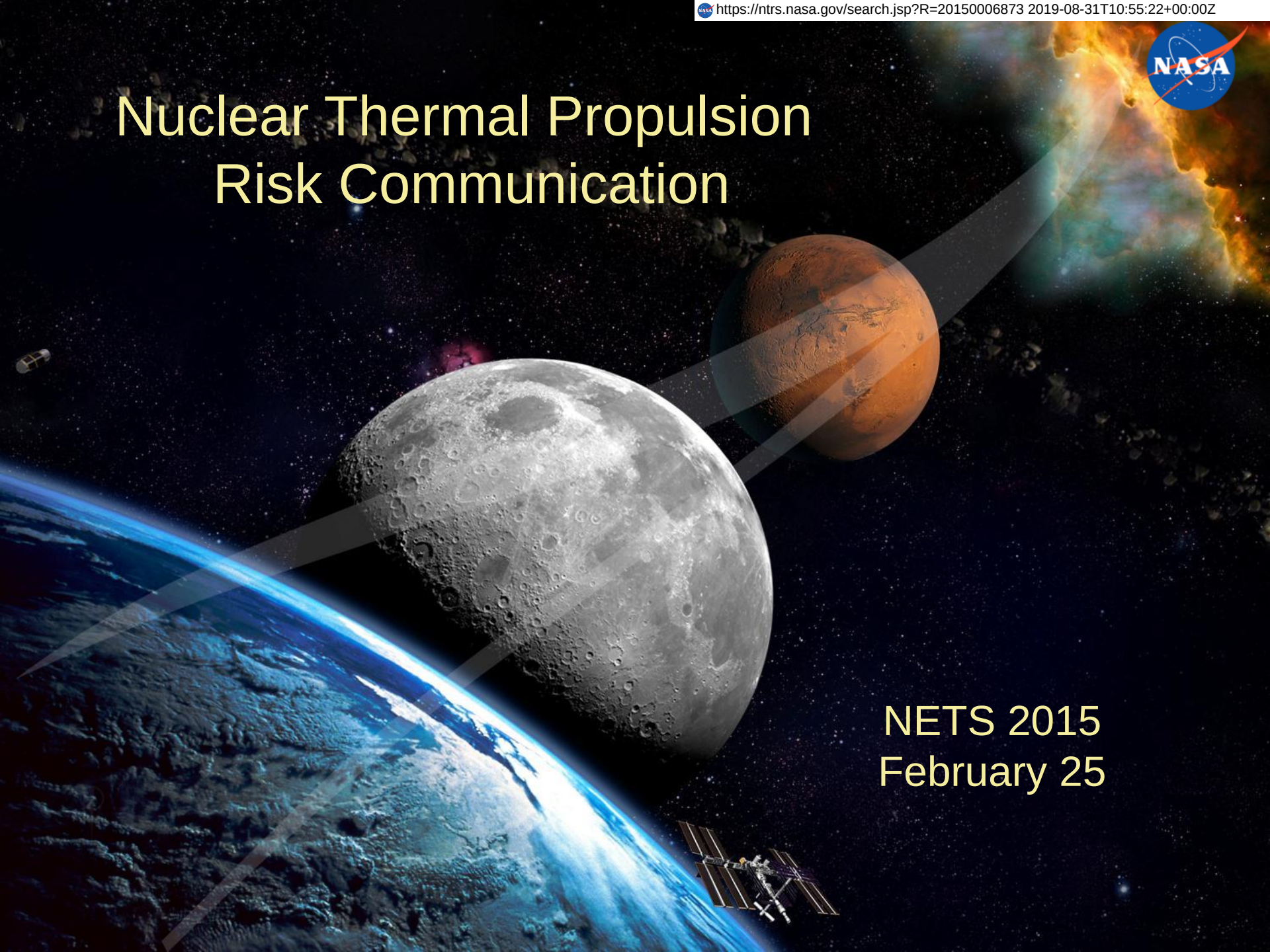
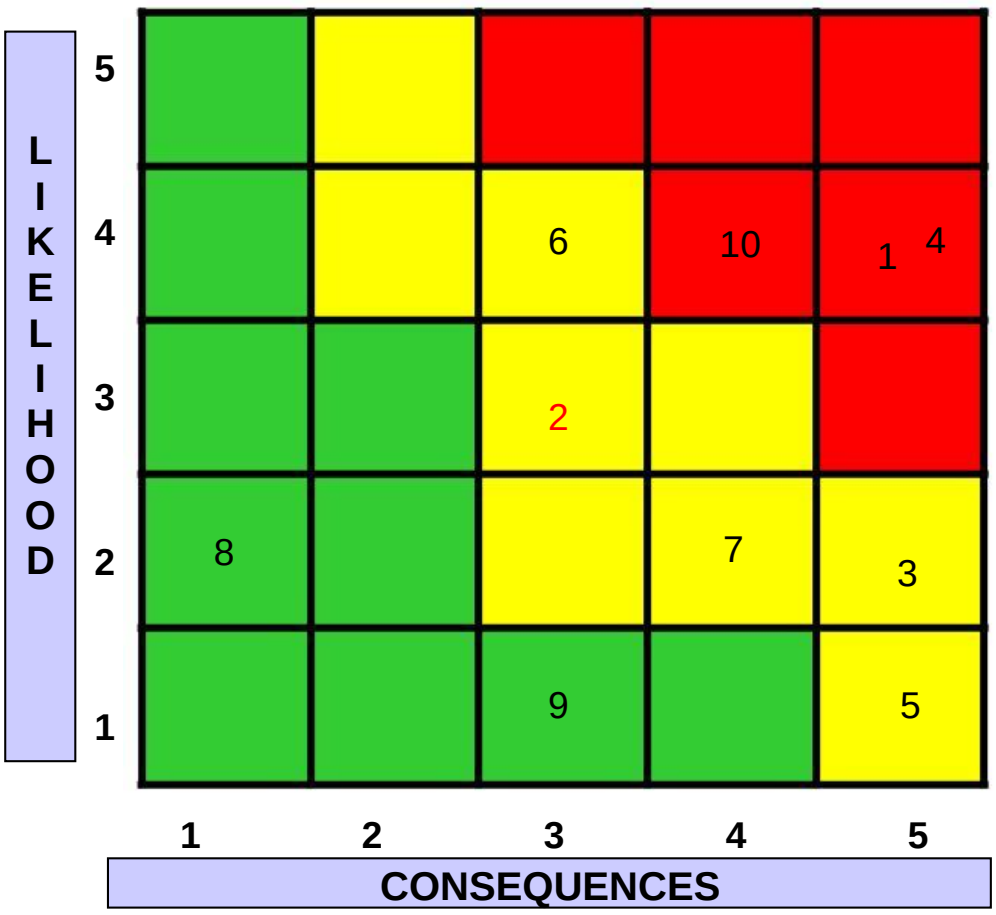
Nuclear Thermal Propulsion Risk Communication



