Public views of using nuclear energy sources in space missions

Michael Maharik and Baruch Fischhoff

Space policy has always been sensitive to public opinion. Recently there has been an increase in public concern over the risks posed by space flight, not just to astronauts, but to the public itself. In order to forestall problems, the US National Research Council has recommended continuously monitoring and addressing public preceptions of space risks. The present study demonstrates a methodology for eliciting public concerns regarding the design of space missions, with a specific focus on the use of nuclear energy sources in space. Applied to a sample of citizens drawn from an environmentalist group, the survey found their opinions to be fairly pointed, consistent and reasonable. The possibilities of incorporating such views in setting space policy are discussed.

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[1]L. Dye, 'Suit alleging plutonium danger will seek to block Shuttle launch', *Los Angeles Times*, 28 September 1989, pp 134–135; T M Foley, 'NASA prepares for protests over nuclear system launch', *Aviation Week and Space Technology*, 26 June 1989, pp 83–87; K Grossman, 'Ulysses: plutonium Shuttle mission #2'. *Just Peace*, Florida Coalition for Peace and
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Energy – reliable, abundant and portable – is essential to developing and sustaining a human presence in space. Traditionally these needs have been met with chemical and solar energy sources. Unfortunately chemical sources have a limited operating life, while solar energy sources have a limited maximum available output, in addition to being infeasible for missions far from the Sun. Nuclear energy sources can not only address these problems, but also provide several other advantages, including compact size, low-to-moderate mass, viability in hostile environments, independence of distance and orientation to the Sun and high reliability. When power requirements exceed the hundreds of kilowatts for an extended period nuclear energy appears to be the only realistic power option.

One threat to this potential is that nuclear energy systems are also representative of a highly controversial technology. For many years the public either accepted or was unaware of the extensive use of nuclear technologies in space missions. However, this (active or passive) acceptance has changed in recent years. Both the Galileo and Ulysses launches have faced public protests, including lawsuits and demonstrations.[1] Figure 1, reproduced from a 'Call to Action' published by an activist group, reflects some of these concerns.

With these protests, the space community is discovering that it has a risk-perception problem, just as many other technologies have had before it.[2] The consequences of such problems can be very large. Not a single new nuclear power plant has been ordered in the USA since 1978, in large part because of public opposition.[3] Recognizing the possible implications of a risk-perception problem for space nuclear technology, the National Research Council advised the responsible federal agencies to address such problems early, arguing that 'it is quite possible that one might end with a technically successful program that, for political reasons, is never permitted to fly. Given public attitudes towards nuclear energy, this risk is not negligible.'[4]

If the space community is to respond effectively it needs a clear, objective reading of the public's precise concerns. Experience with other technologies has shown that it is very easy to misread the public. Sometimes the result is to dismiss the public as irrational; at other times extensive redesign efforts still fail to provide the public with what it

