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Occupational Radiation Exposure History
of Idaho Field Office Operations
at the INEL

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**OCCUPATIONAL RADIATION EXPOSURE HISTORY
OF IDAHO FIELD OFFICE OPERATIONS
AT THE INEL**

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Published October 1993

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ABSTRACT

An extensive review has been made of the occupational radiation exposure records of workers at the Idaho National Engineering Laboratory (INEL) over the period of 1951 through 1990. The focus has been on workers employed by contractors and employees of the Idaho Field Operations Office (ID) of the United States Department Of Energy (USDOE) and does not include the Naval Reactors Facility (NRF), the Argonne National Laboratory (ANL), or other operations field offices at the INEL.

The radiation protection guides have decreased from 15 rem/year to 5 rem/year in 1990 for whole body penetrating radiation exposure. During these 40 years of nuclear operations (in excess of 200,000 man-years of work), a total of twelve individuals involved in four accidents exceeded the annual guidelines for exposure; nine of these exposures were received during life saving efforts on January 3, 1961 following the SL-1 reactor accident which killed three military personnel. These exposures ranged from 8 to 27 rem. Only one individual has exceeded the annual whole body penetrating radiation protection guidelines in the last 29 years.

The collective dose received by the more than 60,000 workers employed by the INEL over the past 40 years was approximately 44,000 person-rem. Over 65% of this exposure was received between 1958 through 1970 when the INEL's major focus was on reactor development and testing. The ten highest individual collective doses received while working at the INEL ranged from 62 to 79 rem.

As a result of the application of the ALARA Principle (keeping radiation exposures as low as reasonably achievable) there has been a nearly continuous decrease in collective dose from the high of 3448 person-rem in 1965 to the current low of 228 person-rem in 1990.

The individual risks resulting from the highest exposures are estimated to range from zero to a maximum of 2% for fatal cancers. The collective

health risk could range from none to 18 fatal cancers based on the best current estimates.

These values are only statistical estimates since the data cannot support any findings linking fatal cancers to exposures received at the INEL.

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ACRONYMS

ACC	American Cyanamide Company
ACXRP	U. S. Advisory Committee on X-ray and Radium Protection
AEC	U. S. Atomic Energy Commission
AEC-HQ	Atomic Energy Commission Headquarters Office, Germantown, MD
ALARA	As Low As Reasonably Achievable
DOE	U. S. Department of Energy
EBR-I	Experimental Breeder Reactor I
ERDA	Energy Research and Development Administration
FRC	Federal Radiation Council
GAO	U. S. General Accounting Office
ICPP	Idaho Chemical Processing Plant
ICRP	International Committee on Radiation Protection
ID	Idaho Field Office of DOE
INEL	Idaho National Engineering Laboratory
LLD	Lower Limit of Detection
MAD	Maximum Accumulated Dose
MPD	Maximum Permissible Dose
MTR	Materials Testing Reactor
NBS	National Bureau of Standards
NCRP(M)	National Council on Radiation Protection and Measurements
NRC	U. S. Nuclear Regulatory Commission
NRF	Naval Reactors Facility
NRTS	National Reactor Testing Station
rem	Roentgen Equivalent Man
RESL	Radiological and Environmental Sciences Laboratory

RPG	Radiation Protection Guides
SL-1	Stationary Low Power Reactor No. 1
SSDC	Systems Safety Development Center
TLD	Thermoluminescent Dosimeters
TRA	Test Reactor Area

DEFINITIONS

Acute Exposure: Denotes radiation exposure of short duration, usually less than 24 hours.

ALARA: An acronym for "as low as reasonably achievable." This is the philosophy which requires that occupational radiation exposures be reduced until further reductions would not justify additional costs.

Collective Effective Dose: The total of all individual doses in the population of concern, such as all the workers under contracts administered by the Idaho Field Operations Office of DOE.

Dose: The quantity of radiation delivered to a specified area, in this study, to the whole body measured in r (roentgen), rads or rem.

Erythema Dose: An abnormal redness of the skin caused by radiation exposure distending the capillaries with blood.

External Radiation: Exposure to ionizing radiation from radiation sources located outside the body which penetrate into the blood forming organs.

Ionizing Radiation: Any emission of energy in the form of particles or waves which is capable of producing electrically charged ions in its passage through matter.

Lower Limit of Detection (LLD): The threshold of detection for the dosimetry device employed.

Maximum Accumulated Dose (MAD): An age-proration formula which equals $5(n-18)$ rem, where n is the number of years of age at one's prior birthday.

Maximum Permissible Dose (MPD): The maximum dose of ionizing radiation that, in light of the present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime.

Mean Dose: The sum of the doses received by individuals divided by the number of individuals for which the sum is taken.

Nonstochastic Effects of Radiation: (Deterministic Effects) are early biological effects in humans which are produced in a determined way for which a threshold exists and above which the effect varies with dose, e.g., skin burns, sterility, loss of hair.

Occupational Exposure: In this report is exposure to radiation workers from external penetrating ionizing radiation fields directly attributable to one's occupation at the Idaho National Engineering Laboratory (formerly the National Reactor Testing Station).

Penetrating Radiation: The emissions of energy, normally gamma rays or neutrons, which are capable of irradiating the blood forming organs, usually the red bone marrow, deep inside the body.

Permissible Dose: (Tolerance Dose) is the amount of radiation exposure which may be received by an individual within a specified time period with the expectation of no harmful biological effect.

Personnel Dosimetry: Devices such as film badges or thermoluminescent materials worn by radiation workers to detect and approximately measure an accumulative dosage of ionizing radiation, also the techniques used to accurately recover the data from dosimetry devices in units of absorbed dose for retention in a personnel record.

Personnel Monitoring: The systematic and periodic check of the radiation dose each worker receives for the purpose of controlling the exposure through the use of personnel dosimetry.

R (Roentgen): The quantity of x-rays or gamma radiation which in a standard volume of air produces ions of one electrostatic unit of charge. Commonly expressed in smaller units of mr (milliroentgen) or 1/1000 R.

Rad (Roentgen Absorbed Dose): The unit of absorbed dose equal to 100 ERGS/gram. A measurement of the amount of energy transferred to matter by ionizing radiation.

Radiation Worker: is an occupationally exposed individual whose work is

- necessarily involved with the likelihood of radiation exposure
- normally performed in a controlled area
- subject to appropriate radiation protection controls

Radiation Protection Standards (Criteria): Recommendations established by national authorities to restrict occupational exposures of workers over various time periods to numerical values dependent upon the type of radiation involved and the portion of the body exposed.

Rem: (Roentgen Equivalent Man) is a measure of the dose of any type of ionizing radiation to body tissue in terms of its estimated biological effect relative to a dose of one-roentgen of radiation by X-rays.

Stochastic Effects of Radiation: (Random Effects) are delayed biological effects in humans which are random in nature, are assumed to be without any threshold level at the low doses of interest in radiation protection, and the severity is independent of radiation dose, e.g., cancer and genetic effects.

Technical Overexposure: Any radiation dose which exceeds any of the radiation exposure criteria established to control occupational exposures. It does not infer that an injury has or will occur.

Whole Body Exposure: Describes the absorbed dose associated with the uniform irradiation over the whole body by penetrating radiation as determined by personnel dosimetry.

1. INTRODUCTION

This study has collected data on the occupational radiation exposure history of personnel working at the Idaho National Engineering Laboratory (INEL) for or under direct contract to Idaho Field Office (ID) of the Department of Energy (DOE) or its predecessor agencies The Atomic Energy Commission (AEC) and the Energy Research and Development Agency (ERDA), during the forty year period of 1951 through 1990. Although the INEL was established in 1949, the use of radioactive materials did not begin until December 1951 at Experimental Breeder Reactor-I (EBR-I) and March 31, 1952 at the Materials Testing Reactor (MTR). Dosimetry service in the form of film badges began earlier in September 1951.

The data collected during this study was limited exclusively to total body exposures resulting from penetrating ionizing radiation. This would include gamma and neutron radiation to the blood forming organs. However, individual neutron exposures were rare and in few cases did they exceed a few percent of the total dose. Therefore, the neutron exposure data was not included in this study as it was too low quantitatively to be of significance.

Non-penetrating radiation exposure to the skin from soft X-rays or Beta particles were also not included along with irradiation by internally deposited radionuclides since historically they have been extremely rare events and as a result a very minor contributor to the effective dose.

The collected data was analyzed to determine the annual distribution of exposure in various ranges and to determine the unique events and the circumstances under which individuals exceeded the radiation protection standards in effect at the time. The term "dose," as used in this report, is a generic term that can apply to any of the relevant dosimetry quantities. The term "exposure" is also used in the generic sense to mean the process of being exposed to ionizing radiation or radioactive material. The real

significance of radiation exposure is determined by the resulting doses, particularly to the blood forming organs.

1.1 Purpose and Scope

The main purpose of this review was to develop a radiation exposure history for ID employees and it's contractors at the INEL, formerly the National Reactor Testing Station (NRTS), from the start of work with radioactive materials in 1951 through 1990. The study was limited initially to available primary and secondary records for operating and construction personnel working under direct contract to Idaho Field Operations Office. Key essential requirements were the following:

- annual doses in various ranges of 1 rem increments;
- number of personnel monitored;
- total ID employment;
- number of personnel exceeding the Radiation Protection Guides in effect at the time;
- events causing individuals to exceed the Radiation Protection Guides;
- significant changes in the data; and
- a database of all reference material for future use.

The goal was to make an accurate and as complete as possible assessment of occupational exposures on a cost effective basis.

Very early in the study, the authors suggested that annual collective dose would be a key index which should be added to the data to indicate

overall trends in radiological workloads, effectiveness of ALARA (As Low As Reasonably Achievable) programs and potential health impact.

This report is semi-technical in nature. The technical aspects are handled in a direct and simple manner while attempting to maintain technical accuracy.

1.2 Methodology

The first phase of data collection was done by EG&G's Operational Dosimetry Unit staff members using the resources of the Systems Safety Development Center (SSDC) and the Radiological and Environmental Sciences Laboratory (RESL) of DOE.

In October 1990, the second phase began with the initial effort of the authors to search for early reports with annual summaries in INEL's technical library. Excellent cooperation was received from Mr. Brent Jacobsen, Manager INEL Technical Library and all of his staff, particularly from the research librarians Jackie Loop, Sandy Biermann and Theresa Oh.

No evidence was found that early ID contractors, such as Phillips Petroleum Company and American Cyanamide Company (ACC), issued annual reports. Even in recent years, summary data on technical activities was sparse. For example, initially in preparing a chronology of major events at the INEL, very few entries were found for the years 1980, 1981, or 1983.

All contractors were encouraged to prepare technical reports of research results, process changes and training manuals. While a copy was always sent to Oak Ridge National Laboratory, the total number of copies in distribution in the early years was very limited. Blocks of ID report numbers were distributed to each operating contractor and records were kept of the title and author each time a report number was issued. As a specific example, Series ID-15,000 was issued to American Cyanamid Company which was the operating contractor for the Idaho Chemical Processing Plant (ICPP) from 1951 through 1954. A check of the Technical Library holdings of ACC reports

indicated only two reports available, IDO-15002 (declassified) and IDO-15065 (classified). A check of Nuclear Science Abstracts revealed that the IDO-15000 series extends through 15107. This indicates at least 105 other reports were published and are no longer available in Idaho.

