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May 1994

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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Abstract

A pilot study was performed to test the mental models methodology regarding knowledge and perceptions of U.S. Department of Energy contractor radiation workers about ionizing radiation and hazardous chemicals. The mental models methodology establishes a target population's beliefs about risks and compares them with current scientific knowledge. The ultimate intent is to develop risk communication guidelines that address information gaps or misperceptions that could affect decisions and behavior.

In this study, 15 radiation workers from the Hanford Site in Washington State were interviewed about radiation exposure processes and effects. Their beliefs were mapped onto a science model of the same topics to see where differences occurred.

In general, workers' mental models covered many of the high-level parts of the science model but did not have the same level of detail. The following concepts appeared to be well understood by most interviewees: types, form, and properties of workplace radiation; administrative and physical controls to reduce radiation exposure risk; and the relationship of dose and effects.

However, several concepts were rarely mentioned by most interviewees, indicating potential gaps in worker understanding. Most workers did not discuss the wide range of measures for neutralizing or decontaminating individuals following internal contamination. Few noted specific ways of measuring dose or factors that affect dose. Few mentioned the range of possible effects, including genetic effects, birth defects, or high dose effects. Variables that influence potential effects were rarely discussed. Workers rarely mentioned how basic radiation principles influenced the source, type, or mitigation of radiation risk in the workplace.

Workers did not judge their risks to be greater than their co-workers for either radiation exposure or harm from that exposure. Workers believed they had the highest probability of receiving external exposure, with a lower probablity for skin contamination and lowest for internal irradiation. However, workers considered internal irradiation more of a concern than external exposure or skin contamination, because of the inescapability and perception of greater potential harm from an internal source.

About half the workers said that if they contracted cancer or other serious diseases in the future, the diseases could not be directly attributed to their radiation exposure on the job, though three attributed a 50% or 100% chance of such a connection.

Outside the science model, workers' values and concerns were assessed. Most interviewees said they respect, but don't fear, radiation, and accepted the radiation-related risks as part of their jobs. On the job, they rely on the support of other knowledgeable workers, especially health physics technicians. Colleagues' complacency or unwarranted fear was seen as increasing other workers' exposure risks. Some workers saw administrative dose limits as overly restrictive. Some interviewees felt managers and others in positions of authority lacked the field experience to understand workers' concerns about specific jobs and procedures.

Workers were also interviewed about their knowledge and perceptions of hazardous chemicals in the workplace. All workers commented explicitly on risk processes and levels of risk with chemicals. A few workers stated that chemicals were more dangerous in the workplace than radiation, yet received less training emphasis or concern.

All workers viewed training as useful for doing their jobs properly and safely. The authors provide training recommendations in content and form. Content recommendations address potential information gaps identified when comparing the worker responses with the science model. Areas to investigate could include training frequency, specificity, and instructional methods.

Recommendations to extend this work include validating the study results with a broad-based survey, refining the science model to focus on factors that influence specific workplace decisions and behaviors, modifying existing educational or training materials to reflect the study findings, and evaluating subsequent worker behavior to assess the effectiveness of the modified training.

Summary

Effective risk communication with workers who encounter hazardous materials is critical because workers' knowledge and perceptions are likely to affect their behavior and thus their risk in the presence of workplace contaminants. Workplace risk communication requires understanding workers' existing beliefs -- in the light of which they interpret or perhaps misinterpret information.

The "mental models" approach is one method that has been proven effective in risk communication and training (Maharik and Fischhoff 1992; Morgan et al. 1992). This approach has six basic steps: 1) establish a model of the current scientific understanding about a risk, 2) establish a target population's beliefs about a risk (their mental models), 3) compare the two sets of models to see where they match and where gaps or misperceptions exist, 4) validate the results of the comparison through a broad-based, structured survey of the larger target population, 5) develop communication guidelines based on the results of steps 3 and 4, and 6) test the impact of the revised communications. In this pilot study, we conducted steps 1 through 3 and derived preliminary conclusions and training recommendations.

We extended the mental models methodology to examine the knowledge and perceptions of U.S. Department of Energy contractor radiation workers about exposure processes and effects of ionizing radiation, as compared with a science model of the same topics. As a secondary emphasis, worker perceptions regarding workplace chemicals were also investigated. Fifteen radiation workers from Westinghouse Hanford Company and the Pacific Northwest Laboratory were interviewed for this study. All worked at the U.S. Department of Energy's Hanford Site in Washington state. To facilitate the comparison between the worker responses and the science model, we chose employees who had been qualified radiation workers for 5 years or less and who did not have a 4-yr college degree.

Conclusions

Comparison of Worker and Science Models

When considered collectively, workers' mental models covered many of the high-level components of the science model, but did not contain the same level of detail. Nor did the workers' mental models reveal links between the characteristics of radiation and workplace practices. For example, workers discussed many administrative controls and some physical controls for managing radiation risk. But they did not cover the wide range of measures for neutralizing or decontaminating individuals following external or internal contamination. Similarly, while most workers discussed the relation of dose and effects, few noted specific ways of measuring dose (including variables such as distribution of dose over time or body area) or factors that affect dose (such as type of isotope and worker weight, gender, and age). When discussing possible effects of radiation exposure, many workers mentioned cancer and a variety of somatic effects. However, few mentioned the range of somatic, teratogenic, and genetic effects.

Workers were knowledgeable about the fundamentals of radiation -- its sources, forms, and properties. However, there was less discussion of how these principles influenced the source, type, or

mitigation of radiation risk in the workplace. For example, workers described many of the sources and behaviors of different radiation forms, but not as a basis for implementing one type of control or another. Similarly, workers mentioned the major exposure pathways, but did not describe irradiation processes (by which radiation travels through the body) or variables. Finally, while most workers mentioned cancer as a possible effect, other effects and effect-moderating variables (e.g., duration of exposure) were not typically discussed.

The fact that workers typically spoke in more general terms about radiation during the 1-hr interview is expected and has been shown in previous mental models studies. However, the potential gaps in worker understanding indicated by the results may be more significant. For example, workers may not have discussed the relationship between the characteristics of radiation and specific workplace practices because they are unaware of these links. If so, they may be ill-equipped in off-normal situations to make job decisions that minimize their risk and are consistent with intended procedures.

Likewise, workers may not have talked about irradiation processes because they don't understand them well. This "gap" could contribute to perceptions regarding internal exposure, as described in the following two sections. Workers may not have described specific actions for decontaminating or neutralizing radiation effects because they are not equipped to take these actions if necessary. They may not have discussed effect-moderating variables, such as age and gender, because they may not realize how these can affect their risk. All of these suppositions should be followed up in a broad-based survey.

Estimated Probabilities of Exposure and Harm

Workers did not judge their risks to be greater than those of their colleagues for either radiation exposure or for harm from that exposure. Half the subjects rated their probabilities of exposure as higher than for someone picked at random from the Hanford community--which could very well be true, in view of the much larger number of nonradiation vs. radiation workers at Hanford. However, they did not believe they were more likely to be *harmed* by exposure than any randomly selected Hanford worker.

Of the various exposure pathways, workers believed they had the highest probability of receiving external exposure, with less chance of skin contamination and even less for internal irradiation. Subjects typically believed the probability of *harm* from internal irradiation was less than or equal to that from skin contamination or external irradiation.

About half the workers said that cancer and other serious diseases have too many causal factors to be attributed to their radiation exposure at Hanford. However, two workers believed the probability would be 50% and two believed it would be 100% that such a health effect, if developed, would have been caused by their jobs.

Values and Concerns

Many workers said they respect, but don't fear, radiation, and accepted the radiation-related risks as part of their jobs. This attitude may reflect knowledge, experience, degree of personal control over the risks, and/or confidence in administrative, personal, and engineering controls.

Despite their low relative probability estimates, workers generally viewed internal radiation exposure as more of a concern than external exposure or skin contamination. The most commonly stated reasons for this concern were the inescapability of an internal source and the greater potential harm from an internal exposure. If one assumes that workers are not comparing a true rem of internal and external exposure (which adjusts for differences in the biological effectiveness, or damage, of different types of radiation) but instead are comparing external contamination to internal contamination, their concern may be well-founded. Indeed, it is more difficult to remove internal contaminants, which may mean that retention time is greater, absorbed dose is greater, and the probability of harm increases.

Workers assess the knowledge and awareness levels of their co-workers. For example, they show a strong reliance on the support and advice of the health physics technicians. On the other hand, several workers expressed a concern about colleagues' attitudes--including complacency or unwarranted fear--that can affect other peoples' exposure risks. Longer-term workers were sometimes viewed as having a more casual attitude toward exposure, possibly because they had not experienced any noticeable health effects over several years of working around radiation. Another concern was administrative dose limits that were perceived as overly restrictive. Some workers also felt that their management was not present often enough in the field to understand their practical concerns with specific jobs and procedures.

Chemicals

Most of the interviewees encountered hazardous chemicals in the workplace. Specific chemicals mentioned were asbestos, ammonia, PCBs, mercury, carbon tetrachloride, nitric acid, lead, alcohol, ferrocyanide, cyanide, acids, and bases. A variety of potential exposure effects were stated, ranging from watering eyes to organ damage and coma. Many control methods were described, including administrative and physical. All workers appeared to have a differentiated model of risk for radiation and chemicals. Interestingly, three workers stated that chemicals were more dangerous in the workplace than radiation, and two felt that chemicals received less training emphasis or concern than radiation.

Training Recommendations

These interview results were based on a small, nonrepresentative sample of workers and need to be verified through additional interviews and a broader-based, structured questionnaire. However, the preliminary data from these interviews and from comparison with the science model suggest the following training recommendations:

- "Background" information about radiation (its sources, properties, characteristics, and so on) should be more directly related to its influence on types of exposure processes, controls, and effects. This would help ground the "theory" more closely in workplace practices and better equip workers to extrapolate from this knowledge to make decisions as well as provide feedback about safety practices. This is consistent with a total quality approach to safety training.

- More focus should be placed on ways to mitigate internal and skin contamination, factors that affect dose, the range of potential health effects from radiation dose, and personal variables that may increase or decrease these effects.

- Differences among terms such as exposure, irradiation, and contamination, and among internal, external, and skin contamination, should be given more focus.

- Radiation training should be investigated to see where worker suggestions can be addressed. Areas to investigate could include offering more frequent training for newer staff, targeting training to knowledge level and worker classification, offering more opportunities to challenge classes by taking a test, using smaller groups for a less-intimidating and more interactive setting, making sure instructors are up to date with actual work practices in the field, including "tips" that experienced workers have learned on the job, and using more innovative and interactive teaching techniques.

Acknowledgments

We gratefully acknowledge the coding assistance of Charles Merritt, Jean Paananen, and Barbara Wise, and Jana Gordon's screening and scheduling of volunteers. We also thank Ann Bostrum, Georgia Institute of Technology, and George Cvetkovich, Western Washington University, for their advice on and peer review of this work. Both professors provided many insights that helped us think through and crystalize the methodology for application to Hanford workers.

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We thank Brad Sewart and Matthew Barnett, Westinghouse Hanford Company, for serving as our "test" interviewees; their responses helped us refine the draft questionnaire and science model. And most of all, we thank the 15 Hanford workers who volunteered to be interviewed and their managers for endorsing their participation.

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1.0 Introduction

The Contaminant Risk Evaluation and Management Initiative of the Pacific Northwest Laboratory (PNL)[a] began in 1991 to develop and prove capabilities related to the assessment and management of environmental and health risks. In 1993, the initiative funded a pilot study to show that the mental models approach, which contrasts the ways that a specific population and experts view a specific risk, could be used to improve risk communication related to health risks. This report documents that pilot study.

1.1 Background

Research has shown that people respond to new information and training based on their existing beliefs. Research has also shown that the way nonexperts intuitively understand phenomena--their "mental models"--differ from the mental models of experts (e.g., Maharik and Fischhoff 1992; Morgan et al. 1992). Risk communication is one way to clarify those differences and help close that gap. When done correctly, risk communication supplies lay people with information they need to make independent, personal judgments about risks to health, safety, and the environment (Morgan et al. 1992).

Risk communication is often used to help lay people understand technical topics and help scientists understand the values lay people use to evaluate technology (National Research Council 1989). However, risk communication also applies to more specialized groups of people. For example, because radiation workers have received workplace hazard training and come in contact with potential hazardous elements in their jobs, their mental models are likely to be more sophisticated and detailed than those of lay people on the same topic. Effective risk communication with these workers--through training and other avenues--is critical because their knowledge and perceptions are likely to directly affect their behavior and thus their risk in the presence of workplace contaminants (Kivimäki and Kalimo 1993). In addition, when directed at the scientific community, risk communication can help establish research agendas that may provide better information to decision makers.

1.2 The Mental Models Approach

Research in communication and learning stresses the importance of organizing communications around people's mental models (e.g., Maharik and Fischhoff 1992; Morgan et al. 1992; Glaser 1982; Gentner and Stevens 1983). Communicators need to know the nature and extent of a recipient's knowledge and beliefs if they are to design messages that will not be dismissed, misinterpreted, or allowed to coexist with misconceptions (Atman et al., in press; Bostrom et al., in press). Consequently, designers of training materials need empirical research aimed at determining what people know, what they need or want to know, and how best to convey that information (Slovic et al. 1981).

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

The mental models approach addresses these three factors in the following ways. To discover what information the audience has, representatives of the target population are interviewed about the topic of interest. To determine what information the audience needs, an "expert" mental model (influence diagram) is developed that contains all concepts deemed important to correctly understand a topic and relate the knowledge to decisions. The interviewee responses are compiled and compared with the expert model to see where they differ. These differences are then validated through a structured survey with a larger sample of the population. Educational or training materials can then be designed for the target population to help close the gap between the two sets of knowledge and perceptions. This may involve emphasizing key facts, correcting misperceptions, or modifying teaching approaches to better address the needs of the target population as highlighted by the comparison to the decision model. Knowledge and behavior of the target population can then be evaluated to determine the effect of the modified training materials.

The traditional approach to eliciting information from target populations is through a standard questionnaire that tests for expert or textbook-type information. The weakness of this approach is that it is difficult to anticipate the respondents' knowledge gaps and misperceptions to be addressed by training. In contrast, the science model provides a basis for uncovering such inadequacies in worker knowledge. Worker interviews, based on the science model, then confirm areas in which additional or modified risk communication is needed.

1.3 Purpose and Objectives of Study

This pilot study was designed to test the mental models methodology regarding knowledge and perceptions of U.S. Department of Energy (DOE) contractor radiation workers about exposure processes and effects of ionizing radiation, as compared with an expert model of the same topics. As a secondary emphasis, worker perceptions regarding workplace chemicals were also investigated. The goal of the research was twofold: 1) to assess the practicality of applying the mental models approach outside a university setting, and 2) to make preliminary recommendations for improved worker training that would provide information that is missing, correct beliefs that are wrong, and put into perspective what may have become exaggerated or ignored. For this pilot study, we stopped short of designing training materials or evaluating the effect of modified training on worker behavior.

To achieve this goal, we established the following objectives:

- apply the mental models risk communication methodology to radiation worker training
- identify potential differences in mental models between workers and health physics experts
- examine a basis for a hypothesized difference in workers' perceptions of internal vs. external radiation exposure
- examine a hypothesis that workers feel they are less vulnerable than others to radiation exposure and resulting effects
- examine workers' attitudes and concerns about radiation

- gather preliminary information on workers' mental models of hazardous chemicals
- obtain worker evaluations regarding existing radiation training.

Most of these objectives are obvious; the following section describes the basis for four of these objectives in more detail.

1.4 Worker Issues Explored

Attitudes toward internal vs. external exposure. It is widely recognized that workers fear a given radiation dose more from intakes of radioactive material (internal exposures) than from being present in a radiation field (external exposures). The DOE *Radiological Control Manual* acknowledges this perception and requires special actions to be taken regarding internal exposure risks (DOE 1992). We wanted to find out whether this perception is true, and if so, what its basis is, because this "internal dose phobia" could result in behaviors that actually put workers at greater risk for external exposures.

Vulnerability. We also wondered whether workers feel particularly vulnerable to radiation exposure and consequent effects. Other research has shown that people feel less at risk than they assume others are from the same hazards (Weinstein 1983, 1984). For example, most adults judge themselves to be safer and more skillful than the average driver (Svenson 1981). We wanted to find out whether this invulnerability phenomenon extended to radiation workers. Do they feel more or less at risk of exposure and its harmful effects than they imagine other employees to be, and what is the basis for those assumptions? Workers' perceptions of their risk probabilities may influence their behavior in the workplace.

Worker concerns. We also wondered whether workers had any concerns about radiation and what might alleviate those concerns. Radiation concerns and fears held by lay people have been well documented (e.g., Slovic et al. 1981). However, because of training and experience with radiation, we expected workers' concerns to be different, or at least of a different magnitude than those of the general public. A related issue is whether workers feel more at risk of contracting cancer or other serious diseases as a result of their workplace radiation exposure. The findings from these questions might be used to correct or improve situations that create concern.

Hazardous chemicals. Finally, we wanted to gather some preliminary information on worker knowledge and perceptions of risks from hazardous chemicals in the workplace. We are aware of little empirical research on worker knowledge and perceptions of chemicals, even though the exposure risks are potentially significant. Findings could be used as a basis for more detailed study of risk perceptions of hazardous chemicals.

1.5 Investigation Team

The multidisciplinary investigation team was selected to include the key areas of expertise required by this work. Dr. Marilyn J. Quadrel, a decision scientist, was the principal investigator. Before joining the Laboratory, she participated in mental models studies for several years at Carnegie-Mellon University, which pioneered the mental models approach to risk communication. Dr. Quadrel

advised the PNL team in adapting the approach for Hanford workers, compiled the coding results, and designed and analyzed the results on estimated probabilities of radiation exposure and harm.
Dr. Daniel J. Strom, a health physicist, has participated in and written about radiation communication and training issues. Dr. Strom developed the "expert" science model of radiation exposure and processes, designed the questions on internal and external dose, advised on many iterations of the code book, and assessed the technical accuracy of respondents' answers.

Andrea McMakin and Regina Lundgren are technical communication specialists who specialize in risk communication. They prepared the informed consent form, supervised the participant selection process and interview transcription, interviewed the participants, summarized anecdotal and non-coded excerpts, and compiled the report from team members' input. Maria Mosely, then a NORCUS (Northwest College and University Association for Science) Master's Degree candidate from Carnegie-Mellon University on loan to the Laboratory in the summer of 1993, specializes in decision analysis and information systems. She designed the phone script used to select interviewees and supervised its use, helped develop the initial code book, and did initial coding. (Ms. Mosely is now a Battelle staff member.)

Kathy Blanchard, Jean Paananen, Charles Merritt, and Barbara Wise, with combined expertise in communication, social science, and public involvement, coded the interviews. Kathy Blanchard performed the coding reliability analysis. The entire team analyzed the coding results and developed conclusions and recommendations.

1.6 Report Format

Section 2.0 describes the study methodology, Section 3.0 describes the science model, and Section 4.0 discusses the coding scheme. Section 5.0 presents results of coding and other aspects of the interviews, and Section 6.0 presents conclusions and recommendations. Section 7.0 lists suggested follow-on studies. Section 8.0 contains references; Section 9.0, a bibliography; and Section 10.0; a glossary. Appendices A through D contain, respectively, the informed consent form, the phone script, the interview questionnaire, and the code book.

2.0 Methodology

The mental models methodology is designed to elicit knowledge and perceptions through interviews. We used a systematic, data-driven methodology to gather and compare information and test our hypotheses. This section describes the interview participants, the solicitation process, and the interview and transcription process.

2.1 Participant Characteristics

Workers at the DOE's Hanford Site were interviewed for this research. The Hanford Site, a 560-square-mile reservation near the city of Richland, Washington, was created in the 1940s to produce nuclear materials for national defense and to manage the resulting wastes. Now the Site is dedicated to waste management, environmental restoration, technology development, and associated research and development.