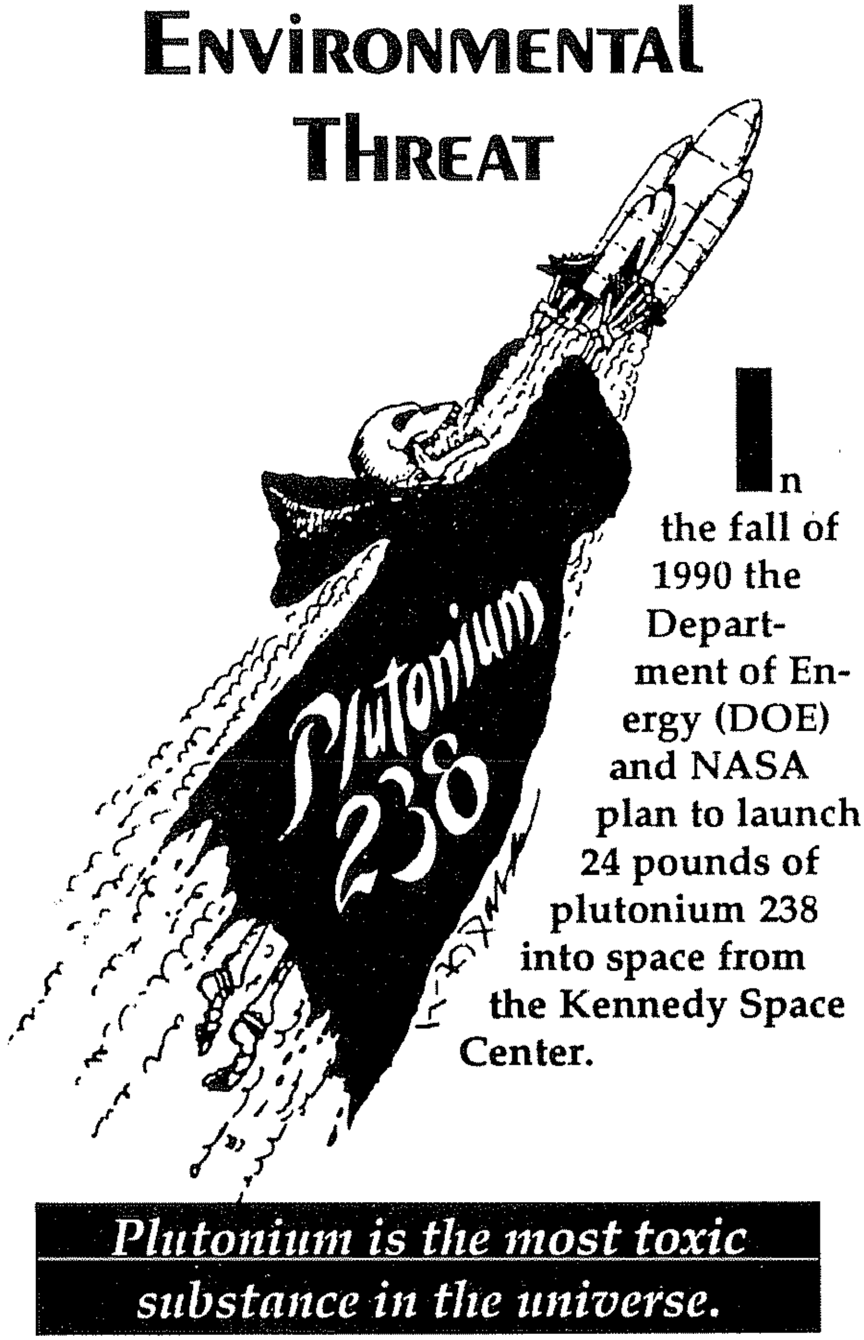

Figure 1. Illustration from an environmentalist pamphlet.

Source: Florida Coalition for Peace and Justice, Summer 1990.

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Justice, Orlando, FL, Summer 1990; K Sawyer, 'Anti-nuclear groups oppose Galileo launch', *Washington Post*, 15 September 1989, p A3.
[2]National Research Council, *Improving Risk Communication*, National Academy Press, Washington, DC, 1989.
[3]W.R. Freudenburg and E A. Rosa, eds, *Public Reaction to Nuclear Power*, Westview Press, Boulder, CO, 1984
[4]National Research Council, *Advanced Nuclear Systems for Portable Power in*
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wants. In either case the result is mutual frustration and growing hostility.[5]

In the hope of reducing unnecessary conflict, we have undertaken a programme of research studying public perceptions of the risks of using nuclear energy in space. These studies have revealed complex patterns of strengths and weaknesses, the details of which were used to fashion a brochure that significantly increased understanding of existing systems. The studies also found that people who know more about the technology like it better – except for people drawn from activist groups with strong pro-technology or pro-environment orientations.[6]

