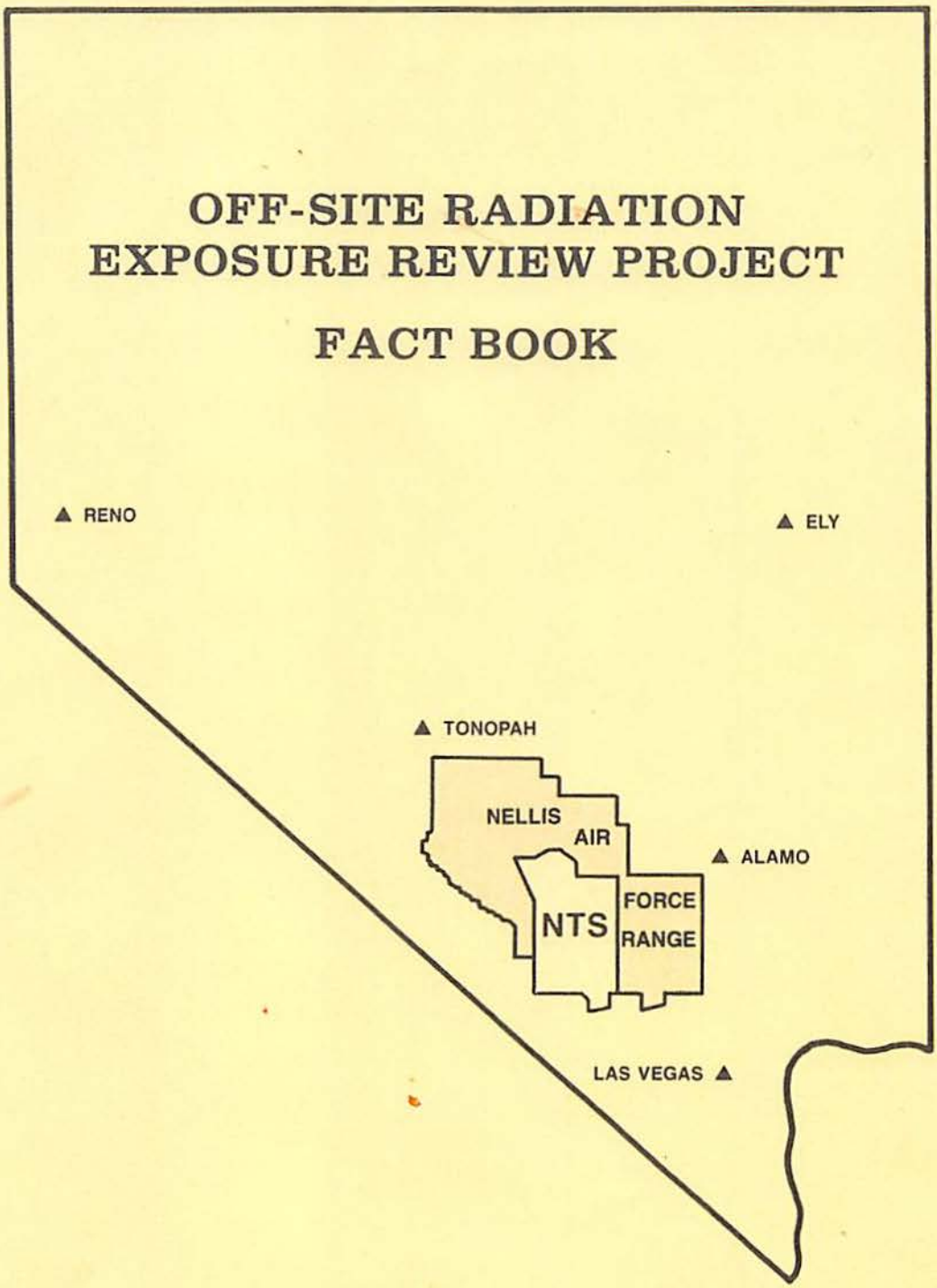
OFF-SITE RADIATION EXPOSURE REVIEW PROJECT

FACT BOOK



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I. INTRODUCTION

Development and testing of nuclear devices* and study of the effects of nuclear weapons have been ongoing tasks of the United States Government since 1941. The first nuclear detonation was accomplished at Alamogordo, New Mexico, on July 16, 1945. After World War II, Bikini and Enewetak atolls, located in a remote area of the Pacific Ocean, were selected as sites for the first two series of postwar nuclear tests. From 1951 through 1958, nuclear tests were conducted in the atmosphere both in the Pacific and at a continental site in southern Nevada. Radioactive fallout from some of the Nevada tests was carried by the wind from the Test Range Complex to communities nearby. Residents were told that fallout radiation levels were being monitored, and they were assured there would be no adverse health effects.

A series of events beginning in 1977--26 years after the first test in Nevada--has rekindled interest in the subject of radioactive fallout from the atmospheric nuclear tests. During 1977, national publicity was given to the claim that there was an excessive number of cases of leukemia among military observers of the SMOKY nuclear test of August 31, 1957. Following this publicity, numerous claims were filed against the U.S. Government through the Department of Energy (DOE) by residents of Nevada, Utah, and Arizona. Claimants maintain that Atomic Energy Commission (AEC) officials were negligent in conducting the nuclear tests during the 1950's. (Nuclear testing functions are now administered by the AEC's successor agency, DOE.) Residents claim the government should have given them more information so they could protect themselves from the radioactive fallout, and that fallout radiation has caused death, ill health, and suffering. The position of the U.S. Government is that doses resulting from exposures to radioactive fallout were not sufficient to cause the injuries claimed. During 1978, as allegations of injury from fallout radiation received more publicity, there was a dramatic increase in the number of damage claims filed; the number of new claims filed has diminished each year since then. As of July 31, 1984, approximately 1,200 damage claims amounting to over $2.75 billion have been filed by off site residents against the U.S. Government alleging injury from fallout radiation due to the nuclear weapons testing program.

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* Underlined words, terms, and acronyms are defined in Appendix A.

In 1978, the Department of Energy staff recognized that resolution of damage claims hinged upon the amount of test-related radiation to which the claimants had been exposed. However, there was no consensus among informed scientists as to the magnitude of external radiation exposures to the public or whether doses resulting from ingestion and inhalation of fallout particles could in fact be determined. Estimation of the radiation dose to an individual required a scientific program to review data on fallout deposition and to assess the contributions from external and internal radiation exposures.

This Fact Book provides brief explanations of why the Off-Site Radiation Exposure Review Project (ORERP) was started, how it is organized, and the method of peer review. The two main project objectives are then presented in some detail. In a sense this is a project status report as of the end of 1984. The descriptions of work being done and the relationships between tasks are not expected to change significantly before the project is completed. Results presented here are preliminary. Final project results will be published in professional journals. Most of the material in this report has been condensed from transcripts of meetings of an advisory group. The transcripts are available from the Coordination and Information Center as explained on pages 8 and 9.

(Another Fact Book, "A Perspective on Atmospheric Nuclear Tests in Nevada", available from the Nevada Operations Office of the DOE, provides historical background and perspective on the testing of nuclear devices and weapons at the Nevada Test Site (NTS). Nuclear tests contributing to off site deposition of radioactive fallout are identified, and the concept of cumulative estimated exposure is explained. The difficulty of associating health effects with radiation is presented, and the status of litigation against the government is summarized.)

