CHAPTER 13

INSTITUTIONAL ISSUES FOR CONTINUED SPACE EXPLORATION: HIGH-RELIABILITY SYSTEMS ACROSS MANY OPERATIONAL GENERATIONS—REQUISITES FOR PUBLIC CREDIBILITY[1]

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Highlighting critical issues arising from the evolution of a large government enterprise is both important and occasionally painful and sometimes provides a basis for exciting next steps. Calling out critical technical issues from past developments inspires engineers and makes visible to policymakers likely requests for program funding to address them. A "critical issues" focus also holds the promise of exploring other sorts of issues: those that arise in deploying technologies.[2] These are particularly interesting when they entail large-scale organizations that are judged to be highly hazardous.

This paper highlights the challenges and issues involved when we wish large, technically rooted organizations to operate *far more* effectively, with *much less* error than they should be expected to exhibit—given what we know about organizations more generally. Recall that "Murphy's Law" and trial-and-error learning are reasonably accurate descriptors of how all organizations generally behave. Routinely expecting otherwise is quite remarkable.

First, let us set a context. In your mind's eye, imagine space-related activities two or three decades into the future. President George W. Bush's current vision for NASA focused the Agency's efforts in the early 21st century, and

1. This paper draws on presentations to the Workshop on Space Policy held by the National Academies of Science in Irvine, CA, 12–13 November 2003; the National Academies' Board on Radioactive Waste Management Panels on "Principles and Operational Strategies for Staged Repository Systems," 27 June 2001, and "Long-Term Institutional Management of Hazards Sites," 7 August 2001, both held in Washington, DC; and the American Association for the Advancement of Science (AAAS) symposium, "Nuclear Waste: File and Forget? Institutional Challenges for High-Reliability Systems Across Many Operational Generations—Can Watchfulness Be Sustained?" held in Denver, CO, 18 February 2003. Since these presentations were given to quite different, nearly mutually exclusive audiences, the various conference sponsors have agreed to this repetition.

2. This conference on "Critical Issues" casts a wider net and includes issues relevant to the understanding of policy development, technical operations as well as systems safety, and the conduct of historical studies of large systems per se.

our reach has extended to periodic flights to the Moon and to an international space platform.[3] With international cooperation, three to four major launches and recoveries a year have become more or less routine. Another six or seven unmanned launches resupply the Station and various probes for scientific programs. Assume that national intelligence and communications demands require another half dozen annually. And imagine that commercial spaceflight enthusiasts have found enough "venture capitalists" and adventurers to sustain several highly visible, elite space experiences. This is edging toward 20 launches a year and evokes images of science fiction and early *Star Trek* tableaux.

This sort of future moves us well beyond the sharply defined, novel images of machinery and spectacularly framed astronauts spacewalking against the black of the heavens. It conjures the extraordinary organizations that these activities imply. There would be the early vestiges of, say, a U.S.–European Union space traffic control—analogous to the existing global air traffic control system—alert to tracking both space vehicles and the detritus of former flights, closely concentrating on bringing each flight to rest without encountering objects aloft or mishaps of human or mechanical origin. Operational scope would be widespread and expected to continue indefinitely. This organizational reach is extraordinary. It immediately raises the question of the "operational sustainability" of NASA's space missions, especially those that propel humans into space.

The missions and the technologies that typify NASA and its industrial contractors prompt demands that NASA programs exhibit highly reliable, humanly safe operations, often projected to continue for a number of management generations (say some 10 to 15 years each). NASA has, in the past, taken up these challenges emphasizing both engineering controls and administrative controls that embrace safety and effective performance.

This paper highlights a third emphasis: the organizational relationships and safety culture of the Agency and its contractors that would manage an astonishing array of complicated technical systems and far-flung facilities making up a global space complex. It draws on work examining the operations of several mature, large-scale technical systems. Then it considers in this light the qualities likely to be necessary in the evolution of NASA's humans-in-space activities if they are routinely to achieve a high degree of public acceptance and sustained credibility.

Putting the question directly: What organizational conditions have arisen when the operating technologies are so demanding or hazardous that trial-

3. President George W. Bush, "A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration," 14 January 2004, folder 12886, NASA Historical Reference Collection, Washington, DC. For NASA's most recent expression of this declaration, see NASA, "The New Age of Exploration: NASA's Direction for 2005 and Beyond," February 2005, same folder. The operative portion from the mission: "To understand and protect our home planet, To explore the universe and search for life, To inspire the next generation of explorers."

and-error learning, while likely, no longer seems to be a confident mode of learning and when the next error may be your last trial?

What can be said about managing large-scale technical systems, responsible for often highly hazardous operations on missions that imply operational stability for many, many years? The institutional design challenges are to provide the work structures, institutional processes, and incentives in such ways that they assure highly reliable operations[4] over the very long term—perhaps up to 50 years[5]—in the context of continuously high levels of public trust and confidence.[6] My purpose here is less to provide a usable explication of these concepts (see the supporting references) and more to demonstrate, by a blizzard of lists, the complexity and range of the institutional conditions implied by NASA's program reach. I foreground properties that are especially demanding, keeping these questions in mind: How often and at what effort does one observe these characteristics in the organizational arenas you know best? Could one imagine such an ensemble within NASA in the foreseeable future?

PURSUING HIGHLY RELIABLE OPERATIONS

Meeting the challenges of highly reliable operations has been demonstrated in enough cases to gain a rough sense of the conditions that seem associated with extraordinary performance. These include both internal processes and external relations. What can be said with some confidence about the qualities NASA managers and their overseers could seek?[7] (See table 13.1.)

4. Initial empirical work included close study of the operations of U.S. Air Traffic Control, aircraft carriers at sea, and nuclear power plants. For summaries, see G. I. Rochlin, "Reliable Organizations: Present Research and Future Directions," and T. R. La Porte, "High Reliability Organizations: Unlikely, Demanding and at Risk," both in *Journal of Crisis and Contingency Management* 4, no. 2 (June 1996): 55–59 and 60–71, respectively; T. R. La Porte and P. M. Consolini, "Working in Practice but not in Theory: Theoretical Challenges of High Reliability Organizations," *Journal of Public Administration Research and Theory* 1, no. 1 (January 1991): 19–47; K. H. Roberts, "New Challenges to Organizational Research: High Reliability Organizations," *Industrial Crisis Quarterly* 3 (1989): 111–125.

5. Prompting the concept of "institutional constancy." See discussion later in this chapter, along with T. R. La Porte and A. Keller, "Assuring Institutional Constancy: Requisites for Managing Long-Lived Hazards," *Public Administration Review* 56, no. 6 (November/December 1996): 535–544.