We chose Hanford workers because the DOE Richland Operations Office and its contractors are accountable for training workers and making sure workers' knowledge, behavior, and attitudes are conducive to a safe and efficient work environment, especially in the presence of workplace hazards such as radiation and chemicals.

Tables 2.1 and 2.2 describe the study population. We wanted workers whose mental models could be differentiated from the science model of radiation. We also needed a study population with similar demographics (specifically, education and work experience) to facilitate comparison and aggregation of responses. Therefore, we chose employees who had been qualified radiation workers for 5 years or less and who did not have a 4-yr college degree[a]. However, some interviewees had taken up to 4 years of college courses. Four people had Associate of Arts (2-yr) degrees in general studies, and one had an Associate of Arts degree in a technical area. (One person had both.) It is unknown whether the remaining 11 interviewees had a degree, and if so, in which area. We tried to get workers who did a variety of jobs that involved contact with radiation.

For this pilot study, 15 workers were interviewed. However, the information seemed relatively representative because after about the tenth interview, responses began to show frequent repetition. This phenomenon was reinforced in a 1992 mental models study on radon (Morgan et al. 1992), in which the authors found that "the number of different concepts elicited ... approaches its asymptotic limit after about a dozen interviews."[b]

(a) One worker was selected on the basis of years worked at Hanford, but with additional experience prior to Hanford, totaled 7.5 years as a qualified radiation worker.

(b) This result may be in part caused by coders' narrow interpretation of comments as they become more familiar with the coding scheme.

Table 2.1. Job Characteristics of Interviewees

Job Title/Description	Time as Qualified Radiation Worker	Training Taken
Filter Tester -- tests filters in equipment, buildings	4 years	Rad worker 1&2, masks, 40-hr hazardous waste training, hazardous waste generator
Communication Specialist -- installs and repairs telecommunication equipment	8 months	Rad worker, special masks, supplied air
Hot Cell Technician -- does remote material handling, decontamination work	2 years, but only around radiation 8 months	Rad worker, mask training
Senior Technician 2 -- procurement technician -- supports operation/hot cell restoration	3 years	Rad worker, hazardous waste, hazardous waste supervisor
Senior Health Physics Technician -- monitors rad levels and dose rates	4 years	Rad worker 1 & 2, recertification training
Hot Cell Technician -- cleans out hot cells	1 year	Rad worker 2, criticality training, RLWs
Lab Technician -- simulates tank waste	3 weeks	Rad worker
Instrument Specialist -- services computers, equipment in radiation labs	2 months	Rad worker 1, General Employee Radiation Training
Senior Technician 1 -- prepares radioactive samples for inorganic analyses	2 ¾ years	Rad worker 2, Columbia Basin College-rad training course
Decontamination and Decommissioning (D&D) Worker -- cleans contaminated areas	3.5 years	Rad worker, hazardous materials, mask, confined spaces
Assistant Wetroom Operator -- decontaminates protective equipment and clothing	3 years	Rad worker
Laundry Worker -- decontaminates protective equipment and clothing	2 months	Rad worker 2, hazardous materials
D&D Worker -- cleans contaminated areas	1 month	Rad worker 2, waste generation
Electrician -- supports D&D with wiring, maintaining electrical systems in old reactors	7.5 years	Rad worker, fissile materials, masks, hazardous materials
Heavy-Duty Truck Driver (Teamster) -- supports D&D by transporting equipment, other labor	1 month	Hanford General Employee Training, Rad worker 2

Table 2.2. Gender and Age of Interviewees

	Number of People in Age Groups				
Gender	20s	30s	40s	50s	60s
Male	4	4	2	0	0
Female	1	3	0	0	1

2.2 Soliciting Volunteers

Before we began soliciting volunteers, we received approval to interview Hanford employees from the Hanford Dose Advisory Committee (chaired by DOE's Diane Clark) and the appropriate managers at Westinghouse Hanford Company, Kaiser Engineers Hanford, and the Pacific Northwest Laboratory, including the Laboratory's Human Subjects Committee. A requirement of that committee was to create an informed consent form for interviewees that explained their rights as study participants, including measures to guarantee privacy (Appendix A).

We solicited volunteers through several sources: a list of employees scheduled to receive whole-body counts (a measurement of internal radioactive materials), names given to us by managers of radiation workers, advertisements placed in company newsletters, and referrals from other interviewees.

We developed a telephone script (Appendix B) designed to determine whether potential participants met the criteria described in Section 2.1. Questions in the phone script were arranged in an order that was designed to put the potential volunteers at ease and to determine early in the conversation whether they met the above-mentioned criteria.

The potential participants were then asked questions about themselves and their work, which enabled us to characterize our study population. The supervisor's name and work phone number were collected. If the candidate met the criteria and agreed to participate, the manager was contacted to gain permission for the worker to miss an hour from work for the interview. A work package number (cost account number) was provided to volunteers to pay for their time for the interview.

Finding interviewees was more problematic and time consuming than any of us would have guessed. Our scheduler called an average of 20 people to get one qualified and willing volunteer. For example, many people on our lists had received radiation worker training as a precaution only and did not actually work around it in their jobs. Also, it was difficult to find people who had been at Hanford for 5 years or less and who did not have a 4-yr college degree. (We established this criteria to ensure responses could be differentiated from the science model and could be easily aggregated.) Also, many workers did not return our schedulers' calls because they were "in the field" all day where telephone contact was inconvenient. It took 3 months to get 15 qualified volunteers, though we continued to interview, transcribe, and revise the science model during this time.

We originally targeted DOE's primary contractors--Westinghouse Hanford Company, Kaiser Engineers Hanford Company, and the Pacific Northwest Laboratory--as having workers most likely to come in contact with radiation. In the end, our 15 subjects represented Westinghouse (9 people) and PNL (6 people), but not Kaiser.[a]

Because many of our radiation workers travel long distances to work and often work in the outer areas of the Hanford Site, efficient scheduling was essential. Initially, participants were scheduled for interviews immediately following their whole-body count in Richland. When we began using other sources of names, we asked interviewees to come to a building in Hanford's North Richland area. We offered to meet them as they came to or from work, so they wouldn't have to make a special trip for the interview.

2.3 Questionnaire, Interview Process, and Interview Transcription

The interview questionnaire (Appendix C) was designed to elicit knowledge, attitudes, and concerns about ionizing radiation, and, as a secondary emphasis, hazardous chemicals. The questionnaire was also designed to compare knowledge-based responses with the science model. (The science model is described in Section 3.0.) The questionnaire approach was patterned after other mental models research (e.g., Morgan et al. 1992), which started with open-ended questions followed by more specific ones. For example, the first question was, "Tell me everything you know about radiation." The intent of the open questions is to minimize the extent to which the questioner's perspective is imposed on the respondent. Then, to ensure that respondents had ample opportunities to address all aspects of the science model, we asked them to describe workplace radiation, exposure processes, mitigation actions, radiation effects, radiation exposure/harm probabilities, concerns, chemicals processes and exposure effects, and radiation training. The questionnaire approach used the "think-aloud" protocols described by Ericcson and Simon (1980).

We developed the questionnaire iteratively after much discussion and after two "test" interviews of Hanford radiation workers. We continued to modify the questionnaire slightly after the early interviews to better target information. For example, beginning with the second interview, we added a table where interviewees estimated probabilities of radiation exposure and harm via different exposure routes. This table facilitated these questions immensely. The questionnaire was not modified after the third interview.

At the interview, volunteers were first asked to read and sign the informed consent form described earlier, then were given a copy to keep. Interviewees were given the opportunity to ask any questions. Permission to audiotape the interview was requested. Two interviewers were usually present; one asked the questions and the other took notes of notable or interesting responses, to get more of a holistic sense of the responses. The interview process took about 1 hour, depending on how long the worker talked in response to questions.

(a) The ad we submitted to the Kaiser newsletter requesting volunteers was rejected as being "discriminatory" and "too sensitive" because it requested staff who did not have college degrees. Other Kaiser employees who were called from our whole body count list were unavailable or did not meet the criteria for inclusion in the study.

As interviews were completed, they were transcribed from the audio tape to a computerized file using standard word processing software. It took an average of 5 hours to transcribe an interview, depending on the length and the ease of understanding the interviewees' speech patterns. The tables of estimated probabilities that each interviewee filled out (described in Section 5.2.2) were typed into the transcripts. Workers' names did not appear in the transcripts or tables of estimated probabilities. Other measures taken to guarantee privacy of the interviewees are described in the informed consent form in Appendix A.

3.0 Science Model

In the traditional mental models process, responses elicited from interviewees are compared with an "expert model." Because we interviewed workers, many of whom have specialized technical knowledge and are presumably "experts" in their fields, we call our expert model a "science model."

The intent of the science model is not to portray the entire universe of processes and effects in a technically correct way so that workers can be educated to agree with the experts' perceptions. Indeed, technical information that is irrelevant to decision making can obscure important messages, making it difficult to remember what can be done about a risk and irritating communication recipients (Morgan et al. 1992).

In a true decision model, only the information needed to make a discrete decision is included. However, Hanford radiation workers make a wide range of highly variable and interdependent decisions, depending on the type of worker, the job, the workplace environment, and other factors. Therefore, for this pilot study, our science model is an influence diagram rather than the traditional decision model.

Our science model comprises a broad set of factors that influence radiation risk. Some portion of these factors influences decisions. The extent to which the factors in the model influence decisions depends on the kind of decision to be made. Because of the broad-based approach, our science model includes detail that might be omitted in a model that focuses only on specific decisions.

Figure 3.1 shows the basic science model developed by our team's health physicist. The model is in the format of an influence diagram showing the relationships among elements that represent a basic body of knowledge regarding ionizing radiation processes, controls, and dose effects. Information is grouped in "tiered" rectangles that contain more detailed elements in rounded boxes.

From bottom to top, the science model lists

- radiation sources, both workplace and nonworkplace
- administrative controls -- procedures to ensure that people and the environment are protected from radiation
- workplace conditions that influence worker exposures
- exposure processes that involve radioactive material as a toxic substance
- irradiation processes that involve both the radiation emitted by radioactive material in or on the body and the radiation emitted by sources outside the body such as nuclear reactors or containers of radioactive material
- radiation dose and related concepts such as dose rate, dose fractionation, microscopic dose distributions, and penetration ability

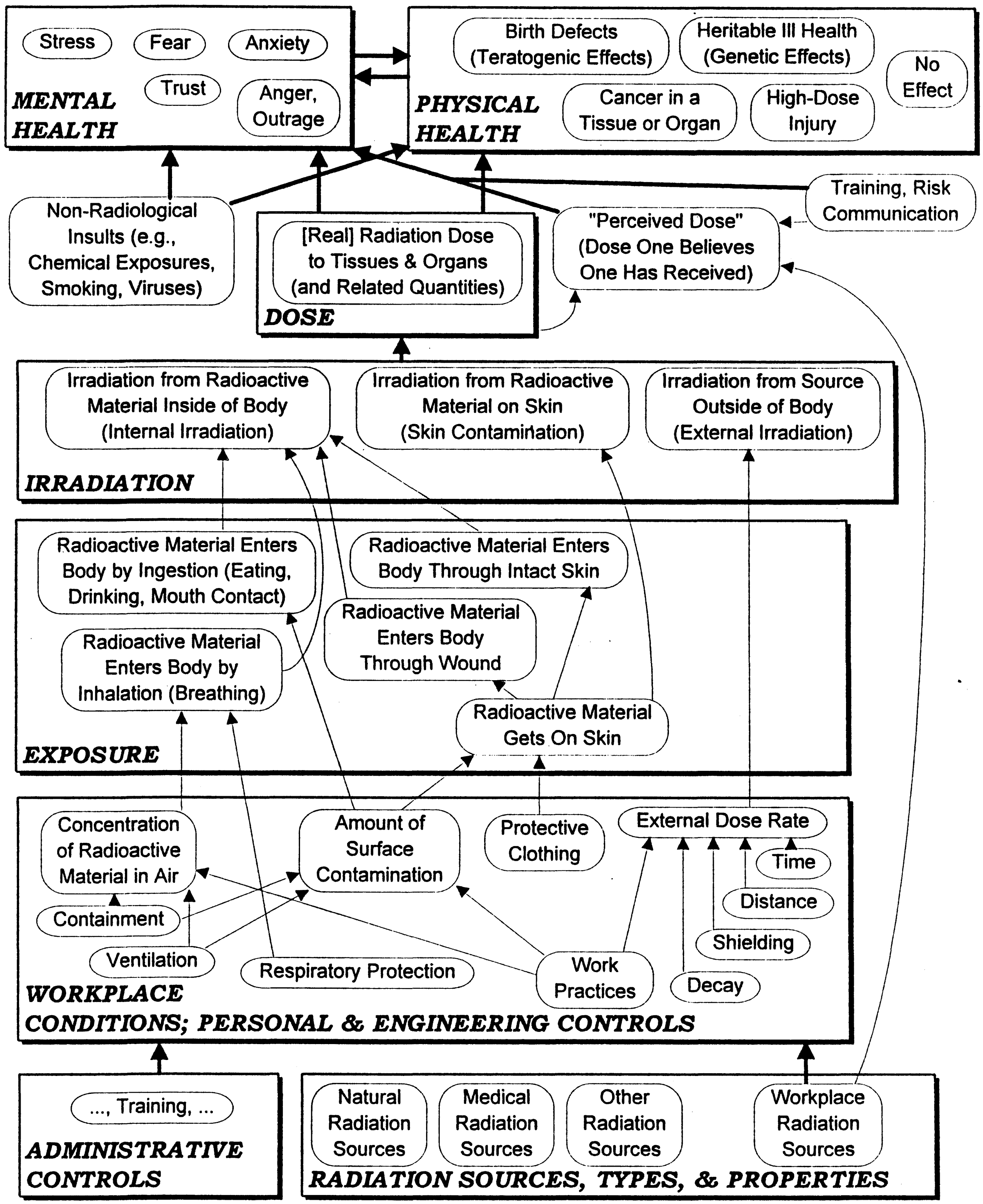


Figure 3.1. Basic Science Model for Radiation Exposure. Heavy arrows show influences on entire boxes; light arrows show influences on elements within boxes.

- physical health consequences known or suspected to be caused by irradiation, including no effect
- mental health consequences that may occur even in the absence of real radiation exposure, but that can be caused by the belief that one has been exposed
- behavioral decisions that a worker or his or her family may make based on the influences listed above.

Also included in the science model are nonradiological hazards, such as chemical exposures, smoking, and viruses, that can influence radiation exposure effects.

Training and risk communication influence the science model in two places. In workplace conditions, especially work practices, training helps minimize worker exposures by teaching proper behaviors. In beliefs about "perceived dose" and mental health, worker peace-of-mind can be enhanced by training and risk communication (Drottz-Sjöberg and Persson 1993). Several of the boxes in Figure 3.1 are expanded in greater detail in subsequent figures and described in the following sections.

The code book, Appendix D, is patterned after the science model and includes much of the detailed information for each set of concepts (e.g., Section 3.2 lists many related administrative controls).

3.1 Radiation Sources, Types, and Properties

Everyone is exposed to ionizing radiation from a variety of sources, including natural background, technologically enhanced natural background, medical, and other human-made radiation sources. In addition, some workers are exposed to radiation in the course of their work. These radiation sources are shown in Figure 3.2a. All potential radiation sources were included in the model to assess workers' mental models of all exposure routes and sources. Background radiation sources include radon and its short-lived decay products in air; natural terrestrial radioactive materials, both cosmogonic and primordial; solar and cosmic radiation; and enhanced exposure to the latter from flying in aircraft above some of the protective shielding of the earth's atmosphere.

Medical radiation sources include medical and dental x-rays, medical administrations of radioactive materials (i.e., nuclear medicine procedures), and radiation therapy for cancer and other diseases.

Other, non-workplace radiation sources include exposure to radiation from accidents happening elsewhere that release radioactive materials (e.g., Chernobyl); commercial and military radiation sources such as industrial radiography; the nuclear fuel cycle, including nuclear power plants, transportation, and waste disposal; global fallout from atmospheric nuclear weapons testing; technologically enhanced radiation exposures from mine and mill tailings, primarily from uranium mines; and consumer products such as uranium in dental porcelain, smoke detectors, gas lantern mantles, and television projectors.

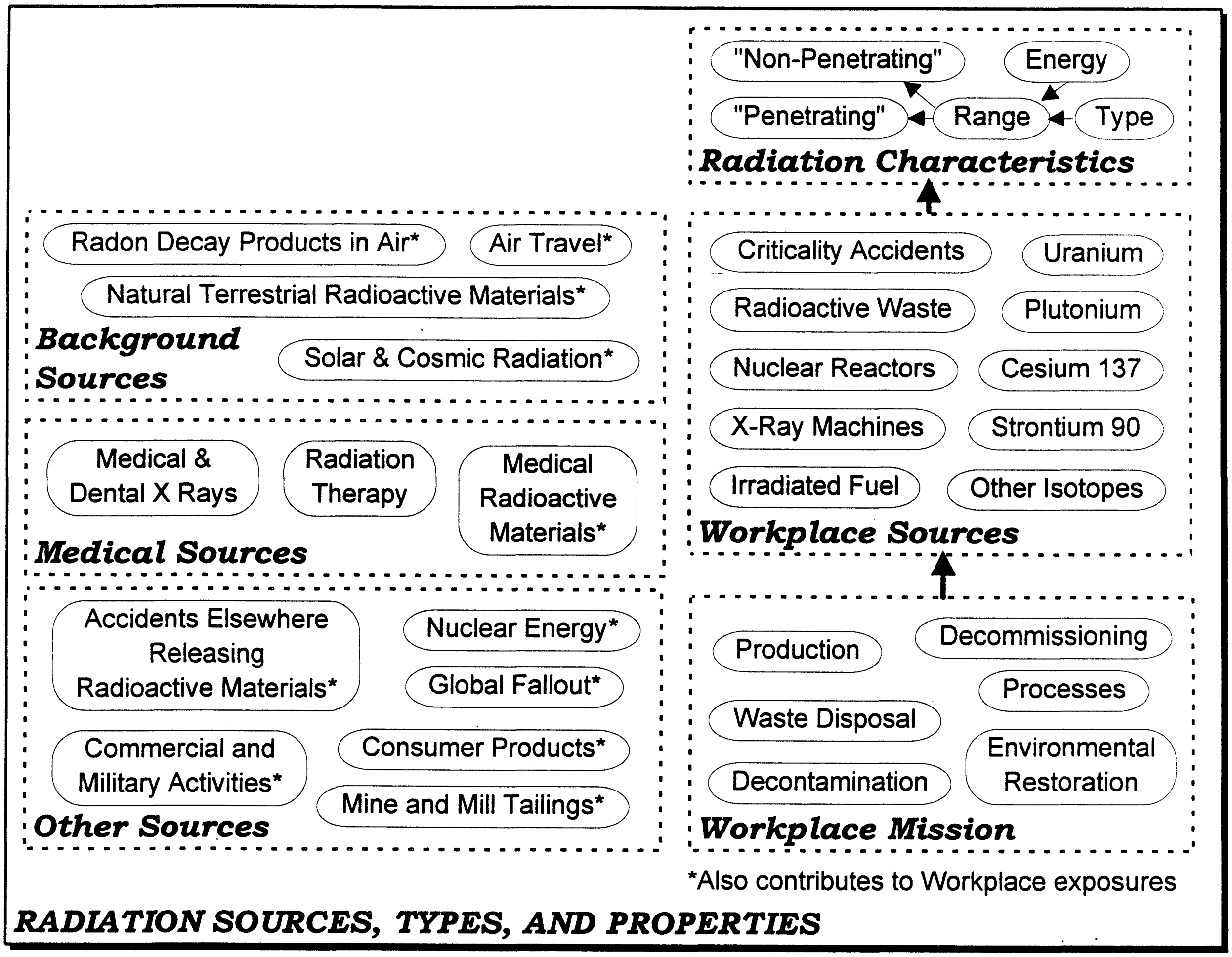


Figure 3.2a. Radiation Sources, Including Background, Medical, Workplace, and Other

Workplace radiation sources at Hanford include nuclear reactors; irradiated fuel; radioactive waste (including waste stored in underground tanks or buried); criticality accidents; specific radioactive materials such as plutonium, uranium, strontium-90, cesium-137, and others; and x-ray machines. Note that while at work, workers continue to receive exposures from background, medical radioactive materials, and "other" radiation sources. Also shown in the "Workplace Mission" box are institutional missions that influence the number, nature, and magnitude of the various workplace radiation sources.