The study reported here demonstrates a procedure for eliciting public

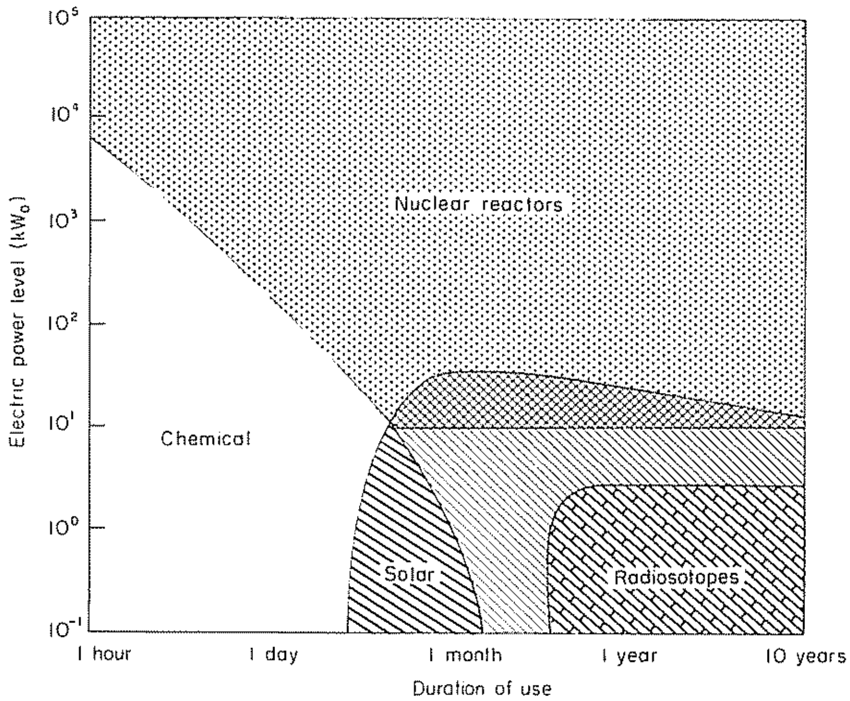

Figure 2. Regimes of possible space power applicability

Source: J.A Angelo and D Buden. *Space Nuclear Power*, Orbit, Malabar, FL, 1985

opinions in a form that might be incorporated in the engineering design process. Responses are presented from 87 individuals drawn from a population of potential opinion leaders. Before describing the study, we briefly describe the technology.

Nuclear energy sources for space use

Two technologies are currently available for space use of the thermal energy liberated by nuclear processes. Radioisotope thermoelectric generators (RTGs) utilize the heat released in the spontaneous decay of radioisotopes, specifically plutonium-238. Nuclear reactors exploit the controlled fission of heavy nuclei (such as uranium-235) in a sustained neutron chain reaction. Of the two technologies, RTGs are generally used when power requirements are below 1 KWe. Figure 2 shows applicability regimes (in terms of power level and duration of use) for currently available sources.

Both nuclear technologies have been used in space by the USA and the (former) USSR since the late 1960s. The USA has launched 25 space systems that derived all or part of their power requirements from nuclear energy sources. They were used for navigational, meteorological and communication orbital applications, and also for lunar, Mars and other planetary missions.[7] Except for one experimental nuclear reactor, all were of the RTG type. The USSR used both types routinely for various applications. At least 33 Soviet nuclear reactors have been deployed in space, mostly for radar ocean reconnaissance missions.[8] These launches have resulted in nine reported aerospace incidents. They include four launch failures, three uncontrolled re-entries from orbit to the atmosphere, one in-orbit incident and one intended re-entry.[9] Detectable, and sometimes considerable, amounts of radioactivity were found in the upper atmosphere following some of these accidents; a wide ground area was contaminated in one case.[10]

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Space, National Academy Press, Washington, DC. 1983.
[5]NRC, *op cit.* Ref 2.
[6]M. Maharik and B. Fischhoff, 'The risks of nuclear energy sources in space: some lay activists' perceptions'. *Risk Analysis*, Vol 12, 1992, pp 383–392; M Maharik and B Fischhoff, 'The relationship between risk knowledge and risk attitudes regarding nuclear energy sources in space', *Risk Analysis*, in press
[7]National Aeronautics and Space Administration, *NASA Facts: Information on the Ulysses Mission's Use of a Radioisotope Thermoelectric Generator (RTG)*, NASA, Washington, DC, 5 July 1990; Jet Propulsion Laboratory, *Powering Deep Space Missions*, JPL–California Institute of Technology, 1989.
[8]S Aftergood, D W. Hafemeister, O F Prilutsky, J R Primack and S N Rodionov, 'Nuclear power in space', *Scientific American*, Vol 244, No 6, 1991, pp 42–47.
[9]The Apollo 13 Aquarius Lunar Module, originally designed to be left in space, served as a translunar trajectory lifeboat for the astronauts following an explosion on the spacecraft, and entered the atmosphere at the end of this improvised task
[10]J.A. Angelo and D Buden, *Space Nuclear Power*, Orbit, Malabar. FL, 1985; Jet Propulsion Laboratory, *Past Accidental and Incidental Releases of Radioactive Material from Space Nuclear Power Sources*, Doc No D-7688, JPL–California Institute of Technology, 27 September 1990.

In a recent report[11] the Committee on Advanced Nuclear Systems identified approximately 20 possible missions with power requirements ranging from tens to hundreds of kilowatts. It recommended a focused federal programme to develop the required space power technologies. Nuclear energy was designated as the sole option for the proposed manned mission to Mars[12] as well as NASA's studies of comets and asteroids (CRAF) and of the Saturnian System (Cassini).[13]

A risk-perception problem would add to the threats that these programmes face from other political and budgetary pressures. Our study is intended to clarify how the space community can address public concerns, whether by better communication or by responsive design.