6. In the context of this paper, sustaining public trust and confidence, while a very important consideration, takes second seat to the issues of reliable operations across multiple generations. Public trust is a condition that evokes high institutional demands and calls for a discussion that extends beyond the limitations of this paper. See, for example, U.S. Department of Energy (DOE), "Earning Public Trust and Confidence: Requisite for Managing Radioactive Waste. Report of the Task Force on Radioactive Waste Management, Secretary of Energy Advisory Board," November 1993, available online at *http://www.seab.energy.gov/publications/trust.pdf*; T. R. La Porte and D. Metlay, "Facing a Deficit of Trust: Hazards and Institutional Trustworthiness," *Public Administration Review* 56, no. 4 (July–August 1996): 341–347.

7. Draw generalized inferences from this discussion with care. These findings are based mainly on three types of organizations, each with a limited number of cases, and bits from others (e.g., K. H.

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Table 13.1. Characteristics of Highly Reliable Organizations (HROs)

Internal Processes

1. Strong sense of mission and operational goals, commitment to highly reliable operations, both in production and safety.
2. Reliability-enhancing operations.
   A. Extraordinary technical competence.
   B. Sustained, high technical performance.
   C. Structural flexibility and redundancy.
   D. Collegial, decentralized authority patterns in the face of intense, high-tempo operational demands.
   E. Flexible decision-making processes involving *operating teams.*
   F. Processes enabling continual search for improvement.
   G. Processes that reward the discovery and reporting of error, *even one's own.*
3. Organizational culture of reliability, including norms, incentives, and management attitudes that stress the equal value of reliable production and operational safety.

External Relationships

1. External "watching" elements.
   A. Strong superordinate institutional visibility in parent organization.
   B. Strong presence of stakeholding groups.
2. Mechanisms for "boundary spanning" between the units and these watchers.
3. Venues for credible operational information on a timely basis.

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Roberts, "Some aspects of organizational cultures and strategies to manage them in reliability enhancing organizations," *Journal of Managerial Issues* 5 [1993]: 165–181). Though these organizations operate in quite different institutional milieus, we cannot say they represent a systematic sample. No one now knows what the population of HROs might be. And highly reliable operations are keenly sought for situations that are not so dramatically hazardous in the physical sense, e.g., HRO operations in financial transactions or in the performance of sophisticated computer chips or large software programs. See K. H. Roberts and C. Libuser, "From Bhopal to banking: Organizational design can mitigate risk," *Organizational Dynamics* 21 (1993): 15–26. In these situations, motivation stems from fear of serious financial losses that are seen as amounting to institutional, not physical, death.

Internal Processes[8]

Organizationally defined intention. High-reliability organizations (HROs) exhibit a strong sense of mission and operational goals that stress assuring ready capacity for production and service with an *equal* commitment to reliability in operations and a readiness to invest in reliability-enhancing technology, processes, and personnel resources. In cases such as our space operations, these goals would be strongly reinforced by a clear understanding that the technologies upon which the organizations depend are intrinsically hazardous and potentially dangerous to human and other organisms. It is notable that for U.S. space operations, there is also high agreement within the operating organizations and in the society at large about the seriousness of failures and their potential costliness, as well as the value of what is being achieved (in terms of a combination of symbolic, economic, and political factors). This consensus is a crucial element underlying the achievement of high operational reliability and has, until recently, increased the assurance of relatively sufficient resources needed to carry out failure-preventing/quality-enhancing activities. Strong commitment also serves to stiffen corporate or agency resolve to provide the organizational status and financial and personnel resources such activities require. But resolve is not enough. Evidence of cogent operations is equally crucial.

Reliability-enhancing operations. These include the institutional and operational dynamics that arise when extraordinary performance must be the rule of the day—features that would be reinforced by an organizational culture of reliability, i.e., the norms and work ways of operations.[9] A dominant quality of organizations seeking to attain highly reliable operations is their intensive technical and social interdependence. Characterized by numerous specialized functions and coordination hierarchies, this prompts patterns of complexly related, tightly coupled technical and work processes which shape HROs' social, structural, and decision-making character.[10]

8. This section draws strongly from La Porte and Consolini, "Working in Practice but not in Theory"; Rochlin, La Porte, and Roberts, "The self-designing high-reliability organization: Aircraft carrier flight operations at sea," *Naval War College Review* 40, no. 4 (1987): 76–90; La Porte, "High Reliability Organizations"; Rochlin, "Reliable Organizations: Present Research and Future Directions," pp. 55–59; T. R. La Porte, "High Reliability Organizations: Unlikely, Demanding and at Risk," pp. 60–71; K. H. Roberts, "Some characteristics of high reliability organizations," *Organization Science* 1, no. 2 (1990): 160–177; P. R. Schulman, "Negotiated Order of Organizational Reliability," *Administration & Society* 25, no. 3 (November 1993): 356–372.

9. K. E. Weick, "Organizational culture as a source of high reliability," *California Management Review* 29 (1987): 112–127; K. H. Roberts, "Some aspects of organizational cultures and strategies to manage them in reliability enhancing organizations," *Journal of Managerial Issues* 5 (1993): 165–181.

10. La Porte and Consolini, "Working in Practice but not in Theory"; Rochlin, "Reliable Organizations: Present Research and Future Directions"; C. Perrow, *Normal Accidents: Living With High-Risk Technologies* (New York: Basic Books, 1984); K. H. Roberts, K. H. and G. Gargano, "Managing a High Reliability Organization: A Case for Interdependence," in *Managing Complexity in High Technology Industries: Systems and People,* ed. M. A. Von Glinow and S. Mohrmon (New York: Oxford University Press, 1989), pp. 147–159.

The social character of the HRO is typified by high technical/professional competence and performance, as well as thorough technical knowledge of the system and awareness of its operating state.

1. Extraordinary technical competence almost goes without saying. But this bears repeating because continuously attaining very high quality requires close attention to recruiting, training, staff incentives, and ultimately the authority relations and decision processes among operating personnel who are, or should be, consummately skilled at what they do. This means there would be a premium put on recruiting members with extraordinary skills and an organizational capacity to allow them to burnish these skills in situ via continuous training and an emphasis on deep knowledge of the operating systems involved. Maintaining high levels of competence and professional commitment also means a combination of elevated organizational status and visibility for the activities that enhance reliability. This would be embodied by "high reliability professionals"[11] in positions with ready access to senior management. In aircraft carrier operations, this is illustrated where high-ranking officers are assigned the position of Safety Officer reporting directly to the ship's captain.

2. HROs also continuously achieve high levels of operational performance accompanied by stringent quality assurance (QA) measures applied to maintenance functions buttressed by procedural acuity.[12] Extensive performance databases track and calibrate technical operations and provide an unambiguous description of the systems' operating state. NASA's extraordinary investment in collecting system performance data is a prime example of this characteristic. These data inform reliability statistics, quality-control processes, accident modeling, and interpretations of system readiness from a variety of perspectives. In some organizational settings, the effectiveness of these analyses is enhanced by vigorous competition between groups formally responsible for safety.[13]

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11. P. Schulman, E. Roe, M. van Eeten, and M. de Bruijne, "High Reliability and the Management of Critical Infrastructures," *Journal of Crisis and Contingency Management* 12, no. 1 (March 2004): 14–28. Also see David Mindell's chapter in this book and his attention to the self "identity" of technical operators.

