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Review of U.S. Army Ionizing Radiation Dosimetry System

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PREFACE

Army civilian and military personnel are exposed occupationally to various forms of ionizing radiation, and the U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC) is responsible for monitoring these exposures. There are several accepted methods for monitoring radiation exposure, the oldest being the film badge method. A modern alternative method, which has achieved widespread acceptance, is the thermoluminescent dosimeter (TLD) badge. Inasmuch as the USAIRDC is in the process of converting from film badges to TLD badges for radiation monitoring, the Army decided to contract for this study to help it optimize the transition to this new monitoring system. The tasks to be performed under that contract were as follows:

1. Review the characteristics of ionizing radiation to which Army military and civilian personnel are exposed occupationally.
2. Evaluate the characteristics and adequacy of the Army's TLD system, including calibration, quality control, and algorithms involved in obtaining and processing TLD data.
3. Recommend the personnel dosimetry data that should be obtained, stored, and accessed, with due regard for good radiation protection practice and applicable legal and regulatory requirements.
4. Recommend applicable state-of-the-art hardware and software capabilities to be employed for data storage, processing, and retrieval.

To conduct the study that led to this report, the National Research Council formed the Committee on Ionizing Radiation Dosimetry (CIRD), composed of nine experts in radiation measurement, data handling, and law. The committee intends the results of this study to be useful to the Army and other groups that monitor radiation.

Regarding the study's perspective, it is important to understand that ionizing radiation stemming from natural origins permeates the air we breathe, the liquids we drink, and the food we eat. This background or natural radiation is inescapable, having existed from the time of the earth's formation. Two man-made developments, medical x rays and

radioactivity, have greatly increased the amount of ionizing radiation to which some persons can potentially be exposed.

Ionizing radiation is easy to measure, even at the very low levels that occur naturally. Since early in this century it has been known that exposure to x rays poses certain health hazards. Among the various hazards associated with x rays, the possible induction of cancer is of greatest concern.

Most cancers apparently originate as a defect in a single cell, which subsequently divides into two cancer cells, which in turn divide to make four cancer cells, and so on in a geometric progression. Each of these divisions may require several weeks, and about a billion cells are required to make a mass of cells large enough to be felt with the fingers. Thus, a cancer lump that one can feel has probably resulted from a carcinogenic event many years earlier.

Employers have for many years monitored the amount of radiation to which their employees are exposed, and this radiation monitoring is advantageous for both the employee and the employer. The employee is alerted to the amount of radiation exposure she or he received during a given monitoring period. If this amount is higher than normal, steps can promptly be taken to reduce any continuing exposure or to correct any instrumentation problems that gave rise to a spurious result. Also, if a valid high exposure does occur, scientific evidence will be available to provide information relevant to any resulting claim for compensation. The employer benefits both from the ability to demonstrate compliance with regulations and from evidence of actual occupational doses received by employees, should a claim be filed at a later time alleging radiation injury and seeking compensation. The need to use the results of radiation monitoring at some future date requires that adequate records be maintained in retrievable form for several generations.

This report contains the committee's conclusions and its recommendations to the Army as to the steps required to satisfy current and anticipated radiation protection regulations covering data to be obtained, stored, and accessed, while at the same time maintaining good radiation protection practice. Additional recommendations are concerned with the Army's TLD system, including staffing and computer capabilities.

John R. Cameron
Chairman, Committee on Ionizing
Radiation Dosimetry

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EXECUTIVE SUMMARY

In a study performed for the U.S. Army, the Committee on Ionizing Radiation Dosimetry reviewed Army techniques for monitoring exposure of its personnel to ionizing radiation. A central aspect of the study concerned a transition in personnel dosimeters employed by the Army; namely, the introduction of thermoluminescent dosimeters (TLDs) to replace film badges for monitoring radiation exposures. The study provided an opportunity to reconsider Army techniques for acquiring, handling, and storing dosimetry data both cost effectively and within an evolving legal and regulatory framework. The committee arrived at conclusions and recommendations in these areas for referral to the Army.

SUMMARY OF THE PROBLEM

The U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC) monitors dose equivalents received by Army civilian and military personnel during occupational exposure to ionizing radiation. These personnel are located at some 775 installations in the United States and abroad. The requirements and framework under which USAIRDC must perform its monitoring functions are specified in Army Regulation 40-14 (AR 40-14) and in other federal regulations.

USAIRDC's recent acquisition of TLD badges to replace film badges for personnel dosimetry posed various technical and data-handling questions regarding transition. This study was requested by the U.S. Army to obtain counsel in four specified task areas, described below.

The committee began its work by assessing the status of USAIRDC radiation monitoring activities, the state of the art in TL dosimetry, and the evolving legal and regulatory considerations. This effort included a series of briefings by persons in the Army program, industry experts, and specialists in the legal and regulatory aspects. The five meetings of the committee were initiated by a site visit to USAIRDC headquarters in Lexington, Kentucky. To provide additional information, the committee formulated a questionnaire which was distributed to the Army installations that monitor radiation exposure.

Committee study, analysis, and deliberations led to its formulating conclusions and recommendations responsive to the four study tasks. The committee's approach to performing each of those tasks and its major conclusions and recommendations--developed in later chapters--are summarized below.

STUDY TASKS, CONCLUSIONS, AND RECOMMENDATIONS

For each study task, the committee arrived at certain conclusions and, for three of the four tasks, formulated recommendations regarding specific actions USAIRDC might consider taking. A summary of the four tasks and their outcomes follows.

Study Task 1

Review the characteristics of ionizing radiation to which Army military and civilian personnel are exposed occupationally.

The committee approached this task in two ways: (a) by obtaining relevant information from USAIRDC, and (b) by formulating a questionnaire (a copy of which is included here as Appendix A) to obtain complementary information. The questionnaire was sent to the Radiation Protection Officer (RPO) at each Army installation that monitors personnel radiation exposure. Based upon these information sources, the committee identified the various species of ionizing radiation typically encountered--and that need to be monitored--at Army installations. Using data supplied by USAIRDC, an analysis was performed on the range of personnel dose equivalents monitored in a typical year (i.e., 1984). These analyses provided the committee with a perspective of Army radiation monitoring activities required to comply with AR 40-14 and other mission and regulatory requirements.

The relevant species of ionizing radiation identified during this study were x rays, gamma rays, beta rays, and neutrons. The classes of Army facilities where ionizing radiation is monitored were grouped in the analysis into various subcategories of medical, industrial, and reactor facilities. Responses were obtained from about 50 percent of the RPOs to whom questionnaires were sent. Ranges of annual dose equivalents reported were tabulated based upon the number of film badges worn, along with the kinds of exposure encountered. About 95 percent of the reporting facilities reported no dose equivalent above 100 millirem (abbreviated mrem) per year*. Similar results were obtained from 1984 USAIRDC data, which indicated that annual dose equivalents of less than 100 mrem were received by about 97 percent of all personnel monitored.

Questionnaire data showed that facilities reporting annual dose equivalents above 100 mrem were large installations that collectively

*The report uses both SI units and the better-known older units, such as mrem.

receive about 18 percent of the badges shipped. Tabulation breakdowns also indicated that significant dose equivalents were mainly received by Army personnel engaged in radiotherapy. About 9 percent of film badges worn by personnel whose RPOs responded to the questionnaire showed annual dose equivalent totals exceeding 100 mrem, and all but about 10 percent of those readings were below 1,000 mrem.

Data from 1984 showed comparable distributions, with less than 1 percent receiving more than 500 mrem whole-body dose equivalents that year, and indicated that over 90 percent of monitored employees were potentially exposed only to x rays and gamma rays. About 10 percent were also potentially exposed to beta radiation, and about 5 percent had the possibility of exposure to neutrons.

Respondents to the questionnaire reported no significant exposures to beta radiation, and the reported exposures to pure beta sources were largely associated with persons engaged in instrument calibration. Other Army installations where sources of beta radiation are encountered include pulsed reactors and radiology departments, and at those locations beta ray energies reported were below 2.3 million electron volts (MeV) and usually between 1 and 2 MeV. Beta radiation accompanied by gamma rays--along with neutrons--was observed at two Army pulsed reactor facilities. Neutron exposures were primarily limited to those pulsed reactor locations.

Study Task 2

Evaluate the characteristics and adequacy of the Army's TLD system, including calibration, quality control, and algorithms involved in obtaining and processing TLD data.

As part of its response to this task, the committee obtained briefings from: (1) representatives of several TLD vendors; (2) a health physicist currently operating the same TLD system as that acquired by USAIRDC; (3) a physicist from the National Bureau of Standards who had evaluated a TLD system from the same manufacturer as that acquired by USAIRDC; and (4) the head of the U.S. Navy Personnel Dosimetry Center, whose organization is handling dosimetry requirements similar to the Army's.

The committee also conducted a careful appraisal of the status of USAIRDC's TLD badges and associated equipment, along with an analysis and evaluation of the capabilities of the integrated USAIRDC TL system. This evaluation identified certain potential inadequacies of the TL dosimeter that had been acquired, and pointed to specific ways that the TLD system could be modified for better performance.

The committee's evaluation of the USAIRDC TLD system identified certain problems in USAIRDC's present capability to estimate incident beta and photon energy. In particular, the committee arrived at a major conclusion reflecting concern about a shortcoming in the TLD badges that USAIRDC has acquired; namely, their possible inaccuracy in estimation of dose equivalent if the photon radiation were incident

obliquely--rather than perpendicularly--on a USAIRDC TLD badge. This problem could lead to estimating an erroneously high photon dose equivalent. The committee reached this conclusion by noting that the response of element 4 (E4) in the TL dosimeter that USAIRDC has acquired varies with the direction of incident photon radiation, particularly at low energies.

To remedy this problem, the committee recommended that USAIRDC:

> Modify the slide around E4 so as to provide optimum isotropic response of this element to photon radiation. Such a modification should be effective over the entire range of energies specified by USAIRDC. (This result may be achieved by installing a ring of lead, lead alloy, or other high atomic number material of sufficient thickness in the slide around E4.) Tests should be conducted to establish the efficacy of any such modification to arrive at optimum composition and configuration.

Two related recommendations of lesser priority were to remedy two additional dosimeter problems identified by the committee. Those problems concerned the limited accuracy of the USAIRDC TL dosimeter in monitoring beta particles and neutrons. In the case of beta particles, the committee found that those with energies above 700 keV will penetrate the 300 mg/cm^2 TLD filter above element 3 (E3), thereby increasing the response of E3 compared to that of E4. This problem can cause errors in estimating exposure to photons. The other problem was that beta particles with energies less than 700 keV will not penetrate the 300 mg/cm^2 TLD filter above element 2 (E2), thereby causing difficulties in using E2 response for estimating beta radiation energies and dose equivalents. Inasmuch as both these measurement problems were remediable by a specific dosimeter modification or substitution, the committee recommended that USAIRDC:

> Replace the dosimeter hanger with one having the same "open window" over both E1 and E2 as the present hanger has over E1, the same filtration over E4 as at present, and a low atomic number, high-mass filter over E3 to provide total filtration of more than 600 mg/cm^2. (An optimum means of achieving E3 filtration of about 639 mg/cm^2 is by using a filter of tetraboroncarbide about 1.9 mm thick.), and
>
> Reduce the filtration over E2 to between 65 and 75 mg/cm^2, excluding any "open window" filtration. (This can be readily accomplished by replacing the UD-802AS holders with UD-802AS2 holders.)

Insofar as the Army's requirement for monitoring dose equivalent from neutrons, the committee noted that monitoring that quantity was more complicated than monitoring dose equivalent of beta or photon radiations, since biological effects of neutrons are a function of the incident neutron energy spectrum. Thus, monitoring of neutron spectral data is essential. However, the committee found that the USAIRDC TLDs are capable of monitoring neutron dose equivalent only if the neutron energy spectrum is known, and that furthermore, if the dosimeters are exposed to combinations of photons, beta particles, and neutrons, these dosimeters are incapable of providing definitive information on neutron dose equivalent. Accordingly, the committee recommended that:

> TLD badges known or suspected to have been irradiated by neutrons should be specifically flagged by the RPO on the dosimeter report form that is returned to USAIRDC.

The committee further pointed out that if USAIRDC elects to use these TLD badges to monitor neutrons, then calibration factors--appropriate to the neutron energy spectrum to which the dosimeter is exposed--will need to be determined for each facility in which neutron exposure occurs. The committee then suggested some details on how to calibrate the dosimeter for this purpose, and recommended:

> This determination should be carried out--at each facility where neutron exposure can occur--by personnel skilled both in neutron measurement techniques (over a wide energy range) and in dosimeter calibration.

The committee also considered overall aspects of operating the USAIRDC TLD system, including appropriate procedures for calibration and quality assurance. In these areas, the committee emphasized the importance of both dosimeter recalibration and quality assurance (QA). QA is primarily a check on operational consistency, and includes correcting for slow changes in the response of elements of individual dosimeters. This is done by determining from time to time the corresponding element correction factor (ECF). Such considerations led the committee to make the following recommendations:

1. All calibration and QA checks should be performed as required according to a rigorous schedule, and the results of these checks should be carefully documented and retained in the USAIRDC records.

2. The USAIRDC TL dosimetry system should be recalibrated at least once per year . . . following thorough internal cleaning of the TLD reader.

3. A group of test dosimeters--having a range of dose equivalents and mixtures of radiation (photon, photon and beta, and photon and neutron)--should be obtained . . . and evaluated at least every 2 years.

The committee suggested that QA procedures, such as those for the determination of ECFs, be performed regularly, and further recommended:

1. USAIRDC should institute a QA program based upon certain instructions and procedures (stated in Chapter 3).

2. USAIRDC should rotate groups of dosimeters through an ECF redetermination on a 2-year cycle until sufficient data are accumulated to verify that this cycle--or a more appropriate one--is adequate to maintain acceptable dosimetry accuracy.

The committee also considered the sensitivity of USAIRDC's TLD elements to environmental and fading effects under field conditions. With regard to the environmental effects, the committee noted that these TLD elements can both react with atmospheric hydrogen sulfide and deteriorate under high humidity conditions. Consequently, the committee recommended:

> USAIRDC should give appropriate consideration to the presence of certain atmospheric constituents that can have potentially deleterious influences on TLD badges. Inasmuch as quantitative data are not available as to the degradation of TLD elements by atmospheric hydrogen sulfide and humidity, it would be desirable for USAIRDC to conduct its own tests on these effects under a range of conditions representative of the users of its dosimetry services.

Insofar as fading effects, the committee noted that the dose equivalent indications of lithium borate and calcium sulfate elements fade up to 10 percent and 3 percent per month, respectively. The committee also noted significant short-term fading problems, which it described, that occur with the lithium borate elements during the first 15 to 20 hours following TLD exposure. These problems led the committee to question the utility of the "preheat" portion of the TLD processing procedure, and to suggest that USAIRDC obtain clarification from the TLD manufacturer in this connection.