Method

Procedure

Responses were collected with a mailed survey. It posed questions on the following topics: (a) the acceptability of space missions for various purposes, whatever their energy source; (b) the kinds of space accidents that generate the greatest concern; (c) the attractiveness of different engineering design philosophies; (d) the faith placed in expert opinion; and (e) the process desired for making decisions about space programmes. Further details of these questions are reported below. In order to facilitate informed responses, brief descriptions were provided on many topics regarding space flight and energy sources. These descriptions were based on earlier studies documenting the state of lay perception regarding these technologies[14] and were refined in pretests. Special attention was given to avoiding any persuasive tone.

Respondents

The study was conducted with randomly selected members of the Audubon Society of Western Pennsylvania. ASWP is a non-profit conservation organization, conducting courses, workshops and festivals, in addition to maintaining and operating private nature reserves. Its goal is primarily educational – making the public aware of the importance of ecologically sound stewardship of the land, and fostering understanding and appreciation of the environment. In all, 87 questionnaires were completed. In other studies[15] we have found ASWP members to have neutral attitudes towards the use of nuclear energy sources in space, with more knowledgeable members being more positive.

Demographic information was collected on: (a) gender (55% male); (b) age (22% between 20 and 40, 32% between 40 and 60, 45% over 60); (c) education (13% high school, 20% some college, 36% bachelor degrees, 31% advanced degrees); (d) working status (57% employed, 2% unemployed, 6% homemakers, 1% student, 34% retired); (e) annual household income (23% between \$10 000 and \$30 000; 32% between \$30 000 and \$50 000; 32% between \$50 000 and \$75 000; 9% between \$75 000 and \$100 000; 4% over \$100 000). Thus the participants in this study were well-educated laypeople, sufficiently involved in environmental issues to join an organization focused on habitat preservation. Although the sample is large enough to provide moderately precise estimates of response by such people, additional sampling is clearly needed before extrapolating to other populations

[11] National Research Council, *Advanced Power Sources for Space Missions*, National Academy Press, Washington, DC, 1989
[12] The Synthesis Group, *America at the Threshold – America's Space Exploration Initiative*, US GPO, Washington, DC, 1991
[13] JPL, *op cit*, Ref 7.
[14] Maharik and Fischhoff, *op cit*, Ref 6.
[15] *Ibid*

Table 1. List of missions.

Code[a]	Type[b]	Mission description
M1	MP	A US military communication satellite for communicating directly to forces on the ground
M2	MP	A US military surveillance satellite that carries a large space radar for tracking enemy ships, planes or missiles
M3	MAD	A US military weapon satellite for destroying missiles in space (Star Wars)
M4	MAO	A US military weapon satellite for destroying enemy satellites
M5	MAO	A US military weapon satellite for destroying targets on the ground with pinpoint accuracy
M6	SE	A scientific satellite that provides data for understanding global climate change (greenhouse warming)
M7	SE	A scientific one-way spacecraft for studying the Sun, aiming to better understand its effects on the Earth.
M8	SNX	A telescope for doing advanced astronomy studies in space, aiming, among other things, to study how the universe was created.
M9	SNX	A scientific one-way spacecraft for studying Jupiter, Saturn and other outer planets of the Solar System
M10	SNV	A spacecraft for carrying people and supplies back and forth from the Earth to a scientific base on the Moon
M11	SNV	A spacecraft for carrying a US crew to Mars
M12	SNV	A spacecraft for carrying an international crew to Mars (crew members from the USA, Europe, Japan, USSR and China)
M13	UL	A civilian satellite for air traffic control that makes air travel much safer over both land and sea
M14	UL	A weather satellite that provides data for much more accurate weather forecasts.
M15	UH	A civilian communication satellite for transferring telephone calls and radio and television programmes across very long distances
M16	UH	A civilian navigation satellite for improving the navigational accuracy of commercial aeroplanes and ships

[a]Codes are used for identifying missions in the text
[b]Legend: M – military; P – passive; A – active; D – defence; O – offence; S – scientific; E – directly related to Earth; N – not directly related to Earth; V – manned; X – unmanned; U – utility; L – low-orbit; H – high-orbit