12. Schulman, "Negotiated Order of Organizational Reliability"; M. Bourrier, "Organizing Maintenance Work at Two American Nuclear Power Plants," *Journal of Crisis and Contingency Management* 4, no. 2 (June 1996): 104–112.

13. T. R. La Porte and C. Thomas, "Regulatory Compliance and the Ethos of Quality Enhancement: Surprises in Nuclear Power Plant Operations," *Journal of Public Administration Research and Theory* 5, no. 4 (December 1994): 250–295.

HROs' operations are enabled by structural features that exhibit operational flexibility and redundancy in pursuit of safety and performance, and overlapping or nested layers of authority relationships.

3. Working with complex technologies is often hazardous, and operations are also carried out within quite contingent environments. Effective performance calls for flexibility and "organizational slack" (or reserve capacity) to ensure safety and protect performance resilience. Such structural flexibility and redundancy are evident in three ways: key work processes are designed so that there are parallel or overlapping activities that can provide backup in the case of overload or unit breakdown and operational recombination in the face of surprise; operators and first-line supervisors are trained for multiple jobs via systematic rotation; and jobs and work groups are related in ways that limit the interdependence of incompatible functions.[14] NASA has devoted a good deal of attention to aspects of these features.

The three characteristics noted so far are, in a sense, to be expected and command the attention of systems engineering and operational managers in NASA and other large-scale technical programs. There is less explicit attention to understanding the organizational relationships that enhance their effectiveness. I give these a bit more emphasis below.

4. Patterns of formal authority in large organizations are likely to be predominately hierarchical (though this may have as much to do with adjudicative functions as directive ones). And, of course, these patterns are present in HROs as well. Top-down, commandlike authority behaviors are most clearly seen during times of routine operations. But importantly, two other authority patterns are also "nested or overlaid" within these formal relations. Exhibited by the same participants who, during routine times, act out the roles of rank relations and bureaucrats, in extraordinary times, when the tempo of operations increases, another pattern of collegial and functionally based authority relationships takes form. When demands increase, those members

14. For work on functional redundancy, see especially M. Landau, "Redundancy, Rationality, and the Problem of Duplication and Overlap," *Public Administration Review* 27 (July/August 1969): 346–358; A. W. Lerner, "There is More Than One Way to be Redundant: A Comparison of Alternatives for the Design and Use of Redundancy in Organizations," *Administration & Society* 18 (November 1986): 334–359; D. Chisholm, *Coordination Without Hierarchy: Informal Structures in Multi-organizational Systems* (Berkeley: University of California Press, 1989); C. F. L. Heimann, "Understanding the *Challenger* Disaster: Organizational Structure and the Design of Reliable Systems," *American Political Science Review* 87 (June 1993): 421–435.

who are the most skilled in meeting them step forward without bidding to take charge of the response, while others who may "outrank" them slip informally into subordinate, helping positions.

And nested within or overlaid upon these two patterns is yet another well-practiced, almost scripted set of relationships that is activated during times of acute emergency. Thus, as routine operations become high-tempo, then perhaps emergencies arise, observers see communication patterns and role relationships changing to integrate the skills and experience apparently called for by each particular situation. NASA has had dramatic experience with such patterns.

Within the context of HROs' structural patterns, decision-making dynamics are flexible, dispersed among operational teams, and include rewards for the discovery of incipient error.

5. Decision-making within the shifting authority patterns, especially operating decisions, tends to be decentralized to the level where actions must be taken. Tactical decisions often develop on the basis of intense bargaining and/or collegial interaction among those whose contributions are needed to operate effectively or problem-solve. Once determined, decisions are executed, often very quickly, with little chance for review or alteration.[15]

6. Due in part to the irreversibility of decisions once enacted, HROs put an unusual premium on assuring that decisions will be based on the best information available. They also try to insure that their internal technical and procedural processes, once put in motion, will not become the sources of failure. This leads, as it has within NASA, to quite formalized efforts, continually in search of improvement via systematically gleaned feedback, and periodic program and operational reviews. These are frequently conducted by internal groups formally charged with searching out sources of potential failure, as well as improvements or changes in procedures to minimize the likelihood of failure. On occasion, there may be several groups structured and rewarded in ways that puts them in direct competition with each other to discover potential error, and, due to their formal attachment to different reporting levels of the management hierarchy, this encourages the quick forwarding of information about potential flaws to higher authority.[16]

15. Roberts, "Some characteristics of high reliability organizations"; Schulman, "Negotiated Order of Organizational Reliability."

16. La Porte and Thomas, "Regulatory Compliance and the Ethos of Quality Enhancement"; Diane Vaughan, *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA* (Chicago: University of Chicago Press, 1990).

Notably, these activities, due to their intrinsic blame-placing potential, while they may be sought by upper management in a wide variety of other types of organizations, are rarely conducted with much enthusiasm at lower levels. In response, HROs exhibit a most unusual willingness to reward the discovery and reporting of error without peremptorily assigning blame for its commission at the same time. This obtains even for the reporting of one's own error in operations and procedural adherence. The premise of such reward is that it is better and more commendable for one to report an error immediately than to ignore or to cover it up, thus avoiding untoward outcomes as a consequence. These dynamics rarely exist within organizations that operate primarily on punishment-centered incentives, that is, most public and many private organizations.

Organizational culture of reliability. Sustaining the structural supports for reliability and the processes that increase it puts additional demands on the already intense lives of those who operate and manage large-scale, advanced technical systems. Operating effectiveness calls for a level of personal engagement and attentive behavior that is unlikely to be manifest merely on the basis of formal rules and economic employee contracts. It requires a fully engaged person responding heedfully to norms of individual and group relations that grow out of the particular demands and rewards of the hazardous systems involved.[17] For lack of a better concept to capture these phenomena, let us accept the slippery concept of "organizational culture" as a rough ordering notion.[18] A culture of organizational reliability refers to the norms, shared perceptions, work ways, and informal traditions that arise within the operating and overseeing groups closely involved with the systems of hazard.[19]

Recall that HROs strive equally for high levels of production and safety.[20] HROs face the challenge of being reliable both as producers (many under all manner of demanding conditions) *and* as safety providers (under conditions of high production demands). While most organizations combine varying

17. Weick, "Organizational culture as a source of high reliability"; Roberts, "Some aspects of organizational cultures."

18. The concept of organizational culture captures the sense that there are norms, values, and "taken for granted" modes of behavior and perceptions that shape interpersonal and group relations. At the same time, the concept retains a high degree operational ambiguity, its use subject to stiff criticism. See J. S. Ott, *The Organizational Culture Perspective* (Chicago: Dorsey Press, 1989); Roberts, "Some aspects of organizational cultures"; G. I. Rochlin, "Les organizations 'a' haute fabilite': bilan et perspective de recherche" (Highly Reliable Organizations: Exploration and Research Perspectives), chap. 2 in *Organiser la fiabilite*, ed. M. Bourrier (Paris: L'Harmattan, 2001).

