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Perception and Acceptance of Risk from Radiation Exposure in Space Flight

Paul Slovic
Decision Research
Eugene, Oregon

1.0 Introduction: The Psychometric Paradigm

What do we know about the perception and acceptance of risk from radiation and other hazards and what are the implications of this knowledge for acceptance of radiation exposure in space?

Research on perception and acceptance of risk had its origin in a stimulating article in *Science* by C. Starr (1969) titled "Social Benefit Versus Technological Risk." Starr's paper sought to develop a method for weighing technological risks against benefits to answer the fundamental question, "How safe is safe enough?" His *revealed preference* approach assumed that, by trial and error, society arrives at an essentially optimum balance between the risks and benefits associated with any activity. Under this assumption, one may use historical or current risk and benefit data to reveal patterns of "acceptable" risk/benefit trade-offs. Examining such data for eight industries and activities, Starr concluded that (a) acceptability of risk from an activity is roughly proportional to the third power of the benefits from that activity; (b) the public will accept risks from voluntary activities (such as skiing) that are roughly 1,000 times as large as it would tolerate from involuntary activities (such as food preservatives) that provide the same level of benefits; and (c) the acceptable level of risk is inversely related to the number of persons exposed to the risk.

My colleagues and I decided to replicate Starr's work by asking people directly about their perceptions of risk and benefits and their *expressed preferences* for various kinds of risk/benefit trade-offs. These studies, in what has come to be known as the "psychometric paradigm," showed that expressed preferences also supported Starr's argument that people are willing to tolerate higher risks from activities seen as highly beneficial. But, whereas Starr concluded that voluntariness of exposure was the key mediator of risk acceptance, expressed preference studies have shown that other (perceived) characteristics such as familiarity, control, catastrophic potential, equity, and level of knowledge also seem to influence the relationship between perceived risk, perceived benefit, and risk acceptance (Slovic, 1987).

Various models have been advanced to represent the relationships between perceptions, behavior, and these qualitative characteristics of hazards. As we shall see, the picture that emerges from this work is both orderly and complex.

1.1 Factor-Analytic Representations

Many of the perceived characteristics of risk are highly correlated across a wide range of hazards. For example, hazards judged to be "voluntary" tend also to be judged as "controllable" and hazards whose adverse effects are delayed tend to be seen as posing risks that are not well known. Investigation of these relationships by means of factor analysis has shown that the broader domain of characteristics can be condensed to a smaller set of higher-order characteristics or factors.

The factor space presented in Figure 1 has been replicated across groups of lay people and experts judging large and diverse sets of hazards. Factor 1, labeled "dread risk," is defined at its high (right-hand) end by perceived lack of control, dread, catastrophic potential, fatal consequences, and the inequitable distribution of risks and benefits. Nuclear weapons and nuclear reactor accidents score highest on the characteristics that make up this factor. Factor 2, labeled "unknown risk," is defined at its high end by hazards judged to be unobservable, unknown, new, and delayed in their manifestation of harm. Chemical technologies score particularly high on this factor. A third factor, reflecting the number of people exposed to the risk, has been identified in several studies. Making the set of hazards more or less specific (for example, partitioning nuclear power into radioactive waste, uranium mining, and nuclear reactor accidents) has had little effect on the factor structure or its relationship to risk perceptions.

Insert Figure 1 about here

Research has shown that lay people's risk perceptions and attitudes are closely related to the position of a hazard within this type of factor space. Most important is the horizontal factor "dread risk." The higher a hazard's score on this factor (the farther to the right it appears in the space), the higher its perceived risk, the more people want to see its risks reduced, and the more they want to see strict regulation employed to achieve the desired reduction in risk. In contrast, experts' perceptions of risk are not closely related to any of the various risk characteristics or factors. Instead, as noted earlier, experts appear to see riskiness as synonymous with expected annual mortality. As a result, many conflicts concerning "risk" may result from experts and lay people having different definitions of the concept.