In 1952, the senior author had prepared a health physics training manual for use by ACC employees at the ICPP which included guidelines for occupational exposure as well as radioactive waste discharge criteria. No traces of this report were to be found.

A search for annual reports providing summary data on occupational exposures, effluent releases, destructive tests, or environmental monitoring data produced the following:

AEC-ID Health and Safety Division Annual Reports 1958 through 1963

AEC-ID Health Services Laboratory Annual Reports 1969 through 1970

In addition, interviews were conducted with several personnel in DOE-ID who had worked with the former dosimetry branch of AEC, ERDA or DOE. The particular focus was to locate annual summaries of INEL occupational exposures since references were found for summaries that had been made at least back to 1955. They were also queried about specific acute incidents involving exposures in excess of Radiation Protection Guides. Wherever possible, individuals involved in these incidents or accidents were also interviewed.

Detailed searches were made of retired files in the Directors Office and the Radiological Sciences Branch of Idaho Operations Radiological and Environmental Sciences Laboratory (RESL).

Contact was also made with a number of retired AEC and contractor employees known to have been collectors of NRTS data and reports, or people with good recall of early high exposure events or exposure records. Complete cooperation was received from all individuals interviewed.

During a search of old files, an undated letter authored by I. Aoki to the dosimetry file, was uncovered. It was entitled "General Information for Evaluating Penetrating Exposure Summary at INEL for the years 1950 through 1979." This letter, along with an interview with the author, revealed that under an earlier computer program the annual dose summaries were easily recoverable and that the collective dose through April 20, 1979 was 41,695 rem for the 43,505 permanently badged employees. This computer program reportedly no longer exists so the data could not be verified or analyzed.

From personal experience, it was known that the AEC Headquarters Division of Operational Safety had issued periodic reports on "Operational Accidents and Radiation Exposure Experience" during the 1943 to 1975 period. These reports focused primarily on industrial accidents producing injuries and fatalities, as well as property damage. The Chief of the Safety and Fire Protection Branch, Mr. Daniel F. Hayes, wisely included in the TID-5360 series of reports, a listing of accidents involving radioactive materials in atomic energy activities as well as reporting on radiation accidents resulting in lost time injuries. A thorough search of the microfiche holdings of INEL's Technical Library revealed eight of these reports along with three revisions which were the forerunners of the program developed by Mr. Charles Eason in 1968 for a central radiation records repository at AEC Headquarters in Germantown, Maryland.

The first document issued under the TID-5360 series and published in 1956 described in narrative form all accidents involving radiation in AEC plants from June 1945 through December 1955. The last publication WASH-1192 (Rev) was published in 1975, at the time of the reorganization of the AEC into two separate agencies, namely ERDA and the Nuclear Regulatory Commission (NRC). This publication covered the entire period 1943-1975 which includes all the operational history of the Manhattan Engineering District and the Atomic Energy Commission. In this report, a table listed the radiation exposure experience in various dose ranges for all AEC and AEC contractor personnel to whole body penetrating radiation. The data for the period 1947-1954 was lumped together as a total in five dose ranges. However, annual

doses were listed for each of the years from 1955 through 1974. Unfortunately, these data were not broken down by the various operation field offices.

These data clearly indicated that each AEC field office had been required to collect annual summaries in prescribed dose ranges and submit them to AEC-HQ for tabulation. A search of old AEC files at the INEL revealed that Form AEC-190 "Annual Summary of Whole Body Exposures to Ionizing Radiation" was used routinely to provide standard input. This data was collected and sent to AEC-HQ between 1955 and 1973.

At this point, two independent sources of data indicated that annual occupational dose summaries were developed for use at the INEL and also for transmittal to AEC Headquarters. After all available resources at the INEL had been utilized, the decision was made in early April 1991 to search the DOE Records Management archives in Germantown, Maryland for pre-1957 ID annual dose summaries and interview a few key individuals from the former AEC Division of Operational Safety who received and compiled the occupational exposure data from the AEC field offices.

While this approach provided some additional detailed information, it was not successful in locating the missing pre-1957 data contained on the Form AEC-190. Having selected and searched eight boxes of files, there was convincing evidence that data of this type was saved and sent to the Maryland Storage Center. Unfortunately, problems were experienced which resulted from the mixed storage of classified and unclassified material in the same boxes and the difficulty of identifying the contents of a particular box based on the terse information originally listed on the Form AEC-135, "Records Storage Receipt" (ID F -1324.2A), by the individual retiring the files.

In an effort to locate annual summaries for missing years, 1951-1956 and several years during the mid 1960s, a search was made of CF-633, an older facility at the INEL, that is now used partially for storage. Several microfiche were found that contained individual and quarterly exposure summaries, but not for the years in question.

Initially, it was thought that the computer program used to record individual exposures would provide the needed data. However, this program was replaced in 1986 and current computer software cannot be used to run it without expensive adjustments.

By September 1991, it was evident that all readily available data had been located. A tabulation of the annual summary data was prepared. This indicated only fragmentary information for the vital period of 1951 through 1957 which was not comparable with the data from the other years. Also, there was no data for 1973.

Earlier it was discovered the Operational Dosimetry Unit of EG&G Idaho had custody of a microfiche containing dose history information for INEL employees from 1951 through 1975. This microfiche was obtained and a hard copy of the 5303 pages was made. The "Master Dump", as this dose history information is called, is in numerical order by health badge number. Dose information is listed by year for each employee.

At that time it was not considered cost effective to extract the missing data manually. However, when no alternative was found Ms. Julie Braun, one of the authors, volunteered to go through the original 5,303 pages of the master dump print out (version #1 1951 through 1975), which listed the radiation exposure for each employee by year. As a result of this major effort, which required more than 170 hours, a more detailed and accurate summary of exposure data for 1951 through 1957 was developed than is available for any other group of years. Mainly, this is because the various individuals requesting data or keeping data summaries used differing criteria to process the raw data into dose ranges and collective doses. This variability in summarized data has plagued almost every aspect of this study. The following paragraphs detail the methodology employed in this data reconstruction effort.

To obtain missing dose information for 1951 through 1957, the hard copy was scanned manually for gamma dose information and recorded in columns by year. Neutron exposures were not included because they were few in number, and subject to large error bands. After scanning the entire printout, the

doses were sorted by ranges: 0.01-1 rem, 1-2 rem, 2-3 rem, 3-4 rem, 4-5 rem, and > 5 rem, to correspond with data obtained from later years. This data was totaled by year to obtain total annual dose by range. All of the ranges were totaled to obtain collective dose by year. For reference purposes, the page number from the hard copy was periodically recorded as a benchmark in the event it became necessary to go back to the original data.

A similar approach was used later to obtain collective dose information for 1965 and 1973. Collective dose information for 1965 had been retrieved from another source but appeared inconsistent with data for previous and later years, as it was 30 to 50% higher. For 1973, collective dose information was not available from any other known source. A statistician was consulted to estimate the collective dose for 1973 but it was later decided to use the Master Dump to give more precision to the statistician's estimate. In comparison, the data was quite close. The 1965 collective dose compiled using the Master Dump was 3448 rem compared to 3578 rem, within 3.7% of the original value. The 1973 collective dose figure estimated by the statistician was within 7.3% of the Master Dump figure, 1091 rem compared with 1011 rem.

2. RADIATION PROTECTION OF WORKERS

2.1 Personnel Dosimetry Program Criteria

The objectives of radiation protection are to prevent acute radiation effects (non-stochastic) and to limit the risks of late health effects (stochastic) to an acceptable level. Several independent protective measures are used so if one measure fails, there are other obstacles to a technical overexposure. Examples of these are: personnel dosimetry, area monitoring, air sampling, and bioassay. Fundamentally, an adequate radiation protection program must meet certain criteria:

- The monitoring program at the workplace must provide accurate dose data for both external and internal exposures.
- The doses received should be well below the exposure standards with a very low probability of unrecorded incidents.
- Complete employee dose records must be maintained which reasonably estimate the dose received.
- Dose history records must be obtained from previous employers when appropriate and entered into the permanent record.

The International Committee on Radiation Protection (ICRP) had originally suggested that individual dosimetry was not required unless the exposure could be reasonably expected to exceed 25% of the appropriate radiation protection standard. Today this recommendation is 10%. It has been the practice at the INEL since late 1951 to provide a dosimetry device to all radiation workers and even to occasionally exposed individuals, such as construction workers and to most visitors.

2.2 ID Personnel Dosimetry Program

Since its beginnings in 1949, the policy of the U.S. Government and its contractors at the INEL has been to keep occupational radiation exposure to the lowest practical level during all activities. Radiation protection of individual workers was achieved through a defense in depth approach, namely:

- plant design using shielding and isolation from the sources of radiation;
- training of radiation workers in self protection;
- supervision of worker activities by management and health physics personnel;
- monitoring of each radiation worker using personnel dosimetry; and
- long term retention (lifetime) of all individual exposure data.

The primary purposes of personnel dosimetry were to assure that adequate protection was provided to each worker, to determine the effectiveness of the radiation protection program, and to show compliance with regulations such as radiation protection standards. Each radiation worker was provided a dosimetry badge as his basic exposure measuring device, which was normally worn on the chest.

Before 1966, this passive device contained a film packet similar to those used for dental X-rays along with one or more filters to permit differentiating between various types of radiation (Beta, gamma and neutron) and their energies based on their capability to penetrate tissue. Ionizing radiation has the capability of darkening film. After chemical processing, the relative darkness of the film can be converted by calibration techniques into units of radiation exposure. Initially the lower limit of detection (LLD) was reported to be 30 mr. However, detailed examination of the

1951-1956 data revealed a number of entries for doses of 5-25 mr. Routinely, any exposures below the 30 mr level were to be recorded as statistical zeroes.

During 1966, the INEL became the first major nuclear installation to make wide scale use of a newer more sensitive and accurate solid state dosimetry system, namely thermoluminescent dosimeters (TLDs). These dosimeters contained materials which, when exposed to ionizing radiation, underwent internal changes. On subsequent heating under controlled conditions, an amount of light was produced, which was directly proportional to the original radiation dose. The new threshold level of detection was 10 mr.

The primary exposure to be determined by the dosimetry system was whether the radiation was capable of penetrating to the blood forming organs, especially to the red bone marrow. Other non-penetrating radiation from Beta exposure and low energy gamma rays which exposed only the skin could also be measured. Uniform irradiation of the whole body was assumed. While this was an idealized concept, a dosimeter worn on the chest under most working conditions would conservatively overestimate the exposure to body organs.