II. OFF-SITE RADIATION EXPOSURE REVIEW PROJECT

A. GENESIS

During 1978, the DOE received several hundred personal injury claims from residents of Nevada, Utah, and Arizona, that alleged harm from radioactive fallout, and many requests for data regarding personal radiation exposures. Many requests for information were also received from congressional sources and from the news media. The task of responding to congressional inquiries and to personal injury claims fell primarily on DOE Headquarters (DOE/HQ) and the Nevada Operations Office (DOE/NV). At the request of DOE/HQ, DOE/NV prepared a Project Plan to address management and coordination of the DOE's response to these inquiries. The plan detailed two main areas of effort: a) centralized information management and coordination and b) data consolidation and dose evaluation.

On March 28, 1979, DOE/NV was directed, within specified budget constraints, to collect, preserve, and disseminate historical data related to radioactive fallout and health effects from nuclear testing. The Reynolds Electrical and Engineering Company, Inc. (REECo), a prime contractor for the DOE at the Nevada Test Site, was directed to establish the capability to perform the data coordination function.

DOE/NV solicited the special expertise of the Lawrence Livermore National Laboratory (LLNL) to perform the complex calculations required for estimation of doses to individuals that could have been due to fallout radiation. The LLNL responded with a proposal to include consideration of inhalation and ingestion pathways in addition to the reevaluation of external exposures estimated in the late 1950's and early 1960's. On June 8, 1979, DOE/NV was assigned a separate task as lead office for dose assessment with the responsibility for reconstructing, insofar as possible, estimates of the exposures to the off site public from nuclear testing at the NTS, and the doses to these individuals resulting from the exposures.

As project plans matured and specific tasks were identified, additional contractors were brought into the program to perform the work as separate task groups. The Los Alamos National Laboratory (LANL) provided expertise in modeling and estimating external radiation exposure. Colorado State University (CSU) utilized their expertise in radioecology to analyze the ingestion of radionuclides from fallout through the food chain into the human body.

Desert Research Institute (DRI), part of the University of Nevada System, accepted responsibility for statistics and data management support. In addition, laboratories of two federal agencies agreed to conduct new studies of where fallout had occurred. These laboratories are the Environmental Monitoring Systems Laboratory (EMSL) of the Environmental Protection Agency, and the Weather Service Nuclear Support Office (WSNSO) of the National Oceanic and Atmospheric Administration.

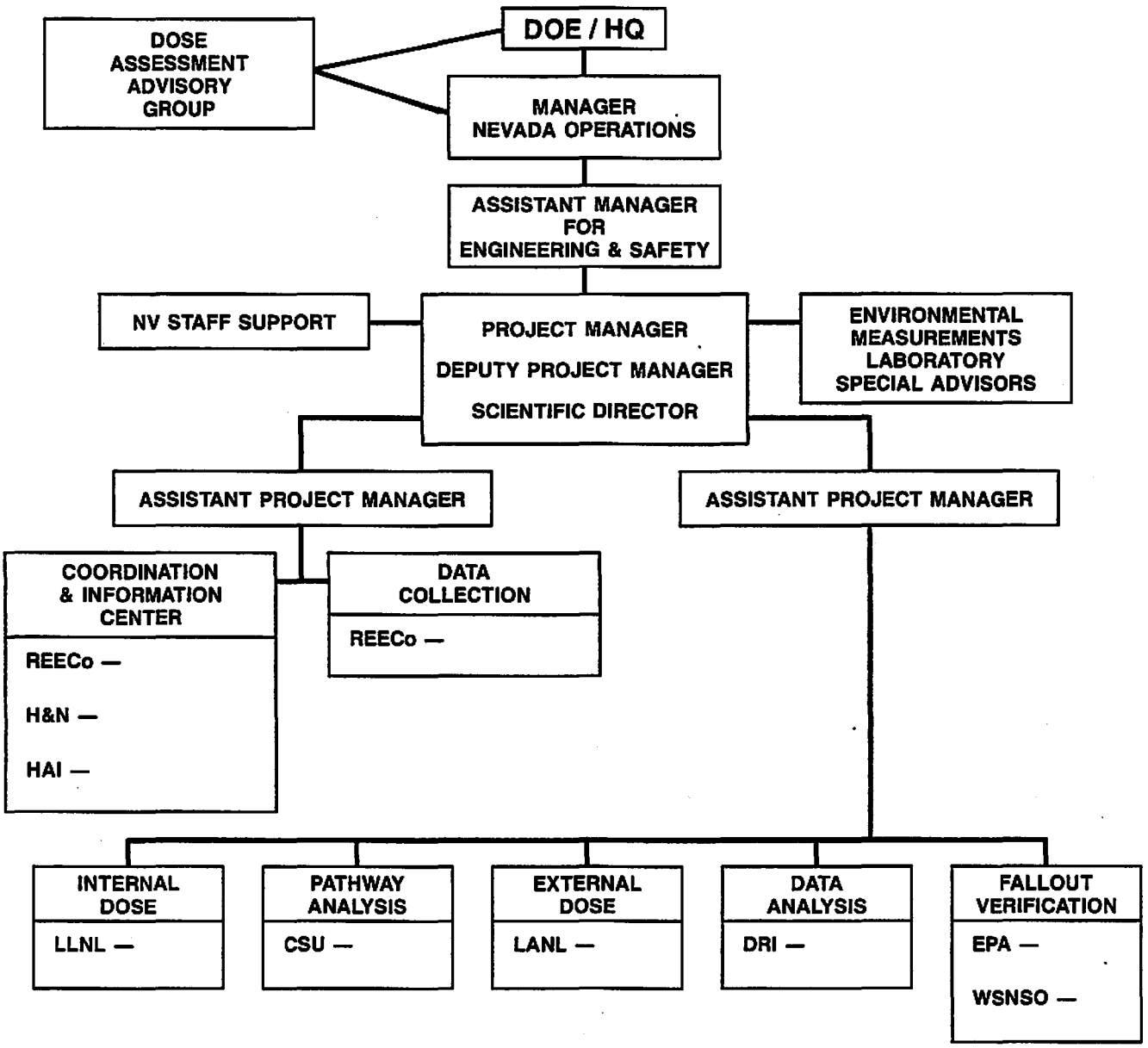
Combination of the data coordination and dose assessment tasks became known as the Off-Site Radiation Exposure Review Project.

As an early step in getting the project underway, DOE/NV management invited the governors of Nevada, Utah, Arizona, and California to a briefing in Las Vegas, Nevada. Representatives of the states of Nevada, Utah, and Arizona attended the meeting on July 13, 1979, at which DOE/NV management and LLNL scientists explained the scope of the anticipated exposure review project and solicited state cooperation. On August 23-24, 1979, the Dose Assessment Steering Group was assembled to oversee the ORERP effort and to provide independent outside review of the project. In order to meet conditions of the National Advisory Committee Act an application was submitted to DOE/HQ for approval. With changes in both name and membership, the Dose Assessment Advisory Group (DAAG) was formally established with publication of a notice in the Federal Register on July 11, 1980.

B. ORGANIZATION

The ORERP organization is shown in Figure 1. Responsibility for project execution resides with the Manager, DOE/NV, who reports to DOE Headquarters. The Dose Assessment Advisory Group has been assembled to provide independent outside review and recommendations to the Secretary of DOE and to the Manager, DOE/NV. Within DOE/NV, the project is administered through the office of the Assistant Manager for Engineering and Safety (AMES). Reporting to the AMES and responsible for direct project oversight is the Project Manager who develops and interprets the charter and scope of effort of each task group; monitors task group progress and coordinates working relationships between task groups; reviews task group reports and materials for public dissemination; reviews and implements recommendations from the DAAG and from DOE/HQ;

Figure 1. OFF-SITE RADIATION EXPOSURE REVIEW PROJECT ORGANIZATION CHART



coordinates technical exchanges with state and local government representatives; and develops budget requirements by task group. The Project Manager works closely with special advisors from DOE's Environmental Measurements Laboratory (EML) in New York. (EML was formerly the Health and Safety Laboratory, or HASL.)