19. Roberts, "Some characteristics of high reliability organizations"; "Nuclear Power Operations: A Cross-Cultural Perspective," *Annual Review of Energy and the Environment* 19 (1994): 153–187.

20. Cf. Rochlin, "Reliable Organizations: Present Research and Future Directions"; Schulman, "Negotiated Order of Organizational Reliability."

degrees of production plus service/safety emphasis, HROs have continuously to strike a balance. In times of routine, safety wins out formally (though watchfulness is harder to sustain); in times of high tempo/surge, this becomes reordered (though watchfulness is much more acute). This suggests an organizational culture integrating the familiar norms of mission accomplishment and production with those of the so-called safety culture.[21]

Elements of the results are operator/member élan, operator autonomy, and intrinsic tension between skilled operators and technical experts.

- Operating personnel evince an intense élan and strongly held expectations for themselves about the value of skilled performance. In the face of hazard, it takes on a kind of prideful wariness. There are often intense peer-group pressures to excel as a highly competitive team and to cooperate with and assist each other in the face of high operating demands. This includes expectations of fulfilling responsibilities that often go well beyond formal role specifications. For example, there is a view that "whoever spots a problem owns it" until it is mitigated or solved in the interest of full, safe functioning. This sometimes results in operators realizing that, in the face of unexpected contingencies, they may have to "go illegal," i.e., to go against established, formal procedures if the safety operating procedures appear to increase the difficulty of safely meeting the service demands placed on the organization. Operator élan is reinforced by clearly recognized peer-group incentives that signal high status and respect, pride in one's team, emphasis on peer "retention" and social discipline, and reward for contributing to quality-enhancing, failure-preventing activities.

- Hazardous operations are often time-critical, where effectiveness depends on keen situational awareness. When it becomes clear that speedy, decisive action must be taken, there is little opportunity for assistance or approval from others.[22] Partly as a result, HRO operators come to develop, indeed insist upon, a high degree of discretion, autonomy, and responsibility for activities "on their watch."[23] Often typified as being "king of my turf," this is seen as highly appropriate by both other operators and supervisors.

21. See G. I. Rochlin, "Safe operations as a social construct," *Ergonomics* 42, no. 11 (1999): 1549–1560; cf. Weick, "Organizational culture as a source of high reliability."

22. See K. E. Weick, K. M. Sutcliffe, and D. Obstfeld, "Organizing for high reliability: Processes of collective mindfulness," *Research in Organizational Behavior* 21 (1999): 81–123, for a related perspective.

23. K. H. Roberts, D. M. Rousseau, and T. R. La Porte, "The culture of high reliability: Quantitative and qualitative assessment aboard nuclear powered aircraft carriers," *Journal of High Technology Management Research* 5, vol. 1 (spring 1994): 141–161.

- But operator autonomy is often bought at a moderate price. The HROs we studied all operated complex technical systems that put a premium on technical engineering knowledge as well as highly skilled operating knowledge and experience. These two types of skills are usually formally distinguished in the occupational roles designations within HROs. Each has a measure of status; each depends on the other for critical information in the face of potential system breakdown and recovery if problems cannot be contained. But in the operators' eyes, *they* have the ultimate responsibility for safe, effective operation. They also have an almost tactile sense of how the technical systems actually function in the organization's operating environments, environments that are likely to be more situationally refined and intuitively more credibly understood than can be derived from the more abstract, cognitively based knowledge possessed by engineers. The result is an intrinsic tension between operators and technical experts, especially when operators judge technical experts to be distant from actual operations, where there is considerable confidence placed on tacit knowledge of system operations based on long operating experience.[24]

These dominant work ways and attitudes about behavior at the operating levels of HROs are prompted by carrying out activities that are closest to the hazards and suggest the important affective nature of HRO dynamics. These patterns provide the basis for the expressive authority and "identitive compliance"[25] norms that sustain the close cooperation necessary when facing the challenges of unexpected high-tempo/high-surge situations with minimum internal harm to people and capital equipment. But HROs operate in the context of many interested outsiders: sponsors, clients, regulators, and surrounding neighborhoods. Relations with outside groups and institutions also play a crucial role.

External Relationships

HRO performance is clearly dependent on extraordinarily dense patterns of cooperative behavior within the organization. These are extensive, often quite intense, and unusual both in terms of achieving continuous reliability and in higher costs. As such, they are difficult to sustain in the absence of external reinforcement. Continuous attention both to achieving organizational missions and to avoiding serious failures requires repeated interactions with—one might

24. G. I. Rochlin and A. von Meier, "Nuclear Power Operations: A Cross-Cultural Perspective," pp. 153–187; Rochlin, "Safe operations."

25. See A. Etzioni, "Organizational Control Structure," chap. 15 in *Handbook of Organizations*, ed. J. G. March (Chicago: Rand McNally, 1965), pp. 650–677.

say pressures from—elements in the external environment, not only to insure resources, but, as importantly, to buttress management resolve to maintain the internal relations outlined above and to nurture HROs' culture of reliability. These cultural characteristics are the most important of all the properties of HROs, for if they are absent, the rest are difficult to achieve and sustain.

NASA has certainly learned how external interests—we will call them "the watchers"—can enter into the Agency's everyday life, especially when major failures are seized upon as a chance to ventilate concerns about operational reliability.[26] "Watchers" include externally situated, independent public bodies and stakeholding interest groups and the institutional processes that assure their presence, efficacy, and use of tools for external monitoring in the interest of hazard evaluations.

Aggressive, knowledgeable "watchers" increase the likelihood that a) reliability-enhancing operations and investments will be seen as legitimate by corporate and regulatory actors, b) such costs *should* be absorbed, and c) regulations and internal social demands should be allowed in the interest of safety. This may mean investing, on one hand, in developing and training external review groups and in some instruments of behavioral surveillance, e.g., random drug tests, and, on the other, assuring these "watchers" that HRO leaders will quickly be held accountable for changes that could reduce reliability in service or safety. These watching groups may be either formal or informal and are found both within the HRO's immediate institutional environment, e.g., congressional committees, and outside it.

It is crucial that there be clear institutional interests in highly reliable performance. This should be evident in strong, superordinate institutional elements of the parent organization, such as agency and corporate headquarters or command-level officers (e.g., utility corporate headquarters, higher military command, and Washington agency headquarters), and sometimes industrial association watchdogs (e.g., the nuclear industry's Institute for Nuclear Power Operators, or INPO).[27]

At the same time, the persistent presence of external stakeholding groups assures attentiveness (and occasional resentment). These groups range from quite formal public watchers, such as regulatory overseers (e.g., state Public Utility Commissions, Nuclear Regulatory Commissions, the Environmental Protection Agency, the Federal Emergency Management Agency, and the Occupational Safety and Health Administration), user and client groups (e.g., instrument-rated pilots using air traffic control services and Congresspersons), to a wide sweep of "public interveners" (e.g., state, local governments, land-

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26. Diane Vaughan's work (cited above) and conference paper contrasting the *Challenger* and *Columbia* accident reports gives eloquent testament to the dynamics of intense external scrutiny.