2.0 Perception of Radiation Risk

Numerous psychometric surveys conducted during the past decade have examined perceptions of risk and benefit from various radiation technologies. This work shows that there is no general pattern of perception for radiation. Different sources of radiation exposure are perceived in different ways. This was evident in the first psychometric study, summarized in Table 1. There we see that three groups of laypersons perceived nuclear power as having very high risk (rank 1, 1, and 8 out of 30 hazards) whereas a group of risk-assessment experts had a mean risk rating that put nuclear power 20th in the hierarchy. Note also that the three groups of laypersons judged medical X rays relatively low in risk (ranks 22, 17, and 24), whereas the experts placed it 7th. Thus we see that two radiation technologies were perceived differently from one another and differently from the views of experts.

Insert Table 1 about here

Figure 1 further illustrates the differences in perception of various radiation hazards. Note that nuclear reactor accidents, radioactive waste, and fallout from nuclear weapons testing are located in the upper-right quadrant of the factor space, reflecting people's perceptions that these technologies are uncontrollable, dread, catastrophic, lethal, and inequitable in their distribution of risks and benefits. Diagnostic X rays are perceived much more favorably on these scales, hence they fall in the upper-left quadrant of the space. Nuclear weapons fall in the lower-right quadrant, separating from nuclear reactor accidents, nuclear waste, and fallout on the scales measuring knowledge, immediacy of effects, and observability of effects.

Although Table 1 and Figure 1 represent data from small and nonrepresentative samples collected a decade or more ago, recent surveys of the general public in the U.S., Sweden, and Canada show consistently that nuclear power and nuclear waste are perceived as extremely high in risk and low in benefit to society, whereas medical X rays are perceived as very beneficial and low in risk. Studies in Norway and Hungary have also obtained similar results.

The powerful negative imagery evoked by nuclear power and radiation is discussed from a historical perspective by Weart (1988). Weart argues that modern thinking about radiation employs beliefs and symbols that have been associated for centuries with the concept of transmutation—the passage through destruction to rebirth. In the early decades of the 20th century, transmutation images became centered on radiation, which was associated with "uncanny rays that brought hideous death or miraculous new life; with mad scientists and their ambiguous monsters; with cosmic secrets of life and death; . . . and with weapons great enough to destroy the world. . . " (p. 42).

But this concept of transmutation has a duality that is hardly evident in the imagery associated with nuclear power and nuclear wastes. Why has the evil overwhelmed the good? The answer undoubtedly involves the bombing of Hiroshima and Nagasaki, which linked the dread images to reality.

Additional insights into the special quality of nuclear fear are provided by Erikson (1990), who draws attention to the broad, emerging theme of toxicity, both radioactive and chemical, that characterizes a "whole new species of trouble" associated with modern technological disasters. Erikson describes the exceptionally dread quality of technological accidents that expose people to radiation and chemicals in ways that "contaminate rather than merely damage; . . . pollute, befoul, and taint rather than just create wreckage; . . . penetrate human tissue indirectly rather than wound the surface by assaults of a more straightforward kind" (p. 120). Unlike natural disasters, these accidents are unbounded. Unlike conventional disaster plots, they have no end.

> Invisible contaminants remain a part of the surroundings—absorbed into the grain of the landscape, the tissues of the body, and, worst of all, into the genetic material of the survivors. An "all clear" is never sounded. The book of accounts is never closed. (p. 121)

Erikson's "contamination model" may explain, in part, the reaction of the public to exposures to carcinogens. Numerous studies have found that a high percentage (60 – 75%) of people believe that if a person is exposed to a chemical that can cause cancer, that person will probably get cancer some day. A similarly high percentage believe that "exposure to radiation will probably lead to cancer some day." The belief that *any* exposure to a carcinogen is likely to lead to cancer tends to coincide with the belief that it can never be too expensive to reduce such risks. Therefore, in an analysis by Tengs et al. (1995) of more than 500 life-saving interventions it is not surprising to find that radiation controls in industry were associated with the highest costs per year of life saved.