The Project Manager is assisted by a Deputy Project Manager and a Scientific Director. The Deputy is responsible for administration of project and task group budgets, for implementing and coordinating routine administrative matters, and is the Executive Secretary of the DAAG. The Scientific Director --a scientist from LLNL--monitors, coordinates, reviews, and directs the scientific and technical activities of the task groups. The Scientific Director was responsible for developing the scientific methodology being used to meet ORERP objectives.

Two Assistant Project Managers, who report to the Deputy Project Manager, are responsible for coordinating day-to-day activities within the project. (The Coordination and Information Center appears as a task group on the organization chart; in actuality it is administered as a separate entity.) The DOE organization is structured so that staff support is available from other divisions within NV, and other DOE contractors can be utilized for special assignments.

C. DOSE ASSESSMENT ADVISORY GROUP

The DAAG was chartered in accordance with provisions of the Federal Advisory Committee Act (Public Law 92-463), OMB Circular A-63 (Revised), and Section 624 of the DOE Organization Act (Public Law 95-91). The initial authorization covered the period from July 1980 to July 1982. The charter has been renewed in 2-year increments; the present charter expires July 15, 1986.

According to the charter, the DAAG is to provide the Department of Energy with independent advice and recommendations concerning the assessment of integrated radiation doses from the deposition of radioactive fallout in areas outside the NTS. The DAAG reviews plans, organization, and technical direction and coordination for the ORERP and provides comments and advice on task group activities and reports. The DAAG reviews task group proposals and, through the review and comment process, assists in guiding the development of each task, subtask, or task group activity. The DAAG also reviews and comments on the work products from the task groups.

Membership on the DAAG includes representatives from various disciplines and from state and public sources. Members were selected on the basis of their preeminence in the fields of radiological and biological sciences, their professional expertise, their insight into the relationships among the various disciplines, and their working experience. DAAG members are listed in Appendix B.

DAAG members receive no compensation for their efforts but are allowed per diem and travel expenses for travel to scheduled meetings. All meetings of the DAAG are open to the public. In addition, the public is invited to submit written questions to the Group and to make statements or to ask questions at the end of each daily session. Verbatim records of all proceedings are prepared, and transcripts are available to the public in the Coordination and Information Center.

III. PROJECT FUNCTIONS

A. COORDINATION AND INFORMATION CENTER

One main objective of the ORERP is to make fallout radiation information available to the public. The Coordination and Information Center (CIC), established for this purpose, is designed to respond to public inquiries and federal requests regarding radioactive fallout on localities surrounding the Nevada Test Site. This center, operated for DOE/NV by REECo, was formally opened to the public on July 23, 1981.

Personnel in the center identify, collect, and organize historical data and information related to radioactive fallout from nuclear testing. They format and code the document collection into a bibliographic data base designed to facilitate search and retrieval. Collected documents are housed in a central repository in Las Vegas, Nevada, where they are available to the public. As of July 1, 1985, the CIC had provided public reference services to 439 visitors and had photocopied slightly over 5,000 documents in response to 1062 requests for information.

Major repositories of historical records pertinent to the ORERP were identified, and these collections were reviewed to estimate the quantity of materials applicable to the ORERP. Then either original documents or reproducible copies were obtained for inclusion in the CIC archives. Documents have been received from major sources such as the DOE/HQ archives, the Defense Nuclear Agency of the Department of Defense, state archives of Nevada and Utah, National Laboratories at Livermore and Los Alamos, the EPA and Public Health Service laboratories, and DOE contractors in Las Vegas. The review and selection process is in progress at several lesser repositories. By mid-1985, about 170,000 documents had been collected, of which 79,000 had been processed through the indexing and preservation system.

Classified documents containing pertinent information are reviewed, and, whenever possible, are declassified. (Information is "classified" when its unauthorized release could damage the national defense of the United States.) In some instances, unclassified data are extracted from classified documents. Declassified documents and unclassified data are made available for inclusion in the CIC archives. By this process, information concerning off site fallout is removed from classified documents and is made available to the public.

The CIC was established to collect, store, and disseminate historical information and data related to the nuclear testing program. When the dose assessment project was authorized, the role of the CIC was expanded to include a Data Collection task group to support the other task groups working on dose assessment. The other task groups requested specific information that was located and supplied by the Data Collection element from documents in the CIC.

Staff of the CIC has located a substantial quantity of information that was not readily available to the public or to the scientific community. All such information has been preserved, and copies of the data sheets and tabulations were provided to the appropriate task group. Historical data concerning measurement of fallout radiation were collected from sources such as monitors' log books, compilations of results from film badges and other radiation recorders, analytic reports of air filters and other environmental samples, personal logs, etc., and have been added to computerized data bases as appropriate. Film badge, survey meter, and air sampler data bases are organized into series and event time groups to facilitate retrievals.

Services available at the CIC include the following:

1. A public reading room where documents of general interest are available for use.
2. Indices to the entire collection (both printed and on microfiche) based on titles, authors, government report numbers and a Keyword in Context (KWIC) list on title words.
3. A research area where requested documents may be used by those interested in detailed studies.
4. A computerized bibliographic data base available on the Department of Energy's RECON System. (A fee is charged for this service.)
5. Staff research assistance to those who request it.
6. Document duplication, at the patron's request, for which a fee will be charged according to an established schedule.

Inquiries sent to the address of the CIC, shown inside the front cover of this Fact Book, will receive prompt attention.

The public is welcome to visit the Center at 3084 So. Highland Drive, Las Vegas, Nevada.

B. DOSE ASSESSMENT

The second main objective of the ORERP is to produce a reevaluation of off site radiation dose to individuals as characterized by region, community or locale, age, and occupation.

As with any complex project, dose assessment has evolved through a number of phases, and the emphasis given to various tasks has changed to reflect progress and needs. The initial effort was to define the problem and propose a plan to solve that problem. Task group efforts were, therefore, directed toward defining sources and pathways of radiation exposure. Nuclear tests conducted at the Nevada Test Site were the primary, though not the only, sources of interest to this project. The pathways included fallout deposited on the ground and on the skin of individuals who were outside when fallout occurred, breathing of air containing fallout particles, and eating or drinking materials that had been contaminated directly or had become contaminated through a more complex chain. (For example, by drinking milk from a cow that had eaten contaminated forage; the milk was not directly contaminated but could contain radionuclides that had passed through the cow's digestive and milk-making systems.)

A serious obstacle to overcome was that the period of primary fallout was 20 to 30 years ago, and the data collected then were not adequate to provide answers to all of today's questions. The approach to this problem has centered on gaining an understanding of past events by mathematical modeling and simulation. After the overall project methodology was developed, the first required task was to search out all available historical data for entry into data banks for later retrieval and use. Mathematical models of the several exposure routes are being constructed. Model predictions are being checked against historical measurements. The various models will be tied together into an integrated unit. And, to the extent that it can reasonably be done, the locations for which estimates may be computed are being extended beyond the area where fallout radiation was monitored during the period of atmospheric testing. These steps have been in progress since early 1979.

The dose assessment function is being accomplished primarily by the six task group elements which are described on following pages.