27. T. Rees, *Hostages to Each Other* (Chicago: University of Chicago Press, 1994).

use advocates, and citizen interest groups). Finally, this important function is also played by professional peer bodies and by HRO alumni who are seen as operationally knowledgeable observers. They are likely to be accorded respect both by other outsiders and by the HRO operators themselves.

An abundance of external watchers seems crucial in attaining continuous, highly reliable operations and a culture of reliability. So are boundary-spanning processes through which encouragement and constraints are exercised in the interest of product/safety reliability. Two types are evident. First, there are formally designated positions and/or groups who have external oversight responsibilities. Two examples of formalized channels are Nuclear Regulatory Commission On-site Residents, two or three of whom are assigned to each nuclear power plant, with nearly complete access to power plant information, review meetings, etc., and, second, military liaison officers who are permanently assigned to air traffic control centers. Sometimes these boundary-spanning activities are expressed in aircraft carriers' operations via dual reporting requirements for nuclear engineering officers to report problems immediately, not only to the ship's captain, but to a central nuclear affairs office at naval headquarters in Washington, DC, as well.

Boundary spanning, and with it increased transparency, also occurs intermittently in the form of periodic formal visits from "check" or review groups, who often exercise powerful sanctions if their reviews do not measure up. These activities come in a number of forms, for example, phased inspections and training checks in aircraft carrier combat preparations, as well as the more familiar Inspector General reviews, and nuclear power utilities requirements to satisfy rigorous performance in responding to the NRC-mandated, biannual activation of power plant emergency scenarios in which all the relevant local and state decision-makers engage in a daylong simulation leading to possible regional evacuation under the watchful eye of NRC and FEMA inspectors.[28]

Finally, external watchers, however well provided with avenues of access, must have available full, credible, and current information about system performance. This almost goes without saying, for these data, often in the form of annual evaluations, hazard indices, statistical summaries noted above, and indicators of incipient harm and the early onset of danger, become a crucial basis for insightful reviews and public credibility.

This is a formidable array of conditions for any organization to seek or to sustain, even for the short term. To what degree would they suffice over the long term? This will become a major challenge for NASA as missions take on multiyear scope and programs are premised on a long-term human presence in space.

28. La Porte and Thomas, "Regulatory Compliance and the Ethos of Quality Enhancement."

ASSURING INSTITUTIONAL CONSTANCY AND FAITHFULNESS IN THE FUTURE

Many highly reliable organizations operate systems whose full range of positive and negative outcomes can be perceived more or less immediately.[29] When this happens, organizational leaders can be rewarded or held accountable. But when operating systems are also capable of large-scale and/or widely distributed harm which may not occur or be detected for several operational generations, our familiar processes of accountability falter and overseers and the public are likely to be concerned that such HROs be worthy of the trust placed in them across several generations. In NASA's case, these challenges stem from the extraordinary reach of the administration's vision for the Agency's future.

NASA is contemplating missions that will send humans in space for several years to facilities that are likely to be designed to last 10 to 20 years (two management generations). Add to this any of half a dozen hoped-for lunar and exploratory missions. In a much more extreme case, the management of nuclear materials, obligations can be expected to continue for at least 50 to 100 years, perhaps centuries.[30] These cases suggest that shouldering an obligation to demonstrate the faithful adherence to a mission and its operational imperatives for a remarkably long time is inherent in accepting the program—even in the face of a variety of social and institutional environmental changes. As the longer term effects of such technologies become more clear, trying to take into account their transgenerational nature presents particularly troublesome challenges for managers and for students of organization.[31] And it is this aspect of highly reliable operations about which the social and management sciences have the least to say.

29. This section draws from portions of T. R. La Porte and A. Keller, "Assuring Institutional Constancy: Requisite for Managing Long-Lived Hazards," *Public Administration Review* 56, no. 6 (November/December 1996): 535–544. It is also informed by my work at Los Alamos National Laboratory (LANL) exploring the organizational challenges posed for the laboratory by its missions of science-based stockpile stewardship (of nuclear weapons), nuclear materials stewardship, and sometimes environmental stewardship. While the operations of the first two, contrasted to the latter, are very different, the challenges provoked by the longevity of the materials involved prompt very similar organizational puzzles. For a similar rendering, see T. R. La Porte, "Fiabilite et legitimaite soutenable" (Reliability and Sustainable Legitimacy), chap. 3 in *Organiser la fiabilite*, ed. M. Bourrier (Paris: L'Harmattan, 2001).

30. Readers can add other technically oriented programs or activities that have a similar extraordinary property, say in the environmental or public works domain.

31. Two conditions, noted here, increase the public demands for constancy because they undermine our typical means of ensuring accountability and are sometimes characteristic of hazardous technical systems. These two are 1) when the information needed to provide unequivocal evidence of effects is so extensive and costly that the public comes to expect that it will not be forthcoming and 2) if harmful effects occur, they are unlikely to be unequivocally detected for some time into the future due to the intrinsic properties of the production processes and their operating

continued on the next page

A partial remedy is to consider what we might call "institutional constancy." More formally, institutional constancy refers to "faithful, unchanging commitment to, and repeated attainment of performance, effects, or outcomes in accord with agreements by agents of an institution made at one time as expressed or experienced in a future time."[32] An organization exhibits constancy when, year after year, it achieves outcomes it agreed in the past to pursue in the spirit of the original public policy bargain.[33]

Conditions Encouraging Institutional Constancy[34]

What little systematic examination of this remarkable intention there is suggests that institutional constancy requires demonstrating to the public or its major opinion leaders that the agency, public contractors, or firms in question (for example, NASA operating very reliably) can both be trusted to keep its word—to be steadfast—for long into the future and to show the capacity to enact programs that are faithful to the original spirit of its commitments.[35] What conditions signal continued political and institutional will, steadfastness in "keeping the faith"? What conditions assure the capacity to follow through for many years, i.e., the organizational infrastructure of institutional constancy?

Institutional purpose. Constancy is about future behavior, and the organization must signal its collective resolve to persist in its agreements, especially

continued from the previous page
environments. While the mind's eye turns quickly to public organizations for examples, the argument applies with nearly equal force to the private sector in the United States, especially to those firms responding to the strong economic incentives for short-term gain with the systematic deferral of costs for some time.