Finally, the committee considered the impact of the transition to TLD's on USAIRDC staffing requirements. The committee concluded that although current personnel could be retrained to perform certain TLD-related production tasks, much of the experience gained by USAIRDC personnel in film dosimetry would not be relevant to requirements for staffing the TLD system. Hence the committee regarded it necessary that USAIRDC acquire personnel skilled in the TLD area to provide it with competence in handling TLD problems in processing, interpretation, calibration, and analysis--especially if the TLD system is expected to keep pace with the dosimetry state of the art. Also, the committee recognized a need for personnel with a strong background in applied health physics to relate to the user community, obtain and evaluate neutron spectra, and keep abreast of evolving radiation protection standards. Accordingly, the committee recommended that:

> The level and number of personnel in the USAIRDC should be increased by the addition of personnel with the above-described capabilities, and persons with these capabilities should be responsible for the day-to-day operation of the service.

The committee further noted that existing USAIRDC technicians could be retrained to perform operational tasks such as badge issuance, receipt, reading, and dosimeter calibration.

Study Task 3

Recommend the personnel dosimetry data that should be obtained, stored, and accessed, with due regard for good radiation protection practice and applicable legal and regulatory requirements.

In responding to this task, the committee took into account dosimetry data-handling policies and requirements associated both with the current legal and regulatory environment for radiation monitoring and with prospective changes in that environment. The committee began by reviewing the evolution of the body of laws and regulations governing Army dosimetry and pertinent to this task.

The committee then reviewed current Army practice in dosimetry procedures--such as recordkeeping--to indicate the degree of conformity with AR 40-14 requirements. The committee noted some departures from these requirements in that certain recording requirements are not being met; for example, in the areas of medical exposures, occupational codes, and the identification of radiation sources and other hazardous substances. However, except for the need to record occupational codes, the committee does not regard these areas of recording as appropriate USAIRDC activities. The committee also reviewed and summarized AR 40-14 directives that provide guidance on personnel who shall be monitored, parts of the body to be monitored, dose equivalents to be recorded, and procedures to be followed after an overexposure.

The committee next considered prospects for changes in Army dosimetry activities that might result from pending changes in federal guidelines stemming from recommendations of relevant national and international bodies. Specific impacts on Army personnel monitoring that are anticipated could include changes in basic standards--which introduce new limits to specific organs--and the introduction of the new concept of an effective dose equivalent, calculated by combining organ dose equivalents using defined weighting factors.

The committee then considered what lessons could be learned by reviewing relevant experience about radiation monitoring that had resulted from litigation flowing from the current legal and regulatory environment. The committee's rationale for doing this was that Army procedures could become at issue in a judicial or administrative proceeding; for example, one brought by a person alleging injury as a result of occupational exposure.

While observing that it is impossible to predict with certainty decisions in future cases, the committee developed several general principles based upon court cases that had been decided in recent years. Claimants have not succeeded in those cases, largely because their employers were able to document that these claimants were only exposed to low levels of ionizing radiation. Thus, the committee arrived at a general principle: good recordkeeping of radiation exposure is likely to reduce future liability.

The committee also noted that good recordkeeping is a function of record quality as well as quantity. The committee then reached a second general principle: records are persuasive...only to the extent that the recordkeeper is able to produce supporting evidence of their accuracy. Such demonstration of trustworthiness might include proof that relevant quality assurance steps had been taken, and that these steps ensured that dose equivalents reported were identified with the correct individual. This consideration leads to the desirability of keeping--along the lines of a suggestion by the American National Standards Institute--data regarding calibration and maintenance of dosimetry equipment that are adequate for this purpose.

The committee noted that there is at present little definitive guidance--e.g., in federal regulations on radiation protection--concerning the retention time of dosimetry records. This is so despite the fact that radiation-induced malignant disease may occur several decades after the period in which an individual was exposed, and deleterious effects of a genetic nature may occur during the lifetime of an offspring. The committee further recognized that unusual personnel exposures--higher than the typical exposure of an individual in a particular working environment--may need to be reviewed after the dosimeter data have been processed.

Based upon good radiation protection practice and the guidance contained in the above findings, the committee concluded that some modifications to current practice should be considered, both to accommodate the changeover in the monitoring device from film to TLD and the anticipated changes in federal exposure limits and procedural philosophy. The committee enumerated various dose equivalents that would--despite these changes--continue being recorded as they are now. The committee anticipates that the new radiation limits will reduce the significance of eye exposure and of localized thyroid and some other single organ exposures, while increasing the significance of neutron exposure.

In view of the trend toward the introduction of organ-specific weighting factors in estimating dose equivalents, the committee concluded that more information should be made available in the future regarding effective photon energy. In order that dose equivalents received by specific organs can be calculated when necessary, the committee recommended:

> Personnel records of dose equivalents should be coded to indicate the known kinds of radiation--along with their associated energy ranges--to which the individual was exposed in his occupational environment.

In regard to the badge-wearing period, the committee concluded that this could be increased, in view of a (usually) negligible penalty in increased fading, and to effect substantial labor-saving. Hence, the committee arrived at the following recommendation:

> The committee supports the Army practice of initially monitoring individuals in a new operation on a weekly basis for the first 8 weeks, but encourages the adoption of a monthly wearing period unless there is clear evidence of wide fluctuation of dose equivalent from week to week. In groups where the dose equivalents are low and stable, the committee recommends that serious consideration be given to instituting a 3-month wearing period, because this procedure would increase the accuracy of cumulative dose equivalent records by reducing the errors inherent in multiple readings of low dose equivalents, particularly when those readings fall below the minimum recordable level.

With regard to data retention, the committee noted that radiation-induced malignant disease may occur several decades after the period in which an individual was exposed, and that deleterious effects of a genetic nature may occur during the lifetime of an offspring. Yet the committee also noted that, although exposure records are highly significant in radiation litigation, federal regulations give little guidance on record retention periods. In view of these considerations and a Nuclear Regulatory Commission (NRC) policy amounting to indefinite interim retention, the committee endorsed the NRC approach and recommended:

> Dosimetry records should be indefinitely retained, pending promulgation of specific regulations.

In view of possible needs to review the accuracy of personnel exposures after the dosimeters have been processed, or to reconstruct dose equivalent to a specific tissue depth, the committee further recommended:

> All data concerning personnel dose equivalents be retained for at least a 1-year period following the processing of individual dosimeters, independent of their dose equivalent readings.

The committee enumerated the specific TLD data included in this category, then developed a rationale leading to the following recommendation, which would provide for an indefinite retention period for the digitized glow curves only in exceptional cases:

> All of the above-listed data should be so retained, except that in the case of the digitized glow curves, "indefinite" retention is recommended only in the following cases:

(a) for individuals who during a particular year have a cumulative dose equivalent of penetrating radiation in excess of 500 mrem (about 0.8 percent of the personnel monitored by USAIRDC in 1984);
(b) for individuals with an annual cumulative extremity dose equivalent exceeding 7.5 rem;
(c) for a particular badge that indicates a calculated dose equivalent of penetrating radiation in excess of 100 mrem, or an extremity dose exceeding 1,500 mrem;
(d) all glow curves of an unusual nature that are not explicable in terms of equipment problems (based upon a short-term review), along with the glow curves obtained by processing the badges immediately preceding and following the badges producing those curves;
(e) all glow curves resulting from questioned dosimeter readings (e.g., in disagreement with other methods of dose estimation);
(f) all glow curves resulting from quality assurance procedures.

Furthermore, the committee also recommended that:

> All data relating to the calibration of the reader throughout its history should be "indefinitely" retained, along with intercomparisons of dose equivalent evaluations.

Finally, inasmuch as RPOs are required to transcribe exposures manually onto a printed form for subsequent insertion into individual medical records, and this practice is error-prone and also can represent a considerable expenditure of effort, the committee recommended that:

> The Army should require the various facilities to insert the quarterly-to-date computer-generated reports directly into individual medical records, rather than continue using manual transcription.

Study Task 4

Recommend applicable state-of-the-art hardware and software capabilities to be employed for data storage, processing, and retrieval.

In response to this task, the committee--with assistance from an outside consultant, RESCO Computer Services, Inc.--reviewed the current data-handling techniques and TL dosimetry system characteristics at USAIRDC in Lexington, and considered what steps should be contemplated in these areas to carry out USAIRDC's mission. To help define an optimum computer system to carry out USAIRDC functions in the most cost-effective manner, the committee regarded several considerations as relevant:

1. Historical data, contained in some 5.8 million records, are currently stored in a computer located at Redstone Arsenal, Huntsville, Alabama, and are remotely accessed by USAIRDC personnel located in Lexington.
2. A new computer and software system will be used with the TLD reader to automate determinations of dose equivalents.
3. Data-handling requirements for a TLD system are different from those for film dosimeters.
4. Certain concerns (proper maintenance of individual dose equivalent records; proper dosimeter documentation; definition of data-retention requirements) identified by USAIRDC regarding the operation of its radiation monitoring program.

In its data-handling analysis, the committee reviewed the USAIRDC's detailed operational mission requirements applicable to both film and TLD badges. These functions include issuing and tracking badges, updating and maintaining dosimetry repository data, and providing summaries of dosimetry results. Then the committee carefully evaluated whether there would be significant modifications in USAIRDC data-handling requirements through the acceptance and implementation of any of the committee's recommendations in response to Study Task 3 on data handling. That evaluation indicated that the implementation of some recommendations would somewhat increase the data-handling and/or storage requirements, and in other cases it would decrease them. In most cases, these individual impacts were usually modest--quantitatively and in other respects. The committee also examined dosimetry data-security requirements, both from the standpoint of the need to conform with the Privacy Act and to prevent unauthorized access to the records.

In the light of these reviews and evaluations, the committee then recognized and explored two basic options for processing TLD dosimetry data: remote processing, characterized by the current method of operation, in which film badge dose equivalent data are entered at terminals locally at Lexington but computer processed and stored at Redstone, and local processing, characterized by a system whereby data would be collected, evaluated, processed, and stored at Lexington. The committee noted that within each option USAIRDC could employ various hardware and software combinations to accomplish the required processing.

The committee examined these options and their pros and cons from technical, functional performance, and cost standpoints. The functional performance requirements for which the remote and local processing options were compared included: the need for prompt notification of unusually high dose equivalents; updating and maintaining the repository data; providing summary dosimetry reports; providing dosimetry histories upon request; and issuing and tracking TLDs. Available computer systems for both the remote and local options were considered. The committee also considered staffing considerations in the information processing and programming area, where it concluded

that USAIRDC would require the services of an experienced systems manager/programmer to modify TLD software, and to develop and maintain software and hardware for the entire records system.

The committee's principal findings, employing only approximate cost estimates, in evaluating the two basic computer options were:

1. The committee concluded that remote processing by USAIRDC introduces the difficulty and inconvenience of matching glow curves stored at Lexington with dose equivalent records stored at Redstone, and that the advisability of selecting the remote system option depends to a considerable extent upon: (a) the cost of implementing and operating an adequate data communications link between the HP 1000 and Redstone; and (b) the processing effectiveness of transferring information between the two locations.

2. Regarding local processing, the committee identified and explored various ways for USAIRDC both to process and store TLD data at the Lexington site. Besides hardware and software considerations, the committee concluded that additional factors would enter into arriving at a possible decision to move the data-handling and storage operations to Lexington. Namely, a new mainframe computer system may require an appropriately conditioned environment; an organizational change may be necessary to assemble the required staff, since special staff support considerations are more extensive for a mainframe system than for a minicomputer; and a centralized repository has several advantages--most importantly, faster response time, local control, and simplified administration. The committee noted that one local option is a series of networked microcomputers to replace terminals presently used at Lexington, in view of technology advances that are rapidly expanding the use of microcomputers in a variety of new applications. The costs of Redstone computer-related services to USAIRDC are difficult for the committee to assess--since they are internalized within the Army--but would be eliminated by local processing and storage.

Based upon the above considerations, the committee made recommendations in several areas. One area concerns implementing further automation of badge and dose-related functions and of dosimetry records. The committee noted that there is no automated process to track which Army installation will receive a particular TLD and to whom it is issued. An "Augmented TLD System" would automate the tracking function, including badge issuance, badge accountability, and association of each dose equivalent with the proper individual--all of which are central to USAIRDC's radiation monitoring responsibility. In view of its favorable evaluation of that option, the committee recommended:

> USAIRDC should implement the Augmented TLD System for either the local or remote processing option.

The committee recognized a clear overall need for USAIRDC to take steps leading to an upgraded computerized data-processing system,

commencing with obtaining accurate cost estimates for the available options, based upon firm price quotes for Army-specified system configurations and/or for satisfying specified functional system-performance requirements. The committee's recommendation in this area is that:

> USAIRDC should conduct a detailed data-processing cost-benefit analysis and, if its results validate the estimates developed in this study, USAIRDC should implement the local processing option. The committee further recommends that this analysis include actual costs relating to the computer services that USAIRDC is presently obtaining--or might obtain in the future--from Redstone, such as the cost of leasing the 14,400-baud data link between Lexington and Redstone.

The committee also noted that this cost-benefit analysis should include the intangible benefits associated with the relative simplicity of the local processing option: such benefits as convenience, local control over use of resources, and avoidance of the need to transmit data over long distances on sometimes noisy data lines. On the cost side, the committee pointed out that local processing could require that USAIRDC add staff, such as a programmer to maintain and create the programs necessary to accomplish the processing tasks now being performed at Redstone.

Another area where the committee suggested an opportunity for data-handling improvement concerns conversion to an "Automated Dosimetry Report," which would assure the maintenance of radiation histories for all individuals currently employed by the Army, and at the same time would obviate the need to do historical searches. Here the committee's evaluation resulted in the following recommendation:

> The Army should convert to the Automated Dosimetry Report in place of DD Form 1141 (an analog document).

The committee noted that inasmuch as 75 percent of all requests for searches come from individuals who are in the Army's employ, this conversion will ultimately result in allowing much of the historical data to be archived off-line.

Finally, insofar as the storage of digitized glow curves, the committee, noting that there does not appear to be a need for on-line storage of glow curve information following initial TLD processing, recommended:

> Glow curves and other raw data should be stored off-line whenever possible.

1

INTRODUCTION

This chapter summarizes the U.S. Army's purpose in sponsoring this study, lists its tasks, and describes the approach taken. Essential background information is presented about ionizing radiations and the quantities and units used to measure them, along with a review of the basic characteristics of film badge dosimetry and thermoluminescent (TL) dosimetry for radiation monitoring applications. The explanation of TL dosimetry also provides background information for Chapters 3 and 4.

THE U.S. ARMY'S PURPOSE IN SPONSORING THIS STUDY

Army personnel are occupationally exposed to various forms of radiation. The U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC), Lexington, Kentucky, is charged with providing worldwide ionizing radiation monitoring services to the U.S. Department of the Army and to the Defense Logistics Agency (DLA). USAIRDC processes radiation exposure data obtained from some 775 facilities located throughout the world. USAIRDC's functions include maintaining personnel radiation dosimetry histories and providing data analysis. USAIRDC keeps in contact with its customers primarily through its radiation monitoring service and related correspondence. That correspondence is carried out between USAIRDC and the military or civilian Radiation Protection Officer (RPO) at each facility. RPOs provide consultation and advice to the facility commander on relative hazards associated with radiation and on the effectiveness of measures to control these hazards.

Inasmuch as the USAIRDC is in the process of converting from film dosimeter badges to thermoluminescent dosimeter (TLD) badges for radiation monitoring--thus requiring a new records system--the Army asked the National Research Council to conduct this study to help optimize the transition to this new monitoring system. The tasks to be performed in conducting the study are enumerated in the Executive Summary.