3.2 Administrative Controls

There are many physical means to control radiation such as minimizing exposure time, maximizing distance between workers and a source, and using shielding, ventilation, or containment. Administrative controls are actions taken to ensure that physical means are used as needed. Administrative controls include legislation creating a competent authority, which, in the case of Hanford, includes the U.S. DOE, U.S. Environmental Protection Agency, and the Washington State Department of Ecology. These governing agencies have defined regulations and orders that establish dose limits and other requirements. Those requirements and licensing actions ensure the existence of a radiation protection program. Positive and negative incentives are provided through civil and criminal penalties (for federal and state laws and regulations), and through award fees and contracts (for DOE Orders). Eighteen elements of a typical radiation protection program at a DOE site are shown in Figure 3.2b. All of these elements influence workplace conditions and thus workplace radiation exposures.

3.3 Workplace Conditions; Personal and Engineering Controls

In Figure 3.1, the box labeled "Workplace Conditions; Personal and Engineering Controls" shows many of the physical conditions in the workplace that influence radiation exposures to workers. Work practices are a key element; it is possible to work in ways that increase or decrease exposure or potential exposure. External dose rates can be mitigated by maximizing distance between workers and the source, minimizing exposure time, maximizing shielding, and waiting for sources to decay before working with them (e.g., the cool-down period for irradiated fuel). Radioactive materials in air or on surfaces are controlled by work practices, containment, and ventilation. Respiratory protection can be used in the workplace to limit intakes of radioactive materials by inhalation. Protective clothing can be used to limit skin contamination.

Exposure and irradiation occur simultaneously for external radiation sources. Workplace conditions influence both exposure and irradiation for intakes of radioactive material and skin contamination, and are detailed in Sections 3.4 through 3.6.

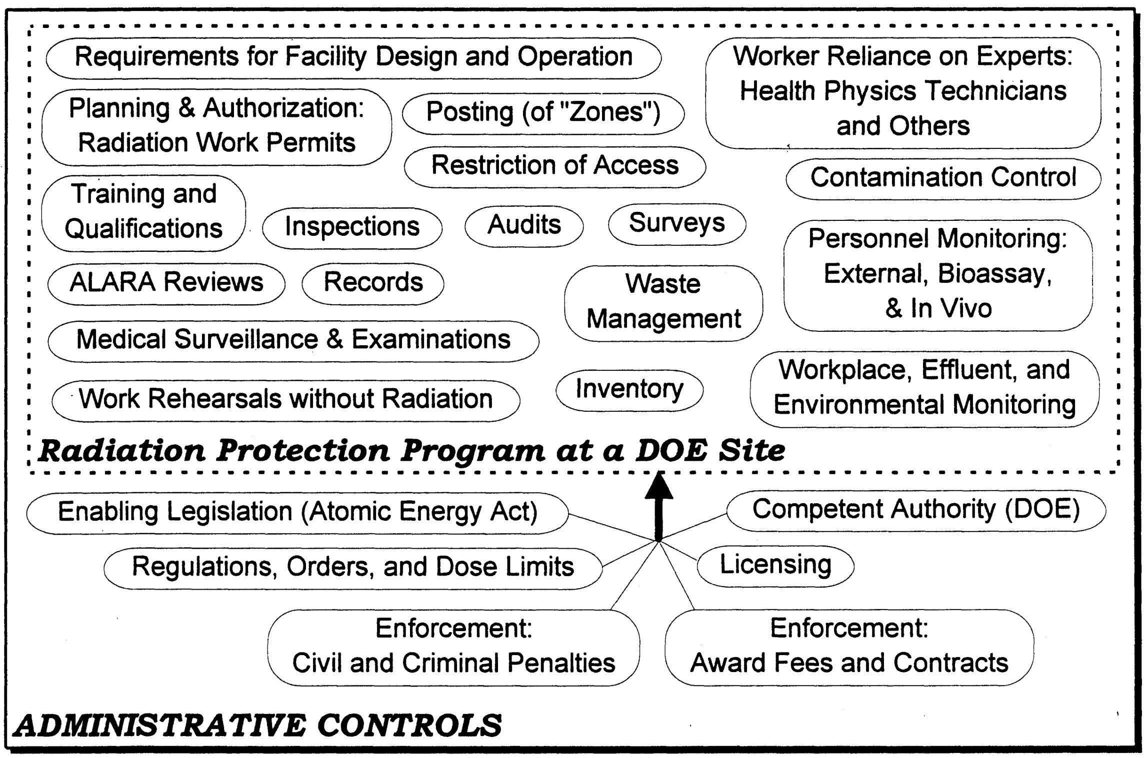


Figure 3.2b. Administrative Controls of Radiation Exposure in the Workplace. ALARA = As Low As Reasonably Achievable.

3.4 Inhalation

Both exposure and irradiation appear in Figure 3.2c. The various factors that influence intake of radioactive material by inhalation (amount inhaled), and the ultimate distribution to various body organs or tissues, retention, decay, and excretion from the body are shown. This figure shows those factors that influence how much radioactivity is in what organs or tissues for how long, factors that must be known to assess radiation dose to each organ and tissue.

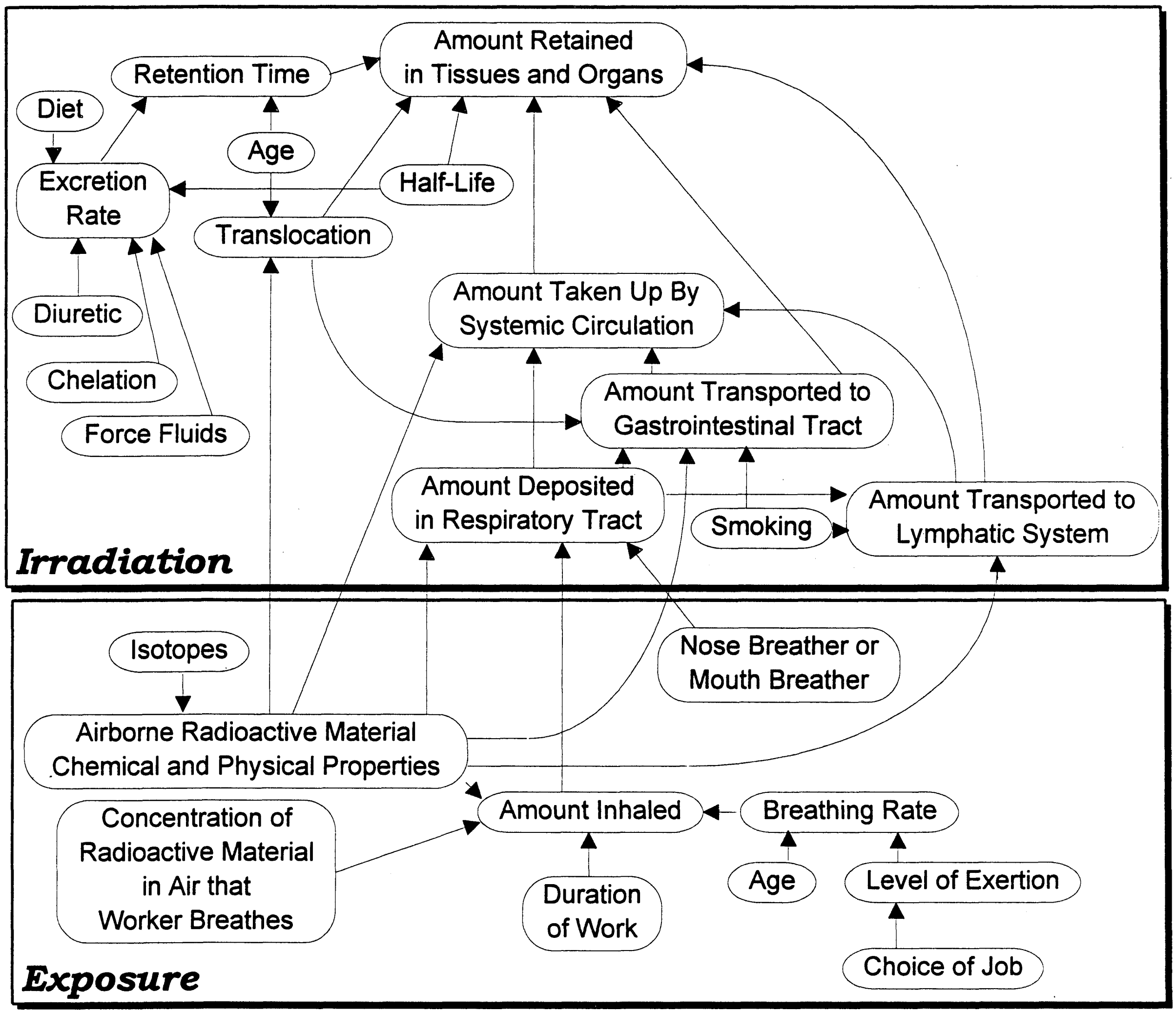


Figure 3.2c. Irradiation from Radioactive Material Inside the Body (internal irradiation) Following Intake by Inhalation. Bottom: influences on exposure. Top: influences on irradiation.

3.5 Ingestion, Absorption through Intact Skin, and Entry through a Wound

Both exposure and irradiation appear in Figure 3.2 d. The influences are much simpler than those for inhalation. The influences are those that ultimately affect the radiation dose.

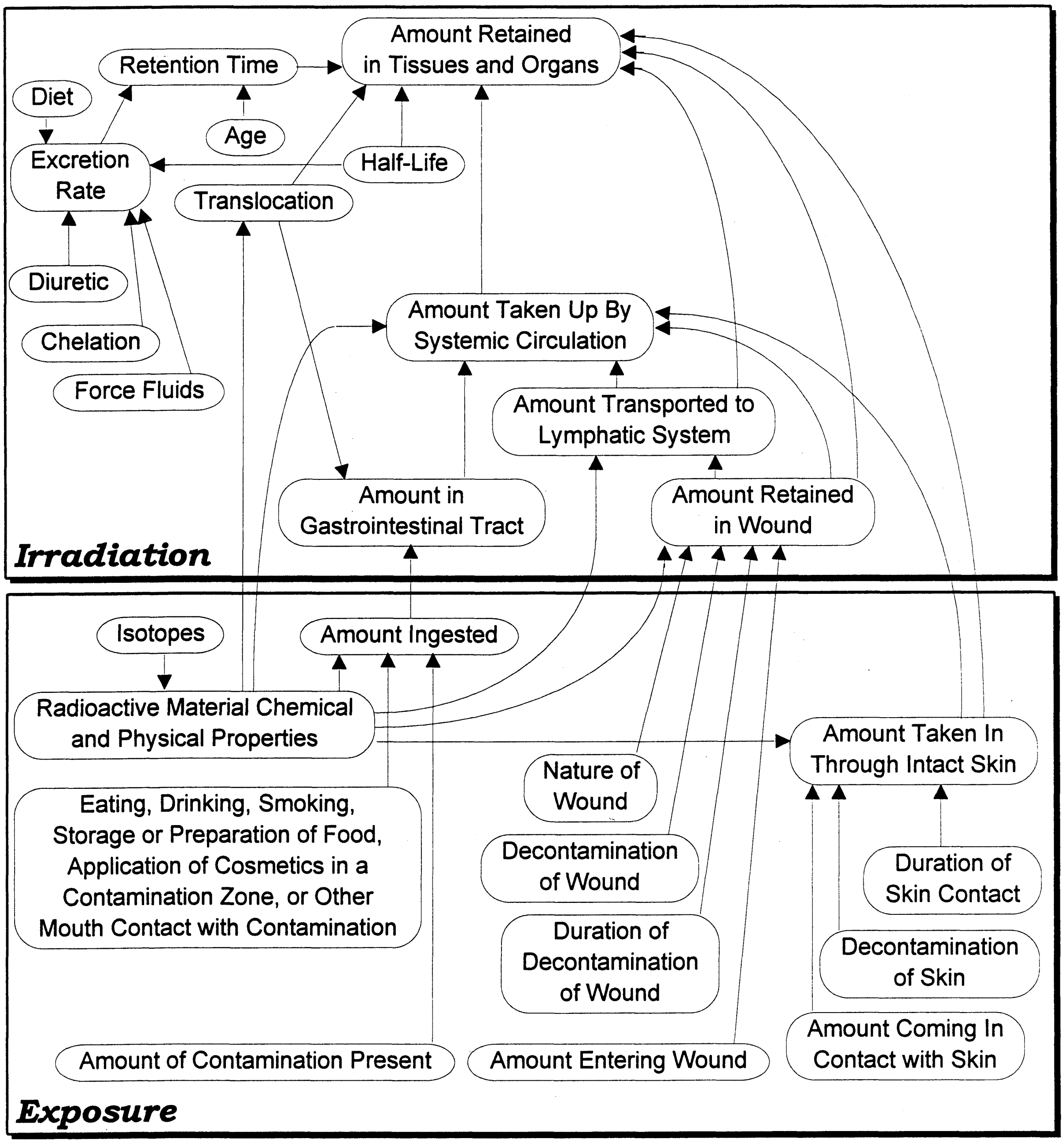


Figure 3.2d. Irradiation from Radioactive Material Inside the Body (internal irradiation) Following Intake by Ingestion, through a Wound, or through Intact Skin. Bottom: influences on exposure. Top: influences on irradiation.

3.6 Skin Contamination

For radioactive materials coming in contact with the skin, but not being absorbed, exposure and irradiation are two distinct steps as diagrammed in Figure 3.2e. The exposure process involves getting the material on the skin, while the irradiation process occurs as long as there is material in contact with the skin.

3.7 Dose to a Tissue or Organ and Related Quantities

The science model converges on radiation dose (in rads and rems, or in grays and sieverts) and related quantities that influence health outcomes, such as dose rate, the distribution of dose over time (fractionation), the types of radiation, the microscopic distribution of dose at the molecular level, the penetration properties of the various radiation types, and their energies. These are shown in Figure 3.2f. Five different dose-related factors are known to affect the probability or severity of biologic response to irradiation. In the figure, these factors converge to one primary influence (thick arrow). The level of detail represented in the figure (and the preceding 3.2-series figures) represent the multiple, potential exposure pathways and subsequent potential dose. As discussed at the beginning of Section 3.0, this model is not intended to be a traditional decision model.

3.8 Physical Health Effects

There are many influences on physical health besides dose and its related quantities. For cancer, the influences of genetic effects, teratogenic effects, and high dose effects are shown in Figures 3.2g, h, i, and j. In particular, cancer causation, or carcinogenesis, is known to be a multi-stage process that is influenced by age, sex, genetic predisposition, presence or absence of protective agents, co-carcinogens, initiators, promoters, and tumor progression agents.

In most cases, low doses of ionizing radiation produce no *health* effects whatsoever, even though microscopic changes and even damage may occur. Cancer and genetic effects are effects whose probability of occurrence is related to radiation dose and other quantities, but whose severity is not dose-related. The most probable outcome for an individual receiving a low dose of radiation is no effect.

3.9 Mental Health Consequences and Behavioral Decisions

In addition to causing biological changes, damage, or harm, ionizing radiation is associated with psychological, psychosomatic, and behavioral effects. Koscheyev and co-workers have documented behavior changes in Chernobyl workers from radiation-induced stress using the MMPI (standard psychological) test (Koscheyev et al. 1993). Collins has investigated effects on the mental health of persons at the Kyshtym, Chelyabinsk, and Chernobyl nuclear accidents (Collins 1992). Collins and de Carvalho have documented stress in people involved in the 1987 Goiânia, Brazil, cesium-137 accident (Collins and de Carvalho 1993).