Results

Mission acceptability

Respondents evaluated each of the 16 space missions listed in Table 1 as being either (a) unacceptable under any circumstances, (b) unacceptable with nuclear energy sources, or (c) acceptable (even) with nuclear energy sources. Two types of mission were typically judged unacceptable under any circumstances: manned missions to other planets (M10, M11 and M12 – 46%, 58% and 51%, respectively) and active military missions (M3, M4 and M5 – 45%, 52% and 43%, respectively). This opposition to manned missions may prove quite significant when plans are revealed for the ambitious US manned Space Exploration Initiative. Scientific missions that were not clearly related to improving life on Earth (M7, M8 and M9) and defensive military missions (M1 and M2) were judged unacceptable by 20–25% of respondents. Missions with practical purposes (M13, M14 and M16) and with scientific goals having clear applications (M6) were considered acceptable by at least 95% of respondents. Communication missions (M15) were almost as acceptable. Thus these people generally accepted space technologies having obvious contributions to life on Earth.

Those respondents who had judged each mission as being acceptable in principle were then asked whether their opinion would change if that mission used nuclear energy sources. The least objection to nuclear energy sources was observed among respondents who had accepted the defensive military missions (M1 and M2) and the pure science missions (M7, M8 and M9); only 20–25% would withdraw their support if nuclear energy were used. The highest rates of conditional rejection were for using nuclear energy sources in utilitarian missions (communications, navigation, weather forecasting: 53%, 47% and 42%, respectively) and a manned mission to the Moon (56%). Possibly, respondents believed that these missions were already being accomplished with conventional energy sources, making nuclear sources unnecessary. Overall there were only two cases (out of the 16) in which a majority of respondents rejected the use of nuclear energy for a mission that they considered acceptable in principle.

The rate of unconditional acceptance (with or without a nuclear energy source) was highest for unmanned scientific missions (M6, M7, M8 and M 9 – 67%, 61%, 59% and 59%, respectively) and lowest for manned scientific missions (M10, M11 and M12 – 24%, 29% and 33%, respectively) and active military missions (M4, M5 and M3 – 29%, 35% and 36%, respectively).

Concern over accidents

Respondents indicated their degree of concern for each of four major classes of accident, using a four-point scale, anchored at 1 = highest concern and 4 = lowest concern. Overall they were much more concerned about failure at launch (mean = 2.00) and uncontrolled re-entry of a satellite from orbit (1.95) than about either a failure in orbit (2.87) or a flyby accident (3.16). Differences between these two groups of accidents were highly significant statistically ($p < 0.0001$) and not significant within them.

The accuracy of these perceptions depends on how 'risk' is defined.[16] Launch failure and uncontrolled re-entry seem to have the highest probability of occurrence.[17] However, the consequences of a flyby accident could be so large as to make it the greatest 'risk' in the sense of 'probability × consequences per mission'.[18] If one's definition of risk considers the number of missions in which each accident is possible, then flyby accidents again drop down the list. Assuming that respondents do consider total (and not per-trip) risk, then their concerns are in the right order.

Preferences for design philosophies

In the lengthiest segment of the questionnaire, respondents evaluated competing philosophies for six aspects of engineering and mission design. Table 2 presents the options that they considered, while Table 3 summarizes their responses. For each option set, their response preferences differed significantly ($p < 0.001$) from a uniform distribution.

Safety philosophy. Almost twice as many respondents preferred one of the two containment policies as preferred one of the two burn-up policies (50.6% *v* 27.5%, $p < 0.025$). Perhaps this reflects a preference for the *status quo* – especially if it can be improved (through hardened containment, the most popular single philosophy). Perhaps it reflects an aversion to dispersing radioactive materials at high altitude (as required by burn-up).

In this case, too, respondents generally fell in line with expert opinion. The initial US policy was 'burn up and disperse'. Over time, though, it has shifted to total containment, under both normal and abnormal circumstances – although the former policy still has its advocates. In this case expert opinion may have followed public opinion or perhaps the two were influenced by common sources (eg changes in images of the environment). It is not surprising that respondents preferred hardening the present containment, especially since the costs in reduced payloads were not made explicit.

Launch risks. Here, too, respondents favoured the design options favoured by most of the engineering community: in-place containment

[16] E.A.C. Crouch and R. Wilson, *Risk/Benefit Analysis*, Ballinger, Cambridge, MA, 1982; B. Fischhoff, S. Watson and C. Hope, 'Defining risk', *Policy Sciences*, Vol 17, 1984, pp 123–139.
[17] GE Astro Space, *Final Safety Analysis Report for the Galileo Mission*, Vol II: *Accident Model Document*, Doc No 87SDS4213, GE, Philadelphia, PA, 1988; NUS Corporation, *Final Safety Analysis Report for the Galileo Mission*, Vol III: *Nuclear Risk Analysis Document*, Doc No NUS 5126, NUS Corporation, 1989.
[18] Interagency Nuclear Safety Review Panel, *Safety Evaluation Report for Galileo*, Vol I–II, Doc No INSRP 89-01, INSRP, Washington, DC, 1989.

