CHAPTER III

"They call the RTGs indestructible… They're indestructible, just like the Titanic was unsinkable."
Alan Kohn, 30 year NASA veteran, former launch safety manager, and Cassini protestor
Grossman 1997a, page 20).

HOW NASA CALCULATES RISK

NASA uses a well-defined technical risk assessment process, probablistic risk assessment (PRA) that was developed over time, and in response to changes in testing ability and modeling theory. PRA has an infrastucture of students and researchers, established models and techniques for analysis. NASA considers PRA the method of choice for certain types of risk assessment, such as those that involve low probability/high consequence results. While there are some communities of researchers that are still analyzing and solving theoretical problems associated with the diverse use of PRA, for NASA's purposes PRA has been "black-boxed" (i.e., NASA scientists can use the techniques and methods without questioning the validity of those techniques (Jasanoff and Wynne 1998; after Latour 1987)).

As the public, and its elected officials, came to demand failure-free management of its technologies, NASA invested in research to provide a means of communicating about risk (Heimann 1997). This approach is used by NASA to increase its risk reliability and the responsiveness within the organization, as described here by Heimann (1997, page 5):

> "The space agency traditionally approaches the launch decision with the assumption that a mission is not safe to fly. Subordinates are then required to prove that such is not the case before the launch is permitted. The null hypothesis, therefore, is that the mission should be aborted"

NASA's Assessment of Risk Factors Associated with the Cassini Mission

NASA bases its safety assessment for RTGs on a series of known facts about plutonium-238. Isotopes of plutonium give off short-range alpha particles that will usually travel no more than about three inches in air. External alpha radiation can be easily stopped by clothing, an outer layer of unbroken skin, or even a sheet of paper. On the other hand, if an individual were to ingest or inhale a small amount of PU-238, the alpha radiation would alter or kill nearby living cells causing organ malfunction or cancer. These types of cancers are always considered latent cancers and are expected to be diagnosed long after the incident occurs. To understand this latency factor, compare the potential cancers from a plutonium release, such as those that occurred in the 1950s during above-ground nuclear weapons testing to current lung and bone cancer rates. It is hard to identify cause and effect, but the rates are increasing whether through modern life and frequent exposure to carcinogens, or because the individual inhaled minute plutonium particles as a child.

Because the danger from PU-238 is from ingesting or inhaling the plutonium, the fuel for an RTG is encased in an inert ceramic matrix, that is resistant to high heat, and that will not shatter into fine, inhalable particles (NASA 1997). This ceramic matrix also provides the fuel with low water solubility so that its migration into ground water or uptake by plants would be minimal. See NASA's online publication: "Environmental Effects of Plutonium Dioxide" for a detailed explanation.

The Cassini power supply, like that of all previous RTGs, was designed to withstand a catastrophic explosion, as understood by NASA. The ceramic/PU-238 is separated into 17 individual golf ball-sized 'modules' which are then encased in iridium to withstand high heat from explosions or a high-atmosphere reentry. Iridium has a very high melting point (2425 degrees C) and is corrosion resistant (NASA 1997). The modules make it less likely, if plutonium were to be released, that all of it would endanger populations. As it is a passive power supply (no moving parts and a subcritical mass) there can be no "runaway temperature increase leading to a meltdown" (DOE 1997). The modules are further protected by graphite blocks which are also highly heat resistant.

NASA's assumptions regarding adequate testing for assessment of risk have been characterized by its critics as severely inadequate. NASA's testing assumptions formed the first critical element of the basis for the risk perception for the STOP CASSINI! campaign. At issue was the concept of single-event failure testing versus multi-event testing (Prettyman 1997). The event tests were for fire, explosive puncture, pressure, and thermal heat. Single event tests look at each factor individually and then combine the factors probablistically to determine the risk. Multi-event tests would expose the power supply to several "threats" at once: fire/pressure/shrapnel/ heat to see if the failure rates increase. A report filed by Reuters News prior to the launch stresses the testing assessment phase of the RTG approval (Young 1997):

> "NASA and the U.S. Department of Energy, which built the probe's three nuclear batteries, say extensive testing of the devices has proved the chances of a radioactive release are minimal. 'We've put them through explosions, we've put them through impacts, we've done pressure tests,' says Beverly Cook of the DOE. 'The bottom line is this. We have tested these to the conditions that we will have if there is an accident.' The probe's power sources generate electricity from the heat produced by the natural decay of plutonium dioxide, a non-weapons-grade material. NASA is quick to stress that they are not nuclear reactors."