As the first peacetime nuclear center developed by the United States Atomic Energy Commission, the scientists and engineers in the original Health and Safety Division of Idaho Operations Office wanted to use the best state-of-the-art dosimetry equipment and techniques available. While many of the key staff had been recruited from the Hanford, Washington project, they chose the Oak Ridge type dosimeter badge. This was a stainless steel unit with cadmium filters and an open window area for the detection of soft energy radiation. From 1951 to 1957, this type of badge along with a single pencil dosimeter formed the basis of the INEL dosimetry program. Since the film badge was a separate device, the worker was also required to wear another badge for security identification. Occasionally, an employee might have forgotten to wear his dosimetry equipment, particularly when he had to change clothes for work in a potentially contaminated area. In 1957, the Hanford type combined security and dosimetry badge was introduced to overcome this difficulty. This plastic badge was a major advancement since it used four

different filters which could better differentiate the type of radiation causing exposure to the film packet. Obviously, field measurements of this nature cannot have the same precision as clinical dosimetry under controlled conditions. However, personnel dosimetry can be expected under routine field conditions to be within $\pm 25\%$.

2.3 Radiation Protection Standards

2.3.1 General Philosophy

Radiation protection standards used by the United States Department of Energy and its predecessor agencies were selected to protect workers from any potentially harmful effects of ionizing radiation over their entire working lifespan, which may be as long as 50 years. They were designed to limit and control radiation exposures so that the level of lifetime risk was no greater than that found in other industries that are considered safe.

Radiation protection standards evolved over the years from recommendations made by national and international bodies of scientific experts. It should be noted that the term "standard" is used in the broad generic sense which includes guides and criteria, as well as, enforceable limits. These criteria are numerous, they are also complex and have changed to generally reflect the latest improvements in both the quantitative and qualitative knowledge of radiation health risks, as well as changes in the basic philosophy of radiation protection. They are gradually evolving into a risk-based system but this ideal goal may not be achieved for years to come.

This is the first time in man's history that a consistent system has been developed for workers safety for potential hazards where it's assumed that there is no threshold for risk. In theory, any dose of ionizing radiation, no matter how small, and no matter its origin, whether from:

- natural background radiation such as cosmic rays or radon from soils;

- medical and dental X-ray examinations;
- radiation from consumer products such as TV sets, watches, smoke detectors, dentures, and glasses; or
- occupational exposure to workers in hospitals, research centers, or nuclear power plants;

may give rise to a cancer or to a genetic effect. Conversely, there is no way to be certain that a given dose of radiation, no matter how large, has caused an observed cancer or genetic effect in an individual, or will cause one in the future.

The best scientific data available indicates that less than one out of every 200 cancers in the United States are caused by ionizing radiation from all sources. For this reason, one should consider radiation to be only a mildly carcinogenic agent. Since the ideal goal of zero risk cannot be achieved, the underlying philosophy is to control individual risks through specific guides and limits and to optimize protection. In other words, a new ethical standard has been established which requires occupational radiation exposures be reduced until further reductions would not justify additional costs. This approach applies to the individual worker's dose, as well as, the collective doses to all workers involved.

The objectives of any radiation protection program can simply be stated as:

1. Prevent acute radiation health effects such as fatalities, sterility, burns, cataracts and blood cell changes which have a threshold dose for causation. These are called non-stochastic effects;
2. Limit the risk of cumulative effects such as cancer and genetic changes which do not have a threshold level and which appear to be random in nature. These are called stochastic effects.

The effectiveness of any radiation protection program is determined by personnel monitoring which involves the measurement of the dose received over a period of time and a comparison with established standards. Standards used to control cumulative radiation exposure are not boundaries or thresholds between "injury" and "safety" in the ordinary sense of the words. Just because a worker's exposure has exceeded any standard at any time, does not imply a radiation injury has or will result. On the other hand, it is statistically conceivable that a worker who has never exceeded a standard could ultimately sustain a radiation injury, such as a cancerous tumor on a low probability basis caused by occupational radiation exposure.

2.3.2 Historic Evolution

Due to the technical nature of this section, the authors, in the interest of clarity and accuracy, have chosen to include phrases and sentences taken directly from publications of the National Bureau of Standards (NBS), the National Council on Radiation Protection (NCRP) and the Federal Radiation Council (FRC). Due to the number of excerpts, the actual references have not been specifically cited.

Professor Wilhelm Roentgen was the first person to become aware of ionizing radiation when he discovered X-rays in 1895. Only seven years later, Dr. W. Rollins was using a very crude criteria for radiation protection. He used a photographic plate to indicate a "safe" exposure. The radiation exposure was not considered harmful if the plate did not appear to be fogged after seven minutes of exposure. This would be an approximate dose of 10 to 20 r of soft X-rays.

Around 1924, some medical groups were utilizing a biological index to protect X-ray and radium workers. They had observed a true threshold effect, namely that X-ray and radium exposures over a period of time could produce a reddening of the exposed skin. This phenomena was called an "erythema dose" and could be produced by exposure to 500 to 700 r of X-rays depending upon many variable biological and physical factors. These groups decided that a

"tolerance dose" would be 10% of the erythema dose, or about 60r per year to the skin.

By 1931, a small group of independent scientists and medical doctors, who had voluntarily organized two years earlier, assumed the task of collecting and analyzing all biological and physical data available in the United States and Europe. They recommended a tolerance dose of 0.2 r/day (approximately 50-60 r/yr). This physical standard was based on ionization measurements by electroscopes. This group was known as the US Advisory Committee on X-ray and Radium Protection (ACXRP). The primary purpose of this group was to take the best available scientific data on the biological effects of radiation, come to a consensus on interpreting the incomplete data and then form recommendations useful to government agencies, industry and practitioners in the field using radiation sources. In the strict sense, the ACXRP was not a standard setting or regulatory organization since they lacked any enforcement authority. Their original recommendations were published in National Bureau of Standards (NBS) Handbook 15, and later renamed NCRP #1, X-ray Protection.

In 1934, a revised physical standard was adopted and called the "permissible dose." NCRP Report #2 (NBS Handbook 18) titled Radium Protection for Amounts up to 300 Milligrams recommended a permissible dose of 0.1 r/day for occupational workers; this could result in an exposure of approximately 25 to 30 r/year.

By 1949, the ACXRP had been reorganized into the National Committee on Radiation Protection (NCRP) and issued NCRP #7 (NBS Handbook 42) which contained the recommendation that the permissible dose be reduced to 0.3 r/week (15 r/yr) for whole body penetrating exposure. This significant change in the guidelines was suggested because of an expected rapid increase in the number of radiation workers throughout the country. It was justified as being achievable and practical at reasonable costs.

This was also the time for the introduction of a new radiation protection concept that occupational radiation exposure should be kept to the

lowest practical level. Over the years, this concept to minimize occupational exposures evolved into what we know today as the ALARA principle by which radiation exposures are kept As Low As Reasonably Achievable taking into account social and economic factors. Thus workers and radiation protection specialists are encouraged to employ protection practices that are better than any prescribed maximum level.

The new proposals of NCRP had been widely circulated during the summer of 1949 and constituted part of the background material for the September 1949 Tri-Parte' Conference held in Chalk River, Canada at which time the essential concepts were accepted. Although NCRP Report #17 (NBS Handbook 59) was not published until September 1954, there were no significant changes. However, since the recommendations were widely adopted as early as 1949, it is usually referred to as the "1949 Report." This is an indication of the relaxed environment in which Radiation Protection Standards were developed and promulgated in earlier years. It should be noted that no detectable health effects had been observed in anyone exposed while working under the earlier criteria going back to 1931. An addendum to NCRP #17 was issued April 15, 1958, to clarify the original document. Because of the great impact anticipated by these recommended changes, a conversion period of not more than five years was adopted.

The new exposure guidelines were never intended to be applied retroactively to individuals who had been covered by previously accepted standards. In most cases, the revised criteria have been made applicable directly to newly designed facilities while an adjustment period of several years has been permitted to gradually modify existing practices and facilities.

Acceptance of the recommendations of the NCRP has never been automatic by either government regulatory agencies or by professional societies. New guidelines need to be evaluated by peer review groups and adapted to the special needs of industry, hospitals and universities. However, there has been an increasing trend by various government agencies to rigidly adopt NCRP

recommendations and incorporate them into codes and regulations, usually after a delay of a few years.

The members of the NCRP have frequently expressed the fear that their recommendations of individual numerical dose values would be rigidly incorporated into codes by regulatory agencies and enforced in the usual dogmatic manner. This has never been considered appropriate because of the incompleteness of the scientific database on biological effects and the high degree of uncertainties involved. Any radiation protection standard does not imply that exceeding the criteria by 0.1 r or even 1.0 r, is "unsafe" since in the same manner being below the criteria by a similar amount cannot be considered "safe." While the risk to the exposed individual cannot be precisely determined, it is believed to be small. Also, it is assumed not to be zero. More important, the risk to the individual is considered so negligible that small deviations from the prescribed criteria are unimportant.

While new data or improved interpretation of the biological effects of radiation have been continually under review on a worldwide scale since 1946, changes in the recommendations have been rare and rather undramatic, occurring about every 8 to 15 years.

One very important example of scientific uncertainty has been the key question of the presence of a "threshold" below which one or more of the several important kinds of biological effects are absent. The answer is of great practical importance to the art of radiation protection. Unfortunately, present knowledge does not allow a definite judgement whether or not a real threshold exists for chronic exposures. As a result, a conservative value judgement has been made to use the unproven hypothesis that no threshold exists for cancer and genetic effects. Thus it is assumed, there may be some degree of risk at any level of exposure whether from natural background radiation, medical or dental X-rays or occupational exposure. Also, contrary to experimental evidence, it has been assumed that there is no biological repair following radiation exposure.

In 1957, NCRP introduced an age proration formula for the Maximum Accumulated Dose, (MAD) which was intended to be an allowable but unusual condition, namely:

$$\text{MAD} = (N-18) \times 5 \text{ rem}$$

N = Age of the Individual

The purpose of this change was to deemphasize the "sanctity" of a firm annual limit such as 5 rem. The previously used limit of 3 rem in a quarter was continued, thus effectively setting a maximum annual allowance of 12 rem for some individuals.

Note that under the MAD concept, a radiation worker beginning work at age 19 over a period of 40 years could theoretically accumulate a collective dose of nearly 200 rem without exceeding criteria.

Practically, this recommendation for whole body exposure means a maximum prospective annual permissible dose of 5 rem. The age-proration formula became a guide to limit accumulated doses with no penalty if the retrospective dose in any one year exceeds the dose limit by a factor of slightly more than 2 (up to 12 rem).

By 1959, NCRP recognized the need to simplify the standards, which in some instances, had become very detailed, complex, and far out of proportion to the biological knowledge. Therefore, the numerical changes in the recommendations reflected the urge for simplification rather than new biological data.

In 1960, the Federal Radiation Council (FRC) was organized in the United States to provide a focal point for interpretation of radiation protection guides for the many government agencies then involved in using radioactive materials or radiation producing devices. This provided an organization within the federal government to review the recommendations of the ICRP and NCRP and to standardize their application. It also provided an additional

layer of review with its resultant delays. The Environmental Protection Agency inherited this role when it was established in 1970.

Staff Report #1 of the Federal Radiation Council (1960) added its endorsement to the use of the 3 rem/quarter and 5 rem/yr standard which had been recommended in 1954 in NCRP report #17, "Permissible Dose from External Sources of Ionizing Radiation". On May 13, 1960, President Eisenhower approved these recommendations as guidelines for Federal Agencies.