In June 1985, the National Research Council, through its Commission on Engineering and Technical Systems, constituted the Committee on Ionizing Radiation Dosimetry, composed of nine experts having a wide range of knowledge and experience. Qualifications of the committee members extended from health physics to radiation physics, radiation dosimetry, radiation hazards, quality assurance, monitoring regulation, data systems, and law. Committee members included scientists familiar with the thermoluminescent dosimeter system that the Army has purchased, current users of TLD systems, and specialists in aspects of the law pertaining to ionizing radiation. The first of five committee meetings was held July 24-25, 1985, at USAIRDC in Lexington, Kentucky, and subsequent meetings were in Washington, D.C. During these meetings the committee obtained the inputs of experts from both the private and public sectors.

SOURCES OF IONIZING RADIATION

Ionizing radiation has pervaded in nature since the beginning of the world. Natural, or background, radiation is--on the average--the largest single source of radiation exposure received by the public and most radiation workers. The next most common source of radiation exposure to the public is medical use of radiation for diagnostic purposes. Other societal sources of radiation exposure to the public account for less than 20 percent of an average individual's total dose equivalent.

Although discovery of x rays in 1895 facilitated great advances in medical diagnosis, these advances were accompanied by an increase in the amount of radiation to which members of the public could be exposed. Even in the early part of this century it was recognized that x rays posed certain health risks, such as skin burns. Hence, early radiation workers were often advised to exercise caution in using x rays.

THE NATURE OF RADIATION RISKS

There may be injurious effects from low doses of ionizing radiation. Radiation cannot usually be positively identified as a cause, or separated from other causes, of a given problem. For example, the consequence of greatest concern is induction of cancer, which can result from many other causes. Any cancerous effects from ionizing radiation are usually delayed by times ranging from 2 years to 30 years following the initial exposure. Another important risk of exposure to ionizing radiation is possible genetic damage. Again, mutations are common even in the absence of radiation, therefore the cause of a given mutation cannot be positively ascribed to radiation.

The biological effects of radiation have been studied extensively for over 50 years, and research continues in this area both to expand

the usefulness of radiation to society and to minimize radiation hazards.

Since 1945, increased awareness of the hazards of ionizing radiation has led to its careful monitoring. Because there may be a long delay, or latent period, between radiation exposure and the appearance of a cancer that might have been caused by that radiation exposure, it is necessary to retain radiation monitoring records for many years in case of any claims or litigations. Most radiation court cases in the 1970s and 1980s claimed injury from radiation exposure in the 1950s and 1960s. Also, the incidence of cancer increases with age. About 25 percent of the U. S. population will have cancer sometime during their lives, usually after age 50. Many people who were occupationally exposed to radiation between the ages of 20 and 40 will have a cancer in later life from natural causes. However, they will tend to remember that they once worked with radiation, and it is natural for them to suspect that their earlier occupational exposure to radiation caused their cancer. Reference to dosimetry records can help confirm or refute their suppositions.

To assure that exposures of radiation workers do not occur undetected, the usual policy in industry is to monitor many more radiation workers than is legally required. Some federal agencies require monitoring those personnel who might receive 25 percent of the permissible limit in a given year. The Army, however, is more stringent, requiring the monitoring of workers who may receive only 5 percent of the annual limit. About 75 percent of monitored Army personnel and employees have monthly radiation exposures too small to measure with film badge monitoring systems.

RADIATION QUANTITIES AND UNITS

To discuss radiation monitoring, it is necessary to use accepted radiation quantities and units. Because this report is intended for a broader readership than radiation specialists, the committee is employing here the older radiation units (still in common use) for the radiation quantities and is placing in parentheses--following those units--their equivalent values in the newer units of the International System (SI).

By way of further clarification, it should be noted that three radiation quantities are in common use: exposure, absorbed dose, and dose equivalent. "Exposure" is related to the ionization of air by radiation. "Absorbed dose" (often simply called "dose") is related to the energy absorbed by the material or body under discussion. "Dose equivalent" is calculated by multiplying absorbed dose by a "quality factor" (QF) for the particular radiation. The QF takes into account the relative biological effect of the particular variety of radiation. QF is unity for photon and beta radiation, while for neutrons it is currently accepted as 10, but this value is being reconsidered and may be increased to 20. (See Appendix B for more complete definitions.)

In radiation monitoring, dose equivalent has become important, and is the quantity mainly used in this report. The rem is the unit originally employed for measuring dose equivalent, but for convenience one-thousandth of a rem--a millirem (abbreviated mrem)--is often used. The new SI unit of dose equivalent is the sievert (Sv), where one Sv equals 100 rem. To appreciate the magnitudes involved, note that a typical dose equivalent from natural radiation is about one-eighth of a rem, or 125 mrem (0.00125 Sv or 1.25 mSv) per year.

There are two general ways that the body is exposed to radiation--from external sources, such as x-ray machines and radioactive materials outside the body, and from radioactive materials that enter the body through the lungs, the digestive tract, or through a wound. This report is devoted to the monitoring of dose equivalent received solely from external sources. Such monitoring also is referred to as dosimetry.

There are several accepted devices for monitoring dose equivalent from external sources, of which the most common at one time was the film dosimeter or film badge. Currently, another widely used alternative is the TLD badge. On the following pages are summarized the major characteristics of film badge dosimetry, TL dosimetry, and applications of TLDs for monitoring photons, beta radiation, and neutrons.

DEVICES FOR RADIATION MONITORING

Radiation workers have routinely been monitored for many years using techniques relying upon the darkening effect on photographic film emulsion caused by its exposure to radiation. Film badges have served, and continue to serve, as a satisfactory method for determining the amount of radiation to which the wearer has been exposed. In the 1960s TL dosimetry became available as an improved monitoring technique. A TLD is usually more sensitive than a film badge and has a much larger useful range of measurement. Currently, many radiation monitoring facilities have converted from film badges to TLDs.

To help provide an understanding of the Army's motivation in shifting to TLDs, background information on film badge dosimetry is presented in the following section. The characteristics of TL dosimetry are described in relatively greater detail in the succeeding section.

CHARACTERISTICS OF FILM BADGE DOSIMETRY

Besides being sensitive to light, photographic film also is sensitive to ionizing radiation. Processed film that has been exposed to x rays or gamma radiation (also called "photon radiation") will exhibit a darkening or increased optical density that can be related to the amount of that exposure. The increased net optical density (above

background density) can be measured with a densitometer and compared with the net optical density of calibrated standard films to estimate exposure. Thus, film packets can be used to measure the wearer's cumulative x- and gamma ray exposure, from which the individual's dose equivalent may be deduced.

The effects of ionizing radiation on film emulsions have been investigated for about 90 years, and film dosimeters based upon these phenomena have been used to monitor Army personnel radiation exposures for more than 40 years. The dosimeters contain film packets similar in size to dental x-ray packets.

Film packets used for dosimetry applications may contain one or more films or film components. The earliest film badges included a thin metal strip wrapped around part of the film packet. This strip, or filter, attenuated low energy x- and gamma radiation to reduce the overresponse of film at low photon energies, thus making the response of the film-filtered area more uniform from low to high photon energies; i.e., less energy-dependent. The filtered and unfiltered areas allowed rough discrimination between high and low energy photons. Film dosimeters designed in later years employed plastic holders for the film packets, and filters were embedded in the plastic.

Typically, four filter areas were used. Each of the areas could employ different metallic or plastic filters. There were often one or more openings in the holder to expose part of the packet to the less penetrating beta radiation. With multiple filters, the film dosimeter could be employed to estimate the photon energy spectrum. The open area of the film could be used to evaluate combinations of low-energy photon and beta exposure, and other film areas could be used to determine photon energy and monitor exposure to higher energy photons.

Film dosimeters also have been designed for monitoring neutron exposure. However, neutron radiation is difficult to measure (see section entitled "Neutron Dosimetry") since it produces little direct ionization.

Accuracy of film dosimeters is affected by a number of environmental factors. For example, damage to films from light leaks, heat, pressure, moisture, and aging of film emulsions increases optical density. These phenomena may lead to overestimating the radiation exposure actually experienced by the wearer. On the other hand, in environments with high humidities, radiation-induced optical density of film emulsions may fade to some degree before the film packet is processed.

A second factor in film dosimeter accuracy is the minimum detectable dose equivalent. For lower dose equivalents, the increase in optical density of a film emulsion becomes small compared to the optical density of an unexposed film emulsion, hence the estimate of dose equivalent becomes increasingly inaccurate. Below about 20 mrem (0.2 mSv), film badges become so inaccurate that the results of using them cannot be reported with any confidence. This minimum detectable threshold was not so important in the past, before the concept of an "as low as reasonably achievable" (ALARA) level of occupational exposure threshold was introduced. Now, however, the need to monitor

low dose equivalents is more important to the radiation protection community, and the earlier inability to report dose equivalents below, say, 20 millirem (0.2 mSv) has prompted the use of other, more sensitive dosimeters.

The U.S. Army presently uses Kodak Type 3 film packets in Tenite II plastic holders having four filter areas. Film dosimetry poses problems relating to automation and accuracy, and because of these and other considerations the Army has begun conversion to an automated TLD system. The basic characteristics of thermoluminescence dosimetry are described in the next section.

CHARACTERISTICS OF THERMOLUMINESCENCE DOSIMETRY

Thermoluminescence dosimetry is based upon the ability of certain solid materials (called "phosphors") to: (1) store some of the energy they have absorbed from exposure to radiation, and (2) release this energy in the form of a luminescent glow when heated at a later time. The intensity of this glow can be related to the magnitude of the original radiation exposure. TL phosphors are almost invariably colorless, insulating solids whose thermoluminescence is produced by adding one or more minor impurity constituents ("activators") to the main "host" solid. The phosphor is heated to well below the temperature at which its own incandescence would mask the luminescence. The heating acts as a trigger to release the stored energy as luminescence, hence the term "thermoluminescence." Once the stored energy has been released, the material no longer has a memory of the radiation dose. A TL reading is thus a "one shot" determination of the dose equivalent. As the irradiated phosphor is heated, the thermoluminescence brightness will vary with time, as shown schematically in Figure 1-1. The curve of brightness vs. heating time or temperature is called a "glow curve."

Ionizing radiation causes the separation of charges in an insulating solid, producing free electrons and entities that behave like particles of opposite charge--"positive holes." Most of these charges recombine quickly, but some of them are attracted to impurities or other imperfections in the solid and become "trapped" at these sites. Depending upon the strength of the attraction, they can be trapped for a short or a long time--one speaks of "shallow traps" and "deep traps." A very nominal temperature, even room temperature, will suffice to liberate charges from shallow traps.

When the charges are released, they recombine with charges of the opposite sign, emitting light in the process. This light is thermoluminescence. Shallow traps are not useful for thermoluminescence dosimetry, where one wishes the material to retain the dose information over many weeks or months. Instead, deeper traps are utilized, since they can hold the charges without loss over these long intervals of time. To empty these traps, with a resulting TL glow, heating to about 200-300^{o}C is required. Traps that are still deeper can store the energy for even longer periods of time; however, they are not useful for dosimetry, since to expel the charges one must heat the material to such high temperatures that the incandescence of

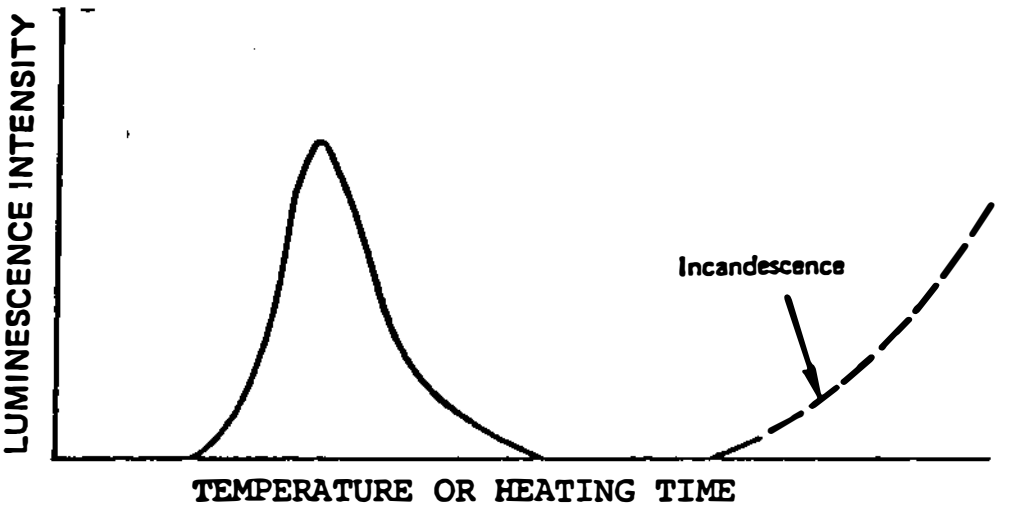

FIGURE 1-1 Simplified glow curve.

the solid interferes with observing its thermoluminescence. Some glow curves for traps of different depths are shown schematically in Figure 1-2.

Ideally, one would like to have a material with a single type of trap of optimum depth, giving a simple glow curve. Other desiderata are a spectral emission (color) of luminescence lying in the highly sensitive range of the photodetector measuring the luminescence (blue in the case of the usual photomultiplier tube detector); stability to multiple repetitions of the heating cycle to which the solid must necessarily be subjected in the "reading" process (if the dosimeter is to be reusable); and inertness to effects of ambient conditions, such as humidity changes, mechanical shock, light exposure, and moderate temperature changes. Despite more than 2 decades of research, no single material has been found which fulfills all these requirements, and compromises have been made in the designing of all existing TLD systems. One of the most common compromises is to accept TL materials that have multiple traps, i.e., a complex glow curve with several peaks, only one or a few of which are useful for thermoluminscence dosimetry.

TLDs have taken a variety of forms: loose powders; powders sealed into small capillary tubes; powders coated onto an electrically conductive filament or substrate hermetically sealed into a glass bulb; a similar arrangement with the powder replaced by a single crystal of the TL material; plastic material impregnated with TL powder; a solid chip of TL material; and a thin powder coating on a plastic base.

Heating methods have generally been by conduction from a hot platen, hot gases, an electrical current through a filament, radiant heating, or induction heating of a metal substrate. The Panasonic TLD system acquired by the Army employs radiant heating, wherein an incandescent lamp is pulsed to provide the TL heating schedule.

The theoretical analysis of glow curve shapes has succeeded only for ideal cases where simple kinetics have been assumed. For TL dosimetry purposes, however, knowledge of the exact shape of the glow curve is not essential; it is necessary only to ensure that the heating schedule is the same from dosimeter to dosimeter. If the heating regime is reproducible, one may use either the area under the glow curve or the peak height of the TL vs. time glow curve as a measure of the thermoluminescence output. Calibration of the dosimeter must, of course, be carried out with the identical heating schedule.

When large, unstable (i.e., low-temperature) glow peaks are present, as with lithium borate, the reading instrument may devote a portion of the heating schedule--the so-called "preheat" cycle--to a procedure designed to erase these peaks before proceeding with the higher temperature or "read" portion of the heating regime. Alternatively, the dosimeter can be separately treated in a low-temperature oven to erase the low-temperature component of the glow curve. As a further alternative, the photodetector can be gated to see only the luminescence from the glow peak that is used for dosimetry; i.e., the "read" peak.