NASA maintains that the radiation risk to humans and the environment in the event of a launch failure will be minimal and that all possible measures have been taken to ensure that the fuel cannot escape its protective shells (NASA 1997). To this end, federal law requires that a specific set of external safety reviews be met before an RTG can be designed into a mission, that an environmental impact statement must be prepared and approved before the fuel can be manufactured, and finally that the President of the United States must give final approval before any SNP launch (Sholtis, Joyce and Nelson, 1990).

NASA notes, in a 1997 pamphlet explaining the use of nuclear power for the Cassini mission (NASA 1997, page 2):

> "Potential RTG accidents are sometimes mistakenly equated with accidents at nuclear power plants. It is completely inaccurate to associate an RTG accident with Chernobyl or any other past radiation accident involving fission. RTGs do not use either a fusion or fission process and could never explode like a nuclear bomb under any accident scenario. Neither could an accident involving an RTG create the acute radiation sickness similar to that associated with nuclear explosions… NASA places the highest priority on assuring the safe use of plutonium in space. Thorough and detailed safety analyses are conducted prior to launching NASA spacecraft with RTGs, and many prudent steps are taken to reduce the risks involved in NASA missions with RTGs."

NASA's assessment is predicated on different aspects and levels of risk during different phases of the mission, which may be as short as seconds, during launch, to years for the transit of Jupiter's orbit. Any potential radiological impact to any physical area was calculated in terms of the mission phase, the probability of an accident with a fuel release occurring in that phase, the amount of fuel which might be released during a specific type of accident, and the radiological consequences of that release. NASA estimates that the likelihood of a plutonium release very early in the Cassini launch was 1 in 1,100 (9.1×10^{-4}), 1 in 476 late in the launch; and that the likelihood of a release during an Earth swingby reentry is

1 in 1.3 million (7.6×10^{-7}) (NASA 1995, pages 2-64–2-67). NASA and DOE maintain that in any case no plutonium would be released into the air during a launch phase accident (the highest potential risk), and only a minimal amount if the iridium-coated modules were to strike rock. If any of the modules were to strike rock, the plutonium release would then affect only a small area “with no expected effect on human health” (DOE 1997).

If plutonium were released in an accident, the predicted consequences to humans were based on health effects risk. This risk is calculated, based on a given accident scenario, with a “probability-weighted health effect as a direct result of that accident scenario.” (See Box 1, NASA Health Effects Risk Assessment, for an explanation of NASA’s risk estimates.) The health effects risk is calculated in terms of additional cancer deaths caused by the failure, as compared to expected cancer deaths that are the result of modern life. Thus it is possible for NASA to state that the expected cancer deaths from an early launch failure would not be discernible from the cancer deaths that will otherwise result from living in Florida.

If the Cassini *launch* were to result in an explosion then there were several possible results and options. First, in the event of a low-level launch or explosion, the result would not be high-heat or high-friction. If the RTG fell into the sea, it could be picked up and no harm would result. If the RTG were to strike rock (land) then the immediate evacuation of an area surrounding the ‘footprint’ of the strike would be effected. The remains of the RTG would be retrieved, and the earth removed to a depth of 6 inches in the ‘footprint.’ The footprint could be as small as .25 miles (within the Kennedy Space Center) or as large as 5.2 miles (including Cape Canaveral and the Merritt Island Wildlife preserve). The likely low-launch footprint for the Cassini mission included the Merritt Island wildlife preserve, a swamp and breeding ground for many endangered species, including the manatee (NASA 1995). When people learned about the threat to the Merritt Island wildlife preserve,the first phase of the STOP CASSINI! protest resulted. As one Cassini protestor put it (letter from Horst A. Poehler to Peter B. Ulrich, NASA Office of Space Science, December 9, 1994):

> "Economic impact discussions do not consider or discuss the impact losses to the homeowner in cases of a nuclear spill… The DEIS fails to examine the Benefit/risk ration (sic) where nuclear spill may place five Florida counties with a population of over 1.5 million and their property values at risk. The expected additional scientific knowledge does not justify the potential risk to the health and property values of the inhabitants that may be exposed."