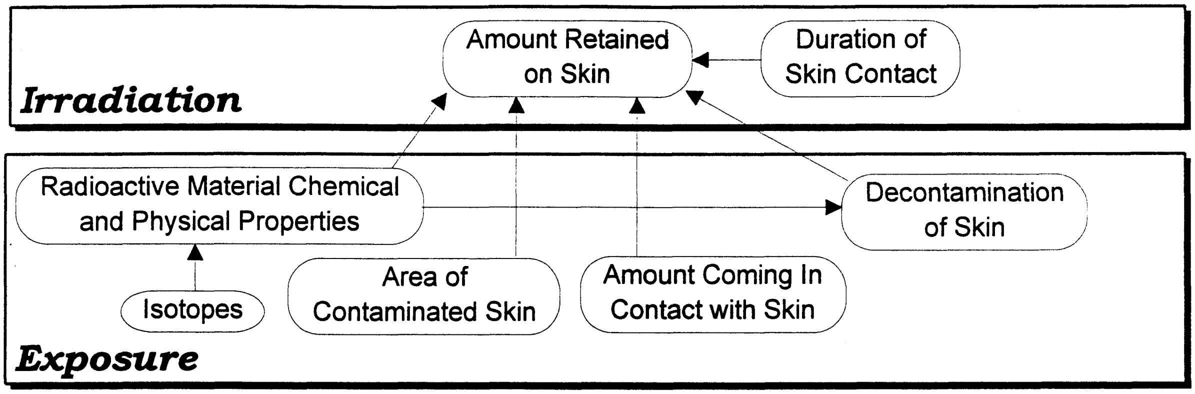


Figure 3.2e. Irradiation from Radioactive Material in Contact with the Skin

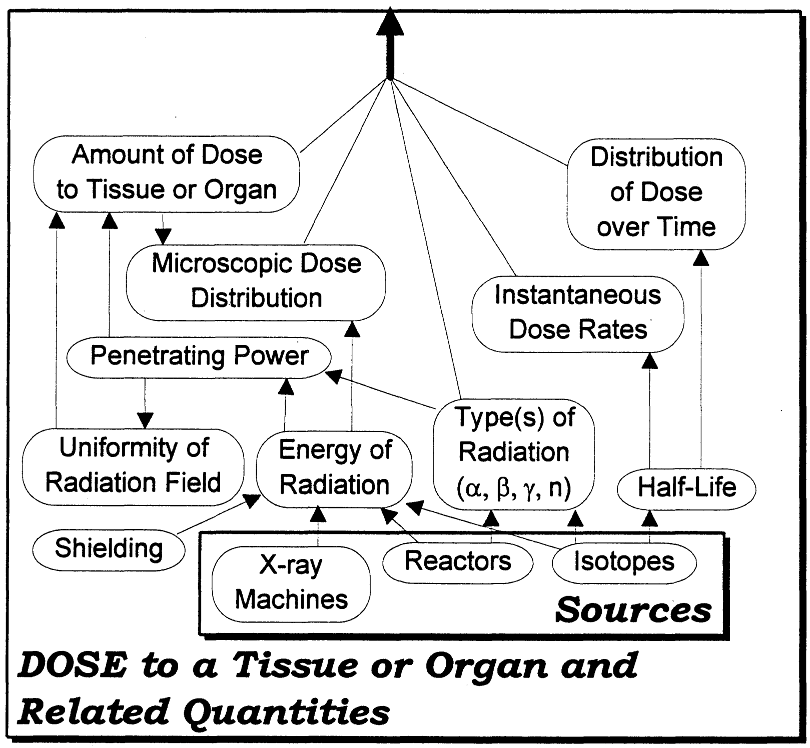


Figure 3.2f. Dose to a Tissue or Organ and Related Quantities

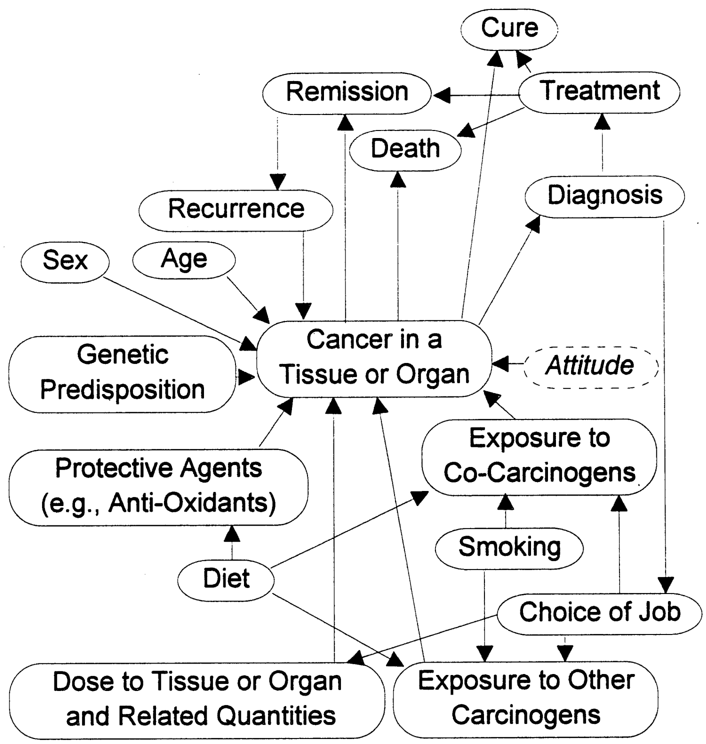


Figure 3.2g. Influences on Cancer in a Tissue or Organ

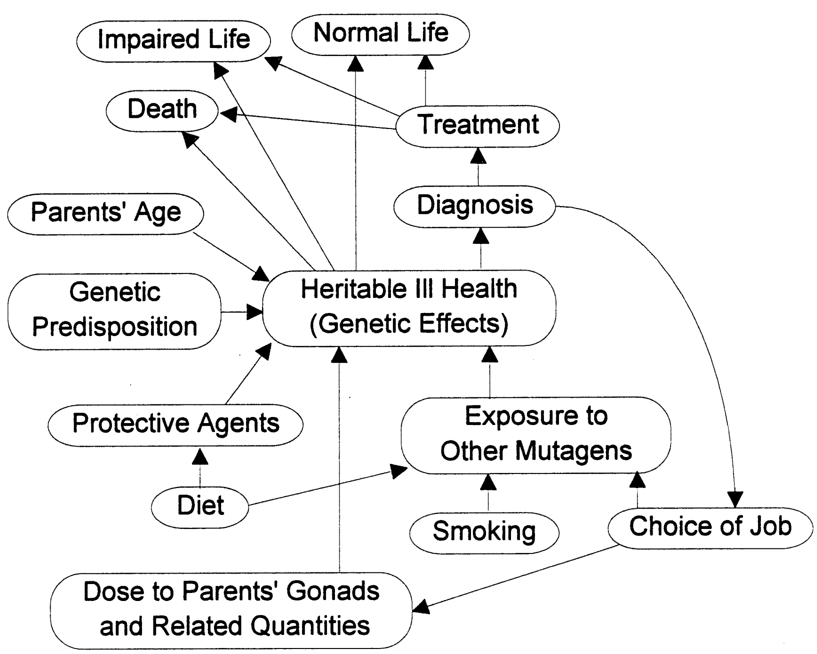


Figure 3.2h. Influences on Heritable Ill Health (genetic effects)

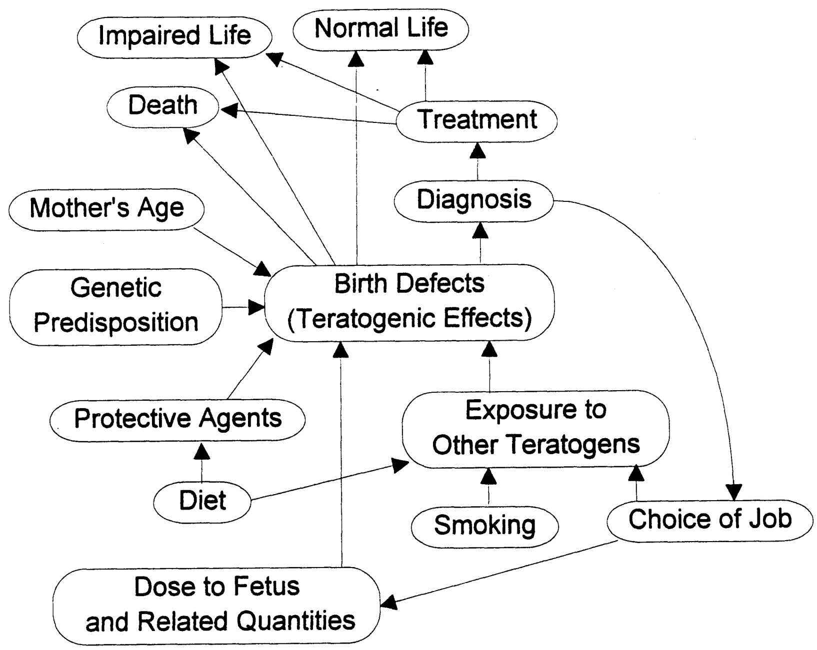
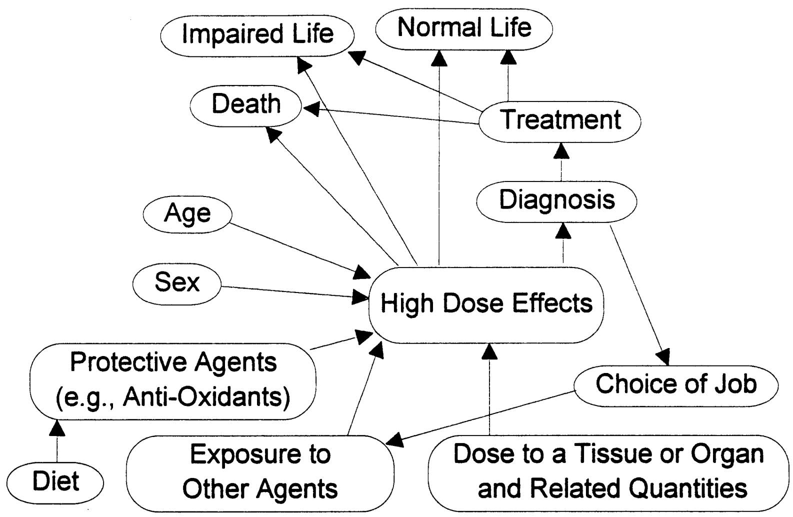


Figure 3.2i. Influences on Birth Defects (teratogenic effects)

There have been so many lawsuits involving radiation that it has been called a "litigen" (Gallo 1991). Psychological, psychosomatic, and behavioral effects are strongly associated with risk perception, which in turn is governed largely by access to information and heavily influenced by the media (Slovic et al. 1991).

For these reasons, the science model includes effects such as anger, anxiety, fear, stress, and trust. Furthermore, the science model includes "perceived dose," which caused mental health problems in the aftermath of the Three Mile Island nuclear accident (NAS 1990; Weart 1988; Collins et al. 1983; Collins 1991). Perceived dose can be based on imaginary and/or real dose. Imaginary dose is simply a belief that a radiation dose has been received, when no dose has been received. Because human beings have no senses that directly detect ionizing radiation at low doses, human inferences about radiation exposures must be made on the basis of other evidence.



High Dose, Deterministic or Nonstochastic Effects (Dose Threshold, Severity Depends on Dose and Related Quantities):

Skin Reddening (Erythema)
Radiation Burns
Hair Loss (Alopecia)
Diarrhea
Nausea
Vomiting
Fatigue
Immune Suppression
Radiation Dermatitis
Cataract
Localized Necrosis
Nonspecific Aging (?)
Hematopoietic Syndrome (Blood changes)
Cerebrovascular Syndrome (Fatal)
Gastrointestinal Syndrome (Fatal)
Death

Figure 3.2j. Influences on High Dose Effects

4.0 Coding Scheme

This section describes how the science model was "translated" into a code book, how the coding process occurred, and how the reliability of the coding process was determined.

4.1 Code Book

The science model was adapted into a code book (Appendix D) used to match the interviewees' responses to specific elements of the science model. The code book was developed by listing (and annotating, in some cases) all pertinent concepts from the science model in outline format.

In general, the big rectangles indicating grouped concepts in the science model (Figure 3.1) were listed as higher-level headings in the code book outline; individual elements inside the science model rectangles were listed in subheadings. For example, the science model rectangle called "Radiation Sources, Types, and Properties" became Category 2, "Properties/Sources of Radiation -- Specific to Model" in the code book. Rectangles called, "Workplace Conditions," "Exposure," "Irradiation," and "Dose" became Categories 3, 4, 5, and 6, respectively, in the code book. "Physical Health" and "Mental Health" in the science model were combined into Category 7, "Health Effects," in the code book. A new category, "Background," was added as Category 1 to include general concepts about radiation.

Category 8 in the code book is called "Not in Science Model." Items in this category are concepts that, while not technical facts that can be mapped onto the science model, nevertheless indicate codeable and potentially important beliefs and perceptions. These concepts included trust; metaphors for internal radioactive materials and external radiation; and attitudes and beliefs of radiation workers, managers, and decision makers. We anticipated hearing comments about many of these concepts during the interviews.

4.2 Coding Process

For this pilot study, 10 interviews were coded. To code an interview, the coder highlighted (marked) statements in the typed transcript that appeared to be reflected in the code book. Then, for each highlighted statement, the coder looked through the code book to match the statement to an item in the appropriate category. For example, if an interviewee said that people can be exposed to radiation internally, by breathing it or by absorbing it through the skin, the coder marked the page and line number of that statement in the code book after 4.1.1, "Internal," "4.1.1.1, "Inhalation," and 4.1.1.3, "Through intact skin."

The coders did not extrapolate meaning or identify implications of the interviewees' statements. An interviewee received "credit" for a concept only as the concept was directly stated. For example, if an interviewee mentioned only that radioactive contamination could be absorbed through skin, but not that such contamination was an internal pathway, the statement would be coded at the "Through intact skin" code, but not at the "Internal" code.

When an interviewee's statement indicated a concept in the code book, but the coder wasn't sure by the statement whether the interviewee really understood the exact concept, the coder marked a "G" for "general" after the coded item. For example, a worker may say, "There are different kinds of radiation, like alpha." This would be coded as a "G" for the code "Types of radiation," but the worker was not given credit for understanding gamma, beta, and neutron radiation types. If an interviewee said the same thing more than once, or paraphrased a previous response, the statement was coded only once.

To summarize the coding results, a team member who did not do the coding compiled the results from all the interviews into a single code book. In the compiled code book, each item mentioned by an interviewee was marked with the number of that interview. For example, after Item 3.3.1.1, "Established radiation protection program," numbers 6, 7, and 13 appeared, indicating that interviewees for those interviews mentioned that concept.

The coding process is somewhat subjective, because the coder must judge whether a response should be credited and then decide how to code the response. To enhance uniformity of results, two people coded each interview and reconciled their results to produce one code book. To reconcile, the individual coders had to reach agreement on any concepts they each coded differently. Typically, the differences could be attributed to individual coders coding at different levels of specificity. In addition, as an independent check, the person who compiled the results of all the code books frequently reviewed the coded transcripts to verify that the workers' statements agreed with the coders' interpretations.

During the coding process, it became apparent that some concepts in the code book needed to be revised, added, or deleted as redundant. Thus, the code book was refined to reflect recommendations of the coders and the team's health physicist. To maintain continuity of previous coding, the outline was not renumbered when concepts were deleted. Previously coded interviews were recoded to reflect the new codes. All interviews were ultimately coded against the same code book. Each interview took about 1 to 3 hours to code, depending on the length and complexity of the transcript.

4.3 Determination of Coding Reliability

As a measure of the coding reliability, one of the team members compared the two independent code sheets for each interview to identify areas of agreement and disagreement between two coders. The measure was based on the following:

$$\frac{\text{total number of common codes}}{\text{total number of coded concepts across two coders}}$$

Three of the interviews could not be compared because of differences in how the coders recorded their codes on their individual sheets; however, after the first coding session, all the coders followed the same procedure for recording. The reliability measure for each interview that could be compared is listed below:

Interview #3 - 36/118
Interview #6 - 13/131

Interview #7	-	6/24
Interview #11	-	12/54
Interview #13	-	21/82
Interview #9	-	46/124

Not surprisingly, reliability scores from these initial coding passes were low, from 9 to 37%, averaging 24%. No one single category captured the areas of disagreement more than another category; rather, the coding differences were spread fairly consistently across all categories. The low reliability scores were in large part caused by limited time and budget for coder training, and multiple code book revisions.

Coding was done at the lowest possible level of detail. Results reported here are several levels of aggregation above that. We expect that reliability scores at the reporting level would be between 50 and 75%.

5.0 Results

Section 5.1 summarizes coding results for workers' mental models of radiation. Section 5.2 summarizes results of workers' attitudes, values, and work practices outside of the science model. In general, we found that workers' mental models lack the detail of the science model with possible gaps in knowledge. Coding revealed no evidence of obvious misperceptions or wrong concepts.

5.1 Workers' Mental Models of Radiation Exposure Processes, Effects, and Mitigative Behaviors

Workers' mental models are described with respect to their background knowledge (Section 5.1.1), workplace conditions (Section 5.1.2); administrative, personal, and engineering controls (Section 5.1.3); exposure and irradiation (Section 5.1.4); dose (Section 5.1.5); and health effects (Section 5.1.6). Section 5.1.7 summarizes the results of workers' mental models. These results are compiled from coding 10 of the 15 interviews.

Figure 5.1 shows how many responses were coded for each part of the science model.

Green boxes indicate concepts that appear well-understood by most of the workers we interviewed, as indicated by six or more responses out of ten. The green box below the diagram, "Background Knowledge about Radiation," was not in the original science model. However, we included it as part of the summary of worker responses because we received many such responses that fit nowhere else in the science model.

Purple boxes indicate concepts that workers may have understood only generally. For these topics, workers gave a general answer, but did not mention the exact concept or level of detail in the code book. The red boxes indicate possible information gaps, with only four or fewer responses recorded. Yellow boxes indicate concepts that were included for completeness in the science model, but were not asked in the narrow scope of this pilot study.

5.1.1 Background Knowledge about Radiation Sources, Types, and Properties

Background knowledge consists of general knowledge about radiation, specifically, its source, types or forms, and general properties or characteristics (e.g., how it "behaves"). Mentions of concepts in this category indicate awareness of the basic variables that characterize radiation risk, including such things as the relative risk of exposure from different sources (e.g., work sources and natural sources), types or forms of radiation, and behaviors associated with different radiation forms.

All of the interviewed workers talked at some length, and quite accurately, about radiation in general. All 10 coded interviews included some discussion of sources of radiation and contamination. Work sources mentioned included high-efficiency particulate air (HEPA) filters, specific buildings, surface contamination, airborne contamination, unstable elements, labs, tanks, hot cells, and fuel basins. Seven interviewees also discussed background (natural) radiation as being distinct from work sources and adding to or differing from work-related risk. Eight interviewees described types of

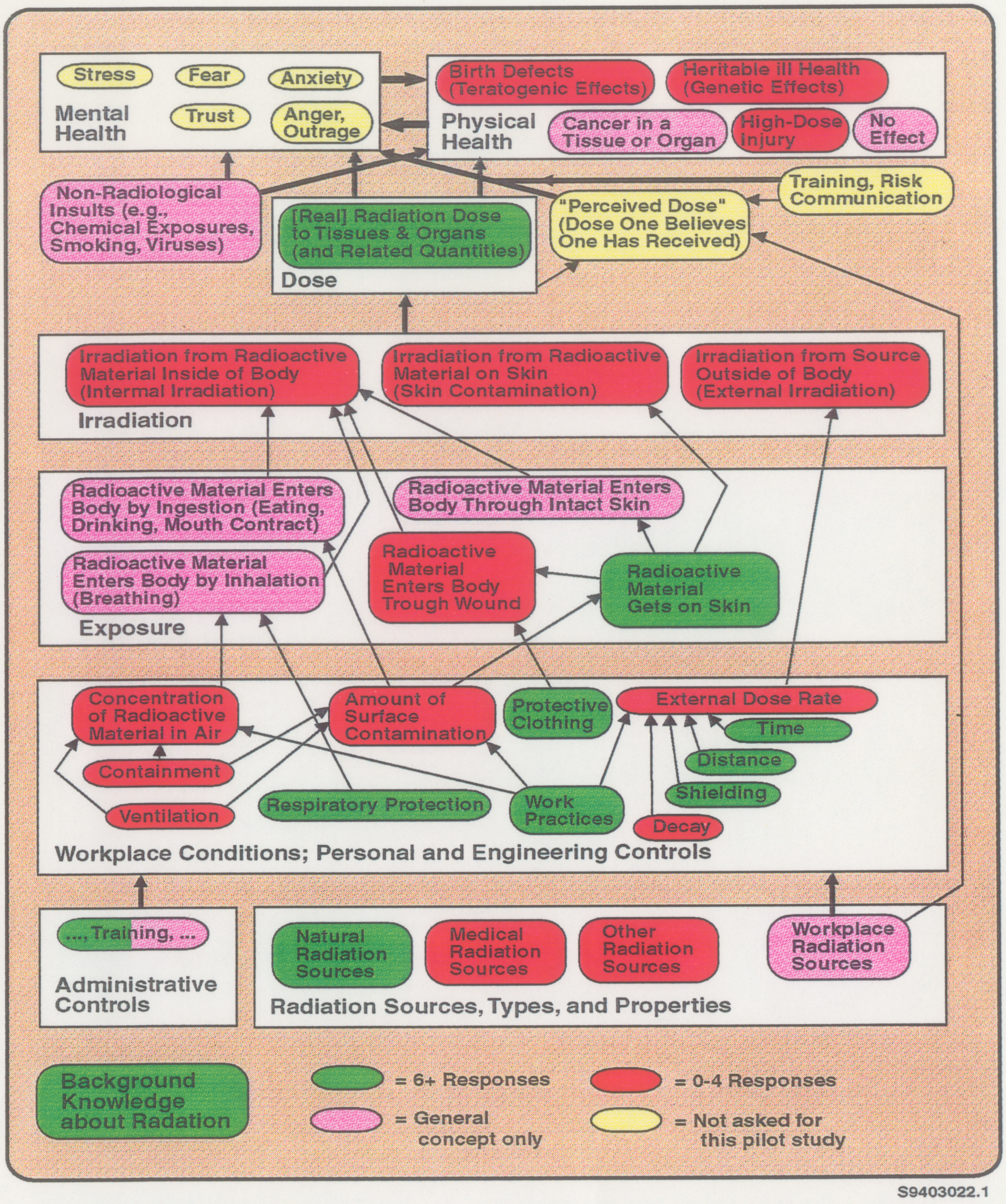


Figure 5.1. Summary of Interviewee Responses Matched with Science Model. Green boxes indicate well-understood concepts. Red boxes identify possible information gaps in worker knowledge. Purple boxes indicate non-specific or inexact responses. Yellow concepts are areas of potential future study.

radiation, such as alpha, beta, gamma, or neutrons; x-rays; radon; particles; or rays. Nine interviewees differentiated among the types of radiation in terms of penetration capability (three responses), general behavior if airborne or ingested (eight responses), or type or probability of harm (six responses). There was little in the science model on background radiation that these interviewees collectively did not describe, and most interviewees discussed a broad range of characteristics.

5.1.2 Workplace Conditions

The workplace conditions category includes knowledge of radiation specific to the workplace, including concentrations of types of radiation in the workplace, source variables that influence those concentrations (e.g., the chemical or physical form of the radiation, the nature of the process that produced it), and source variables that influence mitigation. Mentions of concepts in this category reflect more specific, practical knowledge of radiation beyond background knowledge and indicate that workers have applied their general "textbook" knowledge to their work environment.