1. Data Collection

The primary objective of the Data Collection task group, provided by REECo, is to support project investigators working on the dose assessment function. This task group provides a resource center for other task groups to obtain historical information required for the completion of their tasks, screens collected material, and assists project investigators in searching records for data and information useful to the task group's objectives.

The Data Collection task group assisted the other task groups in various ways, primarily by preparing data for computer-oriented applications. The Data Collection task group encoded and processed estimated exposure data for communities near the NTS as requested by the Internal Dose task group. They encoded survey meter data and geographical coordinates of monitoring points to aid the Fallout Verification task group and assisted the Data Analysis element in digitizing road and community locations as they existed during the 1950s. The Data Collection task group located air quality data and provided this information to the Internal Dose task group. They also assisted the EMSL in generating, evaluating, and verifying other data files.

Task group assistance was more significant during the early years of the project, in 1979-1981, but has diminished as other task groups obtained all the available information and began utilizing it in their work.

2. Fallout Verification

Two primary objectives were identified for the Fallout Verification task group. The Weather Service Nuclear Support Office (WSNSO) of the National Oceanic and Atmospheric Administration was assigned the task of conducting a limited reexamination of the distribution of fallout in locations surrounding the NTS. The EPA's Environmental Monitoring Systems Laboratory (EMSL) in Las Vegas was tasked to develop an environmental data base to support the dose assessment effort.

a. WSNSO. The objectives of WSNSO are to reexamine the off site distribution of local fallout and fallout arrival times for eleven selected nuclear tests, ten of which were important contributors to off site fallout. WSNSO is using radiological measurements made in off site locations after each test and meteorological data collected at and following test time to

reconstruct fallout patterns and arrival times independently of similar work performed during the 1950s and 1960s.

Fallout verification reports have been published by WSNSO for tests HARRY, SMOKY, ANNIE, BOLTZMANN, SMALL BOY, and NANCY. Results of the reanalyses for these tests have differed only in minor details when compared to analyses performed immediately following each test. For the BOLTZMANN test, a significant finding was that the "hot spot" located about five miles west of Warm Springs, Nevada, and frequently referenced in the literature to illustrate the "hot spot" phenomenon, was actually the result of an error in the initial radiological data analysis. The person who analyzed the data collected over the alleged "hot spot" area apparently applied incorrect sensitivity scales to the aerial strip-chart data. The sensitivity scales are used to relate the count rate obtained by detectors in aircraft to the count rate obtained by detectors at ground level. Correction of these errors eliminated the so-called "BOLTZMANN hot spot".

Fallout verification reports are in progress or planned for tests EASY, SIMON, BADGER, BEE, and ZUCCHINI. Given continued close agreement between fallout patterns constructed during the 1950s and current independent reanalyses, there would not likely be a need for extending this work element.

WSNSO is also assisting the task group at LLNL by locating and providing meteorological data required for computer simulation of fallout patterns and times of fallout arrival. Computer simulation is being explored as one means of estimating fallout patterns beyond the area where exposure-rate measurements were customarily made by monitors on the ground. WSNSO is also working with scientists from EG&G, Inc., in rechecking the relationship between radiological data collected at ground level and similar data collected by detectors in aircraft flying over the same ground.

b. EMSL. The objectives of the EMSL are a) to identify all EPA and Public Health Service (EPA/PHS) data which might be useful to the dose assessment effort, statistical analyses, or historical research purposes and, b) to develop computerized data bases for storage and retrieval of these data. Data categories include readings from film badges, thermoluminesent dosimeters (TLDs), and survey meters; results from analysis of samples of air, milk, and water; and records from historical log books, PHS reports, and computer tabulations. The EPA/EMSL has encoded the historical film badge and survey meter

data from original monitoring records, provided geographical coordinates and neartown identifiers for each data point, and has loaded this data into a computerized data base management system. In general, various categories of data were not collected on a continuous basis.

The Film Badge Data Base includes data from the main testing periods between 1952 and 1958, then is continuous from September 1961 through 1964 for a total of about 27,600 entries. Both film badges and TLDs were placed together from the initiation of the TLD program in 1965 until 1970 when use of the film badges was discontinued. (Both systems record radiation exposure, but the TLDs are more sensitive than film badges and are able to record variations in background radiation levels.) Film badge data for the period of overlap have not been entered into the data base. The TLD data base contains a few more than 12,200 records collected from the start of the program to the present; all TLD data have been entered into the data base.

The Survey Meter Data Base includes over 77,000 survey meter readings taken during the main testing periods in the 1950s and 1960s.

Results of sampling and analysis of air, milk, and water are in the EPA's Sample Tracking and Data Management System (STDMS). Air sampling was done intermittently between January 1951 and June 1963, then became continuous to the present. Sampling of milk and water, also intermittent during the early years, began for this program in February 1955 and has continued to the present. These data bases and files contained over 466,000 individual records as of July 1984, and data entry is continuing. The EMSL operates and maintains the TLD and STDMS data bases as part of their routine monitoring program, separate from any ORERP requirements, and will continue this function beyond termination of the ORERP. Data from the period of atmospheric nuclear testing--the historical portion of interest to the ORERP--will be available from both EMSL and the CIC.

The EMSL has transferred a large library of PHS and EPA documents to the CIC. The first transfer involved 42 boxes of old documents; more recently, documents filling about 60 file drawers were transferred. The CIC is processing these documents into the archives. These documents contain the existing record of PHS involvement in the atmospheric testing program. The documents do not all contain information of direct interest to the ORERP, and some documents may be duplicates, but the end result is an important addition to the CIC.

The other task groups have assisted the EMSL by contributing relevant data and by encoding and proof-checking data, and have utilized the data bases for their own purposes. The External Dose group obtained measurements of external exposure. The Pathway Analysis group obtained data sets to be used in verifying pathway models. The Data Analysis group identified and coordinated survey meter measurement points and estimates of the exposure rate and time of fallout arrival. During the early part of the project, the Data Collection group provided the EPA/EMSL with clerical assistance for data encoding and entry.

3. External Dose Assessment

The objective of the External Dose Assessment task group at the Los Alamos National Laboratory (LANL) is to establish the external component of the total dose commitment to the off site public. The external component includes gamma radiation from a passing cloud of fallout debris, beta radiation from fallout particles deposited directly on the skin, and beta and gamma radiation from fallout deposited on the ground.

The External Dose Assessment task group uses exposure rate and time-of-arrival data, along with source terms recently calculated by the group at LLNL, to estimate the external dose at different times and locations. If historical survey meter data are available, these data are used for exposure-rate values for the location and time of interest. If survey meter data are not available, this group uses interpolated exposure rates and times of fallout arrival as determined by the Data Analysis task group from digitized maps of fallout patterns. Modern techniques for statistical analysis are used to derive current estimates of personal exposure which are compatible with all the historical measurements. This task group has found little difference between estimates made in the 1950s and results from current recalculations using the same historical data.

This task group has investigated the effect that buildings had in shielding an individual from fallout deposited on the ground in the immediate vicinity. The amount of shielding provided by a building depends upon the materials used and the style of construction. Earth materials such as rock, brick, and cement products provide more shielding than a wooden structure. Individuals who spent time in a basement were shielded to some extent by the surrounding earth and basement walls, and individuals who spent time on the second floor of a two-story house were exposed to less radiation because of

the added distance above ground level. Because of these relationships, and other factors such as pitch of roof and nearness to other large buildings, it is important to know the construction material and building style in order to calculate the amount of shielding that a building provided. LANL conducted a survey of 446 homes typical of the dwellings of southern Utah during the 1950s, and uses the results of this survey in estimating shielding factors.