Table 2. Engineering policy problems and suggested options.

Safety philosophy
A Present containment: The current design, based on containment of the nuclear fuel in case of re-entry
B Hardened containment: A new design based on containment, including hardening of the encasement, resulting in less weight available for scientific instruments
C Spontaneous burn-up: A new design, based on a spontaneous high-altitude burn-up in case of an uncontrolled re-entry
D Assisted burn-up: A new design, based on high-altitude burn-up, which is made more certain by incorporating a small explosive device that will break the source upon re-entry

Risk during launch stage
A In-place containment: Have the nuclear fuel contained in a strong casing which can survive most launch accidents without being broken apart (current policy)
B Fuel/generator separation: Keep the nuclear fuel separate from the power generator during the time of launch Place the nuclear fuel in a very strong container which can survive any launch explosion. Once it is in space, place it in the energy generator
C. Fuel/spacecraft separation: Send the nuclear fuel and the energy generator into space separately Place the nuclear fuel in a very strong container which can survive any launch explosion and carry it into orbit on a small special launch vehicle that is designed to be especially reliable Once both are in space, place the fuel in the energy generator
D. Fuel/Earth separation: Manufacture the nuclear fuel on the Moon (by mining radioactive material there) Place the nuclear fuel in a very strong container which can survive a launch explosion and then use a small and especially reliable launch vehicle to carry the fuel to rendezvous with the spacecraft in space, where the fuel is transferred to the nuclear energy generator

Quantity of fuel
A Single shot: Launch spacecraft installed with the full amount of nuclear fuel at a single shot (current policy)
B Multiple launches: Perform multiple launches of small amounts of nuclear fuel at a time, and make the final assembly in space

General type of trajectory
A 'One-way' and orbital trajectories: Use nuclear energy sources for space research independently of the designed trajectory, provided that appropriate safety precautions are taken in the design
B 'One-way' trajectories only: Use nuclear energy sources only for deep-space missions, which would mean paying more for orbital missions (because more launches or more expensive designs would be needed)

Orbital trajectory altitude
A High and low orbital altitude: Use nuclear energy sources for orbital missions, independently of the intended altitude, provided that the best available 'booster' systems are installed when required
B High orbital altitude only: Use nuclear energy sources for high-orbit missions only, resulting in paying more for missions that require the use of low-orbit trajectories

Earth flyby trajectory
A A 'one-way' trajectory with or without Earth flybys: Use nuclear energy sources for deep-space research independently of the designed trajectory, provided that the best available measures are taken to prevent an uncontrollable re-entry during an Earth flyby
B No Earth flyby trajectories: Use nuclear energy sources for deep-space missions only if there are no Earth flybys, resulting in paying more for a stronger launching system and possibly delaying the gain of new knowledge

Table 3. Choices among engineering policy options.

Option		Count	Per cent	Option		Count	Per cent
Safety philosophy				*Launch risk*			
Present containment		9	10 4	In-place containment		19	21 8
Hardened containment		35	40 2	Fuel/generator separation		38	43 7
Spontaneous burn-up		11	12 6	Fuel/spacecraft separation		12	13 8
Assisted burn-up		13	14 9	Fuel/Earth separation		7	8 1
None is acceptable		8	9 2	None is acceptable		5	5 7
All are equally acceptable		8	9 2	All are equally acceptable		1	1 2
Don't know		3	3 5	Don't know		5	5 7
	N =	87			*N* =	87	
Fuel quantity				*Trajectory type*			
Single shot		50	58 8	'One-way' and orbital		35	41 2
Multiple launches		9	10 6	'One-way' only		28	32 9
None is acceptable		12	14 1	None is acceptable		8	9 4
All are equally acceptable		6	7 1	All are equally acceptable		6	7 1
Don't know		8	9 4	Don't know		8	9 4
	N =	85			*N* =	85	
Orbital trajectory altitude				*Earth flyby trajectory*			
High- and low-orbit		29	33 3	With or without Earth flyby		44	51 2
High-orbit only		33	37 9	No Earth flybys		30	34 9
None is acceptable		18	20 7	None is acceptable		7	8 1
All are equally acceptable		4	4 6	All are equally acceptable		3	3 5
Don't know		3	3 5	Don't know		2	2 3
	N =	87			*N* =	86	

Options are described in Table 2

(encapsulation) and separation They showed relatively little interest in the more exotic and more expensive options (fuel/spacecraft separation, fuel/Earth separation), suggesting an openness to reasonable compromises

Fuel quantity Almost six times as many respondents preferred the current policy of sending all the nuclear fuel with the spacecraft over a proposal to divide it up over multiple launches. Perhaps they felt that any increase in safety did not justify the great increase in cost. Perhaps they felt that multiple launches mean increased risk, focusing on the probability of at least one accident, rather than on the amount of radioactive material involved.