The STOP CASSINI! protesters pointed out that, while NASA claimed that the risks of a catastrophic launch failure were very small, the efforts required to remedy a failure would be catastrophic to the local Cape Canaveral environment. Cape Canaveral includes both high-density tourist/residence zones (Cocoa Beach and others) and extensive wetlands (the Merritt Island Natural Wildlife Preserve among others). Please see Figure 4, Map of the Cape Canaveral region. The remedial activities identified by NASA's risk analysis included soil removal down to a depth of 6 inches, capping all wells, removing and quarantining all wildlife, and totally evacuating all citizens (NASA, 1995, pages 3-4–3-5). See Table 1: Range of Decontamination Methods for Various Land Cover Types. The FCPJ, representing local citizens, reacted strongly to this potential catastrophe to their lives and their environment, and claimed that the risks involved outweighed the potential benefits from the scientific discoveries that may be made by the Cassini mission.

From the Cassini Final Environmental Impact Statement, NASA 1995, pages viii-ix:

"During the interplanetary portions of the mission, postulated short-and long-term inadvertent reentry accident scenarios could result in releases of plutonium dioxide to the environment. However, NASA is designing the mission to avoid the potential for such accidents. The mission's design ensures that the expected probability of an inadvertent reentry would be less than one in a million. If such an accident were to occur, plutonium dioxide could be released in the upper atmosphere and/or scattered in indeterminate locations on the Earth's surface. Within the exposed population of 5 billion people, approximately 1 billion people (i.e., 20 percent or 1/5 of the population) would be expected to die of cancer due to other causes. The estimated fatalities that could result from an inadvertent reentry with release would represent an additional 0.0005 percent above the normally observed cancer fatalities [*500,000 deaths in addition to the estimated 1 billion cancer deaths*].

The principal method used in this document for characterizing the radiological impacts of each alternative evaluated is health effects risk. Health effects are expressed as the number of excess latent cancer fatalities (above the normally observed cancer fatalities) caused by exposure to the plutonium dioxide fuel. As used in this FEIS, health effects mission risk is the probability of an accident with a plutonium dioxide fuel release (i.e., the probability of an initiating accident times the probability of that accident causing a release of plutonium dioxide, since not all accidents would result in a plutonium dioxide release) multiplied by the consequences of that accident (i.e., the health effects that could be caused by the exposure of individuals to the plutonium dioxide), summed over all postulated accidents. Estimates of health effects mission risk, as discussed in this FEIS, represent the expectation latent cancer fatalities. The expectation health effects mission risk over all mission phases (i.e., the total or overall health effects mission risk) does not include contributions to risk from the long-term reentry scenario.

For the Proposed Action [the Cassini mission], the health effects mission risk considering all launch phases for the primary launch opportunity would be 8.4×10^{-7}. The health effects mission risk from the short term inadvertent reentry accident during the Earth swingby portion of the primary launch opportunity's VVEJGA trajectory [*the actual Cassini trajectory*] would be 1.7×10^{-3} and for the secondary and backup opportunities' VEEGA trajectories would be 1.8×10^{-7}. The total health effects mission risk (considering all launch phases and the Earth-Gravity-Assist trajectories) from the primary launch opportunity would be 1.7×10^{-3} and from the backup launch opportunity would be 1.8×10^{-3}. The health effects mission risks from the Cassini mission would be small and less than the total health risks faced by the public from construction and/or operation of large industrial projects."

BOX 1. NASA Health Effects Risk Assessment.
Source: 1995. Final Environmental Impact Assessment for the Cassini Mission.

Of particular interest to the Cassini mission protestors was the planned "Earth swingby" in August 1999. The swingby gave Cassini the needed velocity to reach Saturn by bringing the spacecraft within 500 miles of Earth's atmosphere at 40,000 mph. NASA maintained that Cassini's navigational capability allows altitude control during the swingby to within an accuracy of two to three miles (NASA

1997). NASA estimates the probability of Earth impact during this maneuver at less than 1 in 1 million (NASA 1995, page viii.). However, protestors contended that NASA's analysis of the potential for the Cassini spacecraft to vaporize if it hits Earth atmosphere at high speed, thereby releasing the fuel at very high atmospheric levels, was inadequate.