Another important factor in assessing external radiation exposure is the amount of time spent out-of-doors. Age and occupation have a bearing on the time normally spent outside where an individual would have been unshielded from fallout radiation. The External Dose task group has included the results of a lifestyle survey into the external exposure model. However, information regarding a specific person will be used, if available, in calculating the radiation exposure for that person instead of using values derived from the survey. Estimates of uncertainty are applied to the lifestyle assumptions because no records are available for specific daily activities which took place 30 years ago.

Using a simulation model to estimate external exposure involves numerous assumptions, each with its own uncertainty. Part of the External Dose task is to identify these areas of uncertainty and develop enough understanding of them to assign or compute a range of probable values that can be used in computing final estimates. The task of identifying uncertainties also produces a list of questions that suggests the need for more investigation. Examples of such topics include evaluation of the effect of wind speed on deposition of particles on the skin or clothing, and the effect that a large building upwind of a residence would have on the level of radiation exposure close to the residence. While dose estimates have been calculated for specific individuals, work continues in refining the model and understanding the uncertainties.

In addition to computing individual estimates of external dose, this task group is calculating estimates of population dose for communities. This information can be used in the future by epidemiologists studying the incidence of various diseases. These calculations consider the exposure rate and time of arrival for each nuclear test producing fallout in a community, the lifestyle of community residents as determined by survey, and utilize census data in deriving estimates of population dose by counties and communities. Preliminary estimates have been generated and are being evaluated to identify any problems which may need further work.

4. Pathway Analysis

The principal objective of the Pathway Analysis task group from Colorado State University (CSU) is to develop a computer model to simulate the transport of fallout radionuclides through foods into the human body.

The simulation model includes the various ingestion pathways necessary to develop a complete assessment of internal radiation dose due to ingestion. The model estimates integrated human ingestion per unit of fallout deposition for at least 20 significant radionuclides and considers such factors as age, food habits, and lifestyle of residents who lived in areas receiving fallout from tests at the NTS. The model is designed to compute intake of radionuclides which contribute to the population-dose estimates for specific counties and communities as well as for specific individuals.

The simulation model is as realistic and site-specific as available data justify. The model predictions are being tested against available data sets and calibrated as necessary to ensure credible accuracy. More than 30 reliable data sets have been found, and the search is continuing. For example, milk samples were collected from dairies near Salt Lake City during the summer of 1962, and the level of iodine-131 was measured at various times following deposition of NTS fallout. The simulation model is used to generate estimates of iodine-131 in milk, and a comparison of predicted to observed values provides a measure of the model's predictive accuracy.

Because milk contaminated with iodine-131 (and other radionuclides) can be a significant contributor to human radiation exposure, an effort is underway to understand the milk production and distribution patterns as they existed between 1950 and 1970. Milk distribution studies are being conducted for Nevada, Utah, Arizona, Colorado, Wyoming, Idaho, and New Mexico.

The Pathway Analysis group has identified about 40 important factors or parameters that influence the final estimates calculated for an individual. These factors include such things as the age of fallout, the concentration of radionuclides in animal feed and in food for human consumption, the amount of feed or food eaten, and many more. The sensitivity of model predictions to each of these parameters is being investigated to determine how to reduce uncertainty in the predictions. The process is complex, and many of these parameters (e.g., transfer of radionuclides from pasture to the cow, to the milk, and to the human thyroid) operate within a wide range of values rather than being constant. Therefore, an additional effort is to develop a version

of the computer code that performs calculations based on probability functions for the most important parameters. The benefit of this procedure is that such calculations can also generate estimates of the degree of uncertainty associated with the final computed values. The most probable final value can then be stated along with an estimate of the range of uncertainty in the answer.

Efforts devoted to validation studies, sensitivity analysis, and probability functions are all aimed at understanding and defining the degree of uncertainty inherent in the models. Results from the lifestyle survey are being incorporated into the model to provide a realistic basis for constructing diets and food consumption rates typical of the areas of greatest interest. These results are considered an integral part of the model and make a significant contribution to defining the degree of uncertainty in the final model estimates.

The Pathway Analysis group will continue performing validation studies, investigating sensitivities, and refining the simulation models as long as the ORERP is active, because each refinement improves confidence in the final output. Research results and documented computer codes will be published and made available for use by others. The computer code will be transferred to the Data Analysis task group to be integrated into the Individual Dose Assessment model which is expected to be operated and maintained for as long as it is useful to the public.

5. Internal Dose Assessment

The primary objective of the Internal Dose Assessment task group at the Lawrence Livermore National Laboratory (LLNL) is to reconstruct the most likely radiation dose to off site residents from ingestion and inhalation of radioactive materials.

The first essential step in reconstructing the most likely radiation dose was to develop a model to compute the inventory of radionuclides generated by nuclear detonations. The quantity and mix of radionuclides depend upon many factors, such as the height of burst above ground, the total yield of the device, whethe. the device was mounted on a tower or was suspended from a balloon, and whether the nuclear fuel was uranium, plutonium, or a combination of the two. The model was based upon many measurements taken on samples obtained by aircraft penetration of nuclear clouds. This led to the creation of an empirical data base on fission yields of particular nuclides that was

used in a general calculational model. The calculational model included all known factors needed to compute the radionuclide inventory for all nuclear detonations generating radioactivity detected outside the NTS. The results of these calculations are called source terms.

Following initial preparation of the model, data from several nuclear tests in 1953 and 1957 were used to compare model output with actual radiation measurements made after the detonations. The initial quantity of each radionuclide was calculated based on the factors mentioned above. Then the radioactive decay and/or ingrowth of each radionuclide was calculated to determine how much of each remained at selected times following the detonation. Given the quantity of each radionuclide at these times, the exposure rate was determined by multiplying by the appropriate exposure-rate conversion factor. The results were stated in terms of the radiation exposure rate for each radionuclide and for the total of all radionuclides. To be consistent with historical presentation of off site radiation data, the level of radiation at 12 hours after detonation (designated as H+12 hr) was selected as the appropriate reference value. (Adjusting the data to 12 hours after detonation does not represent a loss of information because the value at any other time can be calculated from this reference value.)

After the calculational model was thoroughly checked, the calculations were performed for 100 nuclear detonations and 37 tests of nuclear propulsion systems. Results of these calculations have been published. The other task groups use these source terms as the basis for the modeling they do.

The next subtask for this task group was to determine those radionuclides in the complete inventory that, if inhaled or ingested, have the greatest effect on radiation dose to the whole body and to specific body organs. A search of the literature and the experience of the LLNL staff produced a list of different pathways involving about 200 radionuclides. By computing the radiation dose from each radionuclide and each pathway, it was possible to determine that some pathways and many radionuclides would never make a significant contribution to dose. This procedure, called screening, narrowed the scope of analysis to three pathways and about 93 radionuclides. The pathways are external exposure, internal exposure through ingestion, and internal exposure through inhalation; the latter was found to be generally less significant than the other two. The lists of significant radionuclides differ for each pathway. The final dose assessment models will consider all of the significant radionuclides.