In 1964, the National Council on Radiation Protection and Measurements [NCRP(M)] was officially chartered by the U.S. Congress thus providing additional status to the group and its recommendations.

On January 15, 1971, the NCRP in Report #39, "Basic Radiation Protection Criteria" recommended that 5 rem be adopted as the annual limit under most conditions. This, in effect, eliminated the age proration formula of 5 times a worker's age minus 18 years as an accepted criteria. In 1974, the U.S. Atomic Energy Commission established 5 rem as its annual limit. On January 20, 1987, President Reagan formally approved revised guidance on occupational radiation exposure for federal agencies by establishing a 5 rem per year limit, thus officially eliminating the accumulated yearly dose limit of 5 rem for each year beyond age 18. This criteria remained in effect through 1990, as covered in this study.

Radiation protection standards have been made complicated by the need to establish special guides for specific portions of the body, such as the skin, feet and hands, the eyes, the gonads, and for specific organs for internal exposures such as the thyroid and bone. These partial body exposure controls have rarely been more restrictive than the whole body exposure criteria which is the focus of this report.

Figure 1 is a plot of the evolution of Radiation Protection Standards in the United States since 1924. As more advanced information has been obtained and verified, the standards have been altered to reflect the best data on biological effects. Usually for external exposures, this has resulted in a

Figure 1. Historic evolution of radiation protection guides for whole body penetrating radiation exposure.

tightening of the standards. On the other hand, new information on internal exposures have frequently found the original criteria were more rigid than necessary. Over the period from 1951 through 1990, the basic criteria for radiation workers have decreased by a factor of 3 from 15 r/year to 5 rem/year.

Note that the occupational exposure limits were originally based on a daily exposure. These were gradually replaced by weekly, any thirteen week period, quarterly, and annual limits usually with reductions in the overall guideline values. These changes were most welcome to record keeping groups who had the extremely difficult task of manually maintaining current exposure data before the development of automatic data processing equipment.

2.3.3 Emergency Response Criteria

National and international occupation exposure criteria have always accepted a relaxation of the guidelines during abnormal plant conditions for emergency actions, particularly those involving life saving activities. In 1959, emergency preplanning at the NRTS had established an emergency exposure criteria of 100 r whole body for life saving efforts and a maximum of 25 r for all other emergency actions.

In earlier times (1954) "a once in a lifetime" exposure of 25 r whole body exposure could be accepted under emergency conditions without being charged against routine occupational exposure criteria. This exception was never utilized at the INEL, although it could have been applied to four individuals receiving the highest exposures in the rescue efforts in 1961 following the Stationary Low Power Reactor 1 (SL-1) accident. The new ICRP-60, "1990 Recommendations of the ICRP", issued in May of 1991, recognizes that doses up to 50 rem may be acceptable under abnormal conditions.

2.4 Collective Dose

The concept of collective dose is a relatively new one in radiation protection, having been introduced by the ICRP in 1977 when they published

ICRP #26. Collective dose (more technically, collective effective dose), is determined by adding all the effective doses received by whole populations under study over a period of time. The population groups may be as large as the world population, or as small as, a single individual's lifetime occupational exposure. It may include all the workers at a particular nuclear facility, or it may be limited to one working craft. The need for such a unit of dose, which is expressed in person-rem was the realization that radiation exposure causes biological effects which appear to be random in nature (stochastic). Also, as far as health detriment is concerned, there is no difference for one person to receive 1 rem exposure as compared to 1000 people each receiving 1/1000th of a rem for a collective dose of 1 person-rem.

This study was initiated primarily to determine the number and the risks to individual workers from exposure in excess of the radiation protection standards. As the data were analyzed, it became evident that there were two other potential health detriments which could be even more significant, namely, the lifetime exposures to the highest individuals and the collective dose to the whole population of radiation workers at the INEL.

3. OCCUPATIONAL RADIATION EXPOSURE DATA

3.1 Individual Exposures Exceeding Radiation Protection Guidelines

A detailed review of the individual exposure records from 1951 through 1990 revealed that twelve individuals exceeded the annual whole body radiation exposure criteria in effect at the time of their exposures, (Figure 2). The exposures presented in the histogram are the total exposure to each individual for the full calendar year, namely the radiation exposure before and subsequent to the particular accident, in addition to any exposure received during the accident. It was the practice whenever an individual exceeded the RPG that any exposure for the remainder of the calendar year was restricted to essentially background levels. While there are a few uncertainties in some of our other data, there are no uncertainties in this data pertaining to individual exposures. There were no other undetected or unreported accidents involving whole body exposures to penetrating radiation. Nor has any worker accumulated an exposure in excess of the wholebody radiation protection standard through smaller routine doses over the course of the year. These exposures were the result of the following four accidents:

1. July 23, 1956--Exposure During MTR Reactor Shutdown; 21.6 r
2. October 16, 1959--ICPP Criticality; 8.0 r
3. January 1, 1961--SL-1 Maximum Credible Reactor Accident; 15 to 27 rem
4. December 12, 1986, Exposure During Industrial Radiography - ICPP; 7.73 rem

A detailed analysis of each of these accidents is presented in Appendix A. This provides a description of the accident, the causes determined by formal investigation committees, and reference to published reports with complete details.

Figure 2. Histogram of the 12 INEL exposures greater than the radiation protection guides.

In each of these accidents, the acute exposures resulted due to a loss of control over radiation sources, which produced radiation fields considerably in excess of normal operating conditions. In nine of twelve technical overexposures the individuals knew in advance they were entering fields in excess of 100 r/hr. They had volunteered to accept this potential hazard in a lifesaving effort. Four of the individuals received the Carnegie medal for valor.

3.2 Highest Individual Lifetime Exposures

Reportedly, a listing of the ten individuals who had received the highest collective doses of penetrating radiation during their employment at the INEL was prepared around 1980. A search through various files and reports identified a paper presented by Douglas R. Wenzel at an International Atomic Energy Commission Symposium in Los Angeles in June 1979. This paper, titled, "Radiation Exposure at the Idaho Chemical Processing Plant" summarizes the radiation exposure experience primarily for the years 1973 through 1978. For data prior to this period it was difficult to account for the dose received specifically at the ICPP because of the practice of spreading radiation exposure pool which provided maintenance coverage at several other nuclear facilities at the INEL. A graph of the collective lifetime dose for those individuals then working at the ICPP was included with the recognition that a minority of the dose was probably received at other INEL facilities. This plot indicated no total accumulated lifetime doses exceeding 70 rem with five individuals in the 60 to 70 rem range. These eighteen individuals constituted 2% of the radiation workers of which 72% had accumulated less than 5 rem. Since the ICPP data did not fulfill our goal, the authors made a practice of recording the health badge number of any individual with a collective dose in excess of 45 rem whenever they searched the master dump printout. This data was then turned over to the EG&G Operational Dosimetry Unit. Paul Ruhter and Marie Hill developed the final listing of the highest individual lifetime exposures from which Table 1 was prepared.

The highest collective dose received by an individual during employment at the NRTS-INEL was 79.1 rem. This was received by a mechanic over a 40 year

Table 1. Highest Individual Collective Doses for Years 1951-1992.

Identification Number	Occupation	Working Years	Collective Dose in Rem	Year*	Rem*	Employment Status
102	Mechanic	40	79.1	1967	4.3	Retired '92
353	Operator	35	69.4	1971	4.7	Retired '86
626	Pipefitter	25	69.4	1961	4.3	Continuing
424	Pipefitter	23	66.1	1959	5.4	Retired '81
5056	Pipefitter	36	64.1	1959	4.3	Retired '86
159	HP Technician	32	63.7	1973	4.6	Continuing
3056	Pipefitter	33	62.5	1961	4.3	Retired '88
475	Operator	28	62.4	1972	4.5	Retired '84
064	Pipefitter	24	62.2	1965	4.3	Retired '91
020	Operator	38	61.5	1962	9.1	Retired '92
Average		31.4	66.0		4.98	

* Highest annual dose.

period, beginning in 1952 and ending with his retirement in late April 1992. His highest annual exposure of 4.3 rem was received in 1967. He averaged 1.98 rem per year over a period of time when the radiation protection guide varied from 5 to 15 rem/yr. If he had been exposed at the maximum exposure rate each year, his lifetime dose could have been 377 rem. In reality, he had received 21% of that maximum value.

Table 1 presents summary data on the ten highest exposed individuals. An analysis of this data taken from their individual exposure records reveals the following:

- collective doses ranged from 79.1 to 61.5 rem with the mean being 66 rem;
- individuals were mainly maintenance craft personnel, with an average of 31.4 years as radiation workers and averaged slightly under 2 rem/yr;
- the highest annual exposure for any of these individuals was 9.1 rem in 1962;
- none of these individuals were involved in any of the four accidents resulting in exposures in excess of the RPGs;
- neutron exposures were very low, ranging from 0 to 0.37 rem over their working lifetime;
- nine out of ten had received significant skin exposures from soft energy radiation ranging from 20 to 41 Rad. Using the latest tissue weighting factor of 0.01 for skin, the effective dose equivalent would be increased by an insignificant amount of from 0.2 to 0.41 rem for the individuals involved; and
- as of June 1, 1992, eight of the ten workers had retired.

3.3 Annual Radiation Exposure Distribution

The goal for this study was to consolidate all the key data into a single page table for easy use and reference.

Table 2 presents, on an annual basis, the best data available on the radiation exposure distribution for Idaho Field Operations Office employees and contractors. Appendix B has all the original data in the ranges of exposure found in the reference source. We consolidated the ranges from as many as 45 different range categories into 6 simple ranges of, "0-1 rem" to a maximum of "greater than 5 rem (>5 rem)". Complete reference information on each source of data can be found in Section 7.

In selecting the best available data for Table 2 the following three primary criteria were used:

1. Reconstructed data from the Master Dump 1951 through 1957, 1965, and 1973 (see references 1-5, 7, 9, 31, and 47).
2. Annual summary reports to the Division of Operational Safety, Headquarters, on AEC form 190 for 1958 through 1964, 1966 through 1972 (see references #12, 14, 16, 18, 22, 26, 28, 33, 35, 37, 40, 42, 43, and 45).
3. Standardized reports available from the SSDC for 1974 through 1990 (see references #48 through 64).

One of the most striking features of this table is the nearly continuous decrease in the number of exposures in the various ranges above 1 rem/yr after 1965. As radiation protection practices were strengthened, the number of people receiving >3 rem/yr had essentially disappeared after 1979. Over the last ten years, only 53 people have exceeded 1-2 rem/yr.

Because of the greater significance of the data in the column on collective dose, this data has been plotted separately in Figure 3 to

Table 2. INEL historic radiation exposure distribution occupational whole body exposure in rem.