Also a point of contention was NASA's observation that while 1 billion out of every 5-7 billion people on the planet could be exposed to plutonium if the Cassini were to reenter Earth's atmosphere during the swing-by, this number would merely add 500,000 deaths from every 1 billion exposed to the *already predicted cancer deaths* within the next 50 years. This point was a significant protest point during the STOP CASSINI! campaign. True, 500,000 deaths is a small number compared to 1 billion, but NASA makes no observations as to whether or not these additional deaths will be concentrated geographically, and even if concentrated geographically will not be limited to NASA personnel. This argument concerns NASA's assumptions, testing methods, and trust in their own management. See Table 2: Estmated Latent Cancer Fatality Risks to Individuals.

NASA also bases some of its health effects risk assessment on existing levels of plutonium in the atmosphere. Plutonium exists in the atmosphere as a result of nuclear weapons testing and a 1964 launch and subsequent destruction of an RTG. This RTG, the SNAP 9A, burned up in the atmosphere, as it was designed to do, and as a result RTGs afterward underwent significant redesign. The design philosophy at the time was that it was better to spread the threat across the population than to put a specific population at risk. Table 3 shows major sources and approximate amounts of atmopheric plutonium-238 worldwide (NASA 1995, page 3-44). In general, NASA has calculated that, in the event of a system failure, the mechanisms for plutonium dispersion into, and transport through, the environment and thence to humans are extremely difficult and inefficient.

> "Independently reviewed analysis shows that the radiation hazard to the average exposed individual would be minuscule, about 1/15,000 of the lifetime exposure of a person from natural radiation sources" (NASA, 1997, p. 68).

NASA stressed that "while the consequences of a release could range from small to substantial, the probability of an accident occurring that could release plutonium dioxide fuel is extremely small" (NASA 1995, p. 2-62).

The above discussion gives examples of NASA's risk assessment for the Cassini mission and, through the included quotes and charts, gives examples of how NASA communicated information about the risk to the public. The risk from the mission was communicated by using comparisons as examples: the risk from a re-entry during flyby is compared to the number of people who are expected to die of cancer from other sources. NASA's risk assessment was a beginning point of contention during the STOP CASSINI! campaign, and the communication of that risk became a second point of contention.

Sources	**Amount (Becquerels [curies])**
Atmospheric Testing 1945-74 Deposited near testing sites and worldwide	3.3×10^{14} (9,000)
Space Nuclear - SNAP-9A, 1964	6.3×10^{14} (17,000)
Overseas Nuclear Reprocessing Plants, 1967-1987	1.1×10^{14} (3,000) (estimated, due to settling through weather activity)
Chernobyl Nuclear Power Station, 1986	$3.0\ 10^{13}$ (810)
Total	1.1×10^{15} (29, 810)

Table 3, Major Sources of Plutonium-238.
Source: NASA. 1995. Final Environmental Impact Statement for the Cassini Mission.

NASA's Risk Assessment Communication

As described in an essay by Baruch Fischhoff (1995), the field of risk communication has followed a discernible path for the last twenty years. NASA's risk communication methods have followed what may be called the classic development path of risk communication techniques. First came the attempt to adequately quantify the risk, and to communicate the quantification to the actors interested in the technology, usually from the promoting agency to other regulatory agencies (Harvard Group on Risk Management Reform 1995). NASA performed such calculations in preparation for the first flight of an RTG in 1964, where the spacecraft was intended to burn up high in the atmosphere, and communicated it to the executive branch and department of defense (Bilstein 1989; NASA 1997). Security policies regarding the manufacture and use of nuclear fuels created a NASA policy that did not publicly mention the power supplies on spacecraft and which downplayed the radioactive 'elements'. NASA adhered to the safety assessment guidelines prepared by the government to control radioactive materials, and spoke, in general, only to other agencies and to Congress regarding these technologies (Bilstein 1989).

Developmental Stages in Risk Management

- All we have to do is get the numbers right.
- All we have to do is tell them the numbers.
- All we have to do is explain what we mean by the numbers.
- All we have to do is show them that they've accepted similar risks in the past.
- All we have to do is show them that its a good deal for them.
- All we have to do is treat them nice.
- All we have to do is make them partners.
- All of the above.

