Regulatory Fire Test Requirements for Plutonium Air Transport Packages: JP-4 or JP-5 vs. JP-8 Aviation Fuel

PATRAM 2010

October 3-8, 2010

London, UK

Carlos López, Victor G. Figueroa, and Vernon F. Nicolette
Sandia National Laboratories
Albuquerque, NM USA

Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

10CFR 71.74(a)(5) - Accident Conditions for Air Transport of Plutonium

"The package must be exposed to luminous flames from a pool fire of JP-4 or JP-5 aviation fuel for a period of at least 60 minutes. The luminous flames must extend an average of at least 0.9 m (3 ft) and no more than 3 m (10 ft) beyond the package in all horizontal directions. The position and orientation of the package in relation to the fuel must be that which is expected to result in maximum damage at the conclusion of the test sequence. An alternate method of thermal testing may be substituted for this fire test, provided that the alternate test is not of shorter duration and would not result in a lower heating rate to the package. At the conclusion of the thermal test, the package must be allowed to cool naturally or must be cooled by water sprinkling, whichever is expected to result in maximum damage at the conclusion of the test sequence."

Jet Propellant (JP) 4 and 5 Background

- **JP-4 – Specified in 1951 by the U.S. government and phased out in favor of JP-8 in 1996**
  - **Was the primary U.S. Air Force jet fuel between 1951 and 1995**
  - **In cold-weather regions, commercial aviation uses a similar mixture under the name Jet-B**
- **JP-5 – Developed in 1952 for use in aircraft stationed aboard aircraft carriers where the risk from fire is particularly great**
  - **Similar formula to JP-8**
  - **JP-5 remains the primary jet fuel for the NAVY**
  - **Higher flash point than JP-8, but also has prohibitively higher cost, limiting its use to aircraft carriers**
- **Currently, limited availability of JP-4 and JP-5 aviation fuels specified in 10CFR71.74**

JP-4 and JP-5 Difficult to Obtain

- **According to experts in jet fuel supply, JP-4 is very hard to obtain as it is not used much anymore (only in very cold climate regions such as Alaska and Canada)**
- **JP-5 may be easier to get than JP-4, but only through a military supplier**
- **The Defense Energy Support Center is a possible source**
- **As a contractor to the government, Sandia may be able to obtain JP-4 or JP-5 from the Defense Energy Support Center**
  - **Long lead times**
  - **Higher cost likely**

JP-8 as a Possible Substitute

- **In contrast, 10CFR71.73 specifies "hydrocarbon fuel"**
  - **JP-8, which is readily available, can be used**
  - **JP-8 was specified in 1990 by the U.S. government**
    - **Commercial aviation uses a similar mixture under the name Jet-A**
  - **10CFR71.74 was developed when JP-4 and JP-5 were the standard jet fuels**
- **Sandia proposes the use of JP-8 as an alternate jet fuel for the 71.74 test**
  - **Compliance to the regulatory requirement needs to be demonstrated**

A Look at JP-4, JP-5, and JP-8 Properties

Property	JP-4	JP-5	JP-8
Approximate Chemical Formulation	C_9H_{20}	-	$C_{12}H_{23}$
Density, kg/m^3	760 @ 20°C	760 @ 15°C	808 @ 20°C
Heat of Combustion (MJ/kg)	43.6	42.6	43.2
Boiling Range, °C	66-246	170-269	177-266
Vapor Pressure @ 50°C, kPa	27	< 1.5	1.5
Heat of Vaporization (kJ/kg) @ average T_{boil}	252	270	280
Fuel Consumption Rate (mm/min)	4.4	-	4.7