Calculation of the population dose due to ingestion requires a close working relationship between the various task groups. In order to define and establish the working relationships, and at the same time to test the entire computational procedure, the task groups computed the population dose to three counties from three nuclear tests. The counties selected were Washington and Iron Counties in Utah, and Lincoln County, Nevada. The three nuclear tests selected were HARRY, SMOKY, and ANNIE. This exercise was done in modular fashion with the participating task groups providing information and data in the form and format required by the task group using the information. The Fallout Verification element provided fallout pattern maps showing exposure rates and times of arrival of fallout. The Data Analysis group digitized these maps and produced exposure rate data for the desired locations in terms of milliroentgens per hour (mR/hr) at H+12 hr. The Internal Dose Assessment task group used these data along with the source term calculations to produce deposition data in terms of microcuries per square meter ($\mu Ci/m^2$) per mR/hr at H+12 hr. The Pathway Analysis group used these normalized deposition values to calculate intake in terms of microcuries (μCi) per $\mu Ci/m^2$. The Internal Dose Assessment element then computed the dose received through ingestion by multiplying by a dose-conversion factor, expressing the results in terms of rads per μCi. When these factors are all put into an equation and multiplied together, the various units cancel out to leave only rads--the measure of absorbed dose of radiation. Final summary calculations were performed at LLNL by the Internal Dose Assessment task group.

The calculation of dose through inhalation proceeds through a logical sequence using data collected in the 1950s and current models of the human respiratory system. Data were collected at many locations during the years of atmospheric nuclear testing, some by devices that separated particles by size, and some by high volume air samplers which trapped debris on a filter. Calculated values representing radioactivity in air are used as input to a model of the human respiratory system which considers such factors as breathing rate, particle size, length of time contaminated air is breathed, etc. Radioactive particles are lodged in different parts of the respiratory system, and some of these are exhaled later or are moved by body mechanisms into the throat area where they may be transferred to the stomach by swallowing. The model takes all of these factors into consideration.

Screening calculations have led to inclusion of 46 radionuclides into the model that accounts for 99 percent of the dose to the relevant organs by the inhalation pathway. Only a few calculations have been done for specific individuals so far; for these few, internal dose via inhalation has been less than 10 percent of the total dose from all pathways. Because dose via inhalation cannot be ignored, these calculations will be continued even though inhalation constitutes a small part of total dose.

The capability has now been developed to perform the ingestion and inhalation calculations described above for any location of interest for which historical fallout pattern maps were constructed or where exposure rate measurements were made following the nuclear tests.

The Internal Dose Assessment task group has also developed specialized models to supplement the generalized model for calculation of internal dose. One of these is the Fetal Dose Model developed because the growing fetus can receive high radiation doses to the thyroid and the bone marrow during the fetal period of rapid growth while these organs are small and growing rapidly. Other specialized models concern the concentration of iodine by the salivary gland and the lactating breast. Special attention is given to these and other organs that are known to demonstrate a selective preference for and accumulation of certain radionuclides.

The Internal Dose Assessment task group is continuing work on the dose assessment model for inhalation and ingestion prior to transferring this model component to the Individual Dose Assessment integrated model at DRI. They are also working to complete calculations on estimates of the cumulative population dose; however, this must await final analysis of milk distribution and consumption patterns as mentioned above in Pathway Analysis.

6. Data Analysis

The objectives of the Data Analysis task group at the Desert Research Institute (DRI) are to serve as general statistical consultants for the project, to be the focal point for the final dose assessment model as developed by the other task groups, and to continue as Data Base Manager to assist DOE/NV in providing specific individual dose assessments after other project tasks have been concluded. As the project evolved, this task group was assigned additional responsibilities.

One of the early tasks of the dose assessment project was to conduct a lifestyle survey in Nevada and Utah counties surrounding the NTS. The survey was designed to obtain information on dietary, life-style, and agricultural practices for residents of this area during the years of atmospheric testing. The results of the tabulation and analysis of these data are used primarily as input to the Pathways-to-Man model. The Data Analysis task group assisted the Pathway Analysis task group in design of the questionnaire and assisted DOE/NV in obtaining federal approval for the survey by designing the sampling procedure. Students of Dixie College in Saint George, Utah, conducted the survey in Washington and Iron Counties, Utah, and Lincoln County, Nevada. A second survey was conducted by DRI personnel in seven counties surrounding the initial three. The counties included in the extended lifestyle survey were Esmeralda, Nye, White Pine, the northeastern part of Clark, Nevada; Kane, Utah; and the northern parts of Mohave and Coconino, Arizona. Staff at DRI have performed the tabulation and analysis of the responses for both surveys.

An important accomplishment of the Data Analysis task group was development of a procedure for estimating fallout radiation exposure rates at specified locations. Following atmospheric nuclear tests in the 1950s, radiation monitors patrolled roads in the fallout area taking radiation measurements with survey meters. Collected data were plotted on a map, then lines were drawn on the map to connect points of equal value (isolines). A map of the fallout pattern was constructed in this manner for each of 74 nuclear tests. The present requirement is to obtain estimates of the exposure rate between measured points. DRI entered fallout isolines (compiled by WSNSO and its predecessors) into a computer data base for each of the 74 tests, then adapted mathematical analysis techniques for interpolating from the isolines to numerical estimates at each desired location. These estimates are used by LANL and LLNL as a basis for dose calculations. If actual exposure-rate data are available for the specified locations, these data are used instead of the estimates.

Other task groups are developing computer codes which will be used to reconstruct radiation exposure to individuals exposed to fallout. DRI has working copies of these computer codes and is integrating them into a unified system for calculating estimates for the Individual Dose Assessment (IDA). The IDA models are presently being subjected to rigorous testing by the other task groups.

DRI has a lead role in assessing the quality of the data developed for the dose assessment project. Beginning early in the project, DRI sampled and reviewed data collected by the Data Collection and Fallout Verification task groups and performed quality assurance checks for accuracy and completeness of data entry. More recent efforts are concerned with the quality assurance program in effect with regard to laboratory analyses of soil samples. The purpose of this program is to ensure that results of soil analyses are within acceptable limits of variability and accuracy. The process involves laboratory analysis of samples containing none of the elements being sought, analysis of samples prepared with known amounts of the elements being sought, and analysis of duplicate samples to check reproducibility of results.