Trajectory type. About three-quarters of respondents approved the use of nuclear energy sources for 'one-way' missions. Acceptance dropped to 41.2% for orbital missions, consistent with the high level of concern over accidents involving uncontrolled re-entry from orbit. This concern suggests taking seriously expert proposals to ban orbiting reactors.[19]

Orbital trajectory altitude. The wide acceptance (71.2%) of high-orbit trajectories seems consistent with US policy of making orbits high enough to ensure that natural decay of the orbit matches natural decay of the fuel source – so that re-entry occurs when the fuel is spent. The USSR, however, has flown nuclear reactors in low-Earth orbits, requiring a boost system to increase the altitude of the reactor (and hence its orbital lifetime) once the mission is completed, in order to gain sufficient time before the eventual re-entry. Consistent with the concern over the continuing risk with orbiting nuclear sources, 21% of the sample accepted neither of these strategies.

Earth flyby trajectory. Flyby missions with nuclear energy sources were accepted by about half of our sample and rejected by one-third. What is a dazzling technical feat for some people may evoke images of disastrous collisions for others.

Acceptability of experts

Respondents were asked about how much they agreed with those who claimed that using nuclear energy sources in space was safe and acceptable. On a scale anchored at 1 = completely agree and 7 = completely disagree, the mean rating was 3.16 ($s = 1.95$), significantly below the midpoint ($p < 0.0001$) – suggesting general agreement but a large range of opinion.

Those respondents who had not responded with 1, indicating complete agreement, were then asked to rate the extent to which each of seven reasons influenced their scepticism. The scale was anchored at 1 = very much because of this reason and 7 = not at all because of this reason. By far the strongest reasons for not agreeing with the experts were doubting the experts' ability to estimate (a) the probabilty of failure ($x = 3.02$; $s = 0.27$) and (b) the consequences of accidents ($x = 2.78$; $s = 0.26$). They did not, however, doubt the experts' general scientific understanding of the issues ($x = 5.21$; $s = 0.29$) nor their ability to assess the benefits of using nuclear sources ($x = 6.00$; $s = 0.20$). The three other reasons were also deemed moderately weak causes of their scepticism: doubting the experts' assessment of costs ($x = 4.53$; $s = 0.29$), not trusting experts' honesty ($x = 4.32$; $s = 0.30$) and ethical issues ($x = 4.63$; $s = 0.30$). Thus respondents accepted the experts' general competence and honesty, but were sceptical about their ability to estimate two particular quantities, which are, unfortunately, the two components of risk: probability and consequences.

[19] J.R. Primack, N.E. Abrams, S. Aftergood, D.W. Hafemeister, D.O. Hirsch, R. Mosley, O.F. Prilutsky, S.N. Rodionov and R. Sagdeev, 'Space reactor arms control', *Science and Global Security*, Vol 1, 1989, pp 49–72

Table 4. Preference for decision-makers.[a]

Employed scientists[b]	Independent scientists[c]	Elected politicians	Environmental activists[d]	Public at large[e]	Board of laypeople[f]	Preference (%)
	X		X			32 2
	X			X		14 9
	X					11 5
X						11 5
X			X			10 3
X				X		5 8
X	X		X			2 3
X	X					2 3
					X	2 3
		X	X			1 2
		X		X		1 2
X	X			X		1 2
	X		X	X		1 2
X	X	X	X	X		1 2
		X				0

[a]Scientific and commercial civilian applications only
[b]Scientists employed by the relevant agencies (like NASA, Department of Energy).
[c]Scientists from independent institutions (like universities not funded by relevant agencies)
[d]Groups of environmental activists, assisted by experts
[e]Public at large, assisted by experts
[f]Board of laypeople, assisted by experts (like a jury)

Decision-making authority

Respondents were asked to choose which of six groups of people should be involved in setting policy for the use of nuclear energy sources in space. Table 4 shows the percentage of respondents choosing each combination of groups. About one-third preferred the combination of scientists from independent institutions (eg universities that do not have funding from agencies that sponsor space missions) and environmental activists, assisted by experts. Another 15% chose independent scientists along with the public at large, while 12% preferred independent scientists alone. Overall, about two-thirds (65 8%) included independent scientists, while about one-third (34 7%) included scientists employed by the agencies. Very few respondents wanted scientists from both sources (7 0%) or no scientists at all (4 7%). Thus respondents assigned a central role to experts, but disagreed about which experts would serve them best.