Power of a Fire

$$\dot{Q} = \dot{m}'' A \Delta H_c$$

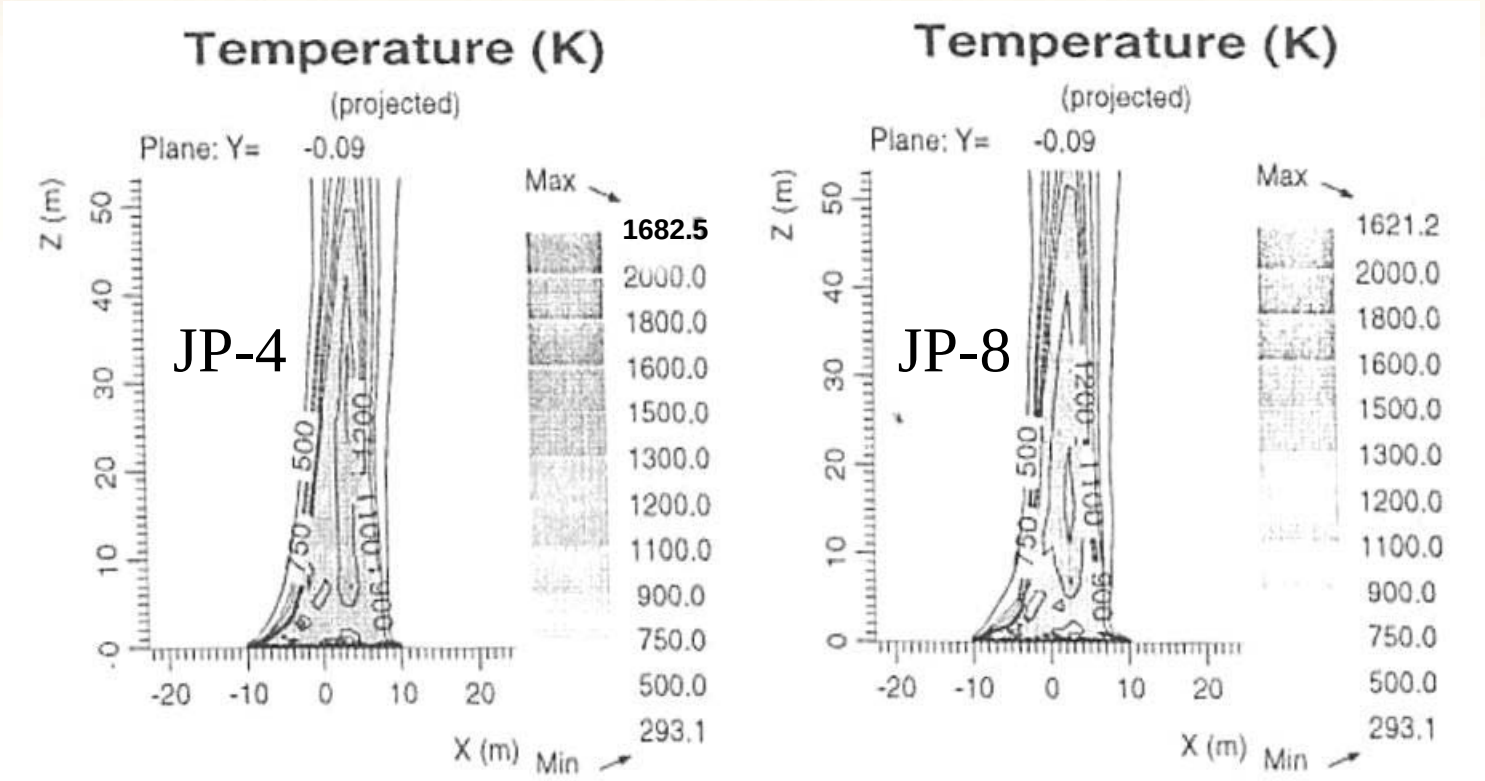
- $\dot{Q}$: **Energy Release Rate**
- $\dot{m}''$: **Mass Flux Rate**
- A: **Pool Surface Area**
- ΔH_c: **Heat of Combustion**