Cal. Year	<Meas	0-1	1-2	2-3	3-4	4-5	>5	Site Pop.**	Total Mont.	Collect. Dose	Rad.Prot. Guides	> Guides
1951	*							2250	*	0	15R	
1952	*	83						2350	*	15		
1953	*	738	34	3	2	2	1	2175	*	209		
1954	*	797	79	26	8	1	2	2525	*	388		
1955	*	1336	120	76	29	10	4	3025	~2700***	839		
1956	*	964	125	61	24	9	11	3625	2810	756		1
1957	*	1243	114	20	4			4550	4338	486		
1958	*	2785	260	143	47	24	29	5000	3288	1854	12 rem	
1959	*	2962	257	196	33	14	5	5075	3467	2462		1
1960	*	4020	220	94	51	11	1	5200	4397	2294		
1961	*	3199	346	201	138	45	19	4920	3948	2700		9
1962	*	3137	229	102	73	49	23	4755	3613	2156		
1963	*	3283	212	87	77	23		5310	3682	2156		
1964	*	2433	190	115	82	15		5900	2835	2330		
1965	*	2547	439	221	180	144	61	6025	*	3448		
1966	*	2400	206	105	83	44		5800	2838	2412		
1967	*	2502	226	109	95	53		5825	2985	2114		
1968	*	2612	163	100	86	44	1	5850	3006	1781		
1969	*	2526	196	81	70	23		5850	2769	1723		
1970	*	2936	168	77	59	33		5755	3273	1655		
1971	*	2723	136	57	27	4		5680	2947	1180		
1972	*	2553	171	89	59	19		5875	2891	1381		
1973	*	2143	183	66	36	18	1	5975	*	1091		
1974	1885	889	133	62	20	1		5950	2990	686	5 rem	
1975	1036	1363	115	51	15			3643	2580	611		
1976	2585	1704	148	75	7			4145	4519	788		
1977	1939	1385	158	94	38	6		5046	3620	929		
1978	2160	2027	161	88	18	3		5901	4457	898		
1979	2782	2318	163	61	3			6188	5327	876		
1980	2672	1724	133	43				6544	4572	593		
1981	2556	1734	36		1			6695	4327	302		
1982	2565	1606	60	6				6653	4237	363		
1983	2780	1655	30					6391	4465	353		
1984	3172	1818	68	7				6842	5065	441		
1985	3470	1881	47	3				7186	5401	420		
1986	4689	2227	133	23		1	1	7853	7074	618		1
1987	3901	1843	45	4				7586	5793	314		
1988	3829	1734	27					7998	5590	233		
1989	4144	1719	83	2				8779	5948	317		
1990	4787	1655	25	5				10295	6472	228		

Totals	79204	5639	2553	1365	596	159	220740	135524	44400		12
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* Data unavailable

** 1951-1974 Total Site Population; 1975-1990 DOE-ID & Contractors

*** Compiled from AEC & Contractor Employment Graph (RESL)

Figure 3. Collective dose for INEL personnel from 1951-1990.

graphically indicate the general trend in the growth and decline of the total dose to workers over the 40 year period.

To the best of our knowledge, personnel working under contract to other Field Operations offices, such as Chicago, Pittsburgh, and Lockland, are not included in this data. Wherever possible we have also removed all visitors from our statistics, since they rarely received any exposure above the lower limit of detection (LLD). Construction personnel under contract to Idaho Field Operations Office have been included. Their exposures were negligible during the first decade and were almost all below 0.5 rem/yr thereafter. In the post 1974 era of more detailed data collection, we were also able to subtract those ID employees and contractors working outside of the INEL, namely personnel working at Grand Junction, Colorado, Butte, Montana, and West Valley, New York.

We were unable to locate any meaningful data on the number of employees receiving less than measurable ($< \text{meas.}$) exposures from 1951 through 1973, nor the total number of employees being monitored from 1951 through 1956.

Finally, the ID working population at the INEL during the key period 1951 through 1973 could not be obtained nor calculated. Combined data for operating and construction employment for the total INEL was obtained but without breakdown according to the various field operations offices. This data could possibly be obtained from early records of the offices involved or from the DOE Headquarters archives. Since this data was desirable only to determine average worker exposure, it was not considered to be worth the additional resources required. Very good ID data for the 1974 through 1990 interval was obtained. The total number monitored was also unavailable for 6 of the 40 years.

3.4 Annual Mean Dose

In almost all reports on radiation exposures to large groups of people, it is customary to calculate the average exposure per person. Certainly, the annual mean dose has meaning as a basis of comparison if the conditions

underwhich the data is collected has a common basis. However, the actual number of people involved as occupational radiation workers is not easily determined. Unfortunately, most organizations making this type of calculation use differing population groups, along with other variables. For example, some use total working population, while others use only monitored personnel, some include visitors and service personnel, such as, utility repairmen and vendors. Many include administrative personnel, such as, finance, purchasing, secretarial, and human resource individuals, who enter potential radiation areas on an infrequent basis. Some employers, for legal reasons involving liability, require the badging of all personnel entering the plant area because of the remote possibility of an accidental exposure. Naturally, the larger the population included in the personnel dosimetry badging requirements, the greater the number of individuals with little or zero exposure, and the lower the average exposure for that organization, if other factors are similar.

This study has produced excellent data on the annual collective doses for ID and its contractors, along with the total number of people who were issued personnel monitoring devices each year. However, difficulty was encountered calculating a meaningful average annual dose. The standard practice for ID has been that all employees entering reactor areas or the Chemical Processing Plant area have a security badge, which since 1957, has always contained a dosimetry device. This means that a large number of nonradiation workers are included in our statistics and are listed in Table 2 as "Total Monitored". There was no convenient or simple way to eliminate the nonradiation workers from our statistics until 1974, when AEC Headquarters required that future reports include the number of people badged for radiation protection purposes who did not receive any measurable exposure. Over the next seventeen years, this data was collected by Idaho Field Operations and indicated about 30% of the people monitored during that period received no measurable exposure (below the lower limits of detection). Since practices were different before 1974, it would not have been valid to extrapolate this average to all the prior years. However, the total number of radiation workers was determined for the years when the radiation exposure distribution

was reconstructed by searching the Master Dump, e.g., 1951 through 1957. This data for 1958 through 1973 is incomplete.

Figure 4 is a best effort to project some sense of the annual mean dose for ID and its contractors over the 1951 through 1990 period. The solid line graph presents the mean dose values for every year available, it was obtained by dividing the collective dose for any year by the total number of employees monitored.* This approach produces artificial numbers since many of the monitored personnel were not radiation workers.

The broken line plot with the small triangle markers, is an incomplete but more significant projection of the annual mean dose to radiation workers. It uses the total monitored figures corrected by subtracting the number of people who received no measurable exposure during the same year. The resulting curve has values 2 to 3 times higher than the base curve. This is a more accurate projection of actual mean dose to the people at risk. However, data is unavailable for 13 of the 40 years, i.e., 1958-1964, 1966 and 1972.

Overall, the graph depicts the graded rise in average exposure through 1955, a sharp drop in 1957, rising to a plateau in 1958 where it essentially remained, except for a sharp increase in 1963 through 1966, until 1968 (10 years). This was followed by a nearly exponential decrease to an average of 0.135 rem in 1990.

Plots of the annual mean dose to ID workers has a visual relationship to the plot of annual quantities of radionuclides in operational releases at the INEL found in DOE/ID-12119, titled "Idaho National Engineering Laboratory Historic Dose Evaluation." The major exception is the broad peak for 1963 through 1966 which appears only in the mean dose graph. This observation is not unexpected, since the dose to workers must have a correlation to the amount of radiation work being performed, which in turn has a correlation (particularly before 1970) to the quantity of radioactivity released to the

*Data on the number of monitored workers was not available for 1965 and 1973.

Figure 4. Total annual mean dose for ID and contractor personnel.

atmosphere. However, the exposures to the workers did not result from the atmospheric releases.

4. CONTRIBUTING CAUSES TO THE MAJOR CHANGES IN OCCUPATIONAL EXPOSURE

4.1 Introduction

Figure 5 is a plot of changes in the annual INEL population versus collective dose over the 40 year history covered by this study.

As far as the collective dose history for ID personnel is concerned, it increased at an average rate of about 230 person-rem over the first fifteen year period through 1965 and then decreased at a slower rate, which averaged about 130 rem/yr for the following 25 years.

There has been an almost constant straight line growth in NRTS-INEL total employees of about 300 employees per year over the entire forty year history. This includes operating and construction personnel from all INEL contractors, since we were never able to break down employment into the number of individuals for each of three or four field operations offices performing research work. The total number of construction workers has ranged from a low of 195 in 1974 to a peak of 1350 in 1957. In only nine years has it exceeded 1000. The average over the forty year period has been 736.

To explain the major increases and decreases in occupational exposures on an annual basis, a "thumbnail sketch" would be required over the 40 year period of all major activities involving the use of nuclear material which could result in the more significant radiation exposures.

A search of the technical library, as well as discussions with long time employees of the INEL Public Information and Human Resources groups, failed to reveal a single major resource which could be utilized. A number of leads with fragmentary data were provided from which the authors compiled a chronological listing which highlights the significant activities involving potential occupational exposures. This listing is available in the project files. These activities included: construction dates, routine and special operations, significant environmental releases, major accidents, destructive

Figure 5. Annual site population vs. collective dose for 1951-1990.

testing, decommissioning, and changes in operating contractors and government agencies. The following were the major sources of information used:

ID, Health and Safety Division Annual Reports, 1958, 1959, 1960, 1961, 1962, 1963

NRTS Thumbnail Sketch, 1966 (These reports were prepared by the ID Public Information office from around 1957 through 1966, on almost an annual basis. The 1966 report summarizes the INEL history up to that time).

ID, Health Services Laboratory Annual Report, 1969, 1970

INEL Annual Reports, 1986, 1987, 1988, 1989, and 1990

INEL History, Ben Plastino Draft, 1990

INEL Historic Dose Evaluation, DOE/ID-12119, Vol. 1, 8/91

INEL News feature articles on anniversaries of MTR, ICPP, EBR-1, and EBR-II.

4.2 Specific Changes by Decade

4.2.1 1949-1960, The Decade of Growth

Although the NRTS-INEL was officially approved for reactor testing on February 28, 1949 and construction activities began a little more than a month later, the first work involving the handling of radioactive materials did not occur until September 1951 at the Experimental Breeder Reactor #1 (EBR-I) and the Materials Testing Reactor (MTR). One or two new reactors or critical facilities were brought on line each year through 1956. The amount of fission product inventory continued to increase in reactors, as well as at the ICPP.

During the five year period (1951-1956) the INEL experienced its first destructive test of a reactor on July 22, 1954, at the BORAX-I facility. As a result, this became the first INEL facility to be decommissioned. The first criticality accident occurred on November 29, 1955 at the Experimental Breeder Reactor 1 (EBR 1) and resulted in core meltdown. The first occupational

exposure in excess of radiation protection guidelines was experienced on July 23, 1956 at the Materials Test Reactor (MTR), when a facility operator received 21.6 rem whole body exposure while doing work inside the reactor dome during a maintenance shutdown.