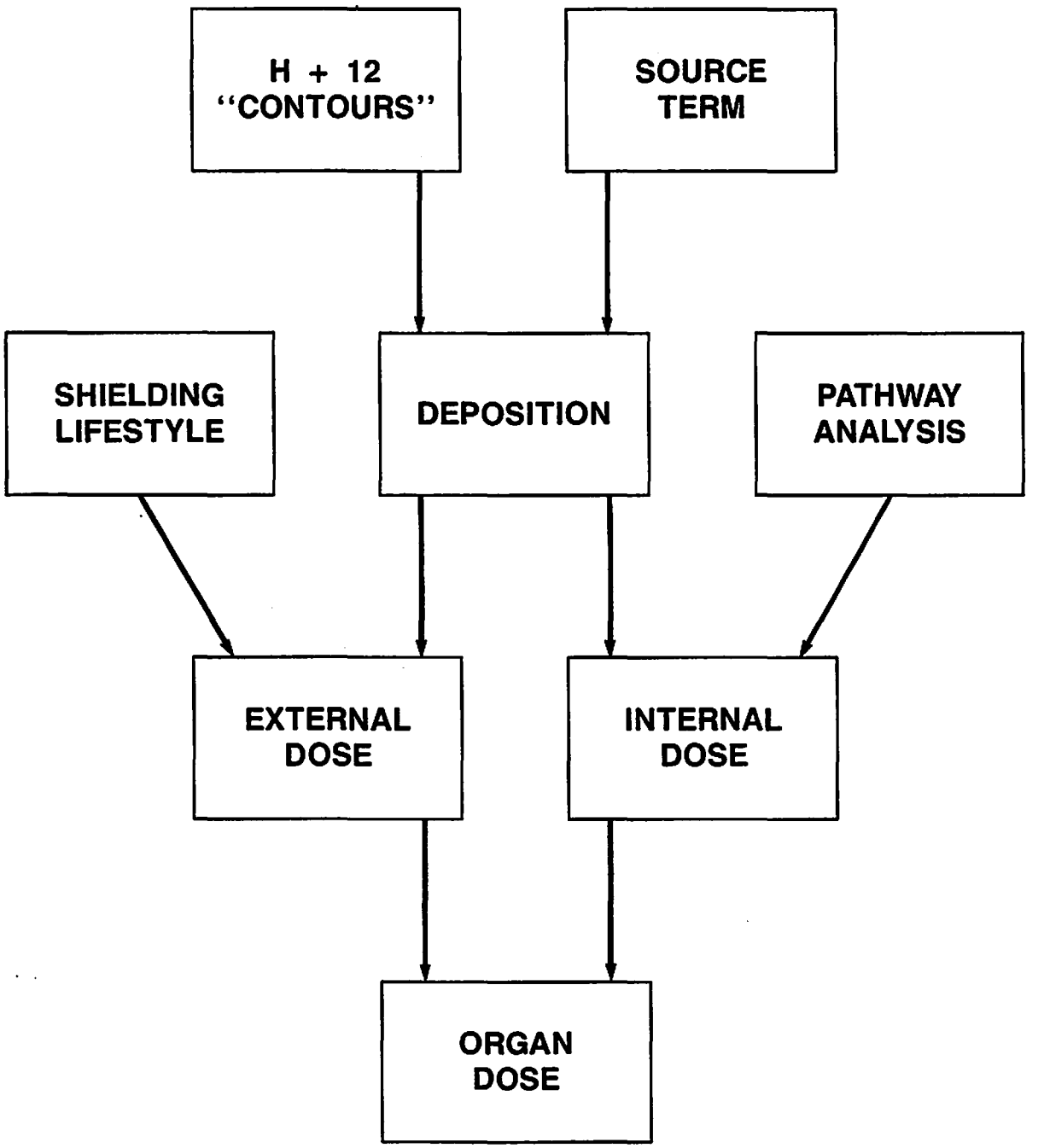
A. DISCUSSION

The above tasks are presented schematically in Figure 2. The methodology for dose reconstruction begins with fallout pattern maps and time-of-arrival estimates for each test (H+12 hr contours), and by computation of the radionuclide mix (source term) which determines the type and magnitude of radiation in the fallout. The calculated exposure resulting from this mix is reduced by shielding and lifestyle factors to yield the external radiation exposure. The mix of deposited radionuclides is utilized with the pathway analysis to calculate the ingestion contribution to internal dose. Total organ dose is the combination of external and internal doses.

Early review of existing data indicated that the nuclear tests HARRY, SMOKY, and ANNIE were major sources of off site exposures. A considerable amount of monitoring data was collected in Washington and Iron Counties in Utah, and Lincoln County, Nevada, during the period of atmospheric testing. Much of the early work of the ORERP has focused on these three tests and on these three counties. A review of the historical data indicates that test HARRY contributed about one-third of the total off site estimated population exposure during the period 1951-1958. Tests HARRY, SMOKY, and ANNIE account for a large fraction of the cumulative estimated population exposure in these three counties from all tests conducted at the NTS.

Preliminary assessment of the total population dose for the three counties and three nuclear tests was completed in 1981. This pilot study provided estimates of radiation doses to eleven body organs; the results, in general, indicate that radiation dose to the skin from beta exposure from direct

Figure 2. SUMMARIZED DOSE RECONSTRUCTION FLOW CHART



deposition is higher than the dose to any other organ. Radiation dose to the thyroid from ingestion of radioiodine is the next highest. For the eleven body organs considered, the dose due to external radiation exposure exceeded the dose due to ingestion and inhalation of radionuclides for all organs except the thyroid and lower large intestine. Work is in progress to complete and refine the calculation of doses resulting from all nuclear tests producing fallout off site and for all populated areas in the fallout region.

Shortly after the start of the ORERP, several task group members were called upon to testify in Federal court in a civil action for damages against the government. The case became known as the "Allen" trial, which was the consolidation of several hundred claims against the government by residents of Utah, Arizona, and Nevada, that allege injury from radioactive fallout. ORERP task groups contributed significant amounts of time and effort in performing calculations of individual exposures and estimated organ doses for submission to the court. Calculational models were thus subjected to intensive review and questioning of assumptions. The process of critical review has continued as task groups have presented preliminary calculations and assumptions to meetings of the DAAG, have submitted technical reports to journals for peer review prior to publication, and have made presentations to peer groups such as the Health Physics Society.

IV. PRESENT AND FUTURE ACTIVITIES

The foregoing text has discussed assessment of radiation exposure at locations for which radiation measurements were routinely made during the era of atmospheric nuclear testing. These locations were usually limited to a distance of 200 miles from the test site beyond which, in general, the off-site radiation monitors did not make measurements of fallout. However, there were nationwide and worldwide networks for detecting fallout by a variety of methods, such as by use of gummed film, fallout trays, precipitation collectors, and air samplers. An effort is currently underway to use new methods for extending the geographical area for which estimates of fallout radiation can be computed. The new methods do not depend upon data collected by the nationwide networks because the sampling points were too far apart, but do utilize some of these old data for corroborative purposes.

A. PHASE TWO

The initial methodology for dose assessment was limited to locations where there were measurements of external exposure rate or where such values could be interpolated from plotted isolines or contours. In general, locations of interest in southern Nevada and southern Utah, where the greatest INDIVIDUAL doses resulted, are within those contours. However, there may be significant POPULATION doses at other locations where actual measurements of the external exposure rates were not made and cannot be interpolated. Staff at EML developed a method of determining cesium-137 originating from NTS events that was deposited at downwind locations. This technique can be used to expand measurements of NTS fallout into other locations such as northern Utah and, perhaps, other states. Research on this methodology has been underway for some years, with hundreds of soil samples being collected and analyzed, and hundreds of gamma ray measurements being made. Early work on this effort was performed by EML in the State of Utah at about the time the ORERP started.

The methodology uses present measurements of cesium-137 and plutonium isotopes in soil to estimate the amount of cesium-137 originating at the NTS as distinct from the portion from global fallout. This distinction is based on the different ratio of plutonium-240 to plutonium-239 for fallout from these two sources. (The ratio is different because of differences in the types and sizes of devices tested at NTS compared to U.S. tests in the Pacific

or to tests by other countries.) This ratio and the ratio of plutonium isotopes to cesium-137 are known for global fallout and can be determined for these radionuclides found in samples of soil. Soil samples are collected from areas, preferably lawns, that have not been disturbed since 1950. The soil samples are analyzed to determine the quantities of cesium-137 and the plutonium isotopes in the soil at the present time. These known and calculated ratios are used to apportion the cesium between the two sources of fallout. The portion of cesium-137 from global fallout is subtracted from the total amount found in the soil samples, and the remainder is considered to be from the NTS.

This methodology is carried a step further to calculate back to the amount of fallout originally deposited during the period of atmospheric nuclear testing. The source term data developed by LLNL are used to estimate the quantities of the other shorter-lived radionuclides deposited along with the cesium-137, and then the external exposure rate can be calculated.