Sandia National Laboratories

Numerical Simulations: JP-4 vs. JP-8

- **Sandia study looked at similarities in fire physics between JP-4 and JP-8 pool fires (Nicolette et al., 1995)**
- **CFD Fire Modeling was performed**
  - **19 m diameter fuel pool**
  - **“Zero” and “non-zero” wind conditions**
  - **Only fully developed regime analyzed**

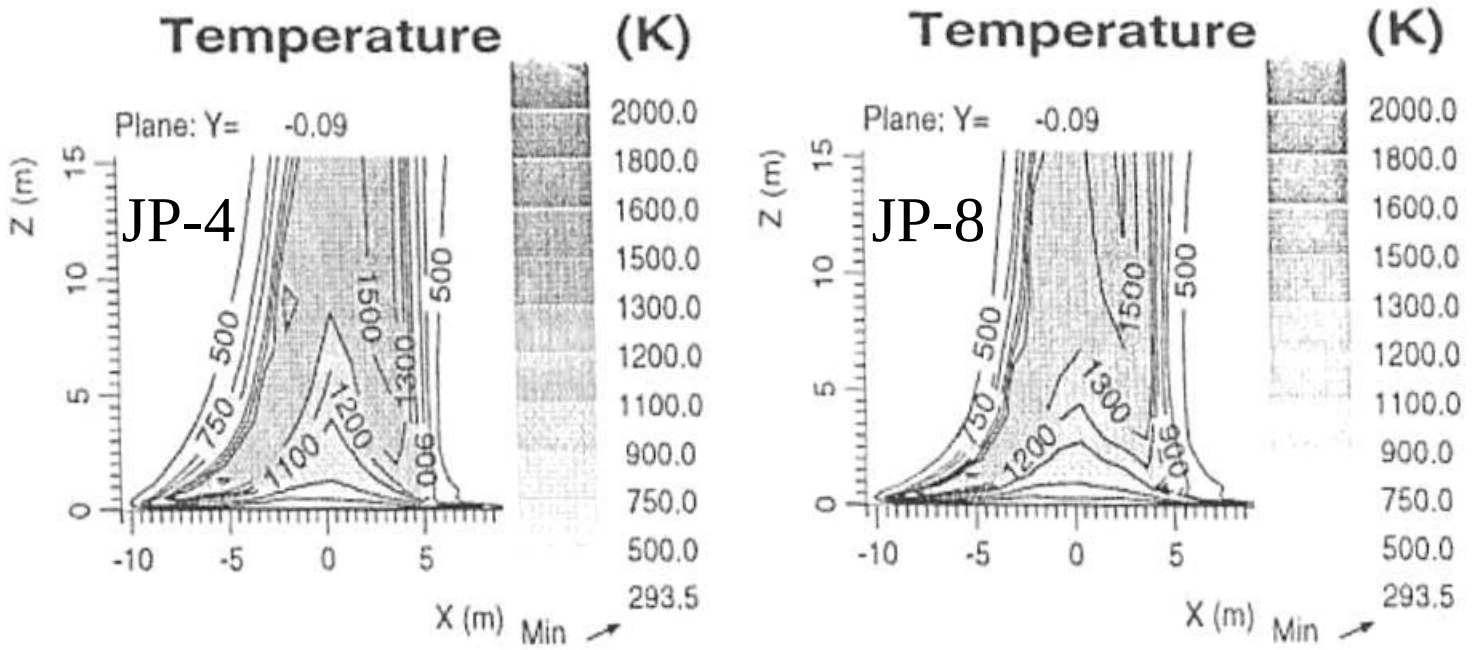
Flame Shape, Height, and Temperature



- **Localized peak temperatures different**
- **Flame volume temperature distribution very similar (1300-1500K for both fuels)**

Sandia National Laboratories

Temperature in Vapor Dome Region



- **Larger vapor dome in JP-4 pool fire simulation**
  - **Larger cooler region in the middle of the fire**
  - **JP-8 pool fire <u>could</u> be more severe for regulatory testing**