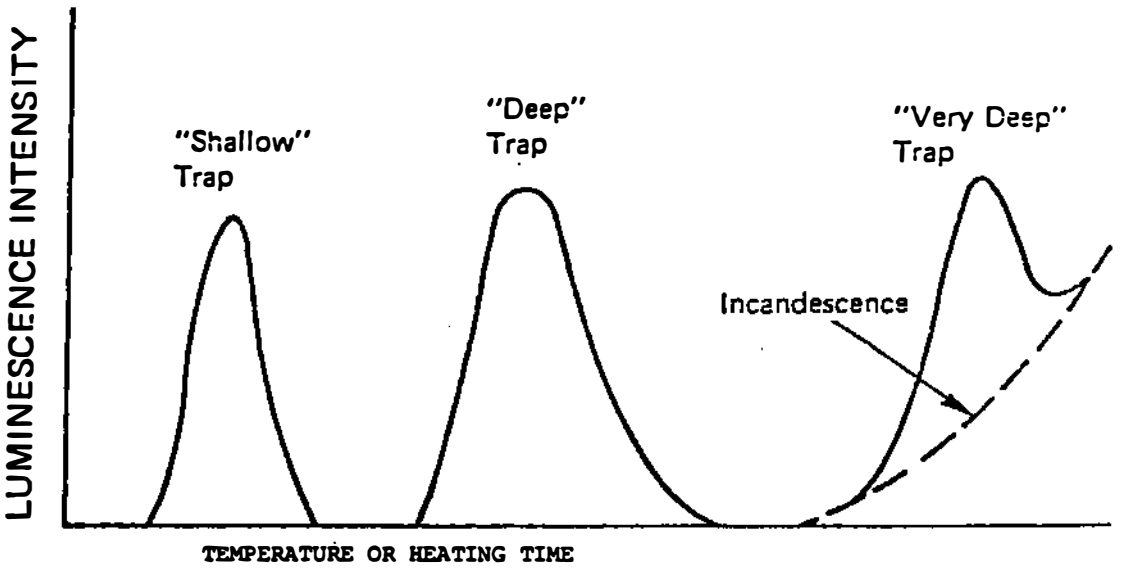

FIGURE 1-2 Schematic glow curves for various trap depths.

If the low-temperature peak is large and overlaps strongly with the "read" peak, the short "preheat" step in the reader may be insufficient to erase the former, and the reading will be in error (too high) because of the inclusion of low-temperature thermoluminescence. Gating of the photomultiplier--or reading of the peak height instead of the area under the glow peak--should help minimize this complication. A low-temperature anneal in a separate oven for an appropriate length of time is a preferable treatment to eliminate the problem. If immediate reading of the exposed dosimeter is not an operational necessity, and if the low-temperature glow peak is of the order of 100°C or less, this peak will decay or "fade" on storage for 24-48 hours at normal temperatures, thus obviating the need for any of the above measures to remove it.

For a given radiation dose, the thermoluminescence brightness (or "yield") of a phosphor depends upon the efficiencies of both the trapping process and the luminescence charge-recombination process. Different phosphors have inherently different efficiencies for one or both of these processes, leading to considerable differences in yields between phosphors. A secondary, but nevertheless important, effect on the TL utility of a phosphor is the spectral distribution (color) of its luminescence; for two phosphors with equal true TL yield, the one whose emission better matches the spectral region of high sensitivity of the photodetector used will give an apparently higher TL yield.

The response of the phosphor to radiation also depends upon the atomic numbers of its chemical constituents and upon the kind and energy of the radiation. These factors jointly determine the dominant mechanism(s) of interaction of the radiation with the phosphor, hence how strongly the radiation is absorbed.

MONITORING OF SPECIFIC KINDS OF IONIZING RADIATION

The relative applicability of various dosimetry devices to monitoring specific kinds of ionizing radiation varies. In the following subsections, consideration is given to factors determining the accuracy with which dosimetry devices--especially the TL dosimeter--are able to estimate dose equivalents for photons, beta radiation, and neutrons.

Photon Dosimetry

At photon energies normally monitored, the primary interactions of TL phosphors are by Compton scattering and the photoelectric effect. Generally, Compton scattering is dominant above about 500 keV, while the photoelectric effect predominates below 50 keV. (Lithium borate is an exception; Compton scattering predominates above about 30 keV.) In the intermediate region, both interactions are important. The Compton interaction is essentially independent of the atomic number of the absorber. The photoelectric interaction is very dependent upon the atomic number, increasing rapidly as the atomic number increases.

Photons from medical x-ray units are generally in the region of 15 to 100 keV. Because of the photoelectric effect, the TL yield from phosphors containing calcium is very much greater for photons from diagnostic medical x-ray units than from therapy sources (500 to 10,000 keV).

The dependence of TL yield on photon energy is shown in Figure 1-3 for four common TL phosphors: lithium fluoride (LiF), copper-activated lithium borate ($Li_2B_4O_7$: Cu), manganese-activated calcium fluoride (CaF_2: Mn), and thulium-activated calcium sulfate ($CaSO_4$: Tm). The yields of the low atomic number lithium-bearing phosphors are relatively energy-independent over the photon range shown, while those of the two calcium-bearing phosphors show considerable energy dependence below about 100 keV. Also shown in the figure (dashed line) is a method of reducing the excess response of calcium-bearing phosphors at intermediate energies by interposition of an appropriate filter, at the expense of sacrificing response at the low-energy end of the spectrum. Use of such filters also introduces a directional dependence of response, since the effective filter thickness varies with angle of incidence of the radiation on the filter.

By combining phosphors having different energy responses (resulting from either their compositional differences or the use of filters), some rough information can be obtained about the spectral quality of the radiation. By similar means, alpha, beta, x-, and gamma radiations can be distinguished from each other.

Beta Radiation Dosimetry

Beta radiation is far less penetrating than gamma radiation, and therefore contributes significantly to the dose equivalent only in the more superficial parts of the body, primarily the skin, extremities, and lens of the eye. An external beta-ray dose equivalent within legal specified limits is assumed to contribute a negligible harmful effect to the body as a whole. Therefore, dose equivalents to the skin, the extremities, and the lens of the eye are excluded from computations of whole body dose equivalent. The main characteristics of a beta-radiation field, which are important in relationship to beta dosimetry, are: (1) the dose equivalent from a beta source falls off much more rapidly than from a photon source and (2) beta radiation fields are grossly non-uniform and generally expose only limited regions of the body. High-beta-radiation fields are mainly encountered when unshielded radioactive sources must be manually handled, resulting in potentially high exposure to the hands or other extremities.

In practical situations, it is uncommon to be exposed only to beta radiation. More typically, any significant exposure to beta radiation will be accompanied by exposure to gamma radiation. Because many dosimeters respond similarly to both kinds of radiation, it is convenient to measure them together.

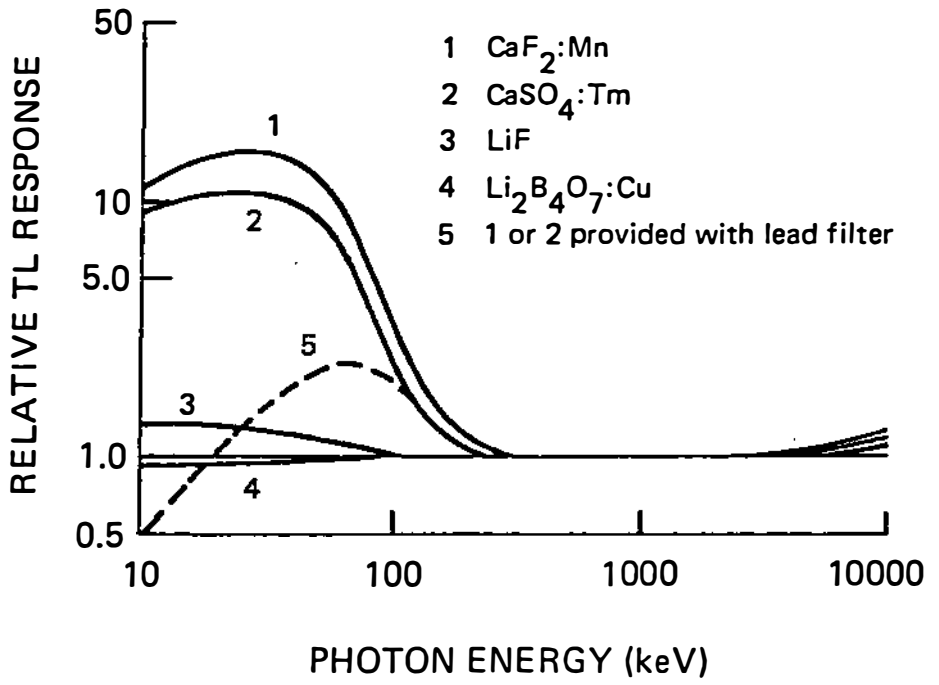

FIGURE 1-3 Energy dependence of selected TL phosphors.

SOURCE: Adapted from Schulman, 1983.

In practice, most radiation workers are not exposed to beta radiation. Overall, less than 10 percent of the people monitored by USAIRDC are exposed to beta radiation. Many beta radiation exposures are non-uniform. The greatest risk is that people will bring their hands close to a beta source. To monitor such non-uniform fields, special dosimeters such as finger-ring badges and wrist badges are employed. The present Army film-badge monitoring service issues wrist film dosimeters to 6.5 percent of all personnel monitored, and TLD finger-ring badges to an additional 4 percent.

Neutron Dosimetry

The goal of neutron dosimetry in radiation protection is to determine the number of rem received by a person wearing a neutron dosimeter, so as to account for and limit total dose equivalent and any possible damaging effects on health. However, neutrons are neutral particles and produce little direct ionization. Hence, they are difficult to monitor. Furthermore, biological effects of neutron radiation are especially difficult to evaluate.

For chronic exposures, neutrons are significantly more effective in producing biological damage than are x rays or gamma photons. Radiation-induced effects in the body can lead to a number of damaging biological end-points, which occur with different probabilities. The problem of selecting a single dosimeter quantity--one that characterizes the neutron field--has never been satisfactorily solved. In fact, a number of investigators have questioned the validity of using a single quantity to characterize the neutron field for purposes of radiation protection.

It is generally accepted that the current status of neutron dosimetry leaves much to be desired. This overall inadequacy has been tolerated in neutron protection because, in many practical situations, the neutron dose equivalent is small or, at best, comparable to the coexisting gamma component. (Only at the higher neutron energies--above several MeV--is the dose equivalent delivered mainly by neutrons.) However, this situation would change if a pending proposal, which would increase the quality factor for neutrons, is adopted.

Until recently, neutron film badges utilizing nuclear emulsions were the most widely used neutron dosimeters. Such badges are presently being used for neutron detection in the USAIRDC film dosimetry system.

The disadvantages of nuclear emulsions for personnel dosimetry are well established: (1) they are insensitive to neutrons below 0.2 MeV; (2) they are sensitive to photons; and (3) neutron track images fade after exposure, particularly in high humidity. Film darkening produced by a few rem of gamma radiation makes track recognition difficult and, at higher gamma radiation levels, makes it impossible.

Neutron film dosimeters are most effectively used in the vicinity of high energy accelerators and radioactive neutron sources. In reactor environments, they have been largely replaced by albedo dosimeters. An

albedo dosimeter records the passage of thermal neutrons that have been moderated by and reflected from the body during exposure to a neutron field.

The Army's Panasonic TLD can be used as an albedo dosimeter for monitoring personnel neutron exposures. One major problem with albedo dosimeters is the strong dependence of their dose equivalent response on neutron energy. Despite this drawback, the albedo dosimeter has been universally accepted, mainly because of its high sensitivity to neutrons with energies below 100 keV. Neutrons in this energy range are encountered in many practical situations in a reactor environment. The problem of the energy dependence of response is generally overcome by field calibration techniques, which estimate the neutron response of the albedo dosimeter for each work location on the basis of survey measurements.

2

CHARACTERISTICS OF IONIZING RADIATIONS TO WHICH ARMY MILITARY AND CIVILIAN PERSONNEL ARE EXPOSED

To monitor radiation adequately, it is necessary to have an understanding of the kinds, amounts, and energies of radiations to be monitored. This chapter relies upon information from two sources: (a) a summary of the U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC, 1985) dosimetry records for 1984; and (b) responses to a questionnaire (a copy of the questionnaire is included as Appendix A) that the committee sent to all facilities monitored by the USAIRDC. The questionnaire was specifically designed to help provide information required to respond to the committee's Study Task 1, to "review the characteristics of ionizing radiation to which Army military and civilian personnel are exposed occupationally."

The USAIRDC film badge monitoring service is comparable to that provided by commercial film badge services. In 1984, about three-fourths of the film badges for individuals monitored by USAIRDC received radiation doses too small to be recorded (USAIRDC, 1985). Over 90 percent of the monitored employees were potentially exposed only to x rays and gamma photons. Less than 10 percent were additionally potentially exposed to beta radiation, and about 5 percent had the possibility of being exposed to neutron radiation. The problem of monitoring this large variety of potential radiation exposures is reviewed in this chapter.

The Army's new thermoluminescent dosimeter (TLD) personnel monitoring system was required to be capable of meeting accepted industry standards for detecting photons, beta radiation, and neutrons at specified dose equivalent levels. It is also intended to be able to separate and identify mixtures of the three kinds of radiations, together with their approximate energies. To evaluate the adequacy of the new TLD system, the committee needed to examine in some detail the varieties of radiation sources to which personnel monitored by the Army film badge service are currently exposed. The method chosen to obtain this information was a questionnaire that was sent to all facilities using the Army's film badge service.

PURPOSE AND FORMAT OF THE QUESTIONNAIRE

The committee first obtained general background information from USAIRDC in Lexington, Kentucky. Data included the kinds and amounts of radiation to which the wearers of USAIRDC dosimeters were exposed at Army facilities throughout the world. Information also was obtained on the percentages of total dosimeter wearers receiving dose equivalents within several specified ranges of cumulative annual dose equivalent. Then, through its questionnaire, the committee obtained supplemental data and information from many of the 775 dosimeter-issuing locations regarding the varieties of radiation sources, energies, and amounts of exposure encountered at those locations.

To evaluate technical aspects of the new TLD system and its capability to monitor existing exposure situations, it was necessary to glean as much information as reasonably could be obtained regarding sources of exposure. The committee solicited--but did not receive--information on possible accidental exposures in situations unanticipated by USAIRDC.

The committee designed the questionnaire to elicit the necessary data without using overly complicated questions, which might have discouraged responses. The questionnaire was general enough so that comments or descriptions could be used where necessary to substitute for technical specifications of radiation sources that may have been unknown to the respondents. The response rate to the questionnaire was about 50 percent. About 775 questionnaires were mailed on October 2, 1985. By December 16, 1985, 388 replies had been received. Analysis of the responses is summarized in the following sections.