NETS 2015
February 25

NTR Full Scale Development (FSD) Risks



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

A notional 5X5 Risk Matrix for Nuclear Thermal Rocket Full Scale Development

A Vision for NASA's Future …

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….

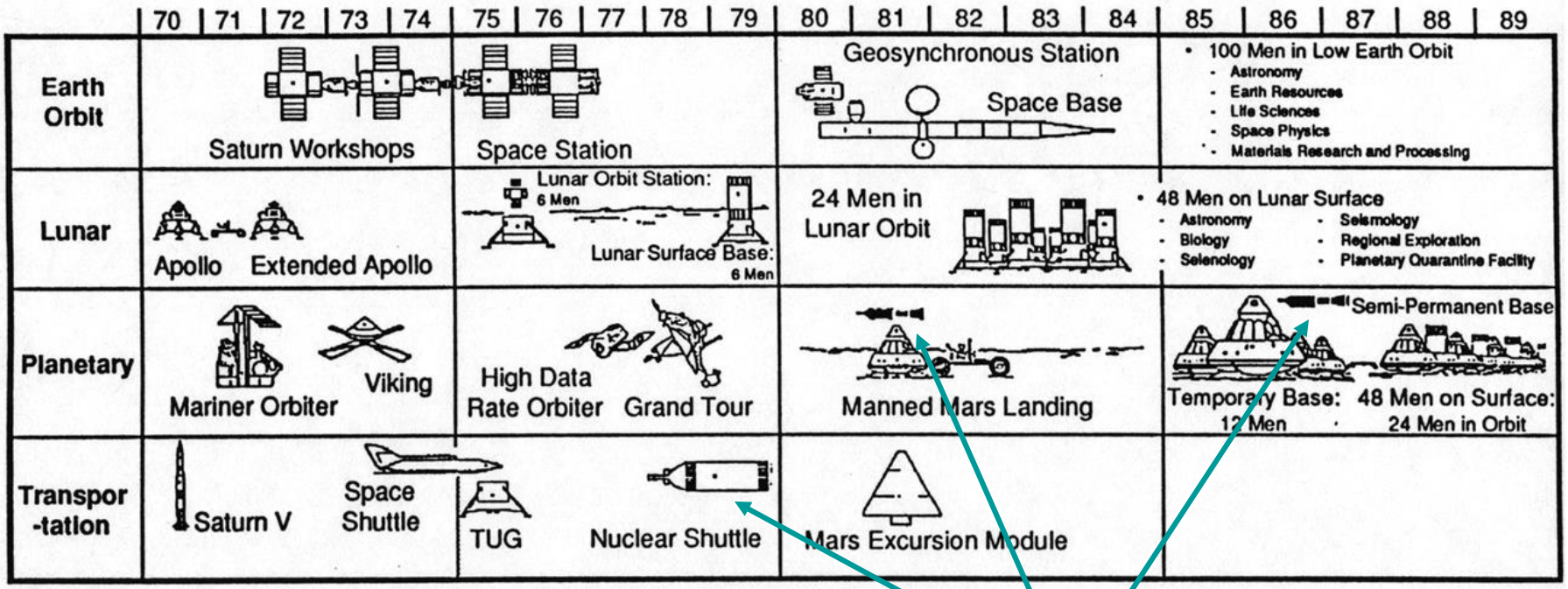
- Secondly, an additional 23 million dollars, together with 7 million dollars already available, will accelerate development of the Rover nuclear rocket. This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the Moon, perhaps to the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

Werhner von Braun's Integrated Space Plan for NASA (1970 - 1990) Utilized Nuclear Thermal Propulsion (NTP)



Presented to President Nixon's Space Task Group and Senate Committee on Aeronautics and Space Science on August 4 and 5, 1969.

75 klb$_f$ NERVA NTR Stage Envisioned for Moon / Mars Mission Applications

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, Werhner von Braun and NASA could not overcome the political winds of change.

Politics on Nuclear

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

Politics on Nuclear (cont'd)

Global Climate Change:
Reduction in Green house gasses has made some vocal anti-nuclear power people pro-nuclear. However, ANS EPA regulations purposefully structured to not allow nuclear to take advantage of CO_2 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)

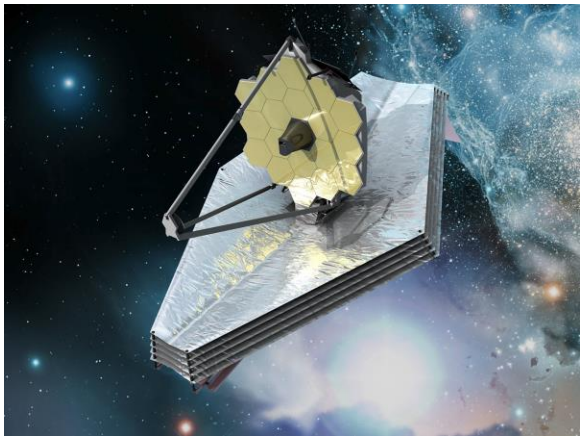
Engine	Thrust	Period	Dev. Dur.	No. of Tests	Hardware Sets	Dev. Cost (FY91$)
F-1	1500K	'59-'66	8 yrs	1564	56	$1950M
J-2	200K	'60-'66	6 yrs	1730	38	$1445M
SSME	470K	'72-'81	9 yrs	615	15	$2405M
F100 ①	24K	'70-'72	3.5 yrs	3000 hrs	50-60	$1600M
RL10A-3②	15K	'58-'63	3+ yrs	2542	20	$370M
OMS ③	6K	'74-'80	6 yrs	720	5	$100M