Box 2. Stages of Risk Management.
Source: Baruch Fischhoff, "Risk Perception and Communication Unplugged: Twenty Years of Process", Risk Analysis, 15:137-45 (1995).

A second stage of an organization's risk communication practice is the recognition of social reaction to the use of a technology and the corresponding internal reactions of the agency promoting the technology. Examples of this second stage are the social protests over nuclear power during the 1970s and regarding nuclear arms in the early 1980s, when the public questioned adoption of such technologies. NASA also felt the effects of public opinion pressure, and during the late 1960s gradually changed its assessment language. Risk assessments were not stated as simple radiation release percentages, but were framed in terms of total radiation exposure over the lifetime of a statistically normalized 'individual' or the so-called "health effects risk" (NASA 1995, page viii). The risk was communicated to the public as negligible when compared to the every day risks from driving cars or experiencing heart attacks.

NASA expanded its risk communication during the 1970s by focusing on social benefits from technology choice, a common tactic of nuclear power utility campaigns. NASA stressed that its sole use of nuclear technologies was for peaceful exploration. Space exploration was to occur peacefully, and ultimately through the earnest cooperation of all nations. Such language was included in the original bill authorizing the development of the space station in 1982. During 1970s and 80s, NASA was also required to complete an environmental impact statement as part of its decision-making processes as required by the 1969 National Environment Protection Act (NASA 1995, page 1-2). By framing the risk as negligible when compared to total radiation exposure from the Sun during a person's lifetime, by comparing the risk to other "normal risks" and by stressing the socially positive impact of space exploration, NASA showed that it recognized the social potential of technological choice in its risk communication practices. See Table 4: Average Annual Effective Dose Equivalent of Ionizing Radiation.

The next stage in NASA's risk communication occurred in the mid-1980s. This stage moved the discussion from whether or not the technology was risky, to whether the regulating or owner agency was responsible or competent enough to use the technology. The *Challenger* accident proved, at least to some, that NASA was no longer trustworthy, and that spaceflight was not safe enough for the participation of regular citizens (Heimann, 1997). NASA, in promoting the space shuttle, focused on the cheap availability of space flight, and declared the Shuttle operational after its fourth flight. One of the ways in which NASA promoted the shuttle was to allow non-military or non-test pilot astronauts aboard. Sally Ride had flown, proving a level of safety where "even women" were allowed to participate. But civilian school teacher Christa MacAuliffe's death on the *Challenger* was the death of a regular citizen in what was supposed to be a well-regulated hazard. NASA was viewed as untrustworthy and 'not safe enough'. The question for NASA became whether or not it could prove itself "capable of institutional learning to create an institutional culture of reliability" (Pidgeon, 1997, page 1).

The *Challenger* accident resulted in intense congressional investigations into all the U.S. space program's efforts. NASA's confrontations with the Congress over the *Challenger* accident caused NASA to restructure its safety assessment and risk reporting processes. NASA's commitment to make safety a high priority became important to the organization internally because reliable management is an expensive and perpetual goal. During a period when NASA leaders actively make safety a very high priority, they will not shift resources to other purposes (such as advanced technology development and upgrade) and thus undermine the resource base that is so critical to maintaining reliable performance (Heimann, 1997, Page 9). At the same time, as NASA prepared to launch the RTG-powered Galileo mission in 1989, NASA characterized the RTG as a risk that had been accepted before. However, the agency had not launched an RTG since the last Apollo mission to the Moon in the late 1970s. The launch risk was balanced against the cost of developing a new power system and the time it might take to do so. In general, during this phase, NASA promoted the RTG as a mature technology, with a good safety record, and very economical.

The third stage in risk communication strategy implemented by NASA during the early 1990s, was the inclusion of public active participation in promoting a technology. Citizen panels were held to discuss the technology, and public approval was courted by the promoting agency (Schwartz and Thompson, Bauer). In response to the fledgling protests over the Galileo and Ulysses missions, where RTGs were launched aboard the space shuttle, NASA convened public panels during the early construction phases of the Cassini mission. NASA included public panels in discussion of the merits of nuclear technologies for space exploration and courted activism from the space associations and pro-space activist groups. The public, especially the pro-space activists, was included in discussions regarding mission design (after the design requirements had been determined) in order to balance the anti-nuclear protests with a more pro-space willingness to accept risks associated with the launch of a nuclear power supply. NASA promoted the concept of “enabling technology” as a justification for using RTGs. NASA voiced its arguments in social, not technological, terms: to reject nuclear power for the space program was to end the American exploration of space. As an enabling technology, the RTG was the only means by which space probes could be sent, and scientific exploration carried out in the Solar System.

