Nuclear Thermal Propulsion
Risk Communication

NETS 2015
February 25
A notional 5X5 Risk Matrix for Nuclear Thermal Rocket Full Scale Development

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Risk Definition</th>
<th>consequence</th>
<th>likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radical irrational public &amp; political FEAR toward space nuclear systems</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Regulatory Process becomes too cumbersome and affect schedule</td>
<td>variable</td>
<td>variable</td>
</tr>
<tr>
<td>3</td>
<td>Security requirement drive development COST too high</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>CFM LH2 zero-boil-off, QD &amp; no leakage technology for FSD</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Nuclear Fuel Element technology not ready for FSD</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Changing ground test requirements due to respond to peoples fears</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Turbopump FSD schedule</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Autonomous Vehicle System Management technology not ready for prototype flight</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Deep-Space Spacecraft System technology (radiation protection) not ready for FSD</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>NCPS FSD schedule is longer than 4 years and political winds start/stop progress</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
President John F. Kennedy …

• First, I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth….

• Secondly, an additional 23 million dollars, together with 7 million dollars already available, will accelerate development of the Rover nuclear rocket. This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the Moon, perhaps to the very end of the solar system itself.

Excerpt from the 'Special Message to the Congress on Urgent National Needs' President John F. Kennedy Delivered in person before a joint session of Congress May 25, 1961

Wernher von Braun envisioned NTP Stage being a “workhorse” space asset for delivering cargo and crew to the Moon first to support lunar base construction, then to send human missions to Mars.

Even with great VISION, Wernher von Braun and NASA could not overcome the political winds of change.

Presented to President Nixon’s Space Task Group and Senate Committee on Aeronautics and Space Science on August 4 and 5, 1969.
The President at the State of the Union 2015:
Negotiations with Iran and reduction of Nuclear Weapons

Very little done since 2009 when he mentioned some support of nuclear power
Yucca mountain defunded in 2009
Incentives excluded from Nuclear programs to reduce green house gases

The People:
Highly vocal minority and a large majority who doesn’t seem to care
According to a Gallop poll, 53% of people favor nuclear energy
According to a Gallop poll, 57% in Favor Keystone Pipeline

The Economics:
Low cost natural gas (and shorter construction time to build)
Deficit spending with majority of funding going to Social Security/Medicare
Once Nuclear Plant is in operation, low cost electricity
Global Climate Change:
Reduction in greenhouse gases has made some vocal anti-nuclear power people pro-nuclear. However, ANS EPA regulations purposefully structured to not allow nuclear to take advantage of CO2 reduction

Terrorism:
Threat of a Global Nuclear War has gone down, but concern of nuclear attack has gone up.

Space Nuclear Power:
Mars Science Lab (Mars Curiosity), launched Nov. 26, 2011
Next planned space nuclear power system is another Mars Science Lab in 2020
The mission has significant benefit

Technology:
Smaller, Safer, and drastically cheaper reactors being pursued
Private enterprise Bill Gates (TerraPower) and Jeff Bezos (General Fusion)

Policy (White House Fact Sheet, June 2012):  
The United States is committed to eliminating the use of HEU in all civilian applications because of its direct significance for potential use in nuclear weapons, acts of nuclear terrorism, or other malevolent purposes.
### Engine Development History (Cost and Schedule)

<table>
<thead>
<tr>
<th>Engine</th>
<th>Thrust</th>
<th>Period</th>
<th>Dev. Dur.</th>
<th>No. of Tests</th>
<th>Hardware Sets</th>
<th>Dev. Cost (FY91$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-1</td>
<td>1500K</td>
<td>'59-'66</td>
<td>8 yrs</td>
<td>1564</td>
<td>56</td>
<td>$1950M</td>
</tr>
<tr>
<td>J-2</td>
<td>200K</td>
<td>'60-'66</td>
<td>6 yrs</td>
<td>1730</td>
<td>38</td>
<td>$1445M</td>
</tr>
<tr>
<td>SSME</td>
<td>470K</td>
<td>'72-'81</td>
<td>9 yrs</td>
<td>615</td>
<td>15</td>
<td>$2405M</td>
</tr>
<tr>
<td>F100 ①</td>
<td>24K</td>
<td>'70-'72</td>
<td>3.5 yrs</td>
<td>3000 hrs</td>
<td>50-60</td>
<td>$1600M</td>
</tr>
<tr>
<td>RL10A-3 ②</td>
<td>15K</td>
<td>'58-'63</td>
<td>3+ yrs</td>
<td>2542</td>
<td>20</td>
<td>$370M</td>
</tr>
<tr>
<td>OMS ③</td>
<td>6K</td>
<td>'74-'80</td>
<td>6 yrs</td>
<td>720</td>
<td>5</td>
<td>$100M</td>
</tr>
</tbody>
</table>