Table 2 summarizes the status of perceived risk for six radiation technologies, contrasting the views of technical experts with the views of the general public. In addition to nuclear power, nuclear waste, X rays, radon, and nuclear weapons, food irradiation (Bord & O'Connor, 1990), and electric and magnetic fields (EMF—a source of non-ionizing radiation), are included in the table, although there is relatively less information about perceptions of these two sources. We see that there is typically disagreement between the experts and the public regarding the level of risk and its acceptability. To my knowledge there have been only two published studies thus far of perceptions of risk from electric and magnetic fields. Both of these studies, by Morgan et al. (1985) and MacGregor, Slovic, and Morgan (1994), found that perceived risks associated with fields from home appliances and electric blankets were relatively low, and that perceived risks associated with large power lines were relatively high. Both studies also showed that, when the respondents were given a briefing about research on health effects of electric fields (which said that many studies had been done but no adverse human health effects had yet been reliably demonstrated), their perceptions on subsequent retest shifted toward higher perceived risk. MacGregor et al. found that this briefing (in the form of a brochure) also led to greater dread (particularly regarding power-line risks), less perceived equity, and increased concern regarding effects of EMF on the nervous system, the immune system, cell growth and reproduction, chronic depression, and cancer.

Insert Table 2 about here

2.1 Lessons

What does this psychometric research tell us about the acceptance of risk from radiation? There seem to be several lessons:

First, although many technical experts have labeled public reactions as irrational or phobic, such accusations are clearly unjustified (Drottz-Sjöberg & Persson, 1993). There is a logic to public perceptions and behaviors that has become apparent through research. For example, the acceptance afforded X rays suggests that acceptance of risk is conditioned by perceptions of direct benefits and by trust in the managers of the technology, in this case the medical profession.

The managers of nuclear-power technologies are clearly less trusted and the benefits of this technology are not highly appreciated, hence their risks are less acceptable. High risks from nuclear weapons are tolerated because of their perceived necessity (and probably also because people lack knowledge about how to intervene in military security issues; they do have such knowledge and opportunities to intervene in the management of nuclear power).

The apathetic response to the risk from radon appears to result from the fact that it is of natural origin, occurring in a comfortable, familiar setting, with no one to blame. Moreover, it can never be totally eliminated.

3.0 Risk Acceptance on the Mountaintop and in the Workplace

As shown above, psychometric surveys can give us insights into the determinants of perceived and acceptable risk from a wide variety of hazardous activities. But what about space flight in particular? Are astronauts adventurers, explorers, or workers, or all of these simultaneously? Certainly there are some missions that are more exploratory and more adventurous than others, a trip to Mars comes first to my mind as an example. In this perspective, we might look for guidance in the acceptance of risk from some of the most dangerous terrestrial activities—such as high-altitude mountain climbing. It is said that about one in ten Everest climbers dies in the attempt; just a few weeks ago eight climbers lost their lives on Everest in a severe storm. Everest climbers, and society, obviously accept a high level of known risk from a voluntary activity that is challenging and highly satisfying to the participants. To the extent that astronauts are adventurers and explorers voluntarily accepting known risks, the threshold of acceptability should be high—as it is for mountain climbers.

On the other hand, astronauts are also workers, and in the future more of their activities will be "routine"—maintaining a space station, for example. When we think of astronauts as workers, we may gain insight into acceptance of risk from a book that Dorothy Nelkin and Michael Brown published titled *Workers at Risk: Voices from the Workplace* (Nelkin & Brown, 1984).

Nelkin and Brown interviewed 75 workers from a wide variety of occupations, all of whom were exposed to rather dangerous chemicals. The book is a qualitative description of these workers' attempts to cope with the fact that their occupations put them in daily contact with dangerous substances. I think that this study definitely has relevance for the astronauts' situations. Nelkin and Brown observed that there were tremendously diverse reactions of workers to these chemical exposures, from very negative, hostile reactions among some workers to others who were really quite comfortable with the exposures, feeling that "It's worth the risk" (see box). They found that people in highly professional and skilled jobs (like astronauts) tended to feel that their work was worth the risks. Such individuals found the benefits high (again we see the relationship between perceived benefit and acceptance of risk), and the work very satisfying. They tended to downplay or deny the risk and really were not dwelling on it as did those who did not like

"It's Worth the Risk"

A number of people, mainly those in professional and skilled jobs, told us frankly that their work was "worth the risks." Aware of the hazards, they accept them as a trade-off for the personally gratifying benefits of their jobs. While often very careful to protect themselves, they measure the risks against the satisfaction of their work and the priorities of their careers. Fire fighters feel the risks are small compared to the satisfaction of saving lives. A deck hand is willing to take risks because she values her autonomy. Artists value the opportunities for creativity. A painter and a rose gardener love the aesthetic quality of their jobs.