Few of the interviewed workers mentioned the above-stated specific concepts. This was true in spite of multiple prompts to say more about workplace radiation and to provide further detail on the general concepts already mentioned. For example, only three individuals indicated a relationship between the nature of the process generating radiation and the type or form of radiation. Only four individuals indicated that the chemical or physical form of radiation influenced concentrations of airborne or surface radiation in the workplace. Those same four individuals and one additional individual noted that work practices (such as length of time in an area and use of protective clothing) were influenced by the form of radiation. Only two said that the type of radiation determines how it moves and where it goes if ingested.

A possible implication is that, while workers understand the basic physics of radiation, they may not be linking their general knowledge to the nature of the risk they face in their jobs. This might limit their ability to make informed judgements when responding to unregulated or novel situations or to be appropriately critical of the regulations and work practices of their company and colleagues. Such a finding would need to be verified using more directed questions with a larger sample of workers.

5.1.3 Administrative, Personal, and Engineering Controls

Administrative, personal, and engineering controls refer to the preventive and decontamination measures that mitigate the dose workers receive. Mentions of preventive concepts (Section 5.1.3.1) indicate an understanding of regulated practices. Mentions of decontamination measures (Section 5.1.3.2) indicate an understanding of measures that will reduce dose once a person has been exposed or contaminated. In general, workers understood prevention, but not the breadth of decontamination measures.

5.1.3.1 Preventive Measures

Although relatively few of the interviewed workers talked about specific workplace radiation concepts or factors influencing exposure and irradiation, each interviewed worker described at least a half dozen of the many specific administrative or engineering controls that help to prevent worker exposure and dose. Dose limitations (six responses), zoning (seven), training (four), personal monitoring (six), and the three basic engineering controls--time, distance, and shielding--(six to seven responses) were among the most-cited preventive measures.

Among the least mentioned were the following administrative controls: quantitative limits for specific external or internal doses, such as extremities or skin (one response) or for special groups, such as pregnant women (no responses); specific types of zones or monitors, such as bioassay for internal dosimetry, personal air monitoring, or derived air concentrations (no responses); environment monitors, such as grab samplers, continuous air monitors (one or no responses for each); and oversight functions, such as inspections, records, audits, and licensing (none to two responses for each). Only two individuals talked about the general principle of radiation protection (to effect a positive net benefit), and only four individuals talked about the general notion of keeping exposure or dose as low as reasonably achievable (ALARA). In addition, relatively few (three or fewer) talked about engineered measures to limit external contact or internal irradiation, including barriers, exhausts, ventilation, filtration, or discharges.

Interviewees talked at some length about personal preventive behaviors, or work practices they themselves could use to prevent radiation exposure or dose. Workers talked about the value of job planning (five responses), wearing protective clothing to guard against external contamination (nine), and wearing respiratory protection (six). Eight interviewees also stressed the general importance of training or of understanding the job and its risks. All personal preventive behaviors in the science model were mentioned by five or more interviewees.

5.1.3.2 Decontamination Measures

Decontamination measures differ from prevention in that they occur following or during an exposure to radiation. These behaviors are often carried out by the exposed individual or a member of his or her work team. Two categories of such behaviors appeared in the science model among the exposure and irradiation concepts (Figures 3.2a and 3.2b): 1) protective measures to decontaminate from skin, and 2) protective measures to remove or neutralize agents from internal exposure.

Surprisingly, the coded interviews contained relatively little discussion of these behaviors, even when interviewees were prompted for "things an individual could do to limit being harmed from an exposure." A total of six interviewees mentioned decontamination from skin. However, two of these mentioned only the general possibility; another four talked specifically about washing or using chemical agents. Fewer yet described measures for addressing internal exposure: while a total of five workers mentioned such measures, only three of 13 possible measures in the science model were noted: chelation (administration of an agent to speed removal), mass action (e.g., blood transfusion), or surgery.

Considered in light of the high level of familiarity with preventive measures, this relative deemphasis on removal or neutralizing actions may (happily) reflect lack of experience with contamination or specific exposures. However, if validated, this may also be cause for some concern because the initiation of these activities is, in case of most contamination incidents, at least partially the responsibility of the worker. The specific de-emphasis of neutralizing measures for internal exposures may also be related to the seeming lack of irradiation information (Section 5.1.4).

5.1.4 Exposure and Irradiation

Exposure refers to ways in which a worker may come into contact with radiation. Irradiation refers to how the radiation may travel or be retained once in the body. Mentions of concepts in this category reflect further knowledge of the variables that underlie administrative, engineered, and personal mitigation strategies, and indicate an ability to extrapolate from specific rules or guidelines to make personal mitigation decisions.

Most of the interviewed workers talked about the major exposure pathways. For internal exposure, all four pathways were described: inhalation (eight responses), ingestion (five), through intact skin (four), and through a wound (two). For skin contamination, eight interviewees mentioned the possibility (three talked specifically about contamination passing through clothing and another three talked about touching a contaminated surface). Finally, external exposure from being present in a radiation zone was mentioned by six interviewees.

On the other hand, very few workers mentioned factors that influence exposure, including breathing rate, which affects probability of inhalation (one response); age or physical health, which affects the radiation path and, thus, probability and type of internal exposure (two responses); environmental conditions that might affect exposure, such as wind or moisture (two responses); work duration, which affects the probability of exposure over time (two responses); choice of job or jobs (one response); failure of engineered controls (two responses); or failure to protect oneself (no responses). Only four workers discussed irradiation variables at all; three of these mentioned that the translocation path affects where an agent goes and, thus, how much of a contaminant might be retained, and one mentioned that contaminants can be transported to parts of the body through the blood stream. None talked about the variables that affect retention, the key factors that determine dose from internal contamination. These variables include the half life of the particular isotope, time, path the isotope takes through the body, and age.

Again, the lack of specific discussion about influencing factors might indicate that these workers are unaware of the uncertainty of a specific exposure or of things they may do, outside of specified guidelines, to mitigate or evaluate their own risk. The marked absence of discussion on irradiation may indicate a general gap in workers' knowledge of internal risks. As will be discussed in Section 5.2.1, if true, this might contribute to the hypothesized "endo-radiophobia," or fear of internal radioactivity (Quinn 1990).

5.1.5 Dose

Dose is the actual measure of exposure. Mentions of dose concepts (e.g., distribution of dose over time, instantaneous dose rates, absorbed dose, nonuniform dose, committed dose, microscopic dose distribution) reflect familiarity with how radiation risk is measured. As with other categories, familiarity with a range of concepts in this category indicates an understanding of the key variables that influence the nature and magnitude of radiation risk. The primary relevance may be for terminology in risk communication; if workers do not mention these concepts, they may be unfamiliar with them or their meanings. In general, these workers did not use many of the dose-related terms in the science model, and few discussed dose-moderating variables. Understanding dose-modifying variables may contribute to more realistic perceptions of personal risk.

Nine of the 10 interviewees discussed the fundamental dose concept, which is that the type, level, and probability of harm from radiation depends on a person's dose. However, few discussed actual measures of dose or the underlying concepts. Four individuals talked about the notion of "dose equivalent;" that is, the idea that different types of radiation (alpha, beta, gamma, neutron) produce different doses. Several others referred to the measure of dose (rem), indicating familiarity with the concept. Three of these same individuals and another discussed dose over a given period of time, distinguishing between chronic or acute doses. Two of these individuals also referred to absorbed dose, or the measure of energy per unit of mass (rad), and one added to this the concept of committed dose from intakes (dose per year).

Fewer still discussed factors that influence dose or its subsequent effects, including a person's weight (no responses), age (three), gender (no responses), diet (including co-carcinogens such as smoking, one response), or genetic predisposition (one response); amount of radiation retained in tissues (one); type of radiation (two); distribution of dose over time (two); and type of job (one). Three workers said that attitude -- that is, whether a person felt stress or fear -- would influence behavior on the job and, thus, dose. Another three named general health (e.g., strength, whether in good shape) or behaviors (a healthy lifestyle) as risk factors for the effects of dose.

In addition to these specific results, there was a range of evidence that workers may be using specific risk terminology interchangeably. For example, exposure, contamination, and dose appeared to be used interchangeably. Radiation, radioactivity, and contamination may also have been confused.

The lack of worker responses about different measures of dose and the improper application of specific terms may be an artifact of this method of gathering data. However, it may also reflect that these workers did not understand distinctions among these terms, their measures, or the underlying science. If true, the latter would likely be more troublesome in that it could affect worker comprehension of other risk information.

5.1.6 Health Effects

Health effects include the four major categories of radiation-related consequences: cancer, teratogenic effects (effects to an unborn child or fetus), genetic effects (that may affect yet-to-be-conceived children), or somatic effects (damage from acute exposures, including such things as hair loss, skin conditions, or vomiting). Death was also included as a possible effect. Mentions of concepts in this category indicate that workers understand the type of risks from radiation. In general, these workers' understandings of the range of effects appear limited.

Seven workers mentioned cancer; however, few mentioned other consequences. Included in the mentioned effects were teratogenic effects (one), genetic effects (two), and several somatic effects, including harm to eyes (one), respiratory conditions (two), or hair loss (one). Two individuals also mentioned somatic effects as a general category. Only three workers mentioned death as a possible effect.

Again, the sparse evidence of effects other than cancer or some somatic effects may simply be a result of the interview method or may reflect the relative importance of these effects as perceived by workers. However, if it reflects lack of familiarity with or appreciation for the wide range of health effects, this might mean that workers were not aware of the range of possible risks.

5.1.7 Summary

When workers' mental models are compared with the science model, there are some areas of significant overlap and several areas where the science model contains detail or breadth that is not reflected in the coded interviews. These workers were knowledgeable about the fundamentals of radiation: its sources, forms, and properties. However, there was less discussion of how these principles influenced the source, type, or mitigation of radiation risk in the workplace. Workers collectively discussed a broad range of administrative controls for managing radiation risk. However, they did not talk about certain categories and did not provide the same level of detail as in the science model, nor did they discuss at the same frequency or breadth the range of measures for neutralizing or decontaminating individuals following external or internal contamination. While most workers discussed the major pathways of radiation exposure, few talked about irradiation (internal exposure) at all, and even fewer talked about factors that affect exposure or retention, the key variables determining dose. Most workers discussed the relationship between dose and effect at some length, describing in some detail the concept of a lower threshold. However, there was little discussion about the range of dose measurements that characterize dose, including the concepts of time, mass, uniformity, cumulative dose, or microscopic dose. Nor did workers discuss dose and effect-modifying variables.

Finally, while these workers clearly understood that cancer is a radiation risk, other risks were not discussed much. There was little talk of factors other than administrative controls and workplace practices that influence dose or effects (e.g., type of isotope, age, gender, diet, other activities).

These findings raise the following questions, which could be addressed in a more structured followup survey to validate and generalize the data described here:

- Do workers understand the properties of radiation, or the logic, underlying the many preventive controls and practices that regulate their work environment (e.g, why barriers are used in some situations and not others, why respirators are used in some buildings but not others, how radiation associated with certain contaminants or waste behaves, etc.)?

- Can workers extrapolate from their basic radiation knowledge to suggest reasonable controls or responses to novel or unregulated circumstances that hold some risk? Related to this, can workers knowledgeably critique whether the regulations they follow are adequate or unnecessary?

- Do workers understand (and have they considered, or do they care about) the range of radiation risks they may face and the wide range of variables (job-related or other) that moderate that risk?

- Do workers understand the terminology that describes radiation risk and that is typically used in radiation training (e.g., rem, rad, radioactivity, radiation)? (For example, it is possible that "endo-radiophobia" is a spurious concern, linked more to semantics that to a true discrepancy between workers' risk understanding and that of experts?)

5.2 Workers' Mental Models of Concepts Outside of Science Model

This section summarizes workers' views on internal and external exposure (Section 5.2.1), their estimated probabilities of radiation exposure and harm from that exposure (Section 5.2.2), their values and concerns (Section 5.2.3), their estimated probabilities of contracting a disease from their radiation exposure (Section 5.2.4), and their knowledge and views on chemicals (Section 5.2.5) and training (Section 5.2.6). Section 5.2 summarizes results from all 15 interviews.

5.2.1 Internal Versus External Exposure

One of the objectives of the pilot study was to determine whether radiation workers perceived internal exposures as being more harmful than external exposures. Health physics experts have long held that, in general, there is an "internal dose phobia," an almost irrational fear of receiving internal exposures, a fear that could lead some workers to put themselves at greater risk of other dangers such as industrial hazards or higher external exposures (DOE 1992; Quinn 1990). For example, a worker could don greater-than-necessary protective clothing and equipment out of fear of receiving an internal dose. However, the bulky and unwieldy clothing and equipment could actually slow the worker down, thus requiring him or her to stay *longer* in a radiation zone and potentially incur more exposure. Also, the addition of more clothing and equipment can make hands-on operations more difficult and thus more subject to an accident.

A related issue is the perceived harm from doses received from various types of exposure. Though an equal dose received from an internal exposure and an external exposure would have the same level of effect (a rem is a rem despite the source), some workers seem to feel that a rem from internal exposure could have worse effects than a rem from an external exposure.

Two interview questions were designed to investigate the existence of the internal dose phobia:

- "Some people distinguish between internal irradiation, that is getting exposed from an intake of radioactive material; external irradiation, getting exposed from a source outside the body; and radioactive contamination on the skin. Do any of these three kinds of exposure concern you more than the others?"

- "Let's say you received 1 rem of radiation from an external source and 1 internally. Is one type of radiation dose worse than the other?" (This question was added to the interview questionnaire beginning with the second interview).

Answers to each of these questions are discussed below. Section 5.2.2 presents related responses regarding worker estimates of internal and external exposure and harm for themselves and others.

5.2.1.1 Distinguishing Between Internal Irradiation, External Irradiation, and Skin Contamination

The interview results did seem to verify the highest level of concern for internal doses; of the 15 people interviewed, 10 felt that internal irradiation was the worst. One interviewee stated, "I'll go to the ends of my [radiation exposure] limits to prevent that [internal radiation] from getting inside of me."

One commonly stated reason for the concern was that one cannot get away from an internal source. This is in contrast to the use of shielding and distance to control external exposure and protective clothing to limit skin contamination, interviewees said. One interviewee stated, "If I've inhaled or ingested it, then I've contaminated my entire body. I haven't just contaminated my outer skin, which can be washed off. But you can't just go and wash me from the inside out." Another reason given was, once the radioactive material was inside the body, there was no way to rid the body of the radiation source completely. Another concern was that internal irradiation would target more sensitive organs: "It [internal irradiation] would be more apt to go to parts of your body that you don't want [it to go to]."

Several interviewees mentioned that an internal source continues irradiating your body once it's inside, and that the radiation source seeks organs and bone, which can lead to serious diseases. Explained one worker: "You can cut off your finger [if it should become highly contaminated], but how many people do you know walking around without a liver?"

One interviewee felt that external irradiation was worse because one could never be sure if one had been exposed. He (correctly) felt that irradiation could come from an angle that would miss the dosimeter; in this way, the dosimeter would indicate a lesser dose than he had actually received. Another interviewee felt that external irradiation was worse because it "radiates through you." That person was most concerned about the high doses possible from some external exposures. One person (correctly) felt that it depended on the type of radiation (alpha, beta, gamma, neutron) as to which exposure was worse.

5.2.1.2 Comparing the Same Dose for Different Exposure Routes

Nine out of 15 people felt that a 1-rem internal dose was worse than a 1-rem external dose. Again, several cited the concern that an internal dose is more difficult to get away from. One interviewee stated, "No matter what, I don't want it internal versus external." Another interviewee, however, couldn't give a reason for the opinion: "I don't know, I just know it [internal dose] would be [worse]."

One interviewee was uncertain which would be worse. Only two (including the one interviewee who was a Health Physics Technician) felt that the two exposures were the same.

5.2.2 Worker-Estimated Probabilities of Exposure and Harm

Many studies of risk perception document a phenomenon of "unrealistic optimism" regarding perception of personal risk. For example, most adults judge themselves to be safer and more skillful than the average driver--a claim that could be true for only half the population (Svenson 1981). The tendency to see oneself as less likely to experience negative outcomes has been reported in a wide range of arenas, including ethical transgressions (Baumhart 1968), business dealings (Larwood and Whitaker 1972), disease (Harris and Guten 1979; Kirscht et al. 1966; Weinstein 1983, 1984, 1987), natural disasters (Johnson and Tversky 1983), and technologies (Johnson and Teversky 1983). Furthermore, several studies have indicated that risk judgments are only occasionally based on actuarial risk factors (Weinstein 1984).

In a typical study, the investigator asks subjects to evaluate their risk of various negative events (e.g., asthma, homicide, fire) relative to that faced by other people their age. Subjects typically rated their risk as significantly less than that of others. However, the degree of optimism was moderated by several variables, including "social distance" (optimism was greater when subjects compared their own risk to that of a general peer and smaller when compared to a close friend or family member), control (optimism was greater for risks over which the subject felt some degree of control); experience (optimism was reduced if the subject had experienced the risk); and low probability events (optimism was reduced for very low probability events).

Similar findings of personal invulnerability, or optimism, among DOE radiation workers may have important implications for risk prevention programs, including worker training. If workers do not perceive themselves to be at risk, or if they believe they are *less* likely than others to experience bad outcomes, they may be less likely to follow safety practices (or they believe that others do not follow safety practices). On the other hand, data showing that workers perceive themselves to be significantly *more* at risk for harm or for experiencing bad health outcomes than are others may indicate that current safety practices are perceived by workers as being inadequate. In this case, heath effects, such as cancer, may logically be perceived by workers to be a direct consequence of their jobs. Whatever the implications, our interest was in validating this phenomenon with DOE workers.

Our study interview enabled us to collect initial data on workers' perceptions of relative risk for exposure to radiation and for harm resulting from exposure. The objective was to establish whether the results on personal invulnerability documented in the literature could be generalized to DOE workers and radiation risks. The data address three questions:

1. Do DOE radiation workers believe themselves to be more or less at risk for from radiation, compared to their colleagues or to "someone picked at random from the Hanford phone book?"

2. Do workers' risk perceptions differ for internal or external radiation?

3. Do the documented comparisons depend on whether the risk is for *exposure* to radiation or for *harm* resulting from radiation exposure?

Thirteen subjects[a] answered 18 probability questions, designed to address three risk perception factors: risk recipient (the worker, a colleague, or a member of the general Hanford community), risk exposure pathway (external irradiation, skin contamination, internal irradiation), and the risk event

(a) The first interviewee answered probability questions, but we hadn't developed the table yet. Subject 15 was not yet interviewed when these results were tabulated.

(risk of exposure, or of harm from exposure). Data were gathered by asking each worker to fill out two tables: the first table recorded probability judgments for three types of exposure to each of the three recipients and the second table recorded probability judgments for harm from each type of exposure for the same three recipients.

Interestingly, the workers' actual estimates of exposure and harm showed significant disagreement: estimates ranged from 0.05 % to 100%, depending on the exposure route and the person being estimated for. However, it is important to note that the probability questions were designed only to test the hypotheses of invulnerability and internal dose phobia. Therefore, the worker estimates were not judged as to how well they matched actual statistical probabilities of Hanford radiation exposure and resulting harmful effects.

Results are shown below. Tables 5.1 and 5.2 provide the fraction of subjects' judgments that showed their personal risk to be either less than, equal to, or greater than a colleague's or someone from the general Hanford community. These tables collapse judgments over the three different types of exposure for each subject. For example, the results comparing probabilities based on risk recipient count responses from each of 13 subjects to questions about three types of exposures.

Based on results with other risks and other populations, we expected that workers would perceive their risk to be lower than that of their peers, particularly compared to the general Hanford community. However, our data did not support this "optimism" hypothesis. As shown in the first rows of Tables 5.1 and 5.2, workers did not distinguish between their personal risk and that of their colleagues for either radiation exposure or for harm from radiation exposure. In addition, reading from the second row in Table 5.1, about half of the comparisons indicate that subjects believe their probabilities of exposure are higher, not lower, than for someone picked at random from the Hanford community. There are many more nonradiation workers at Hanford than radiation workers; these interviewees may correctly perceive their risks of exposure to be greater.