(1) FSD preceded by Dem-Val Program of ~ $200M

(2) RL10A-3 preceded by air breathing hydrogen fueled engine and RL10A-1 programs (400M)

(3) OMS preceded by technology programs
Recent Cost Risk example from NASA
James Web Space Telescope

- “Massive” Cost Growth: $1.5B overrun (30%)
- Original Cost: $5B
- Delay in Schedule: from June 2014 to Sept. 2015 (1 year)
- Technology Investments to buy down risk
- Poor management & inadequate funding reserves

Recent Cost Risk example for DOE MOX Fuel Fabrication Facility @ Savannah River Site

- 310 acre federal nuclear reservation near Aiken, S. Carolina
- Employs more than 10,000 people
- Originally slated to be finished in 2016
- Completion date extended to 2025 (9 year delay)
- Original cost estimate $1.6 billion
- Current cost estimate to finish $30 billion (~19x original budget)
- Why? According to GAO, because of the DOE “record of inadequate management and oversight”

Weapon of WAR: Hiroshima & Nagasaki

**Little Boy**  
Aug 6, 1945 Hiroshima  
90-166k people killed  
~ Half on first day

**Fat Man**  
Aug 9, 1945 Hiroshima  
39-80k people killed  
~ Half on first day

**Fire Bombing of Tokyo**  
Operation Meetinghouse  
March 9-10, 1945  
279 B-29s 1700 tons of incendiary bombs  
100k people killed (2 days)

**Eizo Nomura**, closest known survivor 560 ft from Hiroshima ground zero (hypocenter) of explosion, lived into his 80s

**Tsutomu Yamaguchi** (double hibakusa: explosion affected people), died on January 4, 2010 at the age of 93, after a battle with stomach cancer

**Hibakusha** and their children experience discrimination in Japan due to false perception of the consequences from radiation sickness (hereditary/contagious)

20th day after explosion, the cities were covered in yellow flowers
Modern Hiroshima and Nagasaki

Hiroshima
Population 1.2 M
January 2010

Nagasaki
Population 446,000
January 2009
The 50,000 residents of Pripyat - now a ghost town - were evacuated in a major government operation starting the day after the catastrophe. Now more than 25 years after the city was emptied, it stands untouched from the day everyone left.

While it is illegal to take items in or out of Pripyat, because of fears of spreading the radioactive contamination, a few graffiti artists still manage to sneak in. "There are animal tracks now and again, ranging from birds to fox tracks" said Michael. "The escort told us that wolves had been sighted once. There is also evidence of vandalism but no squatters. It is unclear how people have entered Pripyat unsupervised, perhaps long ago before stricter controls on the exclusion zone were enforced."

After leaving, all visitors granted access are scanned for absorbed doses of radiation. Michael said: "If the safe dose is exceeded, your belongings are removed they give you a chemical shower."
Fukushima: Map of Terror

This is not a map of Fukushima Radiation spreading across the Pacific. This is a map of the estimated maximum wave heights of the Japanese Tohuku Tsunami by modelers at NOAA.

- http://www.enviroreporter.com/investigations/fukushima/a-radioactive-nightmare/
Fukushima evacuation has killed more than earthquake and tsunami, survey says

NBC News report on September 10, 2013

Approximately 300,000 people evacuated their homes near Fukushima Daiichi nuclear plant according to Red Cross figures.

A survey by Japanese newspaper Mainichi on September 9 stated that deaths relating to this displacement – around 1,600 – have surpassed the number killed in the region in the original disaster.

16,000 people were killed across Japan as a direct result of earthquake and tsunami in 2011

According to Mainichi report, 1,599 deaths were in the Fukushima Prefecture

Cause of death include:
Fatigue due to conditions
Exhaustion from relocation
Illness resulting from hospital closures
Suicides

Stress induced by not knowing when they can return
Difficult social and emotional effects