32. T. R. La Porte and A. Keller, "Assuring Institutional Constancy."

33. Think, for example, of the FAA's air traffic control operations, together with air carriers. They have consistently achieved high levels of flight safety and traffic coordination in commercial aviation and flight operations at sea. And the Navy has a long-term record of exceptional safety aboard nuclear submarines. Electrical utilities have made remarkably high levels of electrical power available. Great universities exhibit constancy in commitments to intellectual excellence, generation after generation, through producing very skilled undergraduates and professionals as well as pathbreaking research.

34. Note: There are strong analytical and practical limitations to attaining institutional constancy over many generations, especially a) weak analytical bases for confidently predicting the outcomes of institutional activities over long periods of time, b) limited means to reinforce or reward generations of consistent behavior, and c) scanty knowledge about designing institutional relationships that improve rather than degrade the quality of action-taking in the future that is faithful to the spirit of present commitments and agreements. Incentives to improve conditions that would assure constancy of institutional capacities are scant. And so is interest in analysis that would improve our understanding of institutional and administrative design. Indeed, there is almost nothing insightful in the literature about *increasing* institutional inertia or constancy. It is still an analytical puzzle.

35. While these two qualities are closely related, one can imagine succeeding at one without achieving the other. An HRO might be able to persuade the public that it was firmly committed to certain objectives but actually turn out to be in no position to realize them. Conversely, an HRO could very well be situated, motivated, and structured to carry out its commitments for years to come but be unable to convince the public of its steadfastness.

with strong commitments to trusteeship in the interests of future generations. Measures that reinforce this perception are as follows:

- The necessary formal, usually written goal of unswerving adherence to the spirit of the initial agreement or commitment; documents that can be used in the future to hold each generation's organizational leaders accountable for their actions.

- Strong, public articulation of commitments to constancy by high-status figures within an agency or firm, calling especially on professional staff and perhaps key labor representatives to emphasize the importance of constancy. Coupled with formal declarations, consistent emphasis upon steadfastness within an organization reinforces the otherwise difficult commitments of energy and public witness that are needed by key members of the technical staff and workforce.

- Strong evidence of institutional norms and processes that nurture the resolve to persist across many work generations, including, in the public sector, elements in labor contracts that extend over several political generations.[36] When these exist, they bind workers and their leaders to the goals of the agency, often transcending episodes of leadership succession. The content of these norms and the processes that reinforce them are now not well calibrated, though examples are likely to be found in public activities that draw the deep loyalty of technical staff and former members. This seems to be the case for elite military units, e.g., the U.S. Marine Corps and Navy Seals; groups within the Centers for Disease Control (CDC) and some other public health activities; and some elements within U.S. air traffic control circles. A close examination of the internal processes of socialization the produce such loyalty is warranted.[37]

- Commitments to courses of action, particularly those where benefits may be delayed until a succeeding management or political genera-

36. This point is akin to the arguments made classically by P. Selznick, *Leadership in Administration* (New York: Harper & Row, 1957), and J. Q. Wilson, *Bureaucracy: What Government Agencies Do and Why They Do It* (New York: Basic Books, 1989), pp. 99–102, about the importance of institutional leadership and the character of the organization's sense of mission.

37. For an early exploration of this aspect, see Selznick, *Leadership in Administration*, and his discussion of the transformation of an instrumental organization into one that has been "infused with value," i.e., that becomes an "institution." For a recent project attempting to address these questions, see A. Boin, "The Early Years of Public Institutions: A Research Agenda" (paper issued by the Department of Public Administration, Leiden University, Netherlands, 2004).

tion, are difficult to sustain in the face of U.S. political metabolism. Therefore, vigorous external reinforcement from both regulatory agencies and "public watching" groups must be present to assure that the relevant agencies and their contractors will not flag in attending to the performance promised by one generation to the next. This would include reinforcing the vigor of outside groups by regularly assuring their formal involvement and providing sufficient resources to sustain their expectations and prompt their demands for consultation if the next generation of leaders wavers in its resolve. The optimum would be when these measures lead to laws, formal agreements, and foundation/nongovernmental funding and infrastructure for continual encouragement and sanctions for "keeping the faith."

The infrastructure of constancy. While strong motivations and earnestness are necessary, they alone do not carry the day. Other conditions should also be present to assure interested outsiders that actions will, in fact, be carried out in realizing important commitments across multiple generations. As I outline

Table 13.2. Characteristics Associated with Institutional Constancy
(i.e., Organizational Perseverance, Faithful Adherence to the Mission and Its Operational Imperatives)

1. Assurance of steadfast political will.
   - A. Formal goal of unswerving adherence to the spirit of the initial agreement.
   - B. Strong articulation of commitments by high-status agency leaders calling on staff in achieving constancy.
   - C. Clear evidence of institutional norms that nurture the persistence of commitments across many generations.
   - D. Vigorous external reinforcement from regulatory agencies and public watching groups.
2. Organizational infrastructure of constancy.
   - A. Administrative and technical capacity to carry out constancy-assurance activities reinforced by agency rewards.
   - B. Adequate resources to assure the "transfer" of requisite technical and institutional knowledge across worker and management generations.
   - C. Analytical and resource support for "future impact analyses."
   - D. Capacity to detect and remedy the early onset of likely failure that threatens the future, with the assurance of remediation if failures occur.

these, return in your mind's eye to the U.S. space community and the many organizations revolving satellite-like around the central sun/star of NASA. How many of the conditions I will suggest below already exist within NASA? How difficult would their introduction and persistence likely be? If these seem sparse, or absent, this points to a "critical institutional issue."

These conditions of constancy include the following:

- The technical capabilities and administrative infrastructure which are needed to assure performance, along with agency or contractor rewards and incentives for articulating and pursuing measures that enhance constancy and intergenerational fairness. These would include executive socialization and training processes to reinforce commitments and long-term perspectives to nurture a culture of constancy. Such processes and resources are rarely provided in today's institutional environments. Rather, perspectives and rewards are intensely generation-centric, characterized by quite short-term evaluations, and strongly reinforced by contemporary business and legislative cycles.

- In addition to assuring consistency in organizational culture, the resources and activities needed to "transfer" or "pass on" the organization's critical operating, technical, and institutional knowledge from one work and management generation to the next are crucial. This includes systematic capture of critical skills and operating histories, as well as continuous training and evaluation of each generation's capabilities. Some portion of each future generation should be present in the current one.

The remaining conditions point to keen powers of analysis in service to the future.

- Analytical supports should be evident for analysis and decision-making which take into account the interests of the future and enable work, such as "future impact analyses," that seeks to identify the effects of present institutional actions on future capabilities. Something like this goes on during budgetary planning efforts, but, in the U.S. system, the timeframes are invariably merely short-term, tied to legislative or corporate profit reporting cycles. Scanning further into an institution's future—at least beyond the present generation—is also called for. Analytical capabilities to do this are likely to require at least a small cadre of highly skilled professionals, systems for rewarding their efforts, and organizational and agency venues where their reflections will have a respected voice.