However, this difference does not extend to subjects' perceptions of harm from that exposure. Only 13% of the comparisons showed that workers felt their probabilities of harm from radiation were greater than for another person at Hanford, while 63% of the comparisons showed no difference. In only limited support for the optimism hypothesis, only 21% of the comparisons showed workers

Table 5.1. Risk Comparisons for *Exposure* Relative to Risk Recipient

	Percent of Cases			
	Less Likely	Equally Likely	More Likely	N[a]
Colleague	10	79	10	38
Other	21	21	58	38

(a) N = total number of responses considered in calculating percentages.

Table 5.2. Risk Comparisons for *Harm* Relative to Risk Recipient

	Percent of Cases			
	Less Likely	Equally Likely	More Likely	N[(a)]
Colleague	10	79	10	38
Other	24	63	13	38

(a) N = total number of responses considered in calculating percentages.

thought their chances of being exposed to radiation were lower than for a general Hanford employee, and 24% of the comparisons showed workers judged their probabilities of harm to be less than for others at Hanford.

Tables 5.3 and 5.4 show subjects' judgments of the relative risk from different exposure pathways. These tables collapse judgments over subjects' personal risk and the risks they perceive for a colleague and other Hanford employee. The numbers in the cells show the percentage of judgments indicating that risk for the first listed exposure type (e.g., external in the first row) is less than, equal to, or greater than risk from the second listed exposure type (e.g., skin contamination).

Based on perceptions among radiation protection professionals regarding "internal dose phobia" (DOE 1992), data were expected to show that workers perceived the risk of harm from internal irradiation to be greater than for other pathways. However, the data from this part of the interview did not support that hypothesis.

Subjects typically believed that the risk of external exposure was greater than for skin contamination or internal irradiation, and that the probability of skin contamination was equal to or greater than that for internal irradiation. Moreover, subjects' judgments did not indicate that they believe the

Table 5.3. Risk Comparisons for *Exposure* by Different Paths

	Percent of Cases			
	Less Likely	Equally Likely	More Likely	N[(a)]
External vs. Skin	14	19	167	36
External vs. Internal	0	26	74	39
Skin vs. Internal	02	41	58	36

(a) N = total number of responses considered in calculating percentages.

Table 5.4. Risk Comparisons for *Harm* by Different Paths

	Percent of Cases			
	Less Likely	Equally Likely	More Likely	N[(a)]
External vs. Skin	14	47	39	36
External vs. Internal	23	49	28	39
Skins vs. Internal	19	75	06	36

(a) N = total number of responses considered in calculating percentages.

probability of harm from exposure was greater for internal irradiation relative to either external irradiation or skin contamination. Most subjects (81%) indicated that the risk of harm from internal irradiation was less than to or equal to that for skin contamination, and most (77%) indicated that it was less than or equal to that for external irradiation. (See Section 5.2.1 for a summary of narrative responses regarding concerns about internal and external radiation. See Section 5.2.4 for responses regarding workers' estimates of how likely serious diseases were to have been caused by radiation at Hanford.)

Given the wording of these questions, workers may have "collapsed" possibilities. That is, they considered the possibility of internal exposures and the probability of harm, not the probability of harm given the probability of exposure. If internal exposure is recognized as a very unlikely phenomenon, then the probability of harm it should be even lower. On the other hand, evidence of relative optimism regarding radiation-related workplace hazards among workers may reflect a sense of confidence in the administrative, engineered, or personal safety protection programs that they work within. The following section describes some responses that may explain this relative optimism.

5.2.3 Values and Concerns Expressed About Radiation

In addition to factual information that could be compared directly with a science model of radiation processes and effects, we wanted to elicit more value-based information. This is because risk behavior is based not only on knowledge, but also on perceptions and values regarding the risk (National Research Council 1989).

We asked people whether they had any concerns about radiation, and if so, what would alleviate those concerns. Often anecdotal, the information we received in this part of the interview was perhaps the most fascinating in terms of understanding what drives opinions and behavior.

Research has shown that lay people often express more concern about radiation than other, more familiar hazards that have greater statistical risk (e.g., Slovic et al. 1981). With our worker interviewees, familiarity with and knowledge about radiation risks, as well as the ability to exercise some degree of personal control over it via exposure monitoring and mitigative behavior, seemed to make the risk more acceptable than it is to the general public.

For example, many workers said they respect, but don't fear, radiation. A typical comment was, "I treat radiation just like any hazardous job that you work in. As long as you know what you're doing and you act responsibly, you're going to take the minimum amount of risk necessary to get your job done."

Workers seem to accept the radiation-related risks as part of their jobs. One person said, "We get into a lot of dirty places. Nobody wants to be there, but it's our job to be there. The amount of cases that we have had, people being contaminated...are very, very small."

One person spoke about taking personal responsibility for workplace safety: "You have to look out for yourself. ...If you are in a zone and they recommend you wear this and you don't think that's quite enough, you can request a mask and [supplied] air and tell them you want it all."

Many workers mentioned the help of Health Physics Technicians and other work partners that they trust to help keep their risk down. One person said, "The [Health Physics Technicians] are very helpful and I can trust them if I did get in contact with something, and I think they would be right there to help me." Another person, speaking of a work partner, said, "He goes in [a zone] more than once a week. He knows where he needs to go inside the canyon, where if I go in there, I am not familiar with it."

These generally positive comments don't mean workers were willing to take unnecessary risks. When asked if they had any personal concerns about radiation, interviewees usually mentioned workplace processes and situations that could unnecessarily expose them or hamper their work. Two recurring concerns--colleagues' attitudes and restrictive dose limits--are summarized here. Estimated probability of disease from workplace radiation exposure is discussed in Section 5.2.4.

5.2.3.1 Colleagues' Attitudes

Workers seem to assess the knowledge and awareness levels of their co-workers. Some people stated that their greatest concern was about the attitudes of their colleagues in the workplace and how these attitudes affected their colleague's and subsequently their own work. This concern had several aspects:

1. Did their colleagues understand enough about radiation to respect it and follow procedures, including asking for help from Health Physics Technicians when necessary? One person referred to a co-worker who was taken off the job because he didn't understand the radiation signs and was inadvertently causing contamination incidents.

2. Had their colleagues worked with radiation and radioactive materials for so long as to treat their work with less caution, possibly by bending rules and taking chances? One person, referring to people he worked with, said, "They were more senior workers and they just didn't have concerns about...radiation...They'd say, well, I ate that for breakfast. [They would say] I'm taking this exposure, but big deal, I still haven't seen any health changes yet and I've been here for 18 years..." The interviewee said that attitude "bordered on carelessness." Another person said, "I know people who are chemists, old-timers. Somebody told me he grabbed a 38-R source, and he...put it in a bag and then he got rid of it. My manager would have a fit, something that high, you definitely don't handle with your direct extremities and you handle it as remotely as you can."

3. Did their colleagues have a fear of radiation that either kept them from entering a radiation area or that affected their ability to work while in such an area? One person linked inappropriate fear with greater risk: "Your fear has not allowed you to know what that [radiation] sign is actually telling you. All you see is a red, magenta sign and that's radiation. [In the radiation zone], your fear, anxiety, stress, are you going to do something stupid? .. To forget to do something?"

Some interviewees mentioned auditors and managers as the objects of these concerns-- people who have infrequent contact with radiation but are in positions of authority.

5.2.3.2 Unreasonably Restrictive Dose Limits and Reporting Requirements

Several workers mentioned that with the current trend to keep lowering the allowable dose to workers, the dose limits will become so restrictive as to keep workers from doing their jobs effectively. A typical comment was, "We have so many administrative controls put on us, we don't have the freedoms to do the cutting edge kind of work we need to do here." The fact that when you reach your dose limit and must stop doing radiation work until the next allowable period was seen as inefficient: "What are they going to do, sit and do office work for the rest of the year?"

Some workers expressed frustration that policy-makers aren't aware of what the workers must deal with to do their jobs: "You work around radiation, you're going to become exposed. You're going to become contaminated. It's how it's addressed and how it's handled that's important." Another person said the administrative goal of zero skin contaminations was unrealistic, because in his job, contamination was inevitable: "Certainly, I would do everything to avoid it. It's not like I'm going to work in a glovebox without gloves on, or do stupid things where I'm going to be contaminated. No one wants to do that, but [it's] inevitable that it's going to happen..."

Some felt that the emphasis on the formal and detailed reporting of unusual exposures leads to an inordinate amount of attention on reporting accidents with relatively inconsequential results, and that concern for the workers gets lost in the shuffle. One person said, "My biggest concern...is the amount of paperwork my boss has to do. I kid you not...he has to spend 2 days explaining why I got 100 counts of beta gamma on my hands. We go in and wash my hands with soap and water, then it's gone. He spends two days writing a report on how and why that happened. That seems simply outrageous to me."

5.2.4 Estimated Probability of Contracting a Disease Attributed to Workplace Radiation Exposure

One of questions asked in the interviews was "If you got cancer or some other serious disease, what would be the probability that it was caused by radiation at Hanford?" In asking this question, we wanted to determine whether workers felt that their risks were high enough to result in a serious illness.

Of the 15 people interviewed, 7 said that cancer and other serious diseases have too many causative factors to allow the blame to be placed on any one activity or event. Smoking was the most frequently mentioned factor as well as other types of industrial exposures (lead, asbestos). One gave the risk of work-related disease a 50% chance, and two gave it a 100% chance. One said that there was no way it could be caused by work at Hanford. Another said that genetic tendencies were the primary causes of cancer.

5.3 Knowledge about Hazardous Chemicals

For hazardous chemicals, our interview covered the same basic topics as for radiation: exposure sources, effects, and control methods. However, because the chemical information was gathered only for preliminary screening purposes as the basis for follow-on studies, the questions and answers were much less detailed. We were particularly interested in whether workers' models of chemical risk were greatly different than those for radiation (whether their beliefs discriminated among hazards).

These observations represent what we believe to be significant or meaningful results. The findings may not be inclusive of all responses, because we didn't develop a science model of hazardous chemicals for comparison.

Twelve of the 15 subjects encountered hazardous chemicals in the workplace. Chemicals were used in laboratory research, as solvents, for cleaners, for radiation decontamination, in laundering, in equipment repair, and as herbicides and pesticides. Secondary exposure could also occur in situations such as checking filters in fume hoods or simply by working in a building where chemicals were present, especially if an accidental chemical release occurred. Specific chemicals mentioned were asbestos, ammonia, PCBs, mercury, carbon tetrachloride, nitric acid, lead, alcohol, ferrocyanide, cyanide, nitric fumes, acids, and bases.

Effects mentioned were watering eyes and nose; itching face; breathing difficulty; dizziness; light-headedness; nausea; rashes; freezing the skin temporarily; going into a coma; and damaging the lung lining, liver, and kidneys. Three people mentioned that specific effects were listed in Material Safety Data Sheets (MSDSs) for each chemical.

Control methods identified were to avoid the area whenever possible; be aware of what's there; properly mark and store chemicals; be properly trained; use proper procedures such as using funnels instead of pouring directly into bottles; have room monitors that alarm when a chemical is detected at a prescribed amount; wear gloves and other protective clothing; use ventilation; use compressed air instead of a hazardous solvent for cleaning when possible; know the flammability, threshold limits, warnings, and respiratory requirements for the chemicals as specified in the MSDSs; and preplan for specific operations. If there is an accident, a room can be closed until it is checked by industrial hygiene staff and released for safe use.

Interestingly, three workers stated that chemicals were more dangerous in the workplace than radiation was. One person stated, "Nitric fumes...will damage the lung lining. You have to take a lot of radiation dose to do the same damage over a longer time. Chemicals...require more respect." Another person mentioned the difficulty of definitively detecting chemical exposure, in contrast with radiation exposure: "...with radiation, if you get something on your glove you can go over to the geiger counter and check it, and then change that glove." However, it was mentioned that physical shields such as protective clothing and safety glasses prevent exposure from most chemicals, whereas for some types of radiation, shielding doesn't prevent exposure.

Two interviewees felt that hazardous chemicals received less emphasis than radiation did. One person stated, "I'm probably a little more leery...about the chemicals than I am about the radiation...because I don't know as much. I'm not a chemist." Another person said, "We train for it, but we don't put the same emphasis on [chemicals] that we do on radioactive materials."

5.4 Training

All interviewees had received basic radiation worker training; six had taken the next higher level of training (Rad Worker 2). Several had additional training in specific topics such as air mask fitting, handling of hazardous materials, and criticality safety (see Table 2.1 for details). We asked interviewees whether the training was useful, why or why not, and whether there were things that could be done to make the training more useful.

All 15 subjects agreed the training was useful because it helped them do their jobs properly and safely. This generally positive response could be partly attributed to the fact that we purposely selected people qualified in radiation work for 5 years or less and without a 4-yr college degree. These characteristics may have made the training seem more useful and necessary than for a longer-time worker who's "heard it all before."

Though our interviewees saw training as useful, they had many suggestions for improvement. The most frequently mentioned ones are summarized in the following sections.

5.4.1 Frequency and Length

Three people would rather have more frequent and shorter training sessions: "[A] small burst of information...If you draw it on too long, you start forgetting, then your attention span is gone." One person stated that workers may be inadvertently practicing improper or inefficient procedures in between training: "Like anything, you get in a routine and get so repetitious. It may not be the best way. If you don't go in a zone often, you need the refresher." Two people wanted longer classes, to give them time to absorb material.

Informal training was seen as best; one person suggested short monthly sessions for workers with their supervisors. Another suggestion was to do it all at once and get it over with, rather than breaking one class up over several weeks or months. However, it was recognized that managers don't like having people gone for that long, because it creates work scheduling problems.

5.4.2 Targeting of Workers

Five people mentioned targeting training to knowledge levels/worker classification. The Westinghouse Hanford General Employees Training, for example, was mentioned by a few workers as too general for radiation workers and unnecessarily long. Experienced workers need a different level than less-experienced workers, as do different kinds of workers. One person stated that in the classes that contain many types of workers, "Office workers are always the ones asking the questions. So most of the classes are really generated at educating people who haven't been there before." Suggestions were to have a general class for people who aren't expected to go in radiation zones, plus a hands-on class for people who are.

Two workers felt like they were frequently in training classes, but more wasn't necessarily better. A typical comment was, "It comes to a point where you just shut down and say OK, I'm listening but it's not sinking in." One person suggested more opportunities to challenge classes by taking a test. Another suggestion was to use a pretest to group people with the same knowledge level and category of work. With this smaller group, training is more effective, said one person, because people are less intimidated and feel more comfortable about asking questions.

5.4.3 Applicability to the Workplace

Workers value training that is tailored to their work situations. One radiation worker mentioned, "All these people I am in class with are all office workers. They are talking about tripping over filing cabinets, push the drawers in. There are no drawers at my world." Some of the requirements taught in the class were seen as unreasonable in the work world: "[They tell us,] you can't lift 40 pounds. If I can't lift 40 pounds, I'm not going to do a thing on my job. I've got to carry hoses on this side, I've got to carry a smoke generator, I've got to carry a suitcase on this side and climb stairs." Interviewees prefer teachers who work around radiation frequently. One person said, "I don't trust instructors when they don't know what they're talking about. Just getting a teaching degree doesn't mean you are teaching useful stuff." Some workers advocated teaching things that you learn to do on the job that make your work more efficient and easier, such as tips on putting on protective clothing.

Three people mentioned they wanted less emphasis on theoretical topics and more on practical, on-the-job issues. A typical comment was: "I learned about [atoms] in high school, and I know about that, and if I don't know about that what difference does it make to me when I'm back there working on the back face [of the reactor]." Another comment was, "Once you're on the job, you don't care what makes what work. You're thinking about what it's going to do to you, and what you're going to do to prevent it." Four interviewees felt hands-on training was helpful, such as practicing a task in a simulated radiation zone.

5.4.4 Instructional Methods

Three workers recommended making the classes more interactive to keep the interest level high. For example, one worker liked the way an instructor had taught and reinforced radiation concepts by having students compete in a game patterned after the television quiz show "Jeopardy." Another person recommended the use of video rather than straight lecture. One person described the effects of having a boring instructor as, "You don't pay attention. You fall asleep...it makes such a big difference to have a good instructor."

One interviewee mentioned that more control by instructor would be helpful. In one class, the members cheered when a chemical exploded in a video. The worker described the class attitude as more like "enjoying the show" than paying attention to the content.

6.0 Conclusions and Recommendations

The following conclusions and recommendations are based on a very limited sample of workers. A followup, structured survey would be necessary to validate and generalize these results and to examine their implications for communications and workplace behavior.

6.1 Comparison of Worker and Science Models

In general, workers' mental models, when collectively considered, covered many of the basic components of the science model, but did not contain the same level of detail. For example, some workers were aware that there was a way to mitigate internal contamination via chelation, but no one mentioned concepts such as administering an antidote, inducing vomiting, removing from wound, or irrigating with saline. Similarly, while most workers discussed the relationship of dose and effects, few explicitly noted specific ways of measuring dose (which reflect the importance of variables such as distribution of dose over time or body area) or factors that affect dose, such as weight, gender, and job duration (which reflect variables that would help workers' to estimate their own risk and make personal, informed job choices).

Finally, there were significant discrepancies in the level and breadth of information volunteered by workers during the interviews. While this may be related to the interview method (some workers may have simply talked less), it may also reflect significant differences in level of understanding even among this seemingly homogenous group of workers, underscoring the importance of tailored training.

The following results are particularly noteworthy:

- Evidence linking general radiation, or "textbook," knowledge to workplace practices was generally missing from the interviews. It is possible that the rules and regulations governing radiation jobs leave little room for personal decision making, and training may not prepare workers to apply their general knowledge to make decisions in new situations of "off normal" events and jobs. Under a "total quality management" approach, radiation workers should be equipped to critically examine the rules they work under and to judge the applicability of those rules to both standard and non-standard situations.

- There was a lack of detailed responses about actions to decontaminate or neutralize radioactive agents following an exposure to radiation. If this reflects a real gap in workers' knowledge, they may be ill-equipped to respond to situations that call for such actions or to recognize the need for these actions.

- Some terms (dose, rem, rad, exposure, contamination, radiation, radioactivity) were missed, used interchangeably, or misused. One conclusion may be that some of these workers did not understand the basic principles behind the terms. Another is that they understand the principles, but do not use the language in the same way that experts do. If the misuse reflects real confusion regarding the meaning of such terms, additional care must be taken in communications to ensure the terms, or the phenomena they refer to, are understood and that conclusions from such communications (e.g., tests or surveys) are well-founded.

6.2 Attitude Towards Internal vs. External Exposure

Workers generally viewed internal radiation exposure as more of a concern than external exposure or skin contamination. The most commonly stated reasons for this concern were 1) the inescapability of an internal source, in contrast to shielding, protective clothing, and distance to control external exposure and skin contamination, and 2) the greater potential harm from an internal exposure, specifically, continued irradiation once inside the body and the tendency of internal contamination to seek organs and bone. If one assumes that workers are not comparing a true "rem" of internal and external exposure (which adjusts for differences in the biological effectiveness, or damage, of different types of radiation) but instead are comparing external contamination to internal contamination, their concern may be well-founded. Indeed, it is more difficult to remove internal contaminants, which may mean that retention time is greater, absorbed dose is greater, and the probability of harm increases. This hypothesis relates directly to the terminology issue described in Section 6.1.

6.3 Estimated Probabilities of Exposure and Harm

Workers did not judge their risks to be greater than those of their colleagues for either radiation exposure or for harm from that exposure. Half the subjects rated their probabilities of exposure as higher than for someone picked at random from the Hanford community--which could very well be true, in view of the much larger number of nonradiation vs. radiation workers employed at Hanford.