(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

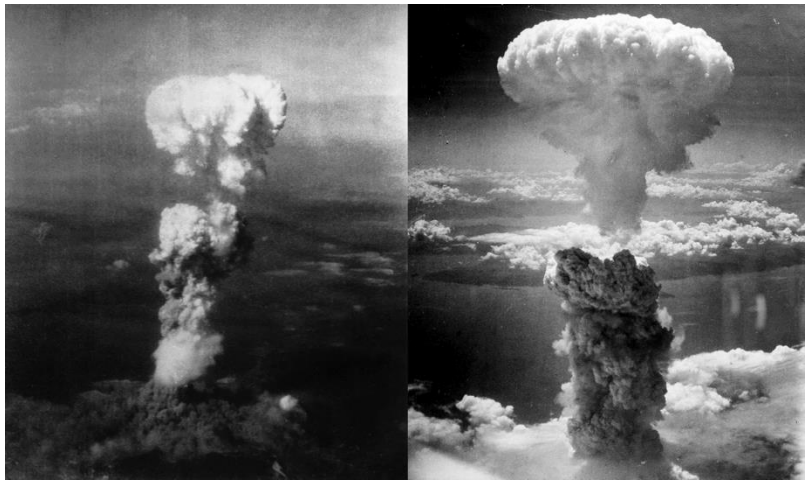
http://spacenews.com/jwsts-latest-15b-cost-overrun-imperils-other-high-priority-projects/

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”

http://www.huffingtonpost.com/elliott-negin/time-to-pull-the-plug-on_b_6466386.html (Huffington Post, Jan. 14, 2015)

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

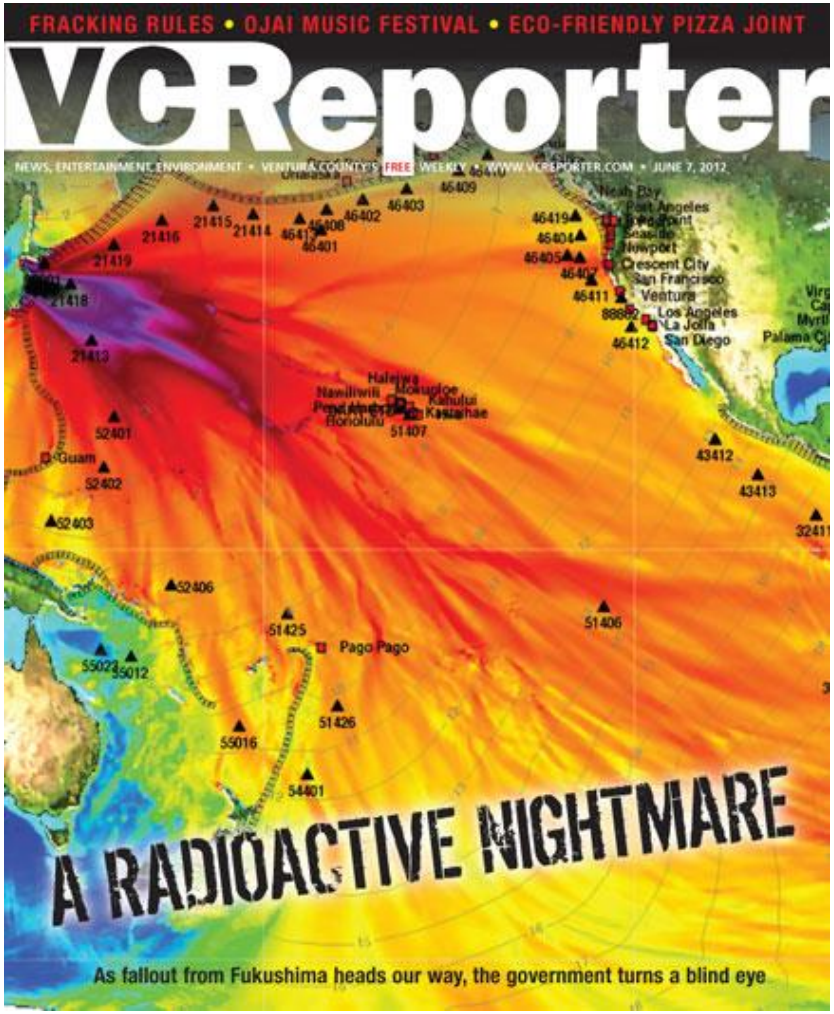
Chernobyl Safety Test Disaster

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 Deaths: none due to radiation

Fukushima evacuation has killed more than earthquake and tsunami, survey says

Officials in protective gear check for signs of radiation on children who are from the evacuation area near the Fukushima Daini nuclear plant in Koriyama, in March 2011.