# Radiation Dosage Comparison

<table>
<thead>
<tr>
<th>Event</th>
<th>Duration</th>
<th>Rem</th>
<th>mSv</th>
<th>Yearly mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>eating 1 banana</td>
<td>instantaneous</td>
<td>0.00001</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>Dental x-ray (panoramic)</td>
<td>instantaneous</td>
<td>0.001</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>living in a stone/brick/concrete building</td>
<td>1 year</td>
<td>0.007</td>
<td>0.07</td>
<td>0.1</td>
</tr>
<tr>
<td>public exposure limit due to NTR testing</td>
<td>1 year</td>
<td>0.010</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>eating 1000 bananas</td>
<td>1 year</td>
<td>0.010</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>20 hour plane flight</td>
<td>20 hours</td>
<td>0.010</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>chest x-ray (2 views)</td>
<td>instantaneous</td>
<td>0.010</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>EPA yearly release limit for nuclear power plant</td>
<td>1 year</td>
<td>0.1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1 mammogram</td>
<td>instantaneous</td>
<td>0.3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Normal yearly background dose to person</td>
<td>1 year</td>
<td>0.4</td>
<td>3.65</td>
<td>4</td>
</tr>
<tr>
<td>a beach in Brazil (Guarapari)</td>
<td>1 year</td>
<td>17.5</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>Ramsar Iran</td>
<td>1 year</td>
<td>25.0</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>No observable effects</td>
<td>instantaneous</td>
<td>25.0</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Possible temporary blood effects</td>
<td>instantaneous</td>
<td>25.0</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Radiation worker one-year dose limit</td>
<td>1 year</td>
<td>5.0</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Space Shuttle Mission 41-C</td>
<td>8 day @ 460 km orbit</td>
<td>0.6</td>
<td>6</td>
<td>255</td>
</tr>
<tr>
<td>Apollo 14</td>
<td>9 day mission to moon</td>
<td>1.1</td>
<td>11</td>
<td>446</td>
</tr>
<tr>
<td>Skylab 4</td>
<td>87 day mission @ 473 km orbit</td>
<td>17.8</td>
<td>178</td>
<td>747</td>
</tr>
<tr>
<td>ISS mission</td>
<td>6 month</td>
<td>16.0</td>
<td>160</td>
<td>320</td>
</tr>
<tr>
<td>Estimated Mars Mission (in space)</td>
<td>3 year</td>
<td>120.0</td>
<td>1200</td>
<td>400</td>
</tr>
<tr>
<td>Estimated Mars Surface</td>
<td>1 day</td>
<td>0.1</td>
<td>0.67</td>
<td>245</td>
</tr>
<tr>
<td>Astronaut career limit (female age 25)</td>
<td>5 years</td>
<td>100.0</td>
<td>1000</td>
<td>200</td>
</tr>
<tr>
<td>Astronaut career limit (male age 55)</td>
<td>20 years</td>
<td>400.0</td>
<td>4000</td>
<td>200</td>
</tr>
<tr>
<td>50 km NW of Fukushima accident (March 16 &amp; 17)</td>
<td>1 day</td>
<td>0.4</td>
<td>3.6</td>
<td>1314</td>
</tr>
<tr>
<td>Severe radiation poisoning</td>
<td>instantaneous</td>
<td>200.0</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Extremely severe radiation poisoning</td>
<td>instantaneous</td>
<td>400.0</td>
<td>4000</td>
<td></td>
</tr>
<tr>
<td>Fatal dose of radiation poisoning</td>
<td>instantaneous</td>
<td>800.0</td>
<td>8000</td>
<td></td>
</tr>
<tr>
<td>People have survived (possibly)</td>
<td>instantaneous</td>
<td>1000.0</td>
<td>10000</td>
<td></td>
</tr>
<tr>
<td>contact with Chernobyl explosion reactor core steam</td>
<td>10 minutes</td>
<td>5000.0</td>
<td>50000</td>
<td></td>
</tr>
</tbody>
</table>
Safe NTR Design, Develop, Test & Execution

- Base of LH₂ Tank
- Helium Pressurization Bottles
- Structural Supports
- Control Drum Actuators
- Housing for Turbopumps
- Turbopump Exhaust (Attitude Control)
- Control Drum
- Pressure Shell
- Propellant Bleed to Turbopump
- Radiation Shield
- Reactor Reflector
- Reactor Core
- Propellant Feed Line
- Nozzle
- Nozzle Extension
Conclusions

• Vision & Leadership
• Regulatory common sense and accountability
  – Cost & Schedule
  – Can do vs. Can’t do
• Competition/Cooperation
• Risk (As Low As Reasonably Achievable, ALARA)
• Productivity (small teams with set goal & appropriate funding)
• Technology & Innovation (increase capability)
  – NTP (450 sec Isp chemical engine to 900 sec Isp NTP)
  – LEU NTP
  – Shortened schedules with innovative design & fabrication processes
• Education of Public
• Luck or Providence