Additional information provided by the Army included a customer listing together with the number of beta-gamma film badges shipped monthly. Along with the standard film badges, additional shipments included wrist film-badge dosimeters (6.5 percent of the total number of badges), neutron film-badge dosimeters (4 percent), and TL ring-badge dosimeters (4 percent). The number of dosimeters shipped included control and environmental badges, visitor badges, and those worn only for training exercises. At some locations, such as weapon storage facilities, contingency dosimeters were stored for possible use in the event of an accident involving radiation exposure.

A summary of the kinds of facilities responding to the questionnaire is given in Table 2-1, together with the varieties of radiation sources encountered. About 95 percent of the reporting facilities reported no dose equivalent above 100 mrem (1 mSv) per year, while those reporting dose equivalent above that level (listed in Table 2-2) are mostly large installations collectively receiving 18 percent of the badges shipped each month.

Included in the information provided by USAIRDC was a summary of the total number of personnel monitored in 1984 and the distribution of measured whole body dose equivalent, which ranged from undetectable to an annual dose equivalent of 12 rem. This information appears in Table 2-3.

TABLE 2-1 Kinds of military and government facilities responding to the questionnaire, and sources of radiation exposure at those facilities

Functions of Facilities	X rays		Gamma Photons	Beta Radiation	Neutrons
	Low Energy	High Energy			
Medical					
Diagnostic	X				
Dental	X				
Radiotherapy		X	X	X	
Industrial					
Industrial radiography		X	X		
Soil moisture gauges			X		
Instrument calibration repair			X	X	X
Military & government					
R&D laboratories		X	X	X	X
State agencies (e.g., National Guard, Civil Defense)			X		
Reactor facilities					
Pulsed			X	X	X
Research			X	X	X

TABLE 2-2 Facilities reporting measurable dose equivalents on questionnaire

Kind of Facility	Kinds of Exposure: X rays Diagnostic & Therapeutic	Gamma Photons	Beta Radiation	Neutrons	Annual Dose Equivalent (millirem): No. of Badges Worn	Below 100	100 to 1,000	Above 1,000
Radiotherapy center	6 MeV	*	*		450	441	9	0
Radiotherapy center	6-14 MeV				200	145	55	0
Radiotherapy center	Diag. & 10 MeV	*			185	165	20	0
Radiotherapy center	*	*	*		330	258	62	10
Radiotherapy center	*	*	*		200	180	16	4
Radiotherapy center	*	*	*		199	167	25	7
Radiotherapy center	4 MeV	*	*		217	181	32	4
Diagnostic radiology	Diag.	*	*		130	125	5	0
Diagnostic radiology	Diag.				10	9	1	0
Diagnostic radiology	Diag.	*			175	166	3	6
Diagnostic radiology	Dental Diag.	*			79	69	10	0
Research	250 keV	*	*	*	466	430	34	2
Research	*	*	*		181	175	6	0
Research	*				700	680	10	10
Research	*				190	171	19	0
Industrial radiography		*	*		14	10	4	0
Nucleonics	*	*			19	16	3	0
Corps of Engineers	*	*	*	*	12	11	1	0
State civil defense		*			91	88	3	0
Total					3,848	3,487	318	43

*Respondents indicated exposure to this species, without specifying its energy.

Table 2-3 shows that during 1984 about 76 percent of the radiation work force monitored received no measurable dose equivalent, about 97 percent received less than 100 mrem (1 mSv) per year, and less than 1 percent more than 500 mrem (5 mSv). It should be noted that Table 2-3 provides information only on whole body dose equivalent, and not regarding dose equivalents to the skin or extremities. This is typical of most evaluations of annual radiation exposures (see, for example, UNSCEAR, 1982; ICRP, 1985; Hughes and Roberts, 1984; Kumazawa et al., 1984). There is little information on the relative frequency and degree of exposure to the skin and extremities relative to whole body dose equivalent.

INTERPRETATION OF RESULTS

Table 2-2 indicates that the highest number of significant dose equivalents are received by workers in radiotherapy departments at large medical centers. Patients undergoing cancer treatment receive large dose equivalents of high energy x rays and of gamma radiation from implants in the form of sealed sources. Under the latter conditions, there can be significant radiation exposure to personnel charged with implanting the source and subsequently removing it following treatment. Sound radiation safety measures and an instilled awareness of the hazards associated with these practices are required to help reduce personnel exposures.

In contrast, diagnostic radiography (except in the case of special fluoroscopic procedures) results in relatively low level exposure with low energy x rays. Such exposures can easily be shielded with lead aprons or gloves. Significant dose equivalents were recorded at a number of military research and development facilities, two of which had pulsed reactors. Conditions leading to personnel exposure in such facilities are described below.

One interesting feature of the survey was that no significant exposures to beta radiation were reported. The few exposures to pure beta sources mainly resulted from using ^{90}Sr-^{90}Y calibration sources at radiac instrument repair facilities. The beta radiation sources are shielded, so that radiation from them is primarily limited to the open-window region of the instrument detector. Beta radiation and gamma photon sources used for instrument calibration are collimated to minimize personnel exposure.

A number of beta radiation sources were also used in radiology departments, both for diagnostic evaluations and for radiotherapy, notably ^{32}P. Beta radiation energies were generally in the region of 1-2 MeV. The highest reported energies were for ^{90}Sr-^{90}Y (2.3 MeV maximum).

Beta radiation exposures also were observed at two Army pulsed reactors (also known as critical assemblies) during their periodic maintenance operations. These exposures were to mixed beta-gamma fields from fission products. Gamma radiation dose equivalents of 200 to 300 mrem (2 to 3 mSv) were recorded during this period. The

TABLE 2-3 Summary of annual dose equivalents for personnel monitored by USAIRDC in 1984

Dose Equivalent Received (rem)	Number of Personnel	Percent of Total
Undetectable	17,350	76.4
Less than 0.10	4,801	21.1
0.10-0.249	303	1.3
0.25-0.499	81	0.4
0.5-0.999	94	0.4
1.0-1.99	35	0.2
2.0-2.99	24	0.1*
3.0-4.99	10	0.1*
5.0-9.99	2	0.1*
10.0 and above	4	0.1*
Totals:	22,704	100.0

*Approximate percentage.

accompanying beta radiation dose equivalent was usually less than half and never greater than the gamma radiation dose equivalent. No attempts were made to evaluate the beta radiation energy spectrum.

Neutron exposures were primarily limited to the two pulsed reactors mentioned earlier. Protection of individuals during operation of each reactor was achieved by evacuating the immediate area prior to a burst. These facilities are operated by remote control. This procedure minimizes the possibility of exposure to both neutrons and their associated gamma photons. The neutron badges consisted of nuclear track emulsions, which are inadequate for the detection of the fission neutrons emitted.

It is of interest to note that a major government radiation research facility which subscribes to the USAIRDC standard film badge service made a decision to use albedo dosimetry for personnel neutron monitoring. As a result, an albedo TLD dosimeter service was obtained from another supplier. Neutron dose equivalents were reported but, on the average, they measured only 20-30 percent of the accompanying gamma radiation dose equivalents. These exposures occurred mainly in the vicinity of experimental reactor ports. Differences in average neutron energy from port to port were large enough to require an independent evaluation of neutron energy--using survey neutron-energy measurements--in order to evaluate the reported albedo dose equivalent.

This facility had an experienced staff of health physicists and adequate instrumentation to perform neutron energy measurements on site, without needing help from outside consultants. It is quite likely that most research reactors would have similar capabilities. At nuclear power reactors, the potential for radiation accidents has prompted the need to install on-site TLD monitoring systems to allow an immediate evaluation of the dose equivalent, when required. It is unlikely that USAIRDC will be providing a service to such facilities.

TRENDS IN REPORTED DOSE EQUIVALENT FOR VARIOUS OCCUPATIONS

In 1982, UNSCEAR published annual dose equivalents from external radiation exposures for a number of occupations and countries. These annual dose equivalents are given in millisieverts per year (mSv/yr), where 1 mSv equals 100 mrem. Similar data are available for all forms of occupational exposures in the United Kingdom (Hughes and Roberts, 1984) and the United States (Kumazawa et al., 1984). Some examples of such data are given in Table 2-4. These data show a range of annual dose equivalents, for different occupations, somewhere between 40-400 mrem (0.4-4 mSv) per year. The mean for all workers was 125 mrem (1.25 mSv) per year. For workers with any measurable exposure, the mean was 220 mrem (2.2 mSv) per year.

Such tables show that, with good radiation safety practice, practically all routine radiation exposures can be kept well below the regulatory whole body limit of 5,000 mrem (50 mSv) per year. Individual limits of dose equivalents are intended to ensure that any

TABLE 2-4 U.S. rates of occupational exposure (1980); means for all workers with measurable exposure*

Occupational activity	Dose Equivalent (mSv y^{-1})
Nuclear fuel cycle	
Fuel fabrication and reprocessing	1.7
Uranium enrichment	1.2
Power reactors	6.5
Waste management	3.8
Uranium mills	2.6
Uranium miners, external plus radon decay products, 0.9 WLM*	3.5
Industry	
Radiographers	4.3
Manufacture and distribution	2.7
Other	2.1
Medical	
Hospital	2.0
Private practice	1.8
Chiropraxy	0.8
Podiatry (1975)	0.3
Dental	0.7
Veterinary	1.1
Government	
Department of Energy	1.6
Department of Defense	0.9
Other agencies	0.6
Other occupations	
Education	1.1
Transportation	2.0
Flight crews and attendants	1.7
Students	1.0
Non-uranium miners plus radion decay products, 0.3 WLM	2.2
Average, all occupationally exposed workers**	
As based on a total of 1740 person-Sv (including 7500 person-WLM at 10 mSV per WLM)	2.2

*WLM is an abbreviation for working level month.
**The mean value for all potentially exposed workers was 1.1 mSv y^{-1}.

SOURCE: Table 30B. U.S. rates of occupational exposure (1980); Kumazawa, S., Nelson, D.R. and Richardson, A.C.B., 1984.

risks from radiation exposure are comparable with, or less than, risks experienced in other occupations.

The tables also can be a useful guide for comparing the average dose equivalent received at any facility with that of workers in the same practice. High values would indicate that additional protective measures should be introduced to provide a safer working environment.

3

EVALUATION OF THE CHARACTERISTICS AND ADEQUACY OF THE ARMY'S TLD SYSTEM

Pursuant to Study Task 2, this chapter evaluates the characteristics and adequacy of the Army's Panasonic thermoluminescent (TL) dosimetry system (Panasonic Model UD-802AS dosimeters with UD-874A hangers and UD-710A automatic reader), including calibration and quality assurance procedures, and algorithms used for obtaining and processing TL dosimeter (TLD) data. Recommendations are made regarding modification to the TL dosimetry system of the U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC) as well as related staffing that would be desirable for optimum functioning of that system.

DESCRIPTION OF THE PANASONIC TL BADGE AND READER

The Panasonic TLD badge (Figure 3-1) employs four thin monograin wafer phosphor "elements." Elements 1 and 2 are composed of copper-activated lithium borate, and elements 3 and 4 of thulium-activated calcium sulfate. Each element consists of a monograin layer of phosphor that is deposited on an opaque plastic substrate, covered with transparent plastic, and held in a plastic slide inside a holder. The phosphor elements are heated in the reader by pulses of infrared radiation from an incandescent lamp (Panasonic Industrial Company, 1983). The radiation pulses are filtered through a silicon filter, then impinge on the opaque substrate. Figure 3-1 illustrates the configuration of the dosimeter elements, their arrangement in the badge, and the operation of the reader.

The small masses of the substrate and phosphor permit very short heating times. As shown in Figure 3-2, the phosphor is not heated at a constant rate, but is subjected to three carefully timed infrared pulses. The first ("preheat") pulse heats the phosphor to a temperature which is intended to "glow out" any unstable traps, such as those responsible for the 100°C glow peak in lithium borate. The second ("read") pulse heats the phosphor through the temperature range of the stable glow peak that is used to measure the dose. The third ("post-anneal") pulse glows out all remaining traps and prepares the phosphor for reuse. All four elements of the badge are read

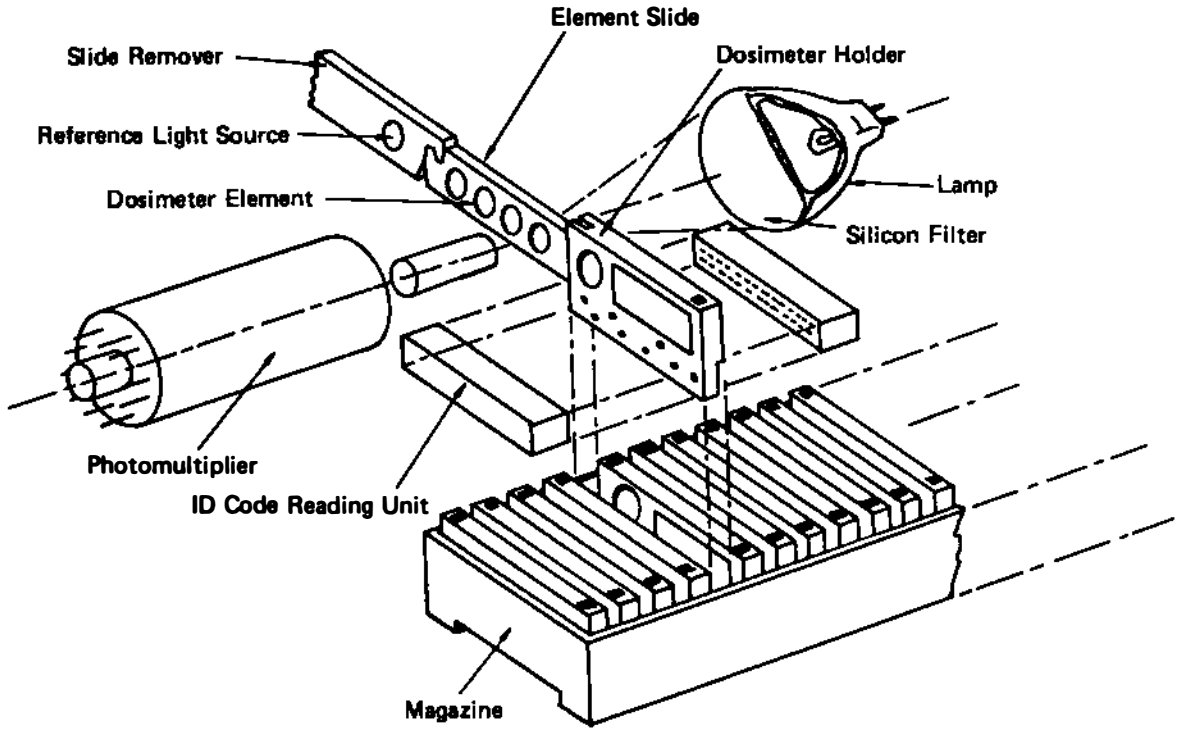

FIGURE 3-1 TLD badge and reader system construction operation.

SOURCE: Panasonic Industrial Company (1983).