Sandia National Laboratories

Large Scale Tests

- **Conducted at China Lake, California**
- **JP-8 takes longer to reach fully developed burning state**
  - **Differences attributable to higher distillation temperature of JP-8**
- **Tests corroborated numerical data in fully developed state**
  - **Very little difference in:**
    - **Video recording of flame shape and height**
    - **Thermocouple measurements**

Summary

- **Main difference between JP-4, JP-5, and JP-8 is volatility**
- **Analyses and tests show that despite differences in volatility of JP-4 and JP-8:**
  - **Shape and size of the flame envelope are very similar**
  - **Temperature distribution is very similar**
- **Vapor dome in JP-8 fire smaller**
  - **Potential for more uniform and severe thermal environment for regulatory testing**
- **Sandia believes that JP-8 is an appropriate alternate jet fuel to conduct the fire test described in 10CFR71.74**

Additional Issues for Discussion

Sandia National Laboratories

10CFR 71.74(a)(5) - Accident Conditions for Air Transport of Plutonium

"The package must be exposed to luminous flames from a pool fire of JP-4 or JP-5 aviation fuel for a period of at least 60 minutes. The luminous flames must extend an average of at least 0.9 m (3 ft) and no more than 3 m (10 ft) beyond the package in all horizontal directions. The position and orientation of the package in relation to the fuel must be that which is expected to result in maximum damage at the conclusion of the test sequence. An alternate method of thermal testing may be substituted for this fire test, provided that the alternate test is not of shorter duration and would not result in a lower heating rate to the package. At the conclusion of the thermal test, the package must be allowed to cool naturally or must be cooled by water sprinkling, whichever is expected to result in maximum damage at the conclusion of the test sequence."

Sandia National Laboratories

§ 71.73(c)(4) – Hypothetical Accident Conditions

"Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C (1475°F) for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800°C. The fuel source must extend horizontally at least 1 m (40 in), but may not extend more than 3 m (10 ft), beyond any external surface of the specimen, and the specimen must be positioned 1 m (40 in) above the surface of the fuel source. For purposes of calculation, the surface absorptivity coefficient must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction, must be allowed to proceed until it terminates naturally."

Sandia National Laboratories

Comparing §71.74 with §71.73

- **Fuel:** JP-4/5 vs. hydrocarbon
- **Test Conditions:** Ambient conditions specified in 71.73 and not in 71.74
- **Fire emissivity:** 71.73 specify a fire emissivity of "at least 0.9" and 71.74 doesn't specify a fire emissivity
- **Position:** package height not specified in 71.74
- **Position:** 71.73 specify "extent of fuel source" (at least 1 but no more than 3 meters) and 71.74 specifies a minimum and maximum "average" extent of "luminous flames" beyond the package in all horizontal directions
  - This requirement in 71.74 is very difficult to prove
- **Alternate Test:** no temperature specified in 71.74
- **Alternate Test:** 71.73 "equivalent total heat input" vs. 71.74 "[no] lower heating rate to the package" (not clear what "heating rate to the package" means)
- **Certification by Analysis:** 71.73 provides parameters for certification by analysis while 71.74 requires physical testing

Sandia National Laboratories

Regulatory Intent

- **10CFR71.55(f)(1)(iv) –** ***General requirements for fissile material packages / For fissile material package designs to be transported by air:***
  - **"The thermal test in §71.73(c)(4), except that the duration of the test must be 60 minutes."**
- **10CFR71.64(a)(1) –** ***Special requirements for plutonium air shipments***
  - **Points to 10CFR71.74**
- **71.55(f) does not specify JP-4 or JP-5 and allows for the use of a "hydrocarbon fuel"**
  - **71.55(f) is a newer regulation than 71.64**
  - **JP-8 could be used**

Sandia National Laboratories