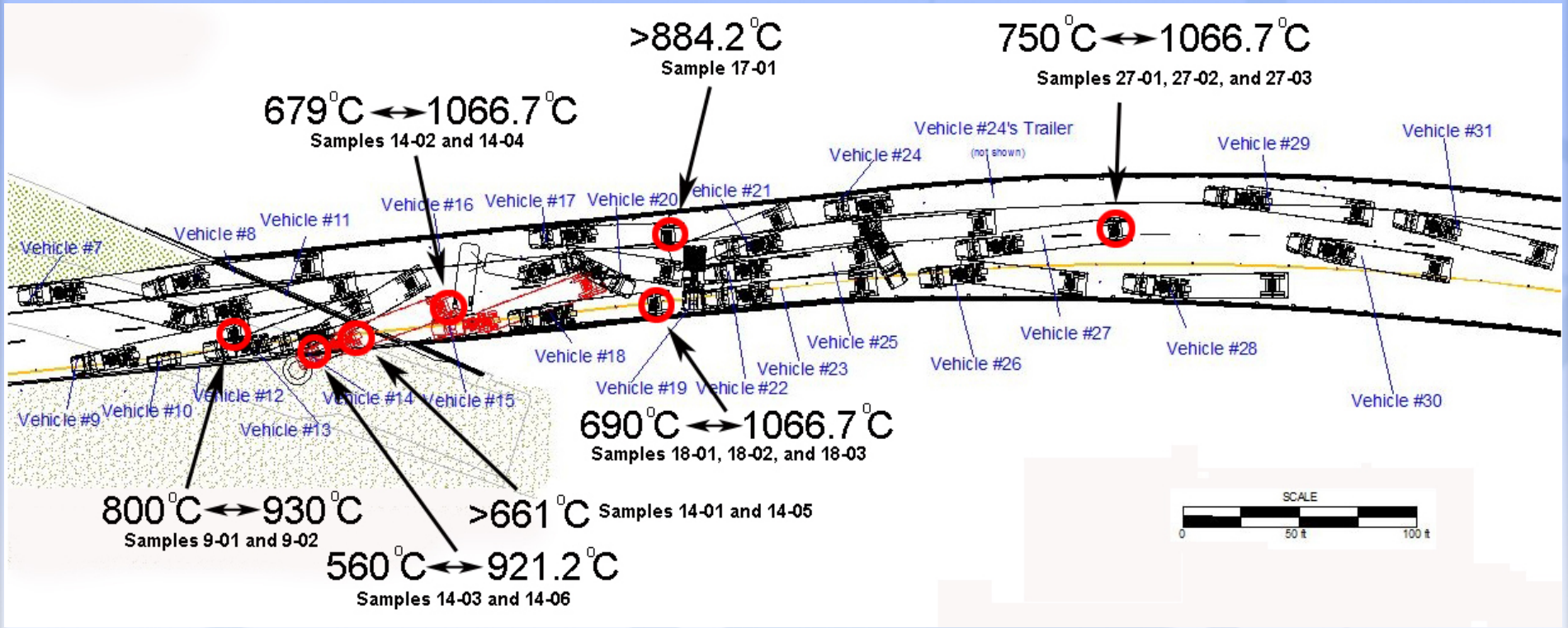
Samples Collected

Sample Identification	Description
Truck Sample 9-01	Melted aluminum and Grade 5 bolt from trailer wheel
Truck Sample 9-02	Brass Schrader valve from trailer wheel
Truck Sample 14-01	Aluminum bracket holding steel cable
Truck Sample 14-02	Copper wire from rear lighting of the trailer with some melted aluminum
Truck Sample 14-03	Brass clamp holding a copper wire from the driver's side engine compartment
Truck Sample 14-04	Melted aluminum and Grade 5 bolt from rear driver's side wheel of trailer
Truck Sample 14-05	Melted aluminum flooring with imbedded steel screw
Truck Sample 14-06	Melted aluminum from the grill of the tractor
Truck Sample 17-01	Partially melted rear brake brass compression fitting
Truck Sample 18-01	Brass clip containing copper electrical wire
Truck Sample 18-02	Melted aluminum and Grade 5 bolt from wheel
Truck Sample 18-03	Melted aluminum and Grade 5 bolt from wheel
Truck Sample 27-01	Melted aluminum and Grade 5 bolt from wheel
Truck Sample 27-02	Melted aluminum from rear of trailer
Truck Sample 27-03	Brass ID tag from axle housing