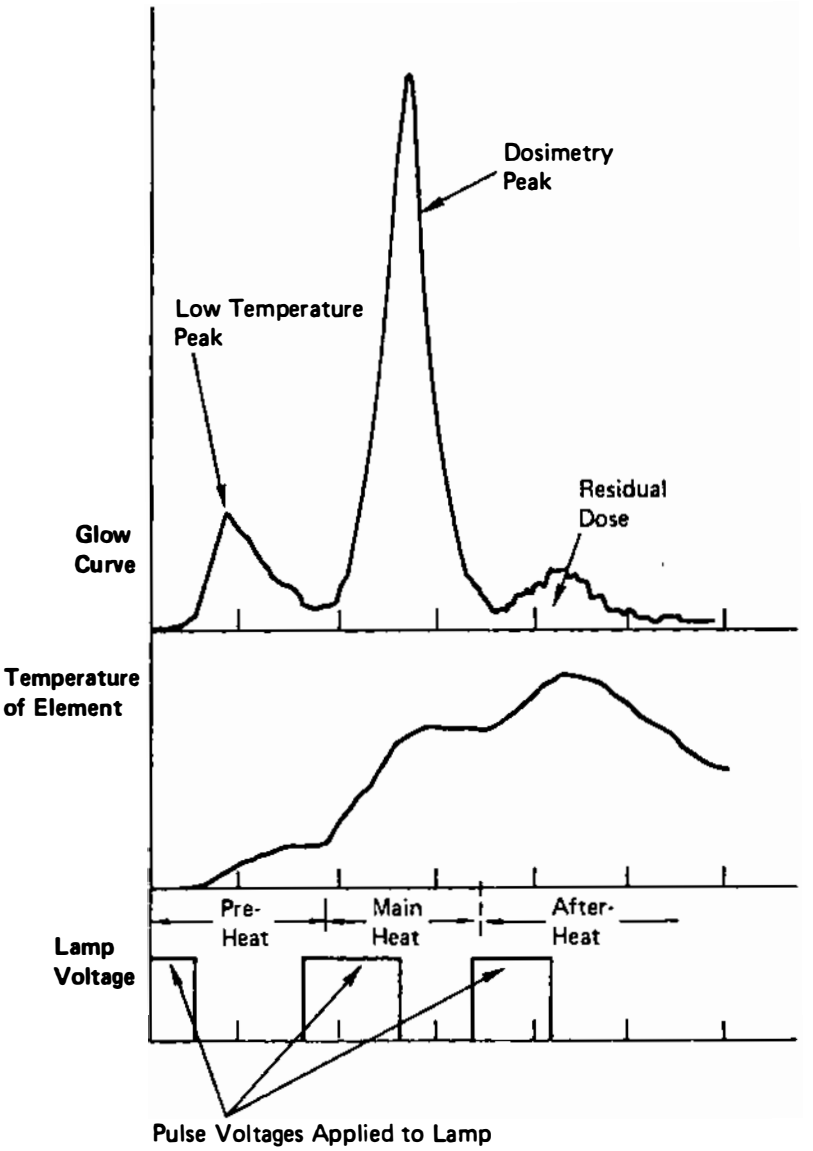

FIGURE 3-2 Glow curve of a $CaSO_4$ element measured by a Panasonic UD-710A reader.

SOURCE: Panasonic Industrial Company (1983).

sequentially in the reader, each element undergoing the heating cycle described above. The total reading time for a badge is ca. 25 seconds. Figure 3-2 shows schematically the relationship of lamp voltage, phosphor temperature, and luminescent glow as a function of time. Low levels of TL output are measured by photon counting, while high levels are measured by a frequency-counter circuit.

The UD-710A reader is a microprocessor-based system with electronic and mechanical features. The mechanical system sequentially extracts the dosimeter slide--from each of 50 dosimeters per tray--for reading, and interprets binary-coded punched holes in the slide holder. Coding includes dosimeter type, identification number, and other information. The electronic system controls the lamp flashes, the photomultiplier tube, and the counters (which measure the thermoluminescent output of each element, as well as performing various internal reader performance checks). The reader's microprocessor program contains parameters for controlling these and other reader functions, such as: reader calibration; conversion from counts to apparent exposure and from apparent exposure to corrected exposure; processing dates; printing; and data processing. The TL response for each dosimeter is recorded as counts in the "preheat," "read," and "post anneal" categories, as well as in graphs of the glow curves, as shown in Figure 3-3.

Calibration of the reader's response, using reference badges of known characteristics and which have been exposed to known dose levels, allows the readings to be interpreted in millirem. The reader sensitivity is checked by comparison with a constant internal light source, and the above calibration is performed periodically by comparison with a selected and carefully preserved pool of reference badges. Since all badges in a specific manufactured lot--indeed, each element of each badge--will vary from the nominal sensitivity value, the response of each element is compared to the average response of the reserved master pool of calibration dosimeters, and so-called "element correction factors" (ECFs) are thus derived for each element. These ECFs then become part of the information recorded for each badge, and the correction factors are subsequently applied automatically by the system.

It has been found by the National Bureau of Standards (1984), in testing ECF-stability using a manual Panasonic reader, that ECFs remain sensibly constant over a considerable period of time, at least 1 year. This manual reader employs a light source whose heating pulse is slower than that of the automatic reader employed by USAIRDC, resulting in a slower readout. Otherwise the two readers are similar electronically. Nevertheless, it may be desirable for USAIRDC to perform a similar long-term stability test on its TLD badges.

Use of differing amounts of shielding, or filtration, over the phosphor elements helps allow approximate spectral information to be deduced using an algorithm (UD802.ALG) provided by Panasonic. That algorithm derives this spectral information (which depends upon the nature of the holder selected and the choice of hanger used to contain the holder) by comparing the TL outputs (referred to as "responses") of the four dosimeter elements in each badge. For example, in the simple

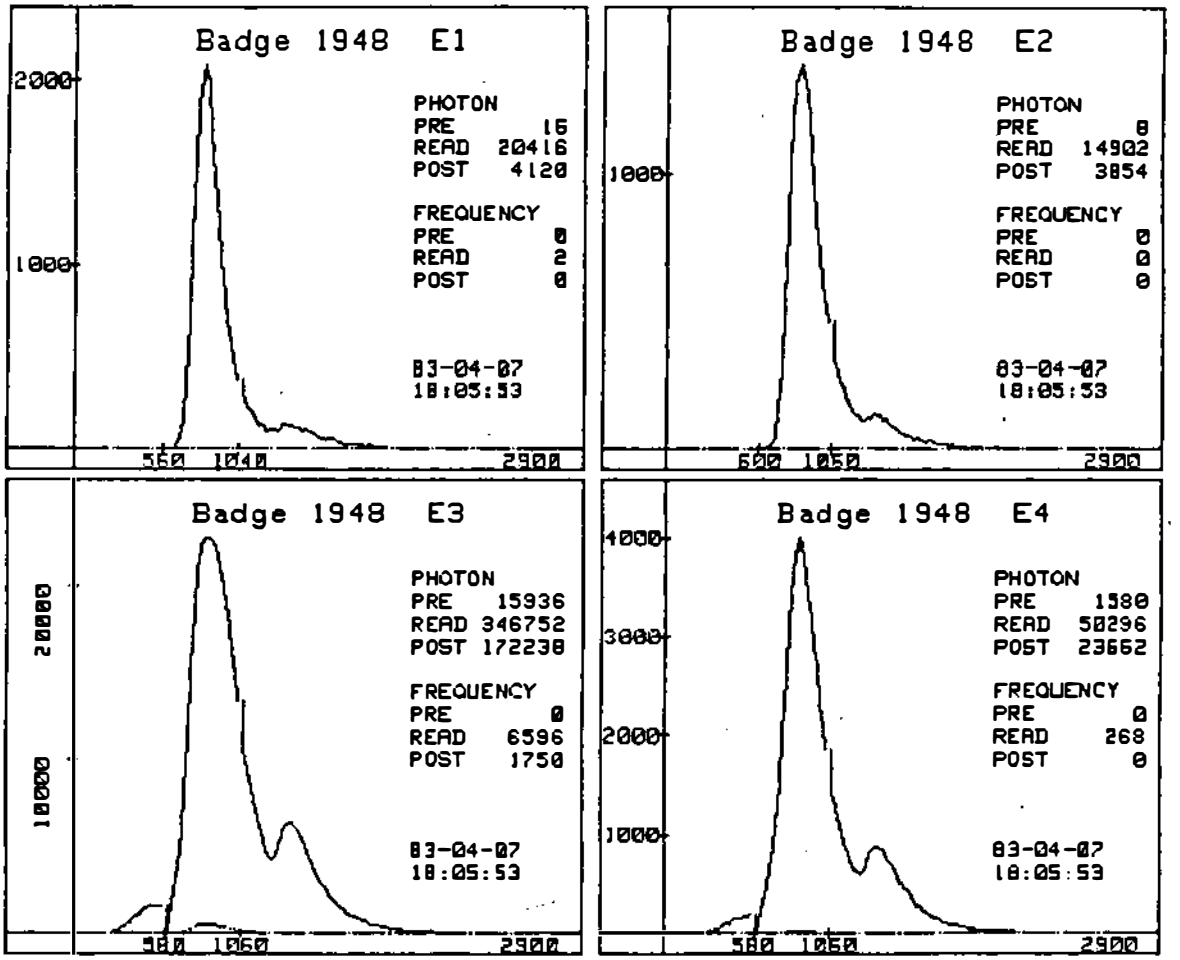

FIGURE 3-3 Sample glow curves from the four TL elements of a Panasonic TLD badge.

SOURCE: Panasonic Industrial Company (1983).

case of monochromatic radiation, soft x rays would produce a high ratio of the response of element 3 (E3) to the response of element 4 (E4), while hard gammas would produce an approximately equal response from these two elements. Spectra also can be calculated by the algorithm for more complex cases, where there is a mixture of broad-band photon radiation, beta radiation, and neutrons. The committee regards the approach built into the algorithm as a reasonable one, but there are problems with its use engendered by limitations of the USAIRDC TLDs as presently configured; for example, when there is exposure to neutrons (see pp. 50-51).

Each variety of Panasonic badge has a hanger with a clip for affixing the complete dosimeter to the wearer's clothing. Some Panasonic TLD users design their own hangers, but USAIRDC uses the Panasonic UD-874A hanger to contain the UD-802AS dosimeter. Table 3-1 lists the approximate filtration, in mg/cm^2, provided by the components of USAIRDC's TLD system.

EVALUATION OF THE PANASONIC TL DOSIMETRY BADGE

This section evaluates the Army's Panasonic UD-802AS TLD (slide and holder) and the UD-874A hanger in which the TLD is inserted. USAIRDC had already procured a supply of these items before this study commenced. Hence this study was limited to evaluating this dosimeter system rather than evaluating various designs of TL dosimeters in a broader study.

Panasonic's initial design development contemplated direct reading of elements to determine dose equivalent at several tissue depths (Panasonic Industrial Company, 1983). Consequently, in the UD-802AS dosimeter and UD-874A hanger, element 1 (E1) is under 17 mg/cm^2 of plastic and is close to the 7 mg/cm^2 density thickness recommended for monitoring dose to the skin; element 2 (E2) and element 3 (E3) are under about 300 mg/cm^2 of plastic, which is the same density thickness as the depth to the lens of the eye; and element four (E4) is under about 1000 mg/cm^2 of lead and plastic. The 1,000 mg/cm^2 represents a density thickness equivalent to the 1-cm tissue depth recommended both in International Commission on Radiological Protection (ICRP) Publication 26 (ICRP, 1977) and in comments preceding its Publication 28 (ICRP, 1978) for monitoring dose equivalent when information regarding dose equivalent distribution to internal target organs is not available and uniform irradiation of the whole body can be assumed.

TABLE 3-1 Approximate filtrations of TLDs used by USAIRDC

Element Number	Filtration (mg/cm^2)			
	Slide	Holder	Hanger	Total
1	11	3	3	17
2	11	160	150	321
3	11	160	150	321
4	11	870*	150	1,020

*75 of plastic plus 795 of lead; other components are all plastic.

Trends in Dosimetry Data Requirements

To evaluate USAIRDC dosimetry data requirements necessitates anticipating trends in regulatory emphasis. From 1977 through 1980, emphasis on monitoring specific tissues was changing. The ICRP made recommendations--in ICRP Publication 26 (1977); ICRP 30, Part 1 (1978); and in ICRP 30, Part 2 (1980)--which are now being considered for adoption by the U.S. National Council on Radiation Protection and Measurements, the U.S. Environmental Protection Agency, the U.S. Nuclear Regulatory Commission, and the U.S. Department of Energy.

Two significant ICRP recommendations were, in effect, that the lens of the eye is not an organ of major concern--because radiation-induced opacities (cataracts) are not life threatening--and that concerns regarding the skin are for cosmetic reasons only, because the risk of skin cancer from nuclear and x-irradiation is very low. Thus, the ICRP deemphasized the importance of the lens of the eye by increasing the recommended annual dose equivalent guidelines from 5 to 15 rem (0.05 to 0.15 Sv) per year. Similarly, ICRP deemphasized the importance of the skin by increasing the recommended annual dose equivalent guidelines from 15 to 50 rem (0.15 to 0.5 Sv) per year.

Another changing concept relates to exposure of red bone marrow, an important target organ in radiation dose equivalent considerations inasmuch as the attendant risk is induction of leukemia. Insofar as the relevant importance of this risk among the risks associated with the 12 organs and tissues considered at risk, ICRP weights dose equivalent to red bone marrow only below dose equivalent to the gonads and breast (ICRP, 1977, 1978). Hence, ICRP stated that "for purposes of calculation, it may be assumed that the average depth to the blood-forming organs is 5 cm," not 1 cm (ICRP, 1955). Thus, it may become important to have information on the penetrating characteristics of radiations to calculate dose equivalent received by the red bone marrow.

Adequacy of the USAIRDC TLD

Because the committee was charged with evaluating the adequacy of the Army's TLD system, both for present and future use, its recommendations are not based solely upon current Army regulations, nor on ICRP-published limits, nor on any fixed set of exposure limits currently favored by a government agency. In particular, the committee evaluated the capability of the Panasonic TLD badge to determine incident beta and photon energy, information which is a prerequisite to calculating dose equivalent at the depth of any target organ. Relevant to this capability, information presented to the committee by USAIRDC indicated that testing of the Panasonic UD-802AS was performed by USAIRDC, and that the dosimeter failed in some USAIRDC tests to meet the original procurement contract specifications.

Information presented by several Panasonic users at committee meetings (in response to requests and questions from committee members) and in a National Bureau of Standards (NBS) report (1984) and presentation (Ehrlich and Soares, 1986) verified USAIRDC test results and identified certain additional problems. Major problems identified are outlined below, then discussed in detail:

1. The response of E4 in the UD-802AS dosimeter is dependent on the direction of incident photon radiation, particularly at low photon energies, based on inferences that can be drawn from the NBS testing report (1984). That report identified such a problem for E4 in tests of the similar UD-801AQ dosimeter (which has identical lead filters in front and in back of both E3 and E4, whereas the USAIRDC's UD-802AS dosimeter has such a filter for only E4). Compared to the ratio of E4 response to E3 response obtained at perpendicular incidence, this effect produces a greater ratio at angles of incidence significantly off perpendicular, thus leading to the inference of higher-than-actual photon energy. Such errors can lead to incorrect estimates of dose equivalent.

2. Beta particles with energies over 700 keV will penetrate the E3 filter and increase the ratio of the response of E3 compared to that of E4. This can cause an indication of apparent exposure to the wrong energy of photons, including an erroneous indication of exposure to very low energy photons, when such exposure has not in fact occurred. This problem results in a corresponding error in estimating dose equivalents.