From Nelkin and Brown (1984, p. 97).

their employment. Nevertheless, despite the fact that some people were very comfortable with the risks of their job, the overall message that Nelkin and Brown took from this extensive series of interviews was that workplace hazard is a serious concern to those at risk.

Nelkin and Brown (1984) concluded:

> Hearing these voices, we believe they carry a critical message—that the pervasive presence of chemical risks in the workplace has profound human costs in terms of anxiety as well as of illness. With the proliferation of chemicals in so many occupations, such concerns are likely to have an increasing effect on collective bargaining, on compensation claims, and on the general morale of the work force. Thus the voices of workers, their identification of problems, their insights, and their views must be heard. They are critical to the creation of a more humane working environment. (p. 183)

I certainly believe that we need to take this perspective with regard to our astronauts as well, and to listen to their concerns about safety.

4.0 Some Concluding Remarks About Acceptance of Radiation Risks in Space

There is no magic formula that leads us to a precise level of acceptable risk from exposure to radiation in space. Acceptable risk levels evolve through a process of negotiation that must integrate a large number of social, technical, and economic factors. The research described above indicates many of the factors that are important in this context. Some of them lead to a high degree of tolerance for radiation risk; others to a low degree of tolerance.

4.1 The Nature of the Hazard Implies a High Degree of Tolerance or Acceptance

Just because the hazard is radiation doesn't mean that exposure cannot be tolerated. We have seen that public reaction to radiation exposure varies widely, depending upon the context of that exposure (see Table 2). Radiation in space is a natural phenomenon and we find that people are much more tolerant of voluntary natural exposures than to exposures imposed upon them by industry or some other human activity. Second, this voluntary exposure cannot be totally eliminated, much as is the case with radon. Third, the risk is latent, unobservable, and small compared to the more immediate risk of accident or failure to accomplish the mission objectives. The chronic, latent, unobservable property of radiation risk means that there will be less pressure to minimize it, in contrast to the reaction after a major accident (e.g., the Challenger disaster).

The social context also fosters a high tolerance for risk in space because the work is exciting, challenging, socially visible, satisfying, and valuable, much as Nelkin and Brown's firefighters who, when interviewed, said that they don't care about the risks from chemical exposures in fires because they are saving people's lives. In addition, I would assume that astronauts have a lot of confidence in the overall system in which they work and identify with NASA's organizational goals and this, too, leads to tolerance for risk. Astronauts are skilled professionals. They are also self-confident individuals, who tend to be listened to and cared about and have been successful takers of calculated risks throughout their careers. So, high levels of risk from radiation in space could be justified and probably would be accepted by all involved.

But we have to also be cognizant of the fact that the values of the astronauts may change over time and as their active flight careers wind down, they might develop a different perspective on the risks from the radiation to which they've been exposed. Society's values may change as well. We have seen occupational risk levels declining steadily over time due to pressure to make things safer. Thus the value systems that are important to the social negotiation of acceptable risk are not stable. As the number of persons exposed to risk increases, we find that tolerance for risk tends to decrease (Starr, 1969). Finally, any noticeable above-normal incidence of cancer among former astronauts could cause problems not only for the astronauts but in terms of the stigmatization of the profession and criticism of NASA's protection of its astronauts. And one might expect that astronauts, being rather fit individuals, might have a lower incidence of cardiovascular disease, which means that their base level of cancer might be high and that any additional cancer burden from radiation could lead to a noticeably higher degree of cancer among older astronauts. These are just a few of the complexities in terms of perception of risk which are relevant to the social negotiation of acceptable risk and I hope that when we hear the perspectives of the astronauts later this afternoon we can perhaps return to some of these issues. Thank you.

Question and Answer Session

Q. I'm Amy Kronenberg. I'm at the Lawrence Berkeley Laboratory. I really enjoyed the presentations and the session. I'm not sure who I should address this question to, but there was an article in last Sunday's *New York Times* magazine section about private missions to Mars. One of the factors that this article, and your example of people climbing Mt. Everest brought to mind is that the choice of an occupation or a task as an explorer may be perceived very differently based on the cost, the literal cost, to society as a whole. The choice of an individual to go on an Everest expedition financed privately may be seen differently than the cost of a space flight funded publicly versus the cost of the space flight funded privately. So the risk perception might be different, as well as the acceptability of the risk. Would like to comment on that?