Material Analyses Results

Vehicle Number	Component/Sample	Condition/ Analysis	Temperature Bound	Temperature Range
9	Graded Bolts	hardness and microstructure	lower	880-930 °C [1,472-1,706 °F]
	Brass Schrader Valve	unmelted	upper	
	Aluminum	melted	lower	
14	Aluminum from Grill of Tractor	melted	lower	560 – 920 °C [1,040-1,690 °F]
	Brass Clamp from Engine Compartment	unmelted	upper	
	Aluminum Flooring (Trailer Front End)	melted	lower	> 660°C [>1,220°F]
	Aluminum Wheels (End of Trailer)	melted	lower	680-1,070 °C [1,256-1,958 °F]
	Copper Wiring (End of Trailer)	unmelted	upper	
17	Brass Compression Fitting Ferrule	melted	lower	> 880 °C [>1,616 °F]
18	Aluminum (at Wheel Level)	melted	lower	690-1,060 °C [1,274-1,940 °F]
	Brass/Copper	unmelted	upper	
27	Graded Bolt	hardness and microstructure	lower	750-1,070 °C [1,382-1,958 °F]

Sample Locations in Tunnel



Newhall Pass Fire: Conclusions

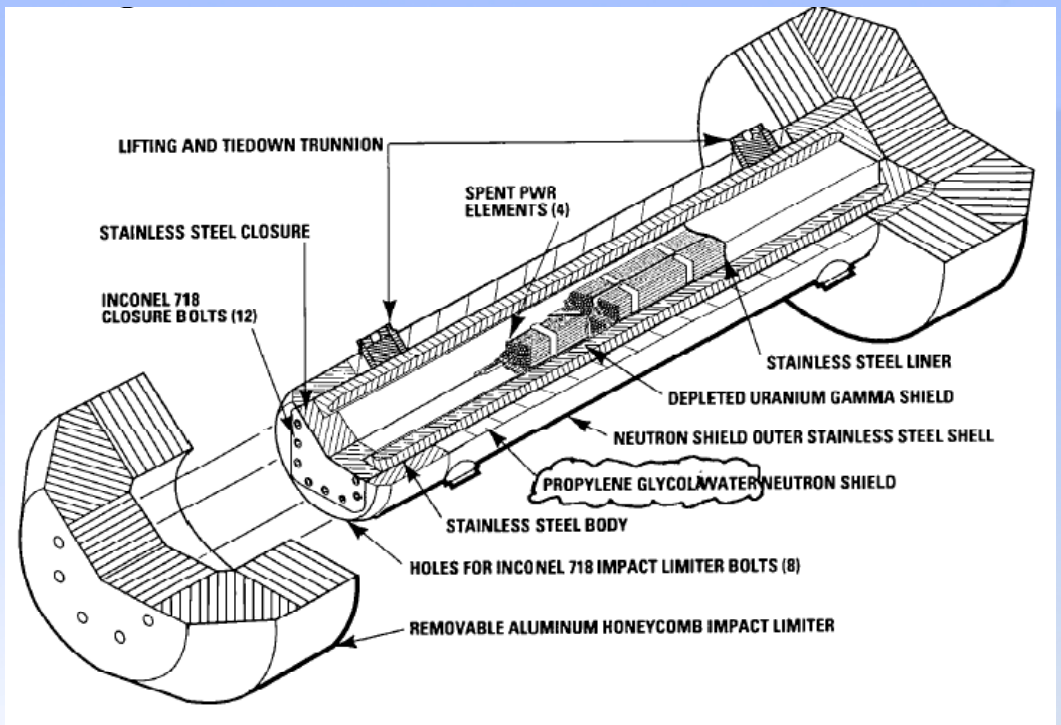
- Temperature in the tunnel reached levels high enough to melt aluminum.
  - greater than 560°C [1,040°F]
- At the location of truck 17, a higher temperature was observed based on a melting point analysis.
  - greater than 884°C [1,623°F])
- Hardness data (from bolts) indicated temperatures between 400 and 800 °C [750 and 1,470 °F].
- Based on materials analyses results, gas temperature varied with time and location and exceeded 884°C [1,623°F] in at least one location.