- And, perhaps most important, publicly obvious, effective capacity would be in place to detect the early onset of likely failures related to the activities that could threaten the future. This analytical capacity should then be joined with institutional capabilities to initiate remedies, along with the assurance of remediation resources in the event failures should occur.[38] Without quite visible, publicly evident, and well-exercised capacity for early warning and *preemptive* remediation, the public is likely to remain skeptical, potentially suspicious, and ripe for mobilization into recalcitrant opposition.[39]

This suite of conditions intended to assure institutional constancy is very demanding and costly. Whether leaders would consider developing them is likely to be contingent upon external demand. Pressure to try is increased when programs exhibit three characteristics. There will be particularly aggressive insistence on faithfulness when agency programs a) are perceived to be large-scale efforts whose activities may occur across broad spatial and temporal spans and seem to pose potentially irreversible effects; b) are seen as intensely hazardous, even if the likelihood of failure is small and accompanied by substantial gains for the program's prime beneficiaries; and c) pose significant risks whose costs are likely to be borne by future generations who receive little benefit.

This third characteristic—temporal asymmetry of benefits and costs—raises a particularly difficult dilemma. Put in question form: should current populations endure costs today so that future populations will not have to?[40] In NASA's case, this would include investing to avoid future risks against the accrual of present benefits, say, in symbolic returns, or perhaps knowledge that is potentially useful in providing novel artifacts. These long-term benefits

38. See, for example, T. R. La Porte and C. Thomas, "Regulatory Compliance and the Ethos of Quality Enhancement: Surprises in Nuclear Power Plant Operations," *Journal of Public Administration Research and Theory* 5, no. 4 (December 1994): 250–295. Cf. K. Shrader-Frechette, "Risk Methodology and Institution Bias," *Research in Social Problems and Public Policy* 5 (1993): 207–223; and L. Clarke, "The Disqualification Heuristic: When Do Organizations Misperceive Risk?" *Research in Social Problems and Public Policy* 5 (1993): 289–312, for discussions of the conditions that result in operator misperception of risk, conditions that would require strong antidotes if constancy is to be assured.

39. This seems clearly to be the case for the many years of political and legal travail experienced by the Department of Energy. See DOE, "Earning Public Trust and Confidence."

40. See, for example, R. M. Green, "Inter-generational Distributive Justice and Environmental Responsibility," in *Responsibilities to Future Generations: Environmental Ethics*, ed. E. D. Partridge (Buffalo: Prometheus Books, 1980); R. Howarth, "Inter-generational Competitive Equilibria Under Technological Uncertainty and an Exhaustible Resource Constraint," *Journal of Environmental Economics and Management* 21 (1991): 225–243; B. Norton, "Environmental Ethics and the Rights of Future Generations," *Environmental Ethics* (winter 1982): 319–338; P. Wenz, "Ethics, Energy Policy, and Future Generations," *Environmental Ethics* 5 (1983): 195–209.

would have to be balanced against present costs and, as importantly, future industrial environmental damage from large-scale facilities, or having to abandon teams of astronauts due to the inability to retrieve them, and, more remotely, infecting terrestrial populations with extraterrestrial organisms.

Uncertainty about the knowledge and technological capacity of future generations exacerbates the problem. An optimistic view assumes that difficult problems of today will be more easily solved by future generations.[41] No problem today is too big for the future. Skepticism about this, however, makes it an equivocal basis for proceeding with multigenerational programs. An inherent part of assuring constancy would be an agreed-upon basis, an "ethic," of how costs and benefits should be distributed across generations. This is especially true when operational effects extend well into the future, for it demands that generation after generation respond to new information and changing value structures in coping with long-term effects.

This array of constancy-enhancing characteristics raises serious, unresolved operational, political, and ethical questions. If an organization's program provokes demands for nearly error-free operations, then assurances of institutional constancy in meeting the conditions for reliability are likely to be demanded as a substitute for accountability.[42] Apprehensive publics seek assurances that these institutions, such as NASA, will be uncompromising in their pursuit of highest quality operations through the relevant lifetimes of the systems in question.

When harmful effects may be visited upon future generations, assurances of continuity or institutional constancy take on increasing importance.[43] Why would this be the case? Those who implement such programs could quite probably escape accountability for failures. They would have retired,

41. For comment on how responsibility should be divided between generations that accounts for changes in knowledge, see W. Halfele, "Energy from Nuclear Power," *Scientific American* 263, no. 3 (September 1990): 136–144; C. Perrings, "Reserved Rationality and the Precautionary Principle: Technological Change, Time and Uncertainty in Environmental Decision Making," in *Ecological Economics: The Science and Management of Sustainability*, ed. R. Costanza (New York: Columbia University Press, 1991).

42. For those HROs whose technical operations and consequences of failure can be seen as having constancy-evoking characteristics, ignoring "constancy magnets" is an institutionally risky business. This is especially the case for the combination of uneven distribution of benefits and costs among generations and the potential for a long lag in discovering information about possibly grievous damages. Setting these matters aside allows festering seeds of suspicion to multiply, and, if coupled with conditions that also evoke "reliability and regulatory magnets," they are likely grounds for political opposition and demands for increasing rigorous regulation as a condition for even initial approval for new projects. But if organizational remedies are called for, how much additional effort and evolution of institutional capabilities could be entailed?

43. While the mind's eye turns quickly to public organizations, the argument applies equally to the private sector in the United States, especially those firms responding to the strong economic incentives for short-term gain and deferral of costs.

died, or moved on. Leaders of such institutions, therefore, are quite likely to be pressed to assure the public (especially able opinion leaders) that, as a condition of winning approval and resources to initiate or continue programs, agencies and corporate contractors involved should credibly be expected to keep agreements and commitments with potentially affected communities far into the future.

CONCLUDING REFLECTIONS

The reach of NASA's space programs continues to levy remarkable operational demands, for the programs imply very long-term management of both the unmanned and manned aspects of space exploration and possibly commercial and security exploitation. This rather cryptic application to NASA's space exploration programs of work done in other technical domains hints at the challenges involved when we insist on extraordinary levels of reliability that should go on for a number of management generations. It suggests an array of conditions that would become increasingly salient as NASA seeks to regularize and sustain its space traffic regime.

These are very demanding conditions for organizational leaders to consider, much less actively insist upon, encourage, and nurture, even if we knew how to establish organizational patterns I have summarized.[44] It is notable that my discussion is based on work dealing with operations that, *unlike NASA spaceflights*, were quite mature, pretty routine, and had managed to continue for some time. Although the HRO field work involved nearly 10 years of observing and intensive subjective onsite experience with each of three large technical systems in the study, it was not so intensive as discovering the process through which these organizations had gone to result in the variegated patterns that were described. We do not know exactly how they got there.