3. While USAIRDC performance specifications called for accurate measurement of dose equivalent from beta particle energies as low as 70 keV, beta particles with energies less than 700 keV will not penetrate the filter over E2, in which case the ratio of E1 to E2 is almost useless in determining beta radiation energy information, and measurement of dose equivalent resulting from beta radiation becomes inaccurate.

Discussion of TLD Problem 1: The following discussion shows how a non-negligible error in estimating dose equivalent might occur, as a basis for supporting a committee recommendation that consideration be given to modifying the USAIRDC TLDs to reduce such errors.

For the UD-801AQ dosimeter, NBS (1984) found that E4 overresponded--by a factor of 1.25 or more at an effective energy of 210 keV, increasing up to a factor of 30 at an effective energy of 38 keV--when photons were incident at 90 degrees or 270 degrees, where 0 degrees corresponds to frontal exposure. Although such overresponse may be quantitatively different for USAIRDC's UD-802AS dosimeters, E4 in those dosimeters also will overrespond.

USAIRDC obtained response curves of E3 and E4 at frontal (that is, perpendicular) incidence. Those curves are shown in Figure 3-4. Although E3 and E4 are identical in construction and made of the same calcium sulfate phosphors, the lead filter in front of E4 decreases its frontal-exposure response relative to that of E3 at lower photon energies. Note that when the badge is exposed frontally to 38 keV photons, the E3 response is about 10.6 times the E4 response. However, photons incident at 90 or 270 degrees will bypass the lead filters in front and in back of E4, thereby causing its response to become comparable to that of E3. Oblique photons also may undergo Compton scattering from the lead filter and from the material around E4 to create even more response in E4 than in E3. Increasing the E4 response to low-energy photons reduces the ratio of E3 to E4. That ratio is employed by Panasonic algorithm UD 802.ALG. Reducing it, as is apparent from Figure 3-4, leads to erroneous indication of exposure to higher-energy photons. Such errors can lead to errors in estimating dose equivalents.

Just as frontal exposure is a special exposure situation where designed functioning of the TLD is optimum, the configuration discussed above is a special exposure condition that results in a maximum departure from designed functioning. Yet another set of exposure conditions results from continually rotating the dosimeter while it is being exposed. Designed functioning would be expected to be intermediate between optimum and maximum-departure functioning for these conditions. Any of the described exposure situations could occur during personnel monitoring under field conditions.

These problems can lead to mistaking low-energy photons for high-energy photons, which in turn may lead to errors in assigning dose equivalents at depths in the body below a few millimeters. The reason for this sensitivity to the inferred photon energy is that higher-energy photons penetrate to greater depths than do low-energy photons. Thus for shallow depths, photon penetration is relatively independent of photon energy, whereas at greater depths, penetration is achieved only by sufficiently energetic photons. An example provided below illustrates how such incorrect photon energy inferences would be interpreted in terms of dose equivalents at a particular body depth.

If E4 overresponds by a factor of 10, exposure to a 38 keV photon can be incorrectly identified--based on Figure 3-4 and using the E3 to E4 response ratio--as a high-energy exposure, say to photons of several

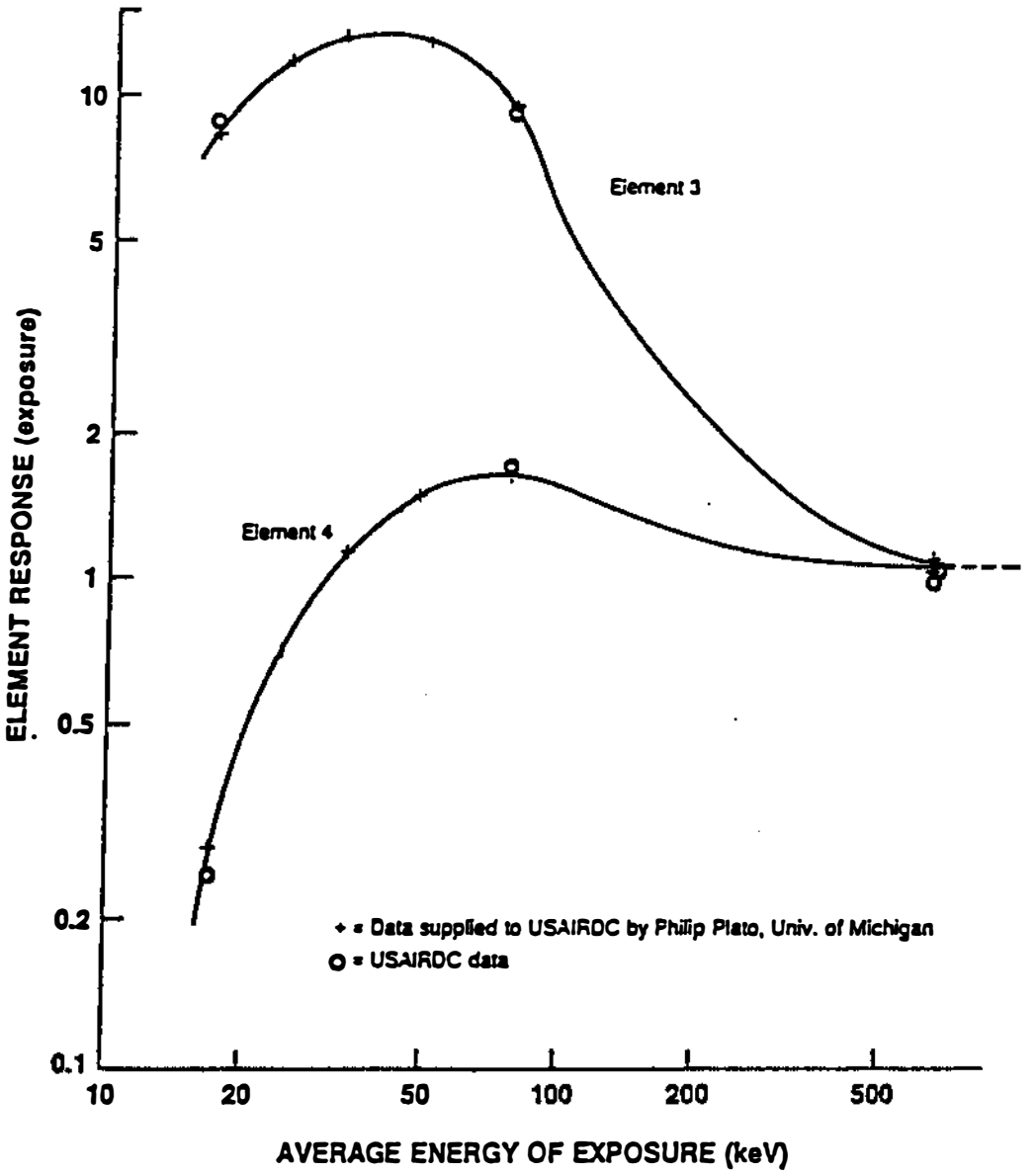

FIGURE 3-4 Response of a Panasonic US-802AS badge per unit exposure at frontal incidence.

hundred keV. The Panasonic algorithm (UD 802.ALG) would then assign a dose equivalent based upon the response of E2, which is located under a filtration of about 300 mg/cm^2. Since this filtration represents the depth to the lens of the eye (3 mm of tissue), the resulting assignment of dose equivalent to that organ would be correct. However, for greater depths, by extrapolating depth dose data corresponding to photons of about 38 keV (half-value layer equal to 4.0 mm of aluminum) following Johns and Cunningham (1983), the dose equivalent at a depth of 5 cm is 39% of that at 3 mm. Thus, assignment of dose equivalent from E2 would result in overstating the dose equivalent by a factor of 2.57 (100/39). Such overstatements of dose equivalents at depths of 1 to 5 cm would be subject to greater error if photons with energies less than 38 keV were incorrectly determined to be higher-energy photons.

Five centimeters is considered the average depth of the red bone marrow, the site of leukemia induction. Should routine reporting of red bone marrow dose equivalent be required in the future, its overreporting could erroneously curtail an employee's utilization in radiation areas.

However, this problem with overresponse of E4 during oblique exposure to low-energy photons is a special exposure conditions, as discussed above. Overstating dose equivalent is erring on the safe side and preferable to understating it. The overstated dose equivalent would probably occur in relatively few of the monitored population and, if near the permissible dose equivalent limit, would certainly be investigated. Nevertheless, these badge deficiencies deserve correction.

According to one of the authors of the referenced NBS report (Ehrlich) and some Panasonic users, all of whom appeared before the committee, one likely solution to these problems is installation of a ring of lead, lead alloy, or other high atomic number material around E4 in the Panasonic UD-802AS dosimeter slide. Such a modification, of appropriate thickness and diameter, would serve to attenuate low-energy photons incident obliquely and minimize both E4 response problems and E3 and E4 response ratio inaccuracy in determining photon energy. Avoidance of dosimeter inaccuracies could decrease an employer's risk of legal liability during any claim procedures or litigation.

Discussion of TLD Problem 2: The committee noted that beta particles having energies above 700 keV penetrate the 300 mg/cm^2 filter over E3. This penetration effect prevents using the responses of calcium sulfate elements E3 and E4 for determination of photon energy in the presence of these high-energy beta particles, since in this case the increased ratio of the responses of these two $CaSO_4$ elements is no longer a valid indicator of the energy of the photons striking the dosimeter. This problem causes an inability to determine dose equivalents for mixtures of low-energy photons and high-energy beta particles. This inability is alluded to in Panasonic's User's Manual (Panasonic Industrial Company, 1983, p. VI.33) where, in describing the algorithm, it is stated, "There is no branch for combinations of low-energy photons and beta particles or neutrons."

Although USAIRDC specifications require that dose equivalents from photons in the energy range of 10 keV to 3 MeV be measured, and that dose equivalents from beta particles with energies as low as 70 keV to "energy levels above 500 keV" be measured, the present performance of USAIRDC's TLDs does not permit the determination of dose equivalent from low-energy photons when the dosimeter also has been exposed to beta radiation. One respondent to the committee questionnaire indicated potential sources of radiation exposure that included both diagnostic x rays and beta sources.

A common beta source is strontium-yttrium-90, with a maximum beta energy of 2.3 MeV. Other beta sources reported in Chapter 2 that are used in radiology departments, both for diagnostic evaluations and radiotherapy, have maximum energies ranging from 1 to 2 MeV. Beta exposures also were reported at two Army pulsed reactors during periodic maintenance operations. These exposures were to mixed beta and gamma radiations from fission products. In these cases, one could expect some high-energy beta particles and a photon spectrum with mostly high energies, averaging about 700 keV, but with some low-energy photons being emitted and scattered.

USAIRDC dosimeter specifications and the above examples of likely combinations of exposures emphasize the operational need for being able to monitor beta radiations having unknown beta particle energy spectra, photon radiations with unknown photon energy spectra, and--on some occasions--to monitor combinations of betas and photons of unknown energies. In the absence of appropriate modifications, the existing USAIRDC UD-802AS dosimeter and UD-874A hanger are probably incapable of performing accurately under these conditions, although the Panasonic User's Manual (Panasonic Industrial Company, 1983, p. I.6) expressed the intention of achieving this capability with the Panasonic TLD system.

However, one probable way of approaching the intended functional capability and of alleviating problem 2 is by increasing the filtration over E3. Adding enough filtration can probably attenuate high energy beta radiation sufficiently to reduce to an acceptable level the errors in photon energy calculated from the ratio of E3 to E4 responses.

One procedure that is likely to accomplish this result, by attenuating beta particles, is to incorporate a high-density, low atomic number material as an integral part of a modified hanger. High-density filtration is needed to minimize filter thickness, while use of a material with low atomic number will avoid attenuating photons excessively. If a low-density plastic were used, the hanger filter would become bulkier and angular dependence could become a problem. An excellent material for this application is tetraboroncarbide, having a specific gravity of 2.5 and an effective atomic number of 5.2.

Designing and obtaining a modified hanger as described above would provide USAIRDC with much better information on photon energy spectra when accompanied by beta radiation. Without such a modification, the dosimeter will not meet USAIRDC specifications when beta radiation and low-energy photons are monitored simultaneously, and will be incapable

of accurately monitoring combinations of beta and photon radiations if the beta and photon energies are unknown. The resulting errors in personnel dosimetry could approach those identified during the discussion of Problem 1, and the employer's legal liability would increase accordingly.

Discussion of TLD Problem 3: This problem is associated with the beta exposure conditions discussed above. Filtration of 300 mg/cm^2 over E2 completely absorbs beta particles with energies of 700 keV or less. Thus, beta particles with energies between 70 keV and 700 keV will penetrate only to E1. This means the stated Panasonic procedure of using the ratio of E1 to E2 responses as an indication of beta particle energy cannot be followed for 70 to 700 keV energies, because E2 response for these energies would be zero. In that energy range one would have to rely solely on E1 response.

Another consequence of the 300 mg/cm^2 filtration over E2 is greater attenuation of low-energy photons by that filtration than by the 17 mg/cm^2 over E1. This results in requiring additional response corrections, or, if the photon energy is not determined, reporting the photon response of E1 as the beta dose equivalent.

These difficulties were recognized by Panasonic in its user's manual (Panasonic Industrial Company, 1983), and led Panasonic to manufacture a different dosimeter designated as Model UD-802AS2, having less filtration over E2, about 75 mg/cm^2. This dosimeter is in a hanger with a covered "open window" over both E1 and E2. Without holders that are appropriately modified in ways such as this, USAIRDC's present dosimeter is useless for providing beta energy information, except at beta energies sufficiently greater than 700 keV (energies large enough to provide a statistically meaningful response in E2 under 300 mg/cm^2).

Remedial Suggestions and Recommendations

In summary, it is apparent that to achieve the intended performance of the Panasonic dosimeter, which was described by Panasonic (Panasonic Industrial Company, 1983) as: "The ratio of the two LiBO [$Li_2B_4O_7$] elements is an indicator of the energy of the beta particles . . ." and ". . . the ratio of the two CaSO [$CaSO_4$] elements is an indicator of the energy of the photons . . .," it will be necessary to make appropriate modifications. One likely improvement is to replace the UD-802AS dosimeter holders with the UD-802AS2 model, and modify the design of the UD-874A hanger. While the current USAIRDC TLD can pass standard tests, limited to frontal exposures and exposures to known radiation sources, this dosimeter is not adequate for monitoring various combinations of exposures encountered under field conditions at facilities serviced by USAIRDC unless appropriate changes, such as holder replacement and hanger modifications, are accomplished.

To enhance the capabilities of the USAIRDC TL dosimeter sufficiently for field use, the committee recommends that USAIRDC improve that dosimeter by making the changes (listed in order of priority) suggested below, following appropriate experimentation as to their efficacy in achieving the desired functional improvements:

Modify the slide around E4 so as to provide optimum isotropic response of this element to photon radiation. Such a modification should be effective over the entire range of energies specified by USAIRDC. (This result may be achieved by installing a ring of lead, lead alloy, or other high atomic number material of sufficient thickness in the slide around E4.) Tests should be conducted to arrive at optimum composition and configuration.