Future Work

- **Modeling Effects of MacArthur Maze Fire on an SNF Truck Transportation Package**
- **GA-4 package selected for analysis**
  - **Relatively high capacity Legal Weight Truck package**
  - **ANSYS model of GA-4 package developed to simulate structural and thermal response of package to fire conditions**
  - **COBRA-SFS model of GA-4 package developed to simulate thermal response to fire conditions, including effect of concrete over package during post-collapse fire and post-fire cooldown**
- **LS-DYNA model of bridge structure created to simulate collapse of I-580 overhead span between Bent 19 and Bent 20**

GA-4 Legal Weight Truck Transportation Package

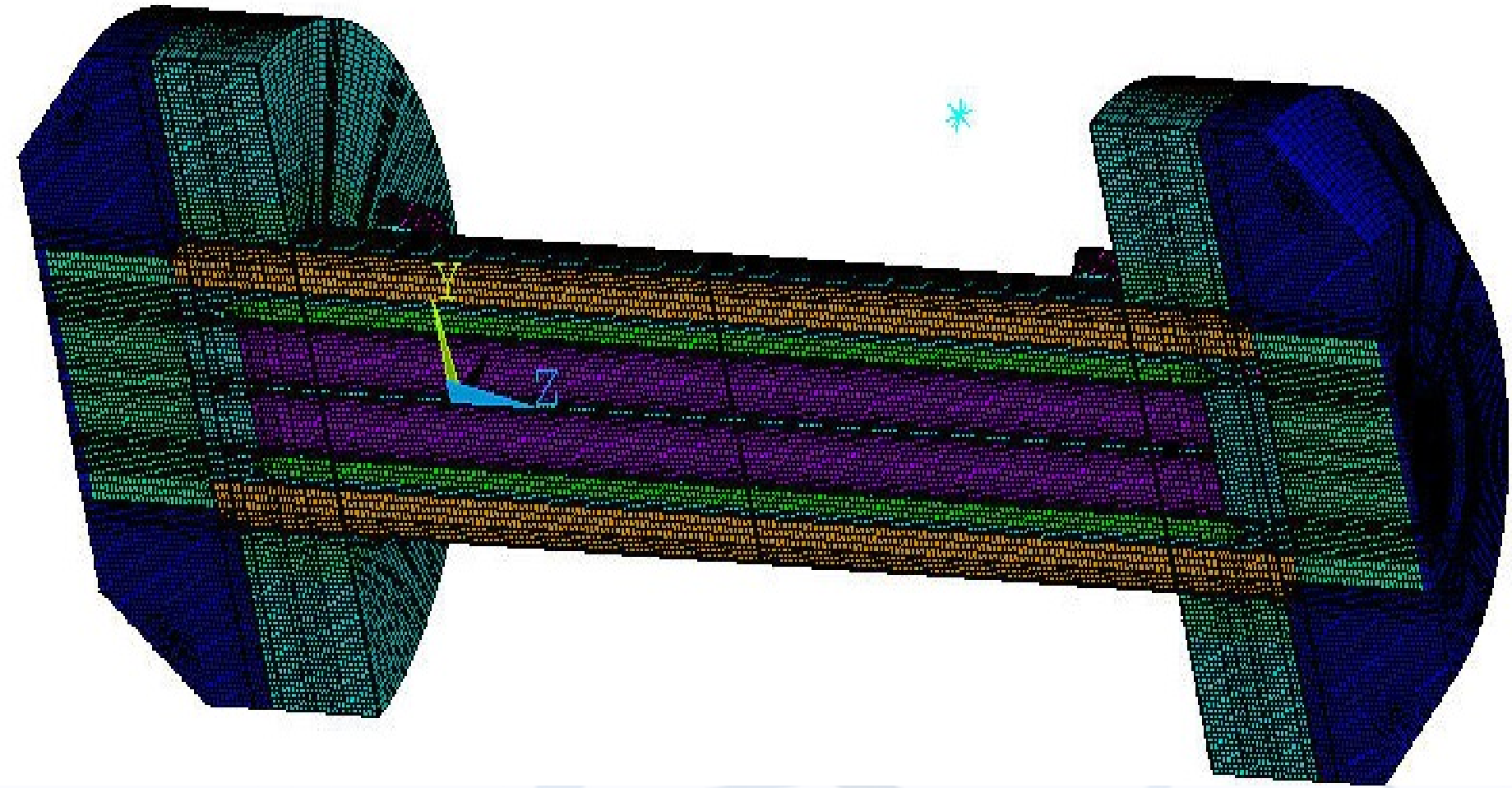
- GA-4 package is designed to transport
  - Up to 4 intact PWR 14x14 or 15x15 spent fuel assemblies