Of the various exposure pathways, workers believed they had the highest probability of receiving external exposure, with less chance of skin contamination and even less for internal irradiation. Subjects typically believed the probability of harm from internal irradiation was less than or equal to that from skin contamination or external irradiation. Interestingly, workers' written estimates of no greater harm from internal irradiation seemed somewhat at odds with the concerns they expressed in the narrative part of the interview about internal irradiation (described above). This discrepancy adds some credibility to the notion that "irrational fear of internal radiation" may be, at least in part, a terminology issue, depending at least in part on how questions are posed and how responses are interpreted.

6.4 Values and Concerns

Many workers said they respect, but don't fear, radiation, and accepted the radiation-related risks as part of their jobs. This attitude may reflect knowledge, experience, degree of personal control over the risks, and/or confidence in administrative and engineering controls.

Half the workers said that cancer and other serious diseases have too many causal factors to be attributed to their radiation exposure at Hanford. However, two workers believed the probability would be 50% and 100%, respectively, that such a health effect, if developed, would have been caused by their jobs.

Workers do assess the knowledge and awareness levels of their co-workers. For example, they show a strong reliance on the support and advice of the health physics technicians. On the other hand, several workers expressed a concern about colleagues' attitudes--including complacency or unwarranted fear--that can affect other peoples' exposure risks. Longer term workers were sometimes viewed as having a more casual attitude toward exposure, possibly because they had not experienced any noticeable health effects over several years of working around radiation. Another concern was unreasonably restrictive dose limits or protective clothing and equipment (which may actually slow the work and increase exposure). It is unclear whether workers have the knowledge to assess this issue (see above); training should equip workers to make such assessment in order to facilitate potentially useful feedback in safety practices.

6.5 Chemicals

Most of the interviewees encountered hazardous chemicals in the workplace. Specific chemicals mentioned were asbestos, ammonia, PCBs, mercury, carbon tetrachloride, nitric acid, lead, alcohol, ferrocyanide, cyanide, nitric fumes, acids, and bases. A variety of potential exposure effects were stated, ranging from watering eyes to organ damage and coma. Many control methods were described, including administrative and physical.

All workers appeared to have a differentiated model of risk for chemicals and radiation. In other words, workers commented explicitly on risk processes and levels of risk with chemicals, as with radiation. Interestingly, three workers stated that chemicals were more dangerous in the workplace than radiation was, and two felt that chemicals received less emphasis than radiation did at Hanford.

6.6 Training Recommendations

All subjects felt radiation training was useful because it helped them do their jobs properly and safely. This response could be partly attributed to the fact that our subjects were relatively new in terms of time qualified as radiation workers (5 years or less). Workers recommended changes in frequency and length of training, targeting of workers, applicability to the workplace, and instructional methods (detailed in Section 5.4).

We recommend that the differences among terms such as exposure, irradiation, and contamination, and among internal, external, and skin contamination, be given more focus in training. As previously found by Keren and Eijkelhof (1991), these concepts were sometimes unclear in workers' minds. (See Section 6.7 for more discussion on this topic.)

We recommend that training provide additional "background" information about radiation (its properties, characteristics, and so on) and relate this information more directly to its influence on types of exposure processes, controls, and effects. This would help ground the "theory" more closely in workplace practices and better equip workers to extrapolate from, and provide feedback about, safety practices under a "total quality approach" to safety.

We recommend that radiation training be investigated to address worker suggestions. Areas to investigate could include offering more frequent training for newer staff, targeting training to knowledge level and worker classification, offering more opportunities to challenge classes by taking a test, using smaller groups for a less intimidating setting, making sure instructors are up to date with actual workplace practices in the field, having experienced workers contribute "tips" that they've learned on the job, and using more innovative and interactive teaching techniques.

6.7 Terminology-Related Insights for Communication and Training

In developing the science model, designing the interview, and interpreting the workers' responses, we became convinced that there is a serious difficulty with some of the traditional terminology used in radiation protection. In particular, the way people in the radiation protection field use the terms "internal exposure" and "external exposure" differs from the ways in which these terms are used by those in the fields of toxicology and industrial hygiene. Furthermore, different professions distinguish between exposure and irradiation.

"Exposure," in the sense commonly used by industrial hygiene personnel and toxicologists, is the act of coming in contact with a hazardous agent by inhaling it, ingesting it, or getting it on the skin (dermal contact). Examples are being exposed to asbestos or being exposed to the measles. "Exposure" also has a common meaning in the sense of exposing film, for example, that makes sense for "external exposure." Irradiation is the process of ionizing radiation encountering matter, such as a person being irradiated by x-rays from a machine in diagnostic radiology. Irradiation can also occur to part or all of the body from radioactive materials that are on or in the body. Thus the traditional health physics term "internal exposure" means "irradiation by radioactive materials inside the body." The exposure process, in the industrial hygiene or toxicology sense, occurs prior to the irradiation process. To a toxicologist or industrial hygienist, the exposure is the process of getting the radioactive material into the body.

We found the terms "internal exposure" and "external exposure" to be confusing for some of the interviewees. In particular, for the case of being irradiated by radioactive contamination on the skin, early drafts of the interview elicited responses that indicated confusion on the part of the respondents. Some viewed skin contamination as external exposure; others considered internal exposure.

Some aspects of all exposures and irradiations are both external and internal. All sources of radiation start out external to the body. All irradiated organs and tissues are internal to the body. The subtle and complex differences among irradiation by an external source, irradiation by radioactive contamination on the skin, and irradiation by radioactive materials inside the body following an intake are shown in Table 6.1.

A confusion about skin contamination arises from the fact that the radioactive material is *outside* the body, but it is also *on* the body, and some of it may be taken *inside* the body, if there is an open wound or absorption through intact skin. Thus the external-internal dichotomization commonly used in radiation protection is inadequate for skin contamination.

For sources of penetrating radiation outside of the body, there is no need to distinguish between exposure and irradiation, because they occur simultaneously. However, for skin contamination and intakes of radioactive materials, exposure to the agent (radioactive material on surfaces or in the air or water or food) precedes irradiation by that agent. In these cases, irradiation can be prolonged after

Table 6.1. Characteristics of Exposure and Irradiation for Three Kinds of Irradiation

Characteristic	External Source	Skin Contamination	Intakes of Radioactive Material
Irradiation Source Is Outside of Body	yes	yes	no
Irradiation Source Is On Body	no	yes	no
Irradiation Source Is Inside of Body	no	no	yes
Exposure and Irradiation	Simultaneous	Sequential (?)[(a)]	Sequential
Course of Irradiation Can Be Altered after Exposure	no	yes	yes

(a) See following discussion about skin contamination.

even a brief exposure. Furthermore, the course of irradiation can be altered after exposure for cases of skin contamination by decontamination (e.g., washing) or intakes (enhanced decorporation, e.g., chelation or other appropriate measures).

We concluded that the term "internal exposure" is an oxymoron, and that its use confuses workers, educated lay persons, toxicologists, and industrial hygienists. To be sure that the interviewees knew exactly what was meant by our questions, we tried to avoid the term "internal exposure" and instead carefully distinguished between the exposure and irradiation processes for radioactive materials in or on the body. This distinction is not usually made in radiological worker training, and this omission may contribute to the confusion we sensed in the interviews.

6.8 Applicability of the Mental Models Approach

The mental model approach is useful for investigating the knowledge and perceptions of radiation workers and comparing them with an "expert" science model to reveal differences. However, it is extremely time-intensive. This study was produced in approximately 800 hours of "charged" person-hours, but actually took closer to 1,200 hours. (About one-tenth of this was devoted to the task of gaining approval of the interview methodology and of the particular approach to handling data; many of the remaining hours were devoted to developing the science model and coding interviews.)

Is the mental models approach worth the cost and time compared with conventional questionnaire methodology? We believe it is, for applications that require risk communication -- such as education, training, decision making, and personal or institutional risk management. In these situations, one must first understand the processes and effects that influence a particular decision or range of decisions. These influencing factors are captured in the science or "expert" model. The questionnaire is then designed--based on that model--to elicit existing knowledge and perceptions from the target population. Only with the comparison of the two models (expert and target population) do gaps and misperceptions between the two become evident. Risk communication materials and activities can then be designed to address these gaps and misperceptions.

Even with the 1200 hours devoted to the present study, insufficient resources were available to support a number of steps that would have improved the validity and reliability of the results described here. These steps include

- alternative representations of the science model to better relate core knowledge to the decisions or behaviors of interest (to better distinguish "must have" information from "nice-to-know" information).

- a larger and more representative sample of workers

- additional iterations of the science model among toxicology and radiation training experts

- additional test interviews for improving the interview approach and developing the coding method

- more in-depth training of coders

- clearer specification of the decisions and behaviors to which the measured knowledge might be applied

These issues are summarized in a recommended research agenda presented in Section 7.0.

7.0 Future Suggested Studies

This was a pilot study with a relatively homogeneous group of 15 subjects, primarily focusing on workplace radiation. The objectives were to test a methodology and to gather data on specific hypotheses about workers' perceptions of radiation risk. The following three sections address suggested follow-on work in both these areas, as well as an extension of the general approach to other arenas.

7.1 Methodological Studies

In theory, some form of the general mental models approach could be a basic, valuable component of all communications or negotiations comprising risk management programs. The question is, how can this be done so that the effort and results are both practical and meaningful?

Mental models approaches have typically focused on single risk management decisions, such as whether to test one's house for radon or whether to place nuclear power sources in space (Morgan et al. 1992; Maharik and Fischhoff 1992). To make the methodology more useful for complex communications such as radiation training that involve many, varied, and potentially unpredictable decisions, or to extend the approach to public involvement and negotiation arenas for environmental remediation where decisions are more aptly points of view that may or may not translate into actions, we recommend the following research agenda:

- Further refine the science model presented here to focus on worker decisions that result in specific behaviors. Use training professionals and others to refine the model so it more clearly reflects information workers must know to reduce and manage their workplace risks, especially in off-normal situations. As part of this process, examine the gaps found in worker knowledge -- is the "missing" information really necessary for the scope of workplace decisions, or is it just "nice to know"? Which decisions do workers have control over, and which are mandated by administrative procedures or engineering controls? To help identify the possible range of workplace decisions, investigate safety and accident data on Hanford workers. The circumstances that led to reported injuries and accidents could shed light on poor or improper worker decisions.

- Further refine the science model presented here for application to public involvement in site risk management. Include risk assessors and systems engineers in refining the model content.

- Develop a more directly automated approach to coding and summarizing interviews to facilitate a broader sample of interviews without adding significantly more time to the data processing task. Specifically, explore methods of coding in real time, during an interview.

- Develop a method for allowing interviewees to review and revise the representation of their understanding of the risk in a manner that would not be overly reactive. This would reduce the problem of interpreting data, but should not suggest areas of knowledge to the interviewee that she or he did not have before the interview.

7.2 Workplace Radiation and Training Studies

The objective of these follow-on studies would be to build on the data presented in this pilot study to 1) validate its results, 2) generalize those results to a broader population of workers, and 3) support more specific recommendations for training. We recommend the following research agenda:

- Perform the same study with additional workers who represent different backgrounds, especially longer-term workers.
- Develop a structured survey to validate and generalize interview data; researchers from Carnegie-Mellon University and elsewhere have provided guidelines for such "post-interview" surveys.
- Further refine the science model as described in Section 7.1.
- Systematically evaluate current training methods and compare their content to the science model to assess gaps or misperceptions in standard approaches. Workers accident and injury reports could be used in part to do this.
- Systematically investigate the types of risk-related decisions that workers make during the course of their jobs and review the type of information they rely upon to make those decisions.
- Develop risk communication/training materials based on the results of these studies.

7.3 Other Areas

The mental models approach may be used effectively in public involvement programs, where interested and affected individuals and organizations influence or participate in a decision process. The following research agenda is proposed:

- Expand or refine the science model to address questions of relevance to the environmental risk management arena, such as final land use at Hanford, as described in Section 7.1.
- Perform a similar, broader-based interview study with specific stakeholders, examining how their belief set(s) differ from risk assessors' or risk managers' understanding of the risk.
- Recommend a research agenda to address points of discrepancy among mental models of stakeholders, risk assessors, and risk managers for which there are currently little scientific data.
- Develop communications activities and materials that clarify differences and establish common ground between the mental models of stakeholders and others.

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10.0 Glossary

Author: Dan Strom, Ph.D., health physics

contamination: *n.* 1. dirt; something where you don't want it. 2. radioactive material where you don't want it.

dose: *n.* the amount of ionizing energy deposited per unit mass, measured in joules per kilogram, rads, rems, grays (Gy), sieverts (Sv), etc.

endo-radiophobia: *n.* fear of internal radiation exposure.

exposure: *n.* the act of being exposed to a harmful agent, such as breathing air containing some hazardous agent (e.g., radioactive materials or smoke or lead or what someone just sneezed...); coming in contact with some hazardous agent (e.g., getting radioactive material or poison ivy or hepatitis on the skin); being present in an energy field (e.g., being in the sunlight, out in the cold, in an external radiation field, in a noisy environment, in a microwave oven when it's on); ingesting a hazardous agent (e.g., drinking hemlock or water containing radium).

genetic (effects): *a.* effects that may affect yet-to-be conceived children.

get crapped up: *v.* to become contaminated with radioactive material.

[ionizing] radiation: *n.* high-speed subatomic particles or photons with sufficient energy to break chemical bonds and cause ionization.

irradiate: *v.tr.* expose something to radiation (like irrigate is to expose to water...).

irradiation: *n.* the process of exposing something to radiation (like irrigation...).

radiate: *v.intr.* to come from a central point: *the flower petals radiate from the stem* (has no special meaning for ionizing radiation - generally not used).

radioactivity: *n.* 1. the phenomenon of spontaneous changes in the atomic nucleus, usually accompanied by the emission of ionizing radiation. 2. radioactive material.

radioactive: *a.* 1. containing radioactive material. 2. possessing radioactivity. 3. U.S. Department of Transportation uses the term as a package containing more than a specified quantity of a particular radioactive material or on a placard on a truck carrying certain kinds and quantities of packages of radioactive material.

radioactive material: *n.* material that undergoes radioactive decay, usually with the emission of ionizing radiation.

ray: *n.* I have no conceptual idea what "ray" means in the context of ionizing radiation. Alpha "rays" are really discrete particles, like balls; to describe a material as emitting alpha "rays" makes as much sense as to describe a pitcher emitting baseball "rays." I know what a sunbeam is streaming through a cloud; I know that what comes out of a ray-gun in a science fiction movie looks like a beam of light. I've seen a laser beam (consisting of gazillions of individual photons) traversing a smoky room. I know that "x rays," like light "rays," can "ray"diate (radiate) from a point. I know that radius is the distance from the center to the circumference of a circle. However, x rays are really discrete particles (called photons) like baseballs. "Ray" is an example of a term which pre-dates quantum mechanics, hopelessly confusing our thinking.

somatic (effects): *a.* damage from acute exposures, including hair loss, skin conditions, vomiting.

teratogenic (effects): *a.* effects to an unborn child or fetus.

Appendix A

Consent Form for Participation in Survey Research

CONSENT FORM FOR PARTICIPATION IN SURVEY RESEARCH

Investigators

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Research Project: DOE Workers' Beliefs Regarding Exposure to Hazardous Agents

Sponsored by: U.S. Department of Energy

INVESTIGATORS' STATEMENT

Need for This Research

We currently have little understanding of how workers believe they are exposed to contaminant risks, how their beliefs of contamination differ for different hazards (such as internal and external radiation), or how their beliefs may affect their behavior in the workplace.

People who design training materials for workers, or people who train workers, need to know three things: 1) what beliefs workers have about exposure to workplace contaminants, 2) what information they need to know to function safely in the workplace in the presence of those contaminants, and 3) how to correct workers' inaccurate beliefs and/or "fill in the gaps" to make worker knowledge more complete.

Purpose of Research

The purpose of this research is to find out what a small sample of Hanford workers believe about three things:

1) how they can be exposed to workplace contaminants, including internal and external ionizing radiation, plus one or more chemicals or elements

2) what effects occur as a result of exposure

3) what they can do to keep exposure as low as reasonably achievable.

Benefits

The benefit to the workers who participate will be the satisfaction of contributing to research that may lead to more effective training materials and training approaches. We will compensate workers, through a work package number, for one hour of their time required for each interview.

Procedures

Up to 20 inteviews will be conducted with employees from Westinghouse Hanford Company, Pacific Northwest Laboratory, or Kaiser Engineers Hanford Company. Participation is voluntary. We selected your name as a person who may work around radiation and has been employed up to 5 years as a radiation worker. Volunteers will give one hour of their time for the interview, with possible followup by phone to clarify responses.

If you decide to volunteer, your participation in this research will involve a private and confidential interview covering:

1. What type of worker you are.

2. What you know about exposure to internal and external ionizing radiation, such as how you are exposed to it, what effects occur from exposure, and what you can do to keep exposures low.

3. What you know about exposure to other workplace hazards such as carbon tetrachloride or lead.

This information will be compared with scientific facts about exposure processes and effects to see where the two groups of information agree and where they differ. Based on the results of that comparison, the research investigators will make recommendations about which worker beliefs should be addressed, corrected, changed, or augmented to make them agree more closely with the scientific facts.

Interviews will be pre-arranged by the research investigators and approved by the workers' supervisors. Interviews will take place at Hanford offices or conference rooms. Interviews will be audio-taped and transcribed later for analysis by the research investigators. Notes may also be taken during the interview. Workers may be asked during the interview to verify whether the notes taken accurately represent what the worker said.

There is a very small chance that after the interview we would contact the workers at a later date to verify or clarify answers to initial questions.

Risks, Stress, or Discomfort

No physical or psychological discomfort is anticipated as a result of these interviews. The interview questions are not a test, only a way to find out what various workers believe. We expect to hear a wide variety of responses from workers.

Results summarizing the interviews will be submitted for publication in September 1993, and possibly after that as well. As with all research funded by the U.S. Department of Energy, published results will be publicly available. In addition, because we must obtain approval from workers' supervisors for time to participate in the interviews, supervisors will be aware of specific workers' participation in the research. And because we are providing work package numbers to cover workers' time for interviews, it would be possible to identify participating workers through the Hanford financial system.

However, your name will not appear in any publication. Therefore, supervisors or others will not be able to identify which responses were provided by which workers. In addition, to keep protect the privacy of the workers, we will

- use a code label to identify answer sheets,

- remove any information identifying workers from the answers they give, and replace that information with the code label,

- erase audiotapes of interviews after the tapes are transcribed,

- keep coding and transcripts in a locked file, and

- not disclose the names or participation to any other person.

Participation in the study is voluntary. You can refuse to participate and/or withdraw at any time without penalty.

Questions

If you have questions about the study, you may ask them now or at a later time. For questions about the study, please contact Marilyn Quadrel, Dan Strom, Andrea McMakin, or Regina Lundgren at the phone numbers listed above.

If you have questions about your rights as a research subject, if you cannot obtain satisfactory answers to your questions, or if you have comments or complaints about the study, please contact

Harold Harty, Chairman
Human Subjects Review Committee
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352
(509) 375-6420

Participant Statement

Your signature here means that

- you have read the investigator's statement above,
- you have had the opportunity to ask questions about the research and what your participation means,
- you understand that your participation is voluntary, and that you may refuse to answer any specific questions or stop the interview entirely at any point,
- you understand that any information that may identify you will be kept confidential,
- you do not waive any rights that are otherwise available to you, and
- you voluntarily consent to your participation in the research described.

______________________________________ _______________
Participant Signature Date

______________________________________ _______________
Witness Signature Date

Appendix B

Phone Script for Screening and Characterizing Participants

Phone Script for Calling Hanford Employees to Create Master List of Potential Interviewees

Hello, I'm ________________ from Battelle. I'm working on a study where we're interviewing Hanford employees to get their views about radiation and hazardous chemicals in the workplace.

We're asking staff from Westinghouse, Kaiser, and Battelle if they are willing to be interviewed for one hour. We have permission from all the contractors and DOE to do this. We will give our volunteers a work package number to cover one hour of their time. We will get permission from the managers of the volunteers to take this hour from work.