Replace the dosimeter hanger with one having the same "open window" over both E1 and E2 as the present hanger has over E1, the same filtration over E4 as at present, and a low atomic number, high-mass filter over E3 to provide total filtration of more than 600 mg/cm^2. (An optimum means of achieving E3 filtration of about 639 mg/cm^2 is by using a filter of tetraboroncarbide about 1.9 mm thick.)

Reduce the filtration over E2 to between 65 and 75 mg/cm^2, excluding any "open window" filtration. (This can be readily accomplished by replacing the UD-802AS holders with UD-802AS2 holders.)

MONITORING OF DOSE EQUIVALENT FROM NEUTRONS

Monitoring of dose equivalent from neutrons is more complicated than monitoring dose equivalent from beta or photon radiations. Different energies of neutrons have different biological effects. Consequently, the dose equivalent received from a given number of neutrons varies with the incident neutron energy spectrum. For an extreme example, the dose equivalent from a given quantity of 1 MeV neutrons is approximately 40 times that from the same quantity of thermal (0.025 eV or room temperature energy) neutrons. Thus, information on the incident neutron energy spectrum is essential to calculate dose equivalent to target organs from neutron exposure. The neutron energy spectrum must be known if recorded neutron dose equivalent measurements are to be meaningful.

Panasonic's UD-802 series of dosimeters is capable of monitoring neutron dose equivalent only if the neutron energy spectrum is known. This also is a shortcoming of all other albedo neutron dosimeters. When a UD-802 dosimeter is exposed to combinations of photons, beta particles, and neutrons, it is incapable of providing definitive information on the neutron dose equivalent. If the neutron spectrum is unknown and the wrong neutron factor is used, the error in determining

neutron dose equivalent can be very large, even in the absence of other radiations. Panasonic recommends using two specially designed neutron dosimeters under mixed field conditions, but the need for neutron spectral information remains.

A review of the questionnaires sent to USAIRDC dosimeter users by this committee indicated that some facilities monitored personnel who could be exposed to combinations of beta, photon, and neutron radiation. Consequently, the committee recommends:

> TLD badges known or suspected to have been irradiated by neutrons should be specifically flagged by the Radiation Protection Officer (RPO) on the dosimeter report form that is returned to USAIRDC.

If USAIRDC elects to use the Panasonic UD-802AS dosimeter to monitor neutron dose equivalent rather than using specially designed badges, it will be necessary to solve the problem (noted above) of large variations in dose equivalents calculated as a function of neutron energy. Therefore, calibration factors--appropriate to the neutron energy spectrum to which the dosimeter is exposed--will need to be determined for each facility in which neutron exposure occurs. Moreover, since the neutron energy spectrum may vary between different work locations and for different operational conditions of a neutron source, several such determinations may initially be required in a given facility.

To calibrate the dosimeter, it should be placed on the surface of a tissue-equivalent phantom having a size corresponding to the adult torso. There are several ways to determine the actual dose equivalent at the point of calibration. For example, the neutron dose equivalent may be determined with a neutron rem meter calibrated by a primary or secondary calibration laboratory and placed at the same location. The neutron-sensitive TL elements also are sensitive to gamma photons, which always accompany neutrons, hence the calibration procedure must include a separate measurement of gamma radiation dose equivalent. When calibrating the UD-802AS dosimeter, the gamma radiation dose equivalent can be determined from the calcium sulfate response, which is insensitive to neutrons. An estimate of effective neutron energy in each location is necessary to evaluate the neutron calibration factors. Such an estimate is commonly made using the Bonner multisphere spectrometer.

It is evident from the above analysis that the determination of neutron calibration factors is somewhat sophisticated and requires considerable expertise. Accordingly, the committee recommends that:

> This determination should be carried out--at each facility where neutron exposure can occur--by personnel skilled both in neutron measurement techniques (over a wide energy range) and in dosimeter calibration.

CALIBRATION AND QUALITY CONTROL OF THE PANASONIC TL DOSIMETRY SYSTEM

Any equipment used for scientific measurements must be recalibrated from time to time to ensure its accuracy. In addition, quality assurance (QA) procedures must be established that detect significant drift in any of the operational parameters before they can introduce significant errors in the data. Recalibration requires comparison to a standard traceable to a national standards laboratory. Quality assurance is primarily a check on operational consistency. Typically, recalibration is performed at least annually, while some QA procedures may be performed daily and others are performed at longer intervals. Quality assurance often requires measurements of individual components of the TL system. Consequently, the committee recommends that:

> It is of utmost importance that all calibration and quality assurance checks be performed as required according to a rigorous schedule, and that the results of these checks be carefully documented and retained in the USAIRDC records.

Calibration

Before shipment from Japan, the Panasonic UD-710 automatic reader is calibrated with a standardized cesium-137 source. This establishes that the response of the reader in units of "mR*" (the units used by Panasonic) is the same as the exposure in mR of cesium-137 gamma rays given to a batch of test dosimeters. The committee has reviewed the calibration procedures described in the Panasonic User Manual for the UD-710 Automatic TLD Reader, as well as those for the establishment of the element correction factors (ECFs), and has concluded that all of these procedures are adequate.

The committee recommends that:

> The USAIRDC TL dosimetry system be recalibrated at least once per year--or whenever the three correction factors (i.e., PCCF, FCCF, and CALI) stated in the Panasonic User's Manual differ from unity by more than 3 percent--following thorough internal cleaning of the TLD reader.

In addition, the committee recommends that:

> A group of test dosimeters--having a range of dose equivalents and mixtures of radiations (photon, photon and beta, and photon and neutron)--be obtained from the NVLAP program and evaluated at least every 2 years.

Quality Assurance

The committee suggests that QA procedures be performed at the beginning of each day, or after 500 dosimeters have been processed. A stock of

100 control dosimeters should be reserved for this purpose, and exposed in batches of 15 or less to cesium-137 gamma rays at least 24 hours before reading, using procedures described in ANSI N13.11-1983, "Personnel Dosimetry Performance Criteria." At least six exposures should be below and six above the crossover point from photon to frequency counting. Typical exposure values are 500 mR (1.29×10^{-4} C/kg) and 5,000 mR (1.29×10^{-3} C/kg).

A daily log should be maintained to determine the need for internal cleaning and/or heat lamp adjustments. The committee recommends that:

> The USAIRDC institute a QA program based upon the instructions in the Panasonic User's Manual and on procedures given in ANSI N13.11-1983.

The required procedures are briefly reviewed below.

Element Correction Factors

A separate aspect of QA is correcting for slow changes in the response of the dosimeter elements of the individual dosimeters. Each dosimeter element will have its own element correction factor (ECF). The optimum time interval for the redeterminations of ECFs--following their initial determination--has not been definitively established.

The committee questioned seven users of the Panasonic TL dosimetry system in regard to their practice for redetermining ECFs. Four users, who recently have implemented their systems, intend to redetermine ECFs once each year until information is accumulated indicating that a longer interval may be acceptable. Three users, who have longer experience with the Panasonic system, have established 2-year intervals for redetermining ECFs. One of these users is contemplating extending that interval.

Each of the users determines ECFs for only part of its dosimeter inventory at a time, based upon the rationale that most dosimeters in a system are being worn or processed at any given time. Effectively, this staggering of ECF determinations allows the observation of ECF changes in relatively small groups of dosimeters, a practice also suggested by Panasonic (Panasonic Industrial Company, 1983).

The committee recommends that:

> The USAIRDC rotate groups of dosimeters through an ECF redetermination on a 2-year cycle, until sufficient data are accumulated to verify that this cycle--or a more appropriate one--is adequate to maintain acceptable dosimetry accuracy.

MISCELLANEOUS PROBLEMS

Environmental Effects

The Panasonic literature indicates that the lithium borate elements (E1 and E2) may be sensitive to hydrogen sulfide in the atmosphere (presumably by reacting with the copper activator to form a copper sulfide). In addition, these $Li_2B_4O_7$ elements are known to be hygroscopic, as discussed by Schulman (1983). Rather severe NBS tests (1984) have shown that the $Li_2B_4O_7$ elements can deteriorate completely under high-humidity conditions over extended periods of time. Inasmuch as TLD badges are likely to be exposed to these and other aggressive environments during their worldwide USAIRDC deployment, the committee recommends that:

> USAIRDC give appropriate consideration to the presence of certain atmospheric constituents that can have potentially deleterious influences on TLD badges. Inasmuch as quantitative data are not available as to the degradation of TLD elements by atmospheric hydrogen sulfide and humidity, it would be desirable for USAIRDC to conduct its own tests on these effects under a range of conditions representative of the users of its dosimetry services.

Fading of Dose Equivalent Indication

According to the Panasonic specification of October 1985, the dose equivalent indication of lithium borate elements fades 10 percent or less per month, and that of calcium sulfate elements fades 3 percent or less per month. Presumably these figures apply after early period (24-48 hour) fading has already occurred. However, data in the Panasonic User's Manual (Panasonic Industrial Company, 1983) indicate very rapid fading during the early period--in the first 15-20 hours, ca. 40 percent for lithium borate and 5 percent for calcium sulfate--when both elements are read on a UD-710A automatic reader. Panasonic also states that the measured fading rates are different when read on a manual reader.

Published literature (Driscoll, 1983; Schulman, Kirk and Wes, 1967) indicates that the ca. 200°C glow peak in lithium borate is very stable, with less than 10 percent per month fading from its initial post-exposure value. This is not compatible with the ca. 40 percent early-period fading shown in the Panasonic User's Manual.

The reason for this discrepancy appears to be the (well-known) existence of a very large undesired low temperature glow peak (ca. 100°C). This unstable glow peak is initially produced by irradiation of lithium borate. It appears along with the desired stable "read" peak at ca. 200°C, and overlaps the latter. The "preheat" section of the reader's heating cycle is apparently too short to get rid of this interfering low-temperature peak; hence, if the badge is read shortly

after exposure, a considerable fraction of its thermoluminescence is counted as a contribution to the "read" peak. The magnitude of the indicated dose equivalent is therefore erroneously higher than that of the real dose equivalent. If reading is delayed for more than 24 hours, the low-temperature peak decays, because it is unstable at ambient temperatures. The magnitude of the "read" peak then corresponds to that of the true dose equivalent received, not to the spurious value augmented by the contribution from the low temperature peak. This explanation, in summary, implies that the "preheat" cycle--which is designed to remove low temperature glow--does not actually succeed in doing so for lithium borate so long as the low temperature peak is still very large, i.e., shortly after irradiation.

There are several ways to minimize interferences from low temperature peaks (see p. 23). One of these applies to the case of USAIRDC operations, where all but a negligible fraction of badges processed will have been exposed in field stations and will have experienced--before they arrive for reading at USAIRDC--much more than the 24-hour "decay" period needed to get rid of the low temperature lithium borate peak. For these dosimeters, the "preheat" cycle is not really necessary and, since this cycle does not seem to operate successfully even when it is required, it is not clear what purpose it serves for USAIRDC operations. Perhaps it serves to check on other "spurious" low-temperature thermoluminescence. The committee was unable to get clarification from Panasonic regarding this point, and suggests that USAIRDC might wish to do so, especially if USAIRDC desires to read dosimeters within 24 hours of their exposure.

RECOMMENDATIONS FOR STAFFING THE ARMY DOSIMETRY SERVICE

Retraining of current film dosimetry technicians is probably feasible for performing certain TLD-related production tasks, such as badge issuance, tracking, and receipt. However, it seems clear that, with a new (or at least unfamiliar) dosimetry system, problems in processing, interpretation, calibration, and analysis may arise. Thus, with the new TL dosimetry system, much of the experience gained in film dosimetry by the USAIRDC will be inapplicable, or of limited value. A staff person with a strong technical background and/or experience with TL dosimetry will be a necessity, especially if the system is expected to keep pace with state-of-the-art dosimetry. In addition, personnel with a strong background in applied health physics will be required to maintain and improve interactions with the user community, make necessary measurements and evaluation of neutron spectra, and upgrade algorithms required to keep abreast of evolving radiation protection standards. At the outset, the required expertise may be temporarily acquired through the use of consultants, but that expedient will not substitute for the continued presence, on-site, of staff with the necessary qualifications. Accordingly, the committee recommends that:

The level and number of personnel in the USAIRDC be increased by the addition of personnel with the above-described capabilities, and that personnel with these capabilities be responsible for the day-to-day operation of the service.

Existing USAIRDC technicians can, with appropriate retraining, continue to perform badge issuance, receipt, reading, dosimeter calibration, and other operational tasks.

4

RECOMMENDATIONS REGARDING PERSONNEL DOSIMETRY DATA THAT SHOULD BE OBTAINED, STORED, AND ACCESSED

In accordance with Study Task 3, this chapter considers and recommends "the personnel dosimetry data that should be obtained, stored, and accessed, with due regard for good radiation dosimetry practice and applicable legal and regulatory requirements." Because the regulation of exposure to ionizing radiation is in the process of change, this chapter discusses both the current legal and regulatory requirements and expected future requirements. The chapter includes a description of the evolution of laws and regulation stemming from recommendations of advisory bodies. Recommendations are made regarding data to be obtained, stored, and accessed that will meet current and impending regulations and, in addition, provide the flexibility needed to meet anticipated future changes in the requirements.

SUMMARY OF ARMY REGULATIONS PERTAINING TO RADIATION

A distinction can be drawn between regulations of federal agencies, which are mandatory, and recommendations of national and international advisory bodies, which do not carry the force of law. Nevertheless, those recommendations have formed the basis for many of the relevant regulations. The primary regulations on personnel dosimetry for the U.S. Army are contained in Army Regulation No. 40-14* (AR 40-14), which is based upon the relevant federal regulations that govern occupational exposure to ionizing radiation. A copy of AR 40-14 is included here as Appendix B.

The regulations cited by AR 40-14 are 10 C.F.R. part 19 (establishing requirements for notices, instructions, and reports by licensees to individuals participating in specified activities licensed by the Nuclear Regulatory Commission [NRC]); 10 C.F.R. part 20 (NRC standards for protection against radiation); 29 C.F.R. 570.57 (defining situations in which occupational exposure to ionizing radiation is considered as hazardous by the Department of Labor); and 29 C.F.R.

*AR 40-14 was issued March 15, 1982, and it also was issued as Defense Logistics Agency Regulation No. 1000.28.

1910.96 (Occupational Safety and Health Administration [OSHA] standards for exposure to ionizing radiation). A more comprehensive summary of the relevant legislative authority for radiation protection is summarized in Figure 4-1, taken from a report by the Office of Radiation Programs of the U.S. Environmental Protection Agency (EPA, 1984).

It should be noted that AR 40-14 2b states:

"This regulation does not apply to the following:

1. personnel exposed to ionizing radiation and radioactive materials resulting from the use of nuclear or thermonuclear weapons in combat military operations
2. personnel exposed to ionizing radiation while being examined or treated for medical or dental purposes."

The concepts in AR 40-14 are based upon the recommendations of the International Commission on Radiological Protection (ICRP, 1978) and of its U.S. counterpart, the National Council on Radiation Protection and Measurements (NCRP, 1976). These recommendations have evolved over the past 5 decades. During the 30 years following the discovery of x-rays, informal measures to reduce x-ray hazards had been recommended by radiological organizations. In 1928 these measures were formalized when the Second International Congress on Radiology created the International X-ray and Radium Protection Commission, which later became the ICRP, to make recommendations for