- Maximum decay heat load of 2.468 kW, with maximum of 0.617 kW/assembly
- Maximum average burnup of 35 GWd/MTU (10-yr cooled) or 45 GWd/MTU (15-yr cooled)

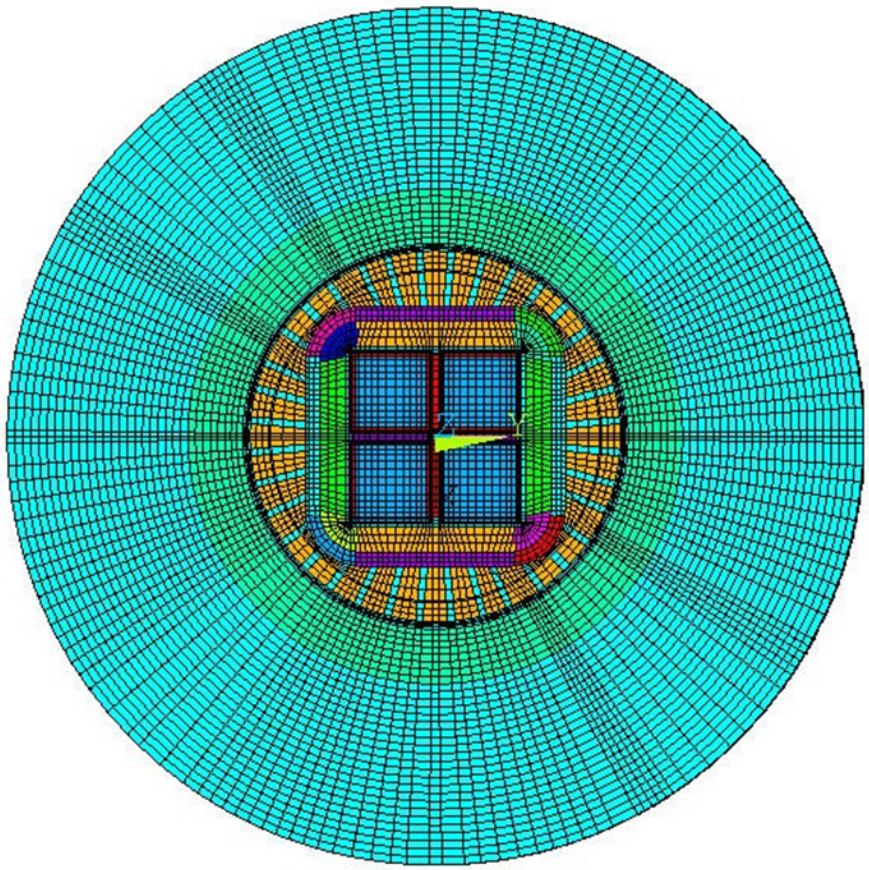
- Stainless steel package body, with
  - Depleted uranium gamma shield
  - Propylene glycol/water mixture for neutron shield
  - Gross wt. 55,000 lb (25,000 kg)