A. That is clearly a relevant factor as a general issue. We even see that there are pressures within the mountaineering profession to see this as something that the public is involved in. That is, if rescuers have to risk their lives and spend a lot of money to rescue people, then that changes the picture and maybe we should regulate mountain climbing more strictly. Those are real pressures in that direction. But I think also that the radiation hazard is not so visible. I mean in climbing, the accidents are visible and dramatic and everyone gets excited about them. In contrast, we're talking here about something very subtle, hidden, unobservable and I don't know that we're going to, at least for a long time, be aware of some of the differences in the levels of risk that we are talking about so I don't know that those pressures would necessarily surface in the same way.

Q. I'm Stan Curtis from the Fred Hutchinson Cancer Research Center. This is a question to both Dr. Whipple and Dr. Slovic. It came to mind as I was listening to Dr. Slovic that we have had discussions about considering two different astronaut groups. One would be the ones who would go up and construct the space station. They might be considered to fall in what might be called the "worker" category. An then there is a second group—those who might undertake a return trip to the moon or a mission to Mars. These people might be considered to fall in what might be called the "explorer" category. My question is whether we should consider developing and applying two different levels of acceptable risk to these two groups? Would either of the last two speakers comment on this?

A. I think that there is a sense in which it would be legitimate to make that distinction because people themselves might make a distinction between routine work and exploration. As part of this social negotiation we could say that, if you're really exploring, you should be allowed to bear a greater risk. But then we get into definitions. People who are building a space station would also be considered explorers by many. So I think we'd have to negotiate that distinction. If there was a clear distinction between routine work versus unique, interplanetary exploration, then I think it fits with everything else we do in society where we have different tolerances as a function of the value and the benefits and so forth. But we'll have to think hard about this distinction.

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Table 1.

Ordering of perceived risks for 30 activities and technologies. The ordering is based on the geometric mean risk ratings within each group. Rank 1 represents the most risky activity or technology.

Activity or Technology	League of Women Voters	College Students	Active Club Members	Experts
Nuclear power	1	1	8	20
Motor vehicles	2	5	3	1
Handguns	3	2	1	4
Smoking	4	3	4	2
Motorcycles	5	6	2	6
Alcoholic Beverages	6	7	5	3
General (private) aviation	7	15	11	12
Police work	8	8	7	17
Pesticides	9	4	15	8
Surgery	10	11	9	5
Fire fighting	11	10	6	18
Large construction	12	14	13	13
Hunting	13	18	10	23
Spray cans	14	13	23	26
Mountain climbing	15	22	12	29
Bicycles	16	24	14	15
Commercial aviation	17	16	18	16
Electric power (non-nuclear)	18	19	19	9
Swimming	19	30	17	10
Contraceptives	20	9	22	11
Skiing	21	25	16	30
X-rays	22	17	24	7
High school and college football	23	26	21	27
Railroads	24	23	20	19
Food preservatives	25	12	28	14
Food coloring	26	20	30	21
Power mowers	27	28	25	28
Prescription antibiotics	28	21	26	24
Home appliances	29	27	27	22
Vaccinations	30	29	29	25

Table 2.

Summary of Perception and Acceptance of Risks From Diverse Sources of Radiation Exposure

	Perceived risk	
	Technical experts	Public
Nuclear power/nuclear waste	Moderate risk	Extreme risk
	Acceptable	Unacceptable
X-rays	Low/moderate risk	Very low risk
	Acceptable	Acceptable
Radon	Moderate risk	Very low risk
	Needs action	Apathy
Nuclear weapons	Moderate to extreme risk	Extreme risk
	Tolerance	Tolerance
Food irradiation	Low risk	Moderate to high risk
	Acceptable	Acceptability questioned
Electric and magnetic fields	Low risk	Significant concerns beginning to develop
	Acceptable	Acceptability questioned

Figure Captions

Figure 1. Location of 81 hazards on Factors 1 and 2 derived from the interrelationships among 15 risk characteristics. Each factor is made up of a combination of characteristics, as indicated by the lower diagram. Source: redrawn from Slovic (1987).