1957 and 1958 saw the largest expansion with five new reactor facilities becoming operational in each year. In 1957 they included, the Heat Transfer Reactor Experiment No. 2 (HTRE-II) and Critical Experiment Tank (CET) for the Aircraft Nuclear Propulsion (ANP) program, the Engineering Test Reactor (ETR) and its criticality support facility (ETRC), the Organic-Moderated Reactor Experiment (OMRE), and the Stationary Low-Power Reactor No. 1 (SL-1). In 1958, the Large Ship Reactor "A" Plant (A1W-A), the Special Power Excursion Reactor Test No. 3 (SPERT-III), the Heat Transfer Reactor Experiment No. 3 (HTRE-III), and the Hot Critical Experiment (HOTCE) became operational. This increased capability for nuclear research produced the sharpest increase in collective dose in the history of the INEL--from 756 person-rem in 1956 to 2462 person-rem in 1959. Operation of the Radioactive Lanthanum Facility (RALA) at the ICPP started with the "cool" runs in 1956, and eight "hot" runs in 1957, twelve in 1958, and sixteen in 1959.

Four more reactors were completed in 1959. Figure 3 may also be referenced for a more detailed visualization of the increases in collective dose.

4.2.2 1960-1970, The Years of Program Change

An additional three reactors were started up in 1960 when the INEL reached its all time peak of twenty-three operating reactors. The collective dose varied up and down between 2156 and 2700 person-rem from 1960 through 1964. This period saw five reactors dismantled or placed on standby following the destruction of the SL-1 reactor in 1961 and the cancellation of the ANP program.

Since the SL-1 reactor accident in early 1961 had such a major impact on the workload and the collective dose of INEL workers, more detailed analysis

is in order. Not only were three military operators killed by the accident itself, but the rescue operations (with some 63 people involved over the first 27 hours), resulted in nine individuals exceeding the radiation protection guide of 12 rem per year. The rescue team received a collective dose of 241 person-rem (an individual mean dose of 3.83 rem). The subsequent operations to collect evidence on the root causes for the accident and the decontamination and dismantling of the reactor facility required an effort in manpower, resources, and occupational exposure unique in the nuclear energy field. This effort extended for eight months through 1961 and continued into mid 1962. The cancellation of the Aircraft Nuclear Propulsion (ANP) program by President Kennedy on March 28, 1961 made available the services of a large staff of General Electric personnel experienced in high radiation field disassembly using direct and remotely operated equipment. These combined efforts resulted in a total collective dose of 1305 person-rem in 1961 or 48% of the total exposure received by ID workers during that year.

For two to three years after the SL-1 accident, collective doses settled back to a level of around 2200 person-rem before suddenly spiking to a recorded value of almost 3600 person-rem in 1965. This sharp rise of about 50% was totally unexpected based on the lack of any specific accident or increase in radiation work at any one facility. At first, the data was considered to be in error by at least 1000 person-rem. A recheck of the original source of data indicated the numerical value was correct. Still questioning the accuracy of this figure, a meticulous reconstruction was made of all individual exposures received in 1965. This required a total of 56 hours to check the Master Dump of over 5303 pages of records. The final tabulation validated a total of 3448 person-rem, within 3% of the original value. This was accepted as the better value. A more detailed look into the radiation work being performed indicated a general increase in late 1964 which extended into mid 1966 at most facilities, resulting in an exceptional number of workers receiving annual doses in the 4 to 5 rem range, as well as, greater than 5 rem. Also, in 1966 the INEL population reached a new peak of 6025 employees, a figure which would not be exceeded for another nine years.

By 1967 it was evident that an almost exponential decline in exposure had been started which continues to the present time. This major change has been the result of two primary factors. First and foremost, has been the increase in emphasis on the ICRP Optimization Concept, that any radiation exposure was to be kept as low as reasonably achievable (the ALARA principle). The second contributing factor has been the decrease in magnitude of the amount of radiation work being performed. Older projects, such as the MTR (4/70), were being phased out at a faster rate than new projects were being constructed. By 1969 the collective dose had been reduced to about 1700 person-rem, the lowest figure since before 1958.

4.2.3 1970-1980, Mission and Organization Changes

The first half of this decade saw very little population change as the number of employees fluctuated mildly between 5700 and nearly 6000. However, there were major organizational changes as Allied Chemical took over the ICPP from Phillips Petroleum Company in 1971, the NRTS was renamed the INEL by Congress in 1974 and later designated a National Environmental Research Park. ERDA replaced AEC for a brief period between 1975 and 1977 before DOE took over. In late 1979, Allied Chemical completed its contract and was replaced by Exxon Nuclear Idaho. In 1975, with ERDA broadening the basic program into non-nuclear research and development, the INEL population shot across the 6000 employee threshold to nearly 9500 personnel in 1979. In 1975, the most recent nuclear reactor, the Loss of Fluid Test (LOFT), became operational.

During this entire decade the collective dose continued to decline for the overall INEL from 1655 person-rem in 1970 to 876 in 1979. New lows in the 600 to 800 person-rem range were recorded in 1974, 1975, and 1976. However, individual facilities did have differing experiences. As an example, by 1973 the ICPP had been operating for 20 years and the Waste Calcining Facility for 10 years as a pilot plant. Both facilities relied on direct maintenance of their aging pumps, valves, and process vessels. In most years the collective dose was directly related to the amount of time the facilities were shut down for maintenance and repairs. In 1975, for example, increased production requirements resulted in almost continuous plant operations. This resulted in

a low plant collective dose of about 340 person-rem since maintenance was minimal. The following year extensive upgrading and expansion of the plant and construction staffs resulted in a near doubling of the collective dose which by 1978 was about 70% of the total INEL collective exposure.

The overall reduction of individual radiation exposures to minimum levels was now becoming an art. The more dynamic application of the ALARA philosophy was led by the Health Physics Group at the Idaho Nuclear Corporation, who introduced new administrative controls in 1974. One of which required each branch manager to set annual exposure goals below 3 rem per year for each radiation worker who had received an exposure of greater than 0.5 rem the prior year.

These controls resulted in the use of added shielding in operating areas and hot cells, a cleanup of plant areas having elevated radiation levels, and a more even distribution of exposures among people in the same maintenance crafts. Each succeeding year the exposure experience was reviewed by branch management and efforts were made to ratchet the exposure goal for each individual to a lower value.

4.2.4 1980-1990, Decade of Diversification

The 1980s saw INEL programs expand well beyond Idaho to Butte, Montana; Grand Junction, Colorado; West Valley, New York; and to support the dismantling of the Three Mile Island #2 reactor in Harrisburg, Pennsylvania. Wherever possible, we have deleted data on individuals working outside the INEL boundaries from this study - particularly their occupational exposures.

New programs, such as, geothermal energy, electric vehicle, and low-head dam hydro-electric systems continued to dilute the nuclear effort. In 1981, the Waste Calciner Pilot Plant (WCF) was retired after eighteen years of converting 3,900,000 gallons of high level waste into a smaller volume and safer solid. This facility had been a major source of exposures during periods of maintenance. The Engineering Test Reactor was shutdown in 1982 and

the last of 38 experiments was completed at LOFT in 1985 with a simulation of the TMI-2 accident with intentional core damage.

The collective dose had nearly leveled off but fluctuated between 600 and 300 person-rem between 1980 and 1986, before continuing its general decline to 228 person-rem in 1988. Thus, a factor of more than ten reduction in occupational exposures had been experienced over the 25-year period since 1965, although the total work force had doubled and the number of radiation workers had decreased by about 40%.

Another change, began as early as 1968, that also impacted the shift in the ratio of radiation workers to support personnel, was the movement of workers who did not need to be based at the INEL site to locations in Idaho Falls. Examples are:

- 1968--Computer Center
- 1976--Technical Support Building (TSB)
- 1978--Technical Support Annex (TSA)
- 1979--Willow Creek Building (WCB)
- 1984--INEL Research Center (IRC)

By 1992, an estimated 4200 (about 35%) out of a total of 12,000 employees were working off-site.

Another indicator of this change in the amount of nuclear related work is the following table which demonstrates the decrease in major nuclear facilities:

Year	Number of Nuclear Facilities Operational
1967	15
1977	11
1987	7

5. RISK ESTIMATES

5.1 Introduction

Once the whole body external occupational exposure had been determined, a statistical estimate could be made of the risks of delayed health effects which might result to exposed individuals on a random basis. These delayed effects may include an increased risk of cancer or an increased risk of transfer of damaged genetic information to future generations. Since the increased risk of fatal cancer (primarily leukemia) is most important and better quantified, the focus has been on risk estimation. However, it was also feasible to estimate the normal probability of nonfatal cancers and hereditary effects since each would be approximately 20% of the fatal cancer projection. It should be noted that these risk estimates are based on large populations (namely one million people) in a working population aged 18-64.

The risk estimates have been made by extrapolating from unknown health effects at high doses (greater than 20 rem) and high dose rates, mainly data from Hiroshima and Nagasaki atomic bomb survivors, to hypothetical effects at low doses and low dose rates (below 0.5 rem/yr) using a linear hypothesis with no threshold below which these effects could occur. The risk estimates available even today are highly uncertain. These large uncertainties are magnified when extrapolated to typical occupational doses. The confidence in the resulting calculations is further reduced because of the conservatism in most of the assumptions. Because of this, the health effects at low doses and dose rates could actually be zero. Therefore, these estimates will be presented as a range of values from zero to an estimated maximum value. Finally, it should be noted that low doses of radiation exposure have not demonstrated any increase in the incidence of cancer or any other diseases. There is no clinical evidence that people living in the United States, or any other part of the world with radiation levels twice the average received in the United States, are at any greater health risk.

The variable risk factors which can be important in estimating the frequency of fatal radiation induced cancers are the following:

- gender, since the risk to males is generally higher;
- age of the individual at the time of exposure, since the risk tends to decrease with age;
- time since the exposure, since biologically it takes a long time for the insulted tissue to develop into a cancer. This latency period is taken to be a minimum of 2 years for leukemia and 10 years for all other cancers;
- dose rate, doses delivered chronically (over years) are less likely to result in cancer than doses delivered acutely (less than one day in an accident situation). Chronic exposures are less risky by a factor of two or more. This reduction takes into account biological repair and other defense mechanisms which occur at low doses and low dose rates; and
- the nominal risk factors used in this report for risk assessment may not be appropriate since they lack a true scientific basis. They were developed for use only in radiation protection to establish worker dose limits. With this caveat they have probably been used inappropriately.

5.2 Individual Workers

5.2.1 Accident Experience

The highest individual exposure received during an accident was 27 rem to two individuals following the SL-1 reactor accident. The highest risk estimates projected to date appeared in ICRP Publication 60 (1990 Recommendations of the International Commission on Radiation Protection).

These values are almost a factor of three greater than those used in earlier reports in the 1980s.

The nominal probability for a working population for high dose/high dose rate exposure leads to fatal cancer risks of 8% per 100 rem. This would indicate the fatal cancer risk for these individuals could be increased by a maximum of about 2%. This would be from an average fatal cancer risk of 16 per 100 individuals to a maximum of about 16.3.

There is an interesting coincidence, the highest acute exposure of 27 rem whole body, is essentially the same magnitude numerically as the chronic exposure received by the average American over their life span of about 75 years at the average exposure rate of 0.36 rem/yr from natural background radiation.