Do you think you'd be interested in being interviewed about radiation and chemicals for an hour at Battelle?

[If no: Thanks anyway. Bye.]

[If yes: Great. What we want to do is put you on a list of potential interviewees. We won't be able to use everyone on the list. We are hoping to get people who have been working with radiation 5 years or less, get an equal number of men and women, and those kinds of things. But we're starting by getting a master list of people who are willing to be interviewed. Once we identify the actual interviewees, we'll let everyone on the list know whether we will interview them or not, and answer any questions they might have.

I'd like to get some background information about you first. Can I ask you a few questions about yourself?

What's your name? ______________________________________
[Note whether they are male or female] _______________
Is this your correct phone number ? ___________
Which company do you work for? ____________________
What is your official job title? ___________________________
What do you do there? ____
What is it about your job that requires you to work around radiation?

How long have you been qualified as a radiation worker?
What kind of radiation training have you had?
Which company sponsored the training?
How many classes and how long ago?
We want to include certain age groups in our study. Do you mind telling me your age? [If yes, ask what category they fit in: 20s, 30s, 40s, 50s, 60s, 70s]?
We want to include people with certain academic backgrounds in our study. Can you tell me how many years of schooling have you had?
Do you have a college degree?
If so, in what?
If we do end up selecting you to be interviewed, what is your manager's name so we can get permission from him/her?

Thank you. It will take us a few days to put together our master list of potential volunteers. I'll be calling you in a week or so to let you know if we'll be interviewing you. We appreciate your interest.

Do you have any questions?

Appendix C

Interview Questionnaire

Interview:
DOE Workers' Mental Models of Workplace Hazards
July 20, 1993

Introductory remarks to interviewee: As you know, we're interviewing workers to find out what they know and believe about radiation and other hazards in the workplace. After we interview everyone, we'll compare what they tell us with the knowledge and beliefs of health physicists and the public. We'll try to find out where there are differences. This isn't a test; we are interested in hearing what you think. Based on what you tell us, we'll probably recommend some ways of improving the existing Hanford training for radiation workers. We'll also use the things you tell us to decide what to focus on for future studies.

[Make sure we have the interviewee's informed consent form. If not, have them fill and out sign one there.]

We'll be taping this to make sure we don't miss anything you say. Is that OK?

We'll start out with some general questions, then get more specific as we go on.

Phase I: Radiation in General

1.1 Please tell me everything you know about radiation.

Anything else?
Can you explain that to me?
Can you tell me more about...?

[Note to interviewer: ask the interviewee to elaborate on any distinctions/comparisons, especially between internal and external radiation.]

Phase 2: Workplace Radiation

2.1 Now tell me what you know about <u>workplace</u> radiation.

Anything else?
Can you explain that to me?
Can you tell me more about...?

2.2 Tell me more about WHERE work-related radiation comes from.

Anything else?
Can you explain that to me?
Can you tell me more about...?

2.3 Tell me more about how a person could be exposed to radiation at work.

Anything else?
Can you explain that to me?
Can you tell me more about...?

[Note to interviewer: ask the interviewee to elaborate on any distinctions/comparisons they make, especially between internal and external radiation.]

2.4 Tell me what you know about effects of being exposed to radiation.

2.5 Are there things a person could do to control being exposed to radiation at work?

2.6 Are there things a person could do to limit being harmed by that exposure?

2.7 Do you have any personal concerns about radiation?

2.8 What would alleviate those concerns/What would make you feel better?

2.9 Some people distinguish between internal irradiation, that is, getting exposed from an intake of radioactive material, external irradiation that is, getting exposed by a source outside of the body. A third possibility is getting radioactive contamination on the skin. Does any of these three kinds of exposure concern you more than any other kind? If so, why?

Phase 3: Probabilities of Exposure

Now I want to ask you to estimate the chances of being exposed to or harmed by external irradiation, skin contamination, and internal irradiation. You can use these scales if you want. [explain scales]

There are several questions in this part, so I'm going to ask you the questions in this order. Using these two tables, I'll ask you to fill in numbers to estimate what you think the chances are of each of the three kinds of exposure, then the chances of being harmed by each of the three kinds of exposure. I'll ask these questions about yourself and others. This part of the interview gets kind of involved, but just hang in there. We don't expect you to give us exact numbers. Just give us your best guesses.

Using the scales, please fill in the boxes below.

PERSONAL PROBABILITIES: <u>EXPOSURE</u> Interview No.______________

Person in Question:	External Irradiation	Skin Contamination	Internal Irradiation from Intake of Radioactivity
You			
Someone picked at random from the Hanford phone book			
Someone you work with			

PERSONAL PROBABILITIES: HARM *Interview No.______________*

Person in Question:	*External Irradiation*	*Skin Contamination*	*Internal Irradiation from Intake of Radioactivity*
You			
Someone picked at random from the Hanford phone book			
Someone you work with			

3.1 Let's go back to your probability -- how might internal or external exposures happen?

3.2 What things might make this more or less likely?

3.3 If you got cancer or some other serious disease, what's the probability that it was caused by radiation at Hanford?

3.4 Say you received a rem of radiation from an external source and one internally. Is one type of radiation dose worse than the other? If so, why?

3.5 (WRAP-UP) Is there anything else you want to say about what we've talked about so far regarding radiation?

Phase 4: Hazardous Chemicals

4.1 Are you exposed to hazardous chemicals at Hanford? What are they?

4.2 How are you exposed to these chemicals?

4.3 Are there any effects of being exposed?

4.4 Are there things you can do to limit your exposure to chemicals?

Phase 5: Training

5.1 What radiation training classes have you been to and when?

5.2 Were the classes useful? Why?

5.3 Do you feel there are ways to make training more useful? Please explain.

Appendix D

Code Book

DATE: 9/16 AM

Interview # ____________

Date ____________

Coder ____________

Influence Diagram/Codebook

1. Background

1.1 Sources of radiation-General (e.g., *Radioactive materials* in HEPA filters, *where the radiation/contamination is coming from*)

1.2 Types of radiation-General (e.g., there are different types of radiation., a*lpha, beta, gamma, neutron, sun*)

1.3 Properties of radiation-General

1.3.1 Penetrating

1.3.2 Ionizing/Non-ionizing

1.3.3 Other

2. Properties/Sources of Radiation -- Specific to model

2.1 Workplace radiation

2.1.1 Chemical/*physical* form influences -

2.1.1.1 Concentrations in workplace (air, surfaces, etc) *Concentration applies to how much radioactivity is in an area - not physical units but rads*

2.1.1.2 Engineering controls

2.1.1.3 Work practices *(Length of time in area, use of protective clothing, behaviors vs engineering controls)*

2.1.1.4 Translocation - *type of radiation determines how it passes and where it goes - moving around in body (e.g., bone seeker, going from lung to kidney)*

2.1.2 **DON'T USE ANY OF 2.1.2 - INCLUDED IN 2.1 ABOVE** --Physical form influences

2.1.2.0 Concentrations in workplace (air, surfaces, etc)

2.1.2.1 Engineering controls

2.1.2.2 Work practices

2.1.2.3 Translocation

2.1.3 Nature of process generating radiation affects type and form of radiation

2.1.4 Amount of radioactive material in process influences -

2.1.4.1 Concentrations in workplace (air, surfaces, etc)

2.1.4.2 Engineering controls

2.1.4.3 Work practices

2.1.4.4 **DON'T USE - INAPPROPRIATE** Translocation

2.1.5 Specific isotopes affect -
2.1.5.1 **DON'T USE THIS** Concentrations in workplace (air, surfaces, etc)
2.1.5.2 Engineering controls
2.1.5.3 Work practices
2.1.5.4 **DON'T USE THIS** Translocation (?)

---

3. Workplace Conditions

3.1 Concentrations of radioactivity in air *(Radioactivity is the same as radioactive material but these are both different from radiation)*

3.2 Concentrations of radioactivity on surfaces

3.3 Controls
3.3.1 Administrative controls
3.3.1.1 Established radiation protection program
3.3.1.2 Principles of radiation protection: must be positive net benefit
3.3.1.3 ALARA *(Use if they specifically identify - if state time, distance, shielding code under 3.3.2)*
3.3.1.4 Limits on individual risk: individual dose not to exceed dose limits
3.3.1.5 Quantitative limits
3.3.1.5.1 Surface contamination
3.3.1.5.2 Air contamination
3.3.1.5.3 External doses
3.3.1.5.3.1 Whole body
3.3.1.5.3.2 Extremities
3.3.1.5.3.3 Lens of eye
3.3.1.5.3.4 Skin
3.3.1.5.4 Intake limit *(Ingestion/inhalation or any internal amount)*
3.3.1.5.5 Special groups
3.3.1.5.5.1 Minors
3.3.1.5.5.2 Pregnant women
3.3.1.5.5.3 Visitors
3.3.1.5.5.4 Public
3.3.1.5.6 Must be below regulation limits
3.3.1.6 Restrict access to areas, zones *(Important concepts are access and zones)*
3.3.1.6.1 For Radiation zones
3.3.1.6.2 For *Surface* Contamination
3.3.1.6.3 For Airborne radioactivity
3.3.1.7 Posting, warning signs
3.3.1.8 Training requirements
3.3.1.9 Experts to advise (e.g., the HP tech)
3.3.1.10 Personnel monitoring
3.3.1.10.1 External dosimetry
3.3.1.10.1.1 TLD
3.3.1.10.1.2 Film Badge
3.3.1.10.1.3 Pocket chamber, self-reader, direct reading dosimeter, pocket ionization chamber

3.3.1.10.2 Bioassay for internal dosimetry
3.3.1.10.2.1 Sample collection
3.3.1.10.2.2 Urine
3.3.1.10.2.3 Feces
3.3.1.10.2.4 Whole body count
3.3.1.10.2.5 Wound monitoring
3.3.1.10.2.6 Chest count
3.3.1.10.3 Personal air monitoring, breathing zone air, monitoring *(Have specific devices that monitor and give the hours*
3.3.1.10.3.1 DAC hours, MPC hours *(DAC=Derived Air Concentration - MPC=Maximum Preventable Concentration (I think))*
3.3.1.10.4 Frisking, personal contamination monitoring, portal monitors
3.3.1.10.5 Nasal swab for inhalation intake confirmation

3.3.1.11 Surveys
3.3.1.11.1 Dose rate
3.3.1.11.2 Surface contamination
3.3.1.12 Workplace, environment, effluent monitoring
3.3.1.12.1 Air sampling, air monitoring
3.3.1.12.1.1 Continuous air monitors
3.3.1.12.1.2 Grab samplers
3.3.1.12.1.3 General area air monitors
3.3.1.12.1.4 Exhaust or ventilation monitors
3.3.1.12.1.5 Stack monitors
3.3.1.12.1.6 Passive monitors
3.3.1.12.2 Water monitoring
3.3.1.12.3 Dose rate monitors, dose rate alarms
3.3.1.12.4 Criticality monitors and alarms
3.3.1.13 Inspections
3.3.1.14 Records
3.3.1.15 Audits
3.3.1.16 Licensing
3.3.1.17 Enforcement (CFR, civil and criminal penalties, DOE Orders, award fees, etc.)
3.3.1.18 Planning Meeting (before beginning actual work)
3.3.1.19 Radiation work permits, Radiation Work Plan (specific formal document)

3.3.2 Protective measures for **Delete distant hazards and insert** *external irradiation*
3.3.2.1 Time
3.3.2.2 Distance
3.3.2.3 Shielding *(same thing as engineering controls - shielding actually absorbs)*
3.3.2.4 Decay

3.3.3 Protective measures to limit contact with skin, body or internal irradiation
3.3.3.1 Containment -- Engineering controls
3.3.3.1.1 Multiple barriers, glove boxes, hot cells
3.3.3.1.2 Negative pressure, exhausts, ventilation
3.3.3.1.3 Filtration of air, water, process
3.3.3.1.4 Control physical and chemical form (e.g., absorb liquid w/ kitty litter
3.3.3.2 Dispersal -- Engineering controls
3.3.3.2.1 Exhaust through a stack
3.3.3.2.2 Discharge into river, ocean

3.3.3.2.3 Dump in land/tanks
3.3.3.2.4 Ship away
3.3.3.3 Exclusion
3.3.3.3.1 Protective clothing
3.3.3.3.2 Respiratory protection

3.4 External <u>*dose rate*</u> *(ambient) - e.g., "hot area" - not dose but how fast picking up dose, would be no dose if not there.*

4. Exposure - *Putting in harms way*

4.1 Pathways
4.1.1 Internal
4.1.1.1 Inhalation
4.1.1.2 Ingestion
4.1.1.3 Through intact skin
4.1.1.4 Through wound
4.1.2 On skin
4.1.2.1 Passes through clothing
4.1.2.2 Touch a contaminated surface
4.1.3 External: present in radiation zone *(External exposure is the same thing as dose)*

4.2 Breathing rate, level of exertion, movement (e.g., sitting down on contaminated ground) affects path, probability of exposure

---

4.3 Age, physical health, affects path, probability of exposure

---

4.4 Environmental conditions affect exposure -- e.g., weather affects concentrations of radioactivity, exposure for airborne radiation

---

4.5 Duration (long term) of work affects exposure

4.6 Choice of job affects exposure to radioactivity, co-carcinogens (risk increasing factors)

---

5. Irradiation - *(Where in the body/how much is retained)*

5.1 Translocation path affects where agent goes, amount retained

---

5.2 Half life of isotope affects retention time

5.3 Retention time affects amount retained in tissue/organs/on skin

---

5.4 Translocation/transport through body affects amount retained in tissues (see 2.5)

5.5 Age affects translocation, retention time

5.6 Protective measures to remove/neutralize agent from internal exposure
5.6.1 Neutralize: administer antidote
5.6.2 Induce vomiting
5.6.3 Sneezing

5.6.4 Gastric lavage (flushing)
5.6.5 Pulmonary lavage (flushing)
5.6.6 Diuretic
5.6.7 Speed passage through GI tract
5.6.8 Chelation (enhanced decorporation): EDTA, An -DTPA -- administer agent that speeds removal
5.6.9 Mass action: force fluids, administer stable compound
5.6.10 Remove from wound
5.6.11 Irrigate with saline
5.6.12 Remove surgically
5.6.13 Amputate

5.7 Protective measures to decontaminate from skin
5.7.1 Monitor, clean, monitor, clean
5.7.2 Wash, shower w/ soap
5.7.3 Gently scrub; do not abrade
5.7.4 Use chemical agents
5.7.5 Nothing can be done for some chemical forms

---

6. Dose *(Amounts - different types result in different doses)*
6.1 Amount of dose to tissue or organ

6.2 Types of radiation produce different doses (different isotopes w/ different half life)
6.2.1 Alpha
6.2.2 Beta
6.2.3 Gamma
6.2.4 Neutron

6.3 Dose concepts
6.3.1 Distribution of dose over time *(Chronic or acute - tortoise)*
6.3.2 Instantaneous dose rates *(receive all the dose at once/periodic "bursts" = hare*
6.3.3 Absorbed dose: energy per unit mass; rad, millirad, gray, milligray
6.3.4 Dose equivalent: absorbed dose * quality factor; rem, millirem, sievert, millisievert
6.3.5 Nonuniform dose: extremity, lens of eye, skin dose, hot particle
6.3.6 Committed dose from intakes: over 50-yr period after intake, amount of activity taken into body ("intake"); amount of activity retained in body ("disposition")
6.3.7 Microscopic dose distribution

6.4 Weight affects dose

6.5 Amount retained in tissue affects dose to tissue/organ

6.6 **DON'T USE** Measures to remove radioactive material from skin/body (see 3.4, 3.5 old codebook)

6.7 **DON'T USE - INCLUDED UNDER 7.1.2** Diet affects exposure to radioactivity, co-carcinogens, anti-oxidants (risk increasing/decreasing factors)

6.8 **DON'T USE** Smoking affects exposure to radioactivity, co-carcinogens (risk increasing factors)

6.9 Type of radiation affects level/type/probability of harm (see 1.2 old codebook)

6.10 Dose affects level/type/probability of harm (see 4.6 old codebook)

6.11 Distribution of dose over time affects level/type/probability of harm

6.12 Non-occupational rad exposure/background exposure affects level/type/probability of harm

6.13 Genetic predisposition affects level/type/probability of harm

6.14 Gender affects level/type/probability of harm

6.15 Age affects level/type/probability of harm

6.16 Treatment affects level/type/probability of harm (surgery, chemo)

6.17 Attitude/stress/fear affects level/type/probability of harm

6.18 Remission/recurrence affects level/type/probability of harm

7. Health Effects

7.1 Cancer
- 7.1.1 Dose to tissue, organ affects cancer
- 7.1.2 Exposure to other carcinogens
  - 7.1.2.1 Smoking
  - 7.1.2.2 Diet
  - 7.1.2.3 Type of job
- 7.1.3 Protective agents (e.g., anti-oxidants)
  - 7.1.3.1 Diet
- 7.1.4 Genetic predisposition
- 7.1.5 Gender
- 7.1.6 Age
- 7.1.7 Attitude
- 7.1.8 Diagnosis
- 7.1.9 Treatments
- 7.1.10 Remission
- 7.1.11 Recurrence

7.2 Teratogenic
- 7.2.1 Dose to fetus and related quantities
- 7.2.2 Exposure to other teratogens
  - 7.2.2.1 Choice of job
  - 7.2.2.2 Smoking
  - 7.2.2.3 Diet
- 7.2.3 Protective agents
  - 7.2.3.1 Diet

- 7.2.4 Genetic predisposition
- 7.2.5 Gender
- 7.2.6 Age
- 7.2.7 Diagnosis
- 7.2.8 Treatment

7.3 Genetic

- 7.3.1 Dose to parents' gonads and related quantities
- 7.3.2 Exposure to other mutagens
  - 7.3.2.1 Smoking
  - 7.3.2.2 Diet
- 7.3.3 Protective agents
  - 7.3.3.1 Diet
- 7.3.4 Genetic predisposition
- 7.3.5 Parents' age
- 7.3.6 Diagnosis
- 7.3.7 Treatment

7.4 Somatic

- 7.4.1 Dose to tissue or organ and related quantities
- 7.4.2 Exposure to other agents
- 7.4.3 Protective agents
  - 7.4.3.1 Diet
- 7.4.4 Gender
- 7.4.5 Age
- 7.4.6 Diagnosis
- 7.4.7 Treatment

7.5 Death

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8. Not in Science Model

8.1 Trust

- 8.1.1 Coworkers
- 8.1.2 HPTs
- 8.1.3 Supervisor
- 8.1.4 Company
- 8.1.5 Self

8.2 Not Trust

- 8.2.1 Coworkers
- 8.2.2 HPTs
- 8.2.3 Supervisor
- 8.2.4 Company
- 8.2.5 Self

8.3 Metaphors for internal radioactive materials
- 8.3.1 Snakebite, sting, injection of poison
- 8.3.2 Corrosion, rust, rot
- 8.3.3 Deterioration, decay
- 8.3.4 Invasion, invasiveness
- 8.3.5 Time bomb
- 8.3.6 Irrevocability

8.4 Metaphors for external radiation
- 8.4.1 **DON'T USE** Wash or scrub
- *8.4.2 Sunburn*
- *8.4.3 Burn (other than sunburn)* e.g., heat burn, thermal burn

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8.5 Attitude and beliefs of rad workers, managers, decision makers
- 8.5.1 Managers don't acknowledge insight, experience of workers
- 8.5.2 Managers do acknowledge insight, experience of workers
- 8.5.3 Rad workers bring skilled experience base when evaluating jobs
- 8.5.4 Issue of knowledge of job procedures, education
- 8.5.5 Fear: can hinder ability to perform
- 8.5.6 Knowledge required to read signs, use common sense
- 8.5.7 Incomplete understanding hinders performance

Questions:

Comments:

Observations:

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(Note: Workers who were interviewed are not listed here.)

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