If the constructs I have outlined here are taken seriously, it is likely to pose unwelcome challenges to agency and program leaders. Our workshop discussions called out a range of critical institutional (as well as historiographical) issues and point toward matters of serious design examination. But the analytical bases for designing and assuring institutional forms at substantial

44. They are also conditions that are not likely to flourish without a high degree of public trust and confidence in operating and overseeing institutions—something that is in increasingly short supply in contemporary American culture. NASA has skated across the increasingly thin ice of waning public confidence in programs involving humans in space. The several high-profile congressional investigations and the Agency's agony over the past decade have eroded a general sense of public confidence in future operations. This in itself should be seen as a major critical institutional issue. For an earlier consideration of this, see T. La Porte, "Institutional Challenges for Continued Space Exploration: High-reliability systems across many operational generations. Are these aspirations publicly credible?" (presented at the Workshop on Space Policy, National Academies of Science, Irvine, CA, 12–13 November 2003).

scale are limited at best.[45] For example, there is scant work on effecting institutional constancy per se, and only limited study of the evolution of highly reliable organizations. A remedy to these important gaps in understanding requires both analytical and experimental efforts to calibrate the dynamics of highly reliable operations, and especially probing the requisites for long-term institutional constancy and trustworthiness.

At least three additional aspects of this challenge are apparent; each prompts a demanding set of research imperatives (see table 13.3).

First, we need to improve our knowledge about the wider institutional currents within U.S. patterns of public and corporate governance that provoke repeated, stubborn resistance to the organizational changes needed to sustain very reliable operations, and reassure citizens that the responsible institutions will be able to keep their word through the relevant program timeframes—and do so in ways that enhance their trustworthiness. Even if there is a reasonably benign political and social environment, these are qualities that are very difficult to establish and maintain. In answering "Why can't we do

Table 13.3. Research Directions: When Highly Reliable Operations, Long-Term Institutional Constancy, and Trustworthiness Are Indicated

Q: Why can't we do it?

A: Institutional impediments to conditions sustaining very reliable operations, institutional constancy, and trustworthiness.

Q: Why do we have to?

A: Technical imperatives requiring very reliable operations over multiple political generations. (Seek technical design alternatives having equivalent physical and organic effects without HRO or institutional constancy imperatives.)

Q: Why do we need to?

A: Alternatively, there are institutional activities that reduce the public's

1. risk-averse demand for very reliable operations of intrinsically hazardous systems,
2. worry about the longer term consequences of operational errors, and
3. sense of vulnerability that fosters a demand for trustworthy public institutions.

45. Some of these are highlighted in the chapters by Diane Vaughan and Philip Scranton.

it?" historical insight surely can be brought to bear. NASA is a particularly visible case, certainly not the only instance in which a public agency seems unable to alter its internal dynamics so that it avoids repeating what outsiders perceive (invariably after a serious mishap) to be dysfunctional organizational patterns. Observers of the Department of Energy's Radioactive Waste Programs are also likely to regard these efforts as deeply flawed. In these and other cases, such evaluations arise during nearly each generation of new management. For NASA, it is observed that dysfunctions have afflicted each of the last seven Administrators with repeated problems in the evolution of NASA's institutional culture. The conference papers contributed by Scranton and Vaughan give witness to many of these debilitating dynamics. Some of this is internally self-inflicted, to be sure. But for my part, I suspect more important sources lurk in NASA's relations with Congress and the Agency's extensive contractual community. In the early pages of the *Columbia* report, these sources of dysfunction were noted. They then escaped detailed examination thereafter. In the future, these should be the objects of as much analysis as NASA's internal dynamics. The historical community seems particularly positioned to furnish keen insight into what—in repeated instances—seems likely to be the result of a much deeper structural relationship than merely a series of very able people somehow succumbing to individual weakness and local bureaucratic perversity.

Second, we need to deepen our understanding of the technical sources that drive systems operators toward "having to" attain very high reliability. Technologies vary in the degree they require closely harmonized operator behavior. They also vary in their intrinsic hazardousness. Both of these characteristics can be shaped by the engineering design teams who provide the technical heart of operating systems. What is it about technical communities that prompts their members to propose technologies that require extraordinary behavior as a *condition* of delivering the hoped-for benefits? Is this intrinsic to some technical domains and not others? This suggests studies that calibrate the degree to which present technical and operational directions in the development of, at least, environmentally sensitive operations, materials management, and transportation and biological technologies a) require highly reliable operating organizations, b) imply long-term operating trajectories and potentially negative effects, and hence c) produce a requirement for high levels of public trust and confidence. In-depth sociological and historical studies could, one imagines, shed light on these matters.

A better understanding of these relationships can be crucial in democratic societies. It can be argued that the more the requirements for HRO, institutional constancy, and public trust and confidence are present, the more demanding the institutional challenges will be in sustaining public legitimacy. A closely related emphasis follows: what changed within technical design communities would be necessary for them aggressively to seek technical design alternatives that provide equivalent physical and organic effects varying the degree to which they produce demands for high-reliability operations over many work generations.

But wait, wait! Is there an alternative to the two research and development vectors just noted? They are very demanding R&D domains. Actually realizing the organizational imperatives that lurk within such designs is even more difficult to assure within private or public enterprises in the U.S. and abroad. Indeed, even entertaining the desirability of such changes is disputed by institutional leaders and provokes strong managerial reluctance to consider them seriously. So why are we trying? "Why do we need to?"

The need to try (or act as if we were trying) stems, importantly, from the public's expressed worry about their own exposure to what they perceive to be "risky systems." They worry and appear to have a very low tolerance for risk-taking. It could be argued, we need to try because "they" demand it. However, an alternative program of research and activities could be launched.

What activities could be carried out which would *reduce* the public's risk-averse demand for very reliable operations of intrinsically hazardous systems, *reduce* the public's worry about the longer term consequences of operational errors, and *lessen* the public's sense of vulnerability that nourishes a deep longing for trustworthy public institutions? As far as I know, there is very little systematic work exploring the grounds upon which alert publics would come to understand the rationality of accepting the likelihood of increased exposure to malfunctions of hazardous technical systems in the interest of smoothing production flows or stabilizing revenue streams for major investors. Nor do I know of any efforts to understand the basis for convincing the public explicitly that it would be acceptable to engage in developments that promise attractive short-term benefits which would export severe costs across several future generations to their grandchildren's children. Worries about the potential for immediate exposure to personal injury or environmentally derived insult, and a more diffuse concern that important dangers may await our children some years from now, continue to spawn irritating (probably irrational) objections to developing and deploying exciting new technical possibilities. Well, perhaps they could produce untoward surprises, but they are (probably) manageable. We can count on clever technical solutions.

"Why can't they trust us?" Indeed, this deserves analytical attention as well. Why do alert publics feel so vulnerable that they increasingly wish for trustworthy institutions? What developments could be devised that publics would relax their demand for trustworthiness and accept technical leaders and provide support for the technical future we designers see? In effect, "Why," as Henry Higgins and one technical designer put it, "why can't they be more like us?"