Discussion

One way of responding to public opinion is by ignoring it, hoping that one has the political muscle needed to overcome any resistance to one's plans. In today's world this is becoming increasingly difficult, especially for programmes that depend on the public's goodwill for support.

A second response is to provide the public with information, hoping that it will bring the sceptics around This has been NASA's strategy, as expressed in the materials it distributes to citizens who raise questions.[20] Although NASA's materials might be better were they based on scientific studies of lay perceptions,[21] this strategy has some potential. We have found that people like the present respondents can absorb a good deal about these technologies. Moreover, the more that they know, the more favourable they are – unless they have prejudged the issue (either favourably or unfavourably).[22]

However, information will not work when people do not trust the experts or when that information reveals more clearly risks that people consider unacceptable. The present study revealed some of each kind of principled resistance. For example, respondents doubted experts' ability to estimate risk levels and saw little value in several kinds of mission (rejecting some regardless of their energy source)

A third response is to give people what they want, in the sense of

[20]J. McDonald, Launch Approval Planning Group, Jet Propulsion Laboratory, personal communication, March 1991.
[21]M. Maharik, 'Public perceptions of the risks of an unfamiliar technology: the case of using nuclear energy sources for space missions', unpublished PhD dissertation, Carnegie Mellon University, 1992.
[22]Maharik and Fischhoff, 'The relationship between risk knowledge ...', *op cit*, Ref 6.

technologies with acceptable risks. In some cases this will be impossible: the mission is too important to be foregone, but has an inherently problematic design. In other cases, though, public concerns could be incorporated in the charge to designers. With some ingenuity (and perhaps some additional expenditure) a design could be created without the objectionable features For example, the present respondents would be much more satisfied (a) if some manned missions were done with instruments and (b) if flyby missions utilized planets other than Earth. Both changes may be within our engineering capability. The costs of such design changes would have to be weighed against the possible costs of delay (and even mission cancellation) due to protests and litigation.

Before undertaking such efforts, however, one needs confidence that the public's concerns represent a stable target. It would be more than frustrating to redesign a mission only to be told, 'No, that's not what we really wanted.' One obvious step in this direction is to replicate studies like the present one with other samples (also chosen from individuals who might become opinion leaders) and different methods (eg going into greater detail about proposed designs). The analysis of those studies should pay particular attention to the reasonableness and the coherence of responses. One does not want to meet demands that are divorced from reality nor ones that are unrelated to one another. The present study, like the others in our project, provides some reason for optimism: Respondents were moderately well-informed on a topic far from their everyday experience; they were able to absorb additional information; they generally respected the experts, despite having some localized scepticism; most accepted the use of nuclear energy sources on many missions; their objections showed a fairly consistent pattern.

Nonetheless, the present study is best viewed as a feasibility study, demonstrating the possibility of eliciting – and satisfying – lay concerns. Dealing with the public requires detailed empirical study, every bit as much as other elements of mission design. The costs of erroneous intuitions here can be very large.[23]

Finally, it should be noted that dealing with an analytically derived representation of public concerns (however carefully prepared) is not the same as dealing with the public itself. Our respondents expressed (Table 4) clear opinions regarding who should be at the table when policy decisions are made. One possible way to address these desires, without extravagant changes in the design process, is to create advisory panels, including independent experts and lay leaders, along with agency experts and managers These panels could meet periodically for briefings on the status of the programme and consultation on issues that arise. Panel members could help derive the implications of general public opinions, like those elicited here, for specific design decisions. Doing so would not only help avoid unnecessary mistakes, but also create a group of credible public advocates for decisions that are made.

[23]B. Fischhoff, A. Bostrom and M.J. Quadrel, 'Risk perception and communication', *Annual Review of Public Health*, Vol 14, 1993, pp 183–203; G.M. Morgan, B. Fischhoff, A. Bostrom, L. Lave and C.J. Atman, 'Risk communication', *Environmental Science and Technology*, Vol 26, 1992, pp 2048–2056.