5.2.2 Lifetime INEL Experience

The ten highest individual collective doses received during the history of the INEL have been in the range of from 60 to 80 person-rem. Since these were chronic exposures, we have used the nominal probability for fatal cancer risks of 4% per 100 rem whole body exposure (a conservative factor of 2 less than for acute exposures). The increased risk of fatal cancers for this extremely limited population could be from an average incidence of 16 per 100 individuals to about 16.5.

5.3 Collective Dose to Working Population

Over the 40 year period, well over 250,000 person-years of work was performed by over 60,000 people. The collective dose was about 44,500 person-rem. Again, we have used the nominal probability for a working population for radiological protection purposes, i.e., low dose and low dose rate exposures. This value for whole body exposure is estimated to be a maximum of 4% per 100 rem. This calculates to be from none to 18 fatal cancers that could result to this population from their occupational exposure. In other words, when one considers that the average fatal cancer rate in the United States is 16% for

large populations, this estimate suggests that the expected total of 9600 fatal cancers for this working population of over 60,000 people could be expected to increase to a maximum of 9,618 for an increase of about 0.19%.

There also may be an additional none to a maximum of 4 nonfatal cancers and conservatively, from none to 4 severe hereditary effects during their lifetime.

Finally, these values are only statistical estimates since the data cannot support any findings linking any cancers to exposures received at the INEL.

6. CONCLUSIONS

6.1 Observations

The INEL was originally selected as an isolated location where hazardous reactor testing could be performed. Over the first forty years, more than sixty destructive tests or incidents took place. There has never been a radiation caused fatality. While the SL-1 reactor accident in early 1961 did result in the death of three maintenance personnel, the steam explosion was the cause of death, although the radiation exposures involved were in the lethal range.

In general, nonstochastic effects such as burns, cataracts, blood cell changes, and sterility, could not have occurred because the acute exposures have been well below the high thresholds for any such effects. There has been only one radiation injury in the history of the INEL and it did not involve work under Idaho Field Operations Office jurisdiction. The injury was a 10% loss of hearing in one ear in July 1955, as the result of a highly radioactive particle found in the ear of a worker at the Naval Reactor Facility.

During the first seventeen years of work at the NRTS, the period when the largest amount of hazardous radiological work was being performed, there was a total of 275 lost time injuries with only the one mentioned above due to radiation. Most of the others were caused by gravity, either falling people or falling objects.

Occupational exposures at the INEL have been a small source of detriment to the working population as a whole. The importance of these exposures has been mainly to the few individuals involved and even there the maximized health risk is small.

The Idaho Field Operations Office has developed and implemented a comprehensive dosimetry program which adequately measures and documents the exposure of contractor and federal personnel to ionizing radiation. Radiation dosimeters worn by workers are periodically analyzed and the results recorded

in individual personnel exposure records which are summarized on an annual basis. These dosimetry records are available to the individual, health protection personnel, and management. They are considered private information, just like medical records. A potential public onus can be placed on individuals involved in radiation accidents. Therefore, the individual's identity is concealed in this report by using occupational titles and by arbitrarily assigning numbers.

Personnel dosimetry data has never been classified. Before 1960 a few incidents did involve classified processes or equipment. In all cases, classification practices were never used to prevent disclosures of plant problems or to conceal occupational radiation exposures. After investigations were carried out to determine root causes, an unclassified report was prepared for use by the industry to prevent any repetition.

This study of exposure records and accident reporting revealed no undocumented accidents or unexplained exposures in excess of radiation protection criteria.

Other general observations of note are the following:

- Acute high radiation exposures have been easily avoided by employing the ALARA philosophy, administrative controls, preplanning work assignments, and adequate shielding.
- Health Physicists have always been aware of major exposures (greater than the RPG) before the processing of the personnel dosimeter. In other words, the processing of the passive dosimeter device has never revealed an unknown major whole body exposure, but rather, confirmed that such an exposure had occurred. Usually, other personnel or area monitoring instruments have revealed the presence of high radiation fields.
- Over the forty year history of the NRTS-INEL, radiation protection guides for workers have changed remarkably little (a factor of 3)

as new radiobiological information has slowly become available. One can project that future changes will be relatively minor.

- No worker ever exceeded the age proration formula of five times their age in excess of eighteen years.
- No individual was ever involved in a second incident that resulted in exceeding the Radiation Protection Guide.
- No one ever exceeded the annual guide by the collection of small, chronic exposures; an acute incident was always involved.
- The number of workers exceeding 5 rem/yr whole body exposure over the forty year period has been relatively small (159). A few did receive this level of exposure two or three times during the earlier years when the annual exposure criteria was 12 or 15 rem/yr. However, since 1974 when the 5 rem/yr criteria was recommended, only one worker has exceeded this value.
- Since 1965, exceeding 5 rem/yr has been a rarity (3 times) because of improved plant design and administrative controls. The last such exposure was in 1986.
- Because occupational exposures usually have a log-normal distribution, emphasis on reducing the higher levels of exposure, those greater than 1 rem/yr, will not significantly reduce the collective dose. Because of the successful application of the ALARA philosophy, dose limits have essentially lost their relevancy. It is indeed rare for an individual to even approach the dose limit. Since 1980, only three individuals have exceeded 3 rem in a year.
- The ICPP has been the major source of the highest exposures and collective dose at the INEL. This was basically due to the 1950 through 1960 plant design which provided for direct maintenance.

As the reprocessing plant and the original waste calcining plant aged, they required more and more repairs and maintenance. It is during the shutdown periods when shielding is removed that the vast majority of occupational exposures occur. It is interesting to note that 11 of the 12 exposures in excess of the radiation protection criteria occurred during shutdown periods.

The public most likely has the false impression that nuclear reactors are the most hazardous facilities. However, since these plants spend most of their time on line, operating with all their shielding in place, about 75% of the exposures occur during shutdown periods when some of the shielding has been removed.

6.2 Suggestions

While it was not the intention of this study to make an appraisal type audit of the actual dosimetry records, a few suggestions are offered which should be factored into future practices.

- The identification of each employee should be completed in all details.

- A number of employees were identified on the master dump only by initials for their first two names, i.e., R. E. Smith, E. B. Johnson, J. C. Clark.

- In many more cases only the middle initial was used.

- In a few cases, the social security number was not available.

- Form IDF-5484.1B, titled "Previous Radiation Exposure History," which documents the individuals prior exposure either at the NRTS,

while working for another Field Operations Office contractor, or for work at other nuclear facilities outside of Idaho, contains a fundamental flaw. It does not request an annual breakdown of previous occupational exposure. Instead, one usually obtains a single dose number which is a hash total of all exposures received over several years of work. Unfortunately, there have been cases where this collective dose has been entered as the exposure received in the prior year to INEL employment. As an example, this happened in 1958 when the Idaho Field Operations Office took over dosimetry service for the Naval Reactor Facility. Employee exposures from 1952 to 1957 were entered as being received in 1957. This is a generic problem which is quite common for the industry, particularly during the early years.

There was little evidence of real effort to identify and preserve historic data. As one example, considerable difficulty was experienced in obtaining information on the total number of employees working at the INEL each year before 1974, much less a breakdown by individual contractor.

The whole question of dosimetry record keeping has evolved over a period of decades. Initially, there was little guidance from the Washington Headquarters staff. In 1974, a standardized format was introduced. However, each change in the federal agency involved, each change in the operating contractor, and some major reorganizations within the contractor have resulted in changes in the reporting criteria or record summary format. As a result, it is very difficult to compare data from one year to another, or between laboratories. As examples, some early dosimetry data combined skin and penetrating exposures. Post 1990 data will combine internal and external exposures into a total effective dose equivalent. Prior to 1990, dosimetry data was recorded as separate entries for internal exposures, non-penetrating exposures (skin doses), neutron exposures, and gamma penetrating exposures.

This was done since an approved method for integrating the various dosimetry measurements has not been developed.

- Dosimetry record keeping should avoid the use of special purpose operating systems or computer hardware. Otherwise future access to the data may be very difficult or highly expensive.
- Another example is that cumulative data on work injuries and fatalities was not readily available. This was partially due to a redefinition of "disabling injuries" in the mid 1970s, which provided an improved standard for reporting but at the cost of losing the capability of comparing data with earlier years.
- This study has identified twelve individuals who at one time exceeded the radiation protection criteria, along with the ten individuals who received the highest occupational exposures during their employment at the NRTS-INEL. The publication of this study may raise questions or concerns about potential health risks to these and other individuals. Some interest and concern was evident when a few of them were interviewed to obtain more information about the accident in which they were involved. Now that better risk estimates are available from the ICRP as of 1990, we recommend that members of the Medical and Health Physics staffs sit down with each of the individuals to review their exposure record and discuss in realistic perspective the small risk involved as the result of their occupational exposure history.
- We also suggest that this type of study and analysis of radiation exposure experience be repeated every five or ten years to provide applied health physics personnel with feedback on the successes and failures of their program to control occupational exposures. It would also provide valuable information for employee and public relations purposes. Finally, it would bring together historic

data in a convenient format on a timely basis, while most of the individuals involved are readily available.

- Based on over forty years of dosimetry experience, it might be timely to review the entire program to revalidate basic philosophy and practices.
- This report should provide added incentive for applied Health Physicists to continue reduction of INEL-wide collective dose, individual lifetime occupational doses, as well as, individual annual exposures in accordance with the ALARA philosophy, provided it can be done on a cost effective basis.

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1971	43.	LETTER to Martin B. Biles, Director Division of Operational Safety, HQ DATED 2/28/72 FROM W.L. Ginkel, Manager Idaho Operations Office SUBJECT: 1971 WHOLE BODY RADIATION EXPOSURE SUMMARY ATTACHED: AEC-190 & AEC-191 Radiation Summary Reports
1972	44.	MEMO ROUTE SLIP to C.W. Sill, A.H. Dahl, J.H. Spickard DATED 3/12/73 FROM D.I. Walker SUBJECT: NRTS HISTORY ON EXPOSURES ATTACHED: Graph TITLED "WHOLE BODY RADIATION EXPOSURE DISTRIBUTION-1972, AEC-190, Commentary dated 3/10/73 and Table TITLED "EXTERNAL RADIATION EXPOSURE"
	45.	LETTER to Martin B. Biles, Director Division of Operational Safety, HQ DATED 3/5/73 FROM W.L. Ginkel, Manager Idaho Operations Office SUBJECT: 1972 WHOLE BODY RADIATION EXPOSURE SUMMARY ATTACHED: AEC-190 & AEC-191 Radiation Summary Reports