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 –around1600- 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

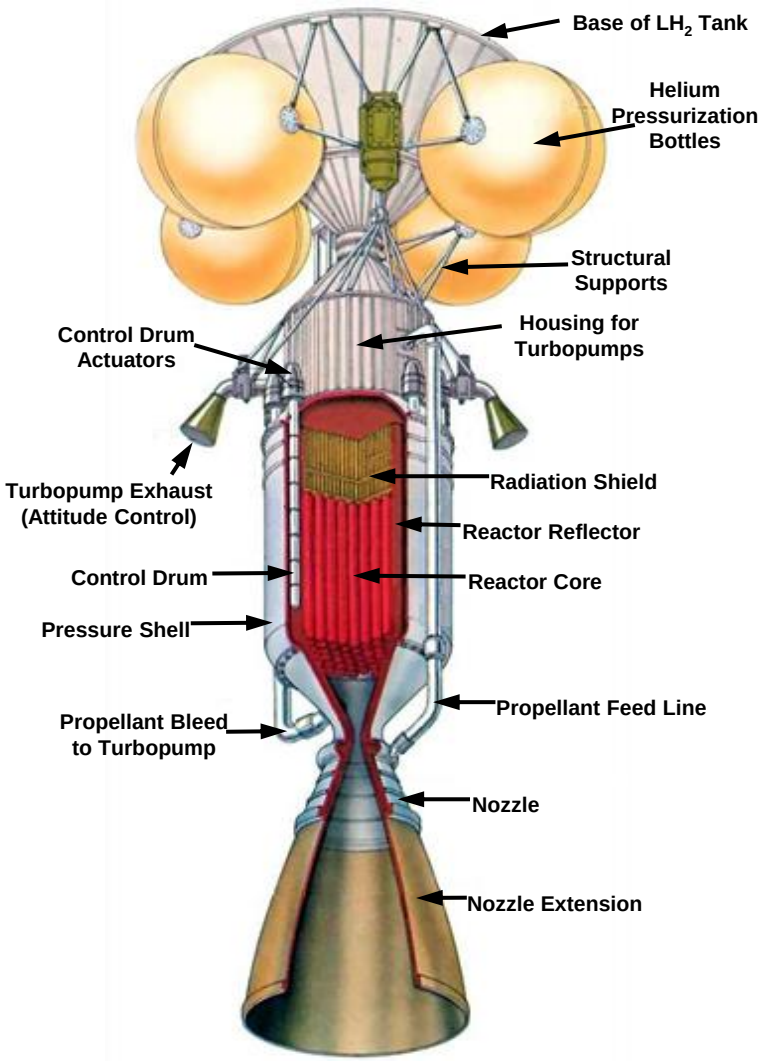
Stress induced by not knowing when they can return
Difficult social and emotional effects

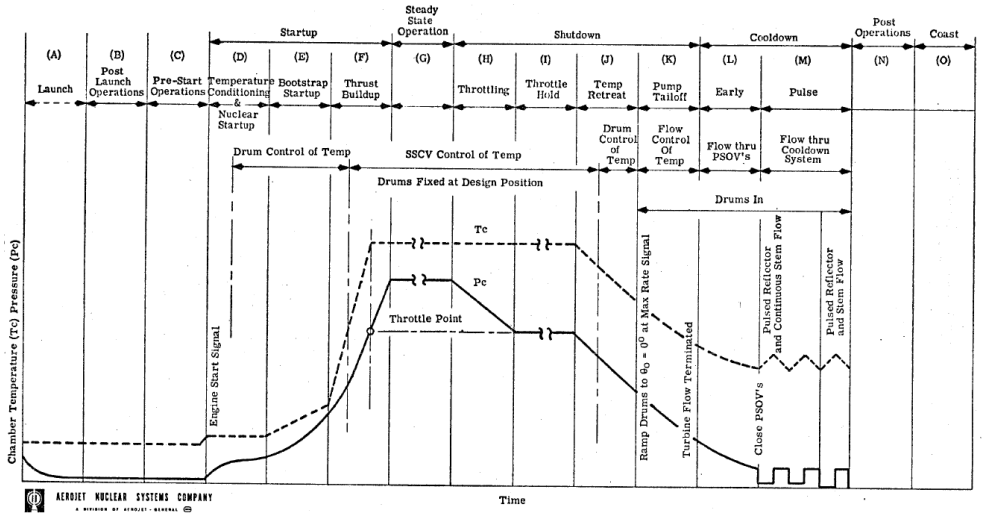
http://www.nbcnews.com/news/world/fukushima-evacuation-has-killed-more-earthquake-tsunami-survey-says-v20420833

Radiation Dosage Comparison

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

Safe NTR Design, Develop, Test & Execution





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