However, NASA's "enabling technology" argument had an unintended consequence—it focused opposing arguments into a binary choice. Interested parties were left with a yes/no decision: accept nuclear technology for space or do not go to space. Many different choices can diffuse technological protest, both by empowering individuals with alternatives to the risk, and by reducing the numbers of people sensitized to the risk issues. Many choices can also prevent protest from coalescing into a social movement. The binary choice, presented in NASA's enabling technology argument, allowed for polarization and intense disagreement (Bauer 1995). Future exploration will again face this go/no go argument which may become the center of the controversy for a nuclear-powered Mars exploration program.

Another important element of NASA's risk assessment is the concept of acceptable risk. Risk is defined and calculated by the assessor and presented to the sponsoring agency, who then assesses the assessment. The programmatic risk, for the agency, may be couched in terms of acceptability (Heimann 1997). NASA space shuttle safety documents stress that risk to humans in spaceflight is significant and that all possible precautions are made to protect the astronaut (Vaughan 1997). This risk reduction perspective is significantly represented in NASA's budget. However, acceptable risk *for the public* is not defined. Baruch Fischhoff, in "Acceptable Risk: a Conceptual Proposal" notes that no fixed level of risk is ever accept-able (1994, page 1; after the Environmental Protection Agency) indicating that:

> "the acceptability of risk is a relative concept and involves consideration of different factors. Considerations of these judgments may include: the certainty and severity of the risk; the reversability of the health effect; the knowledge or familiarity of the risk; whether the risk is voluntarily accepted or involuntarily imposed; whether individuals are compensated for their exposure to the risk; the advantages of the activity, and the risks and advantages for any alternatives."

Acceptable risks are inherent to any human activities and especially those involved with risky technologies, such as automobiles. Whether the judgment of acceptability is performed by an individual, an organization, or a federal agency, the concept of acceptability of a risk is always a factor in decision making. NASA operates in an environment complicated by the technologies it must use to carry out its programs. The decision to use SNP implies that use of the technology is considered an acceptable risk. Heimann, in *Acceptable Risks: Politics, Policy, and Risky Technologies* discusses NASA's use of acceptable risk (1997, page 164; italics original):

> "NASA officials readily admit that the launching of *Challenger* was a mistake, but they also add that it was considered an acceptable risk at the time. In fact, when discussing the agency mission at NASA, one often hears mention of the term acceptable risks. This is a necessary concept inasmuch as the agency is unable to eliminate risk altogether. NASA must often carry out its mission while lacking information about the technology employed and the environment in which it operates."

NASA's risk assessment methodologies are accepted by the DOE, the Nuclear Regulatory Commission, and the White House. These assessment methodologies have not come under significant scrutiny since the Challenger accident, where the assessments themselves were not called into question, but rather the communication of the risk was the issue discussed in Congressional hearings (Vaughan 1997). NASA has never failed to receive permission to build a mission using an RTG. But it has not attempted, in recent history, to get permission to flight test a nuclear reactor. NASA will need both permissions granted before it can begin actual development of a human mission to Mars.

NASA's risk assessment methodologies were the focus of the STOP CASSINI! campaign. The concept of acceptable risk prioivided an additional focus for the protest on the distribution of the risk (Heimann, 1997, page 165).

> "…any decision that sets levels of acceptable risks will create groups of winners and losers. People who are aware of agency decisions and can expect to lose from such a policy typically rebel against such actions; they often seek to reverse the policy decision through their activity in the political process. Thus, explicitly announcing the point at which risks move from acceptable to unacceptable would encourage these people to attempt overturning policies that the agency believes is in the best interest of the public."

The technical risk assessment was the initial target of protest. Later, the protest expanded its focus, and the concept of acceptability became the foundation for additional protest of the technology in general. These issues were subsumed in turn under ethical discussions regarding the use of any nuclear technology. NASA's risk communication methods, i.e., how the agency communicated risk assessment internally and externally, were critical elements in shaping the protest.