Soil sampling and analyses have been conducted by teams from the various ORERP task groups. DRI selected sampling sites based on EML criteria. LLNL performed gamma ray measurements to verify that these sites were undisturbed since 1950. REECo collected the soil samples and is performing cesium and plutonium analyses of the samples. The Pacific Northwest Laboratory is performing mass-spectroscopy analysis to determine the ratios of the plutonium isotopes. All of this work is being accomplished in accordance with the advice, criteria, and recommendations of EML staff. Preliminary results show acceptably close agreement between the new methodology and results derived from historical measurements of fallout deposition.

EML started the program of soil collection and analysis in Utah, and the ORERP is extending the effort to surrounding areas. By project completion, the extended region will include parts of southern Idaho, southeastern Oregon, southeastern California, northern Arizona, northwestern New Mexico, western Colorado, the southwest corner of Wyoming, and all of Nevada and Utah. Limited work is being done in additional states to evaluate the possibility of using this technique to extend the assessment area even further.

B. INDIVIDUAL DOSE ASSESSMENT MODEL

Upon completion and implementation of the individual dose assessment model, an individual who was a resident in a fallout area during the era of atmospheric nuclear testing may request an analysis of his/her own exposure and radiation dose. The individual will be asked to provide specific information regarding locations and periods of residence. Most of the required information can be indicated on a questionnaire designed with multiple choice answers to pertinent questions.

C. PROJECT COMPLETION

The dose assessment models should be operational before the DAAG charter expires in July 1986. Final results should be available during the year following completion of laboratory work. Scientific developments will be reported in professional journals as the project continues. Several options of bringing the ORERP to an official close are being considered, but the Coordination and Information Center and the Individual Dose Assessment models, with necessary data files, will be maintained as long as their usefulness to the public remains.

The DOE will formalize and publicize a standard set of procedures to be followed for submission of inquiries. This will take place once all the models have been integrated and tested as a unit. It would be premature to send inquiries before DOE/NV formally announces that it is ready to perform this work.

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APPENDIX A. ACRONYMS AND GLOSSARY

ACRONYMS

AEC Atomic Energy Commission. (See DOE.)

CIC Coordination and Information Center. Operated for DOE/NV by REECo, the Center maintains an archive of information related to nuclear testing and radioactive fallout.

CSU Colorado State University, Fort Collins, Colorado.

DAAG Dose Assessment Advisory Group.

DOE Department of Energy. The Atomic Energy Commission (AEC) was established on 1 August 1946 and abolished on 19 January 1975 when many AEC functions were transferred to the newly created Energy Research and Development Administration (ERDA). ERDA was abolished on 1 October 1977 and the agency's functions were transferred to the new DOE.

DOE/HQ Department of Energy Headquarters in Washington, D.C.

DOE/NV Department of Energy Operations Office in Las Vegas, Nevada.

DRI Desert Research Institute. One component of the University of Nevada System.

EG&G EG&G Energy Measurements Group, Inc., Las Vegas, Nevada.

EML Environmental Measurements Laboratory. A DOE laboratory located in New York, New York.

EMSL Environmental Monitoring Systems Laboratory. An EPA laboratory located in Las Vegas, Nevada.

LANL Los Alamos National Laboratory. U.S. Government laboratory located in Los Alamos, New Mexico, and operated by the University of California.

LLNL Lawrence Livermore National Laboratory. U.S. Government laboratory located in Livermore, California, and operated by the University of California.

NTS The Nevada Test Site, a 1,350-square-mile area in southern Nevada in Nye County and about 65 miles northwest of Las Vegas, Nevada.

OMB Office of Management and Budget of the U.S. Government.

ORERP Off-site Radiation Exposure Review Project.

PHS U.S. Public Health Service, whose radiation monitoring functions were taken over by the EPA in 1970.

Rad Radiation Absorbed Dose. The unit of absorbed dose of ionizing radiation. A dose of 1 rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.

RECON Remote Control, DOE's bibliographic data base located at Oak Ridge, Tennessee.

REECo Reynolds Electrical and Engineering Company, Inc., operating contractor for the DOE at the Nevada Test Site and in Las Vegas, Nevada.

TLD Thermoluminesent dosimeter. A dosimeter is an instrument used to detect and measure accumulated radiation exposure; thermoluminescence refers to the release of the accumulated energy in the form of light upon heating of the absorbing medium.

WSNSO Weather Service Nuclear Support Office located in Las Vegas, Nevada.

GLOSSARY

Beta Beta particle. Charged particle emitted from the nucleus of an atom as part of the decay process, with a mass and charge equal in magnitude to that of the electron.

Dose A measure of the energy absorbed in tissue by the action of ionizing radiation on tissue. The unit of absorbed dose is the rad.

Dose Commitment Dose calculated to be accrued in the future as a result of a present release of radioactivity.

Exposure A measure of the ionization produced in air by x or gamma radiation. The special unit of exposure is the roentgen. (See roentgen.)

Fallout The process or phenomenon of the fall back to the earth's surface of particles contaminated with radioactive material following an atmospheric or uncontained nuclear detonation. The term is also applied in a collective sense to the contaminated particulate matter itself.

Film Badge A pack of photographic film which measures radiation exposure for personnel monitoring.

Gamma (rays) Electromagnetic waves of very short wavelengths produced during the disintegration of radioactive elements.

H+12 hr In this expression, H is the time of detonation to the nearest minute, and '+12 hr' means twelve hours after detonation.

Ionizing radiation Electromagnetic radiation (gamma rays or X rays) or particulate radiation (alpha particles, beta particles, neutrons, etc.) capable of producing ions, i.e., electrically charged particles, directly or indirectly, in its passage through matter.

Leukemia A disease in which there is excess production of white blood cells.

Microcurie One-millionth of a curie. One curie equals 37 billion nuclear transformations per second. One microcurie equals 37 thousand nuclear transformations per second.

Milliroentgen (mR) One-thousandth of a roentgen. (See roentgen.)

Nuclear device A device designed to produce a nuclear explosion for purposes of testing the design, for verifying nuclear theory, or for gathering information on device performance. Many devices were designed for diagnostic purposes and not as bombs or weapons.

Nuclear weapon A nuclear device designed to be used as a bomb or weapon in which the explosion results from the energy released by reactions involving atomic nuclei, either fission or fusion, or both.

Nuclide A general term applicable to all atomic forms of the elements; often used incorrectly as a synonym for isotope. Nuclides comprise all the isotopic forms of all the elements.

Off site Generally refers to any location outside the Test Range Complex, which is defined below.

Population Exposure The collective exposure to a population which equals the sum of individual exposures to the members of the population. It is equal to the number of people multiplied by the average exposure of these people.

Radiation The emission and propagation of energy through space or through a material medium in the form of waves and/or particles. Only alpha, beta, gamma, x-ray and neutron emissions resulting from nuclear detonations and detonation products are intended herein.

Radioactive Of or exhibiting radioactivity.

Radioactivity The property of unstable nuclei of atoms of emitting particles or rays in the process of becoming stable.

Radionuclide A radioactive nuclide. (See nuclide.)

Roentgen (R) The special unit of exposure to ionizing radiation. It is that amount of gamma or X rays required to produce one electrostatic unit of charge of either sign per cubic centimeter of air at standard temperature and pressure.

Source term The inventory of radionuclides generated by a nuclear detonation.

Survey Meter Any portable radiation-detection instrument especially adapted for surveying or inspecting an area to establish the existence and amount of radioactive material present.

Test Range Complex An area that includes both the Nevada Test Site and the adjacent government-controlled Nellis Air Force Range (formerly the Las Vegas Bombing and Gunnery Range).

Yield The total effective energy released in a nuclear explosion. It is usually expressed in terms of equivalent tonnage of TNT required to produce the same energy release in an explosion.

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