ANSYS Model of GA-4 Package

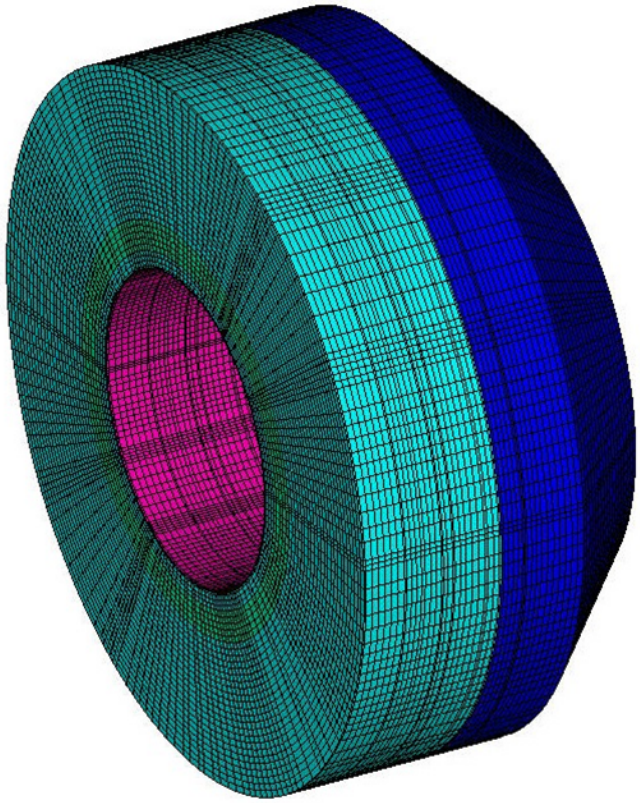


Package axial cross-section

ANSYS Model of GA-4 Pacakage: Basic Geometry

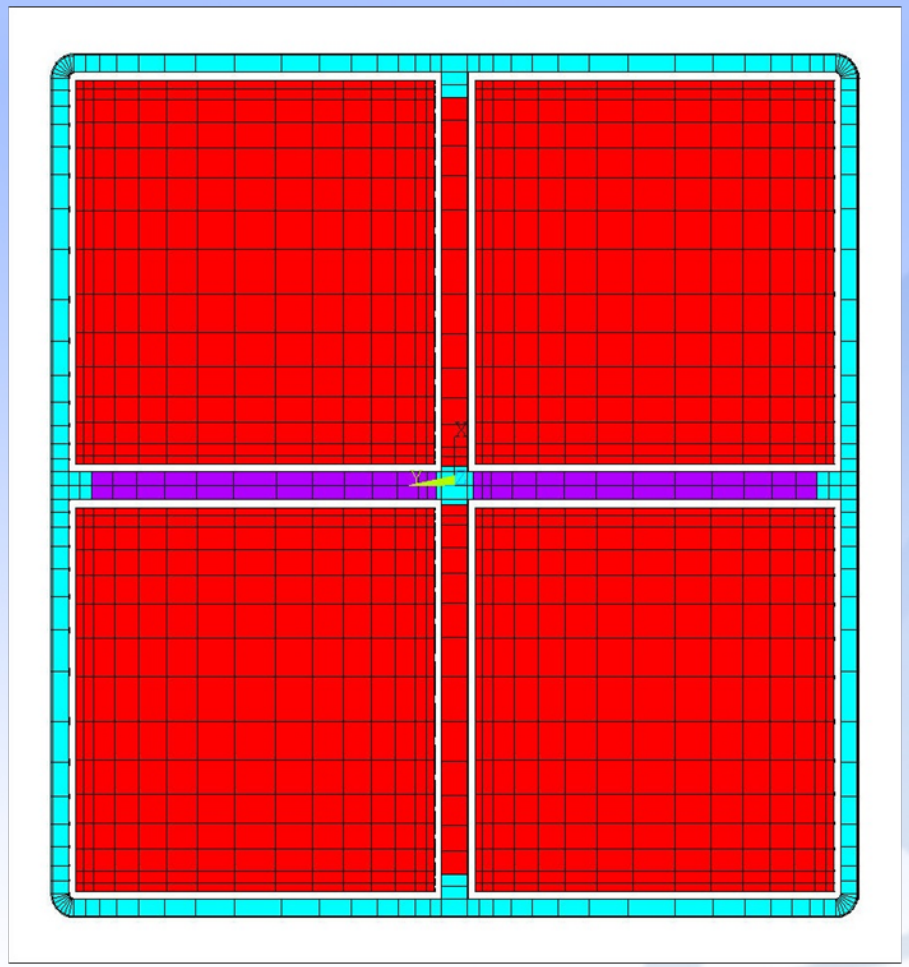


Package cross-section at package mid-line

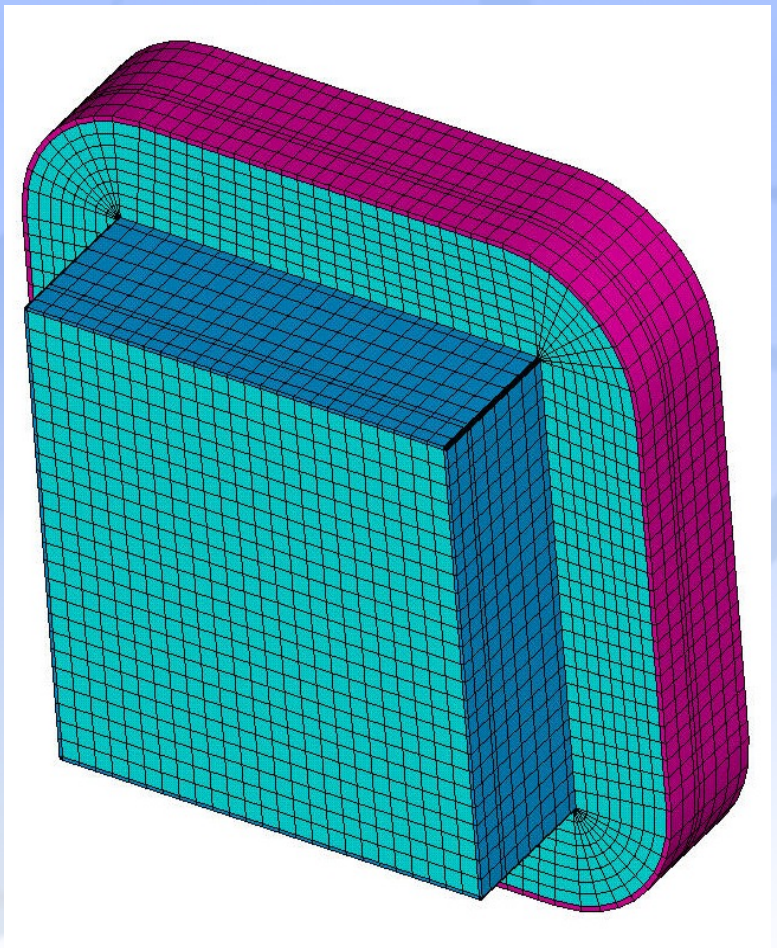


Impact Limiter Structural Details

ANSYS Model of GA-4 Package: Internal Geometry Details

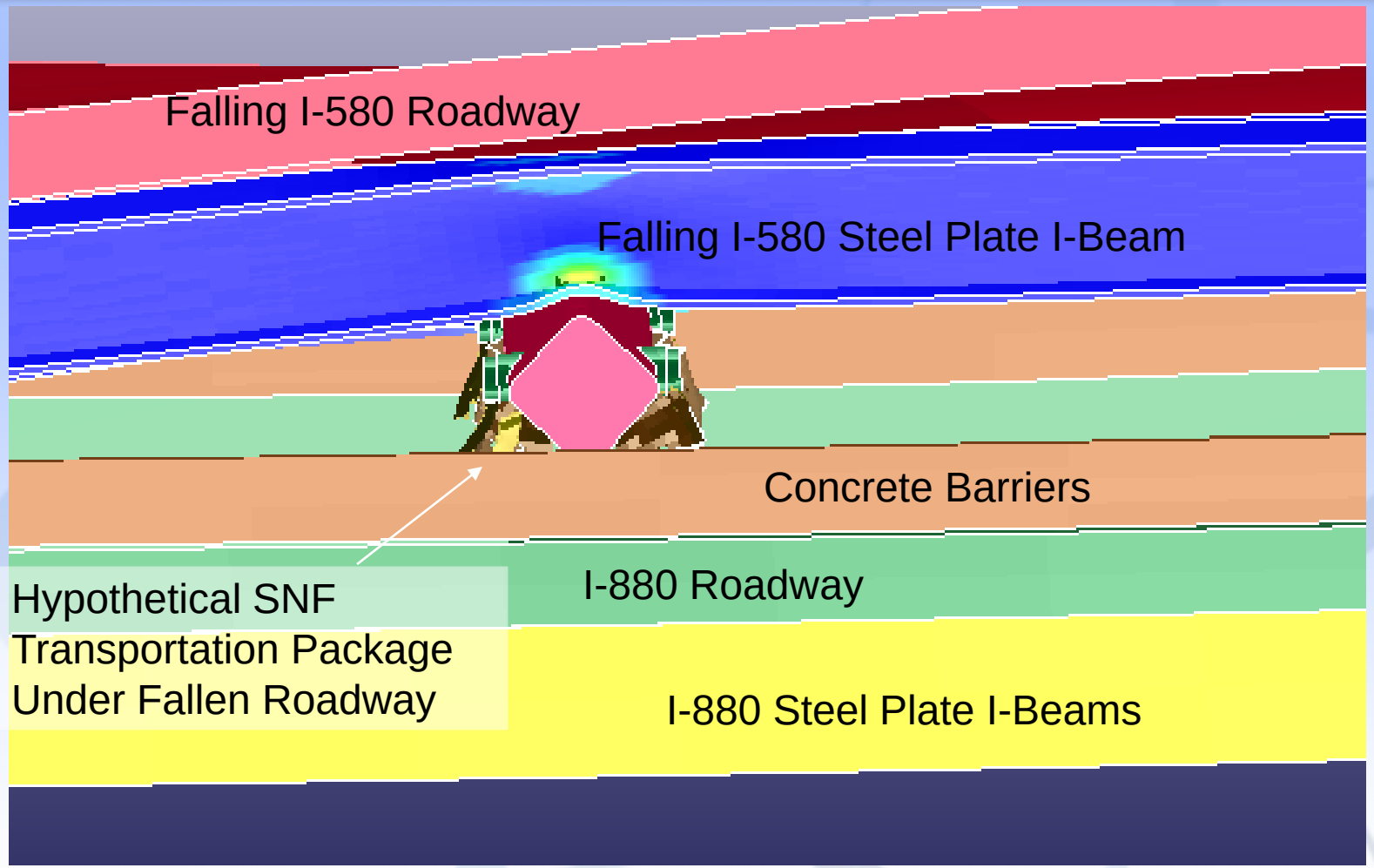


Fuel Assembly and Basket Structure



Package End Cap Details

Evaluation of Structural Impact on SNF Transportation Package



Evaluations of Package Response to Newhall Pass Exposure

- **GA-4 Package Model**
  - **ANSYS and COBRA-SFS models**
  - **Same analysis approach**
  - **Develop and apply NHP boundary conditions**
- **Potential for other package investigations**

Communications

- Reports (NUREG/CR)
  - Materials analyses (NUREG/CR 6987)
    - http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6987
  - Fire Modeling Report(s)
    - MacArthur Maze fire model
    - NHP to be a combined report
  - Transportation package response
    - For truck transport SNF package

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NIST
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