Year	Reference File #	Original Source
1973	46.	LETTER to Martin B. Biles, Director Division of Operational Safety, HQ DATED 3/7/74 FROM R. Glenn Bradley, Manager Idaho Operations Office, signed by Carl R. Mainstrom SUBJECT: 1973 WHOLE BODY RADIATION EXPOSURE SUMMARY ATTACHED AEC- 190 & AEC-191 Radiation Summary Reports
	47.	1973, Master Dump, dated 12/10/75
1974	48.	ERDA 76/119, SEVENTH ANNUAL REPORT OF RADIATION EXPOSURES 1974 FOR AEC AND AEC CONTRACTOR EMPLOYEES
1975	49.	ERDA 77-29, EIGHTH ANNUAL REPORT OF RADIATION EXPOSURES FOR ERDA AND ERDA CONTRACTOR EMPLOYEES, 1975
1976	50.	DOE/EV-0011/9, NINTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1976
1977	51.	DOE/EV-0066/10, TENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1977
1978	52.	DOE/EV-0066/11, ELEVENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1978
1979	53.	DOE/EP-0039 (revised from DOE/EV 0066/12), TWELFTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1979
1980	54.	DOE/ER-0040, THIRTEENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1980
	54a.	IAEA-SM-242/35, OCCUPATIONAL RADIATION EXPOSURE IN NUCLEAR FUEL CYCLE FACILITIES, VIENNA, AUSTRIA, 1980 PP 463-472 RADIATION EXPOSURE AT THE IDAHO CHEMICAL PROCESSING PLANT, D.R. WENZE, J.J. CEBE, J.R. LOVELL
1981	55.	DOE/EP-0040-1, FOURTEENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1981

Year	Reference File #	Original Source
1982	56.	DOE/EP-0040/2, FIFTEENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1982
1983	57.	DOE/EP-0040/3, SIXTEENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1983
1984	58.	DOE/EH-0011, SEVENTEENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1984
1985	59.	DOE/EH-0036, EIGHTEENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR THE DOE AND DOE CONTRACTOR EMPLOYEES, 1985
1986	60.	DOE/EH-0069 (Revised), NINETEENTH ANNUAL REPORT OF RADIATION EXPOSURES FOR THE DOE AND DOE CONTRACTOR EMPLOYEES, 1986
1987	61.	DOE/EH-0128, TWENTIETH ANNUAL REPORT, RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1987
1988	62.	DOE/EH-0171P, TWENTY-FIRST ANNUAL REPORT, RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1988
1989	63.	(DRAFT) TWENTY-SECOND ANNUAL REPORT, RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES, 1989
1990	64.	1990 DRAFT REPORT, ANNUAL RADIATION EXPOSURE DATA
1992	65.	CHRONOLOGICAL FILES

Appendix A
Radiation Exposure Data Sheets

Exposure During MTR Reactor Shutdown

Date: July 23, 1956; approximately 2200 hours

Facility: Materials Testing Reactor (MTR); Test Reactor Area (TRA)

Operator: Phillips Petroleum Company

Type: An exposure in excess of Radiation Protection Standards during reactor shutdown.

Severity: One technical overexposure; 21.6 rem to a facility operator.¹ Seven other exposures ranging from 2.5 rem to 10.6 rem.

Description: Several hours after a routine reactor shutdown, the top of the reactor vessel was removed to install instrument cables to experiments in the reactor through access ports. The fuel discharge tube cover, with radiation levels of about 500 r/hr, was lifted and temporarily stored in the upper part of the reactor vessel dome. Later the water level in the dome was lowered several feet. A small crane was used to lower an operator, by bosun chair, to facilitate experimental removal. An H. P. technician on top of the reactor monitored the work with a portable high range survey meter. When the instrument went off scale at greater than 5 r/hr, he believed his instrument had malfunctioned. Upon obtaining a second instrument he verified the high radiation fields and stopped work. The operator's removal from the tank was delayed by a malfunctioning crane. After a total of about 3 minutes exposure, the working area was evacuated.

Probable Causes: Management oversight

Inadequate work planning

Failure to believe radiation instrument

Crane malfunction

References: "A Summary of Industrial Accidents in USAEC Facilities, 1956" TID-5360 Supplement 1, Revision 2, pp. 18 (8/19/67)

1. Total exposure for 1956 was 22.1 rem.

ICPP Criticality Incident

Date: October 16, 1959, approximately 0250 hours

Facility: Idaho Chemical Processing Plant (ICPP), Process Equipment Waste Collection Tank

Operator: Phillips Petroleum Company

Type: An acute radiation exposure following a criticality excursion, in addition to chronic low level exposures over the prior nine months, resulted in a total exposure in excess of a guideline.

Severity: A maintenance worker received 8.0 rem whole body following a release of airborne radioactivity which, in addition to his prior total of 4.2 rem, exceeded the NCRP recommendation of 12 rem/yr. However, this criteria was not adopted by the Federal government until the following year. He also received a skin exposure of 32 rem exceeding the criteria of 30 rem/yr. A process operator received 6.0 rem whole body and a skin exposure of 50 rem.

Five other plant personnel received whole body doses ranging from 1.2 to 3.9 rem and skin doses of 2.9 to 10 rem.

Property loss was \$62,000 to recover the enriched uranium from the contaminated solution.

Description: An accidental transfer, most likely by siphoning, of about 200 liters of enriched uranyl nitrate solution from critically safe process storage tanks to a geometrically unsafe tank through a line formerly used for transfers.

Probable Causes: Management oversight

Lack of careful attention to initial operations of seldom used equipment

Equipment design flaws

Lack of equipment training for operators

Incomplete operating procedures

Reference: IDO-10035, "Nuclear Incident at the Idaho Chemical Processing Plant on Oct. 16, 1959" W.L. Ginkel, et. al. (1960)

Maximum Credible Reactor Accident

Date: January 3, 1961; 2102 hours

Facility: Stationary Low Power Reactor (SL-1) Site, Army Reactor Area (ARA). 3Mw(t) Prototype Boiling Water Reactor

Operator: Combustion Engineering, Inc. (CEI)

Type: Criticality accident - steam explosion during maintenance shutdown of reactor.

Severity: Three killed

Nine technical overexposures ranging from 15 rem to 27.3 rem whole body to rescue team personnel

Uncontrolled release of fission products into the atmosphere with offsite exposure

Property loss estimated at \$4,400,000

Description: Experienced technician manual withdrawal of central control rod 80 times the distance specified by the Standard Operating Procedure. A nuclear excursion occurred with an energy release of 130 Mw-sec. Steam formation produced a "water hammer", lifting the pressure vessel nine feet. Fuel temperature reached 2060° C. 20% of the reactor fuel was destroyed. Radiation levels in the reactor room were 500-1000 rem/hr. Approximately 500,000 curies of gross fission products were released in the building with 1100 curies escaping to the atmosphere. 80 curies of Iodine 131 were released over a 30 day period. The calculated Effective Dose Equivalent to an infant at the nearest site boundary was 7 mrem.

Probable Causes: Inadequate design feature permitted criticality by withdrawal of a single control rod

Emotionally unstable operator deliberately withdrew control rod at a rate and distance beyond reason

References: "Final Report of SL-1 Recovery Operation" (7/27/62), IDO-19311

"The Health Physics Aspects of the SL-1 Accident", John R. Horan and William P. Gammill, Health Physics, 196B, Vol. 9, pp. 177-186

"Idaho National Engineering Laboratory Historical Dose Evaluation" (8/91); DOE/ID-12119, 2 Volumes

Industrial Radiography Accident

Date: December 9, 1986, ~0400 hours

Facility: Idaho Chemical Processing Plant (ICPP), L-Cell,
Building CPP-601

Operator: Northwest X-Ray, Inc. - subcontractor
Ovard and Collins Construction Co. - general subcontractor
for construction
MK-Ferguson - construction management prime contractor
Westinghouse Idaho Nuclear Company (WINCO) - prime
operating contractor

Type: An exposure in excess of Radiation Protection Standards
during routine gamma radiography.

Severity: One technical overexposure to the radiographer of 7.73
rem² whole body, approximately 1000 Rad to skin of right
palm, 90 Rad to lens of right eye, 70 Rad to lens of left
eye.
The assistant radiographer's exposure was 3.5 rem whole
body, approximately 28 Rad to the right hand and 6 Rad to
the lens of the eyes.

Description: A radiographer and his assistant were exposed to an
unshielded Iridium-192 source of approximately 51 curies
after the control cable to the radiographic source became
disconnected. Their radiation survey instrument was
inoperable but initially indicated an off-scale reading.
They continued to work for 5-15 minutes before leaving the
area.

Probable Causes: Equipment malfunctions
Radiography staff insufficiently trained or supervised
Failure to follow standard operating procedures

Reference: "Investigative Report of an Industrial Radiography
Accident at ICPP Occurring December 9, 1986. (2/87),
DOE/ID-101567

2. Total exposure for 1986 was 9.3 rem.

Appendix B

Original Data Collected on Annual Exposures

Table B1. Original Data Collected on Annual Exposures.

Ref.	Cal. Year	Col. Dose	Total Monit	Total Emp.	0.00 0.200	0.201 0.400	0.401 0.600	0.60- 3.00	0.50 3.00	0.601 0.800	0.801 1.000	0.50 1.00	1.001 1.500	1.501 2.000	0-1	1-2	2-3	1-5	2-5	3-4	3-5	4-5	5-5	>5	5-10	6-7	7-8	8-9	9-10	10-12	11-12	5-12	>12	10-15	>15	15-16	21-22	23-24	12-25	>25	25-26	27-28		
1	1951	0		2250											0	0	0			0	0			0																				
2	1952	15		2350											83	0	0			0	0			0																				
3	1953	209		2175											738	34	3			2	2							1																
4	1954	388		2525											797	79	28			8	1			2																				
5	1955	839		3025											1336	120	76			29	10			3										0										
6			4704												4403			276							25																			
7	1956	756		3825											984	125	81			24		9	5				2	2					1											
8			2810												2556			244																										
9	1957	486		4550											1243	114	20			141		0	0																					
10			1412	4338											4167																													
11	1958	1854	3542	5000											3001	277	156			54		25	11				9	4	4	1														
12			3288												2785	260	143			47		24	11				9	4	4	1														
13	1959	2462	3524	5075											3288					51		43	19				9	9	5	2														
14			2271	3467											2958	257	196			33		14	2						2															
15 & 16	1960	2294	4307	5200											278					51		11	1																					
17			7727																	135																								
18	1961	2700	4075	4920											333					144																								
19			3038	3648											3199	346	201			138		45	8																					
20			7237																	222					28																			
21	1962	2156		4765																																								
22			3613												3137	229	102			73		49	9																					
23			8423																	138					28																			
24	1963	2158	7138	5310	5178	624														276					0																			
25			8238																	138																								
26			3682												3283	212	87																											
27	1964	2330	8248	5900																77					0																			
28			2835												2433	190	115																											
29	1965	3579	2803	6025											2287	218	111			98		78																						
30			7896																	333																								
31			3448												2547	439	221			180		144																						
32	1966	2412	7165	5800																187																								
33			2838												2400	206	105			83		44	0																					
34	1967	2114	8233	5825																																								
35			2085												2502	226	109			95		53			0																			
36	1968	1781	8086	5850																130																								
37			3006												2612	183	100			88		44																						
38	1969	1723	7768	5850																																								
39			2190												1833	187	79			69																								
40			2769												2626	196	81			70																								
41	1970	1855	7034	5765																																								
42			3273												2938	168	77			59	33																							
43	1971	1180	2947	5080											2723	136	57			27																								
44	1972	1381	8333	5875											7902	259	101			52																								
45			2891												2553	171	89			59																								
46	1973		2714	5975											2445	138	71			40																								
47			1091												2143	183	66			36																								

Table B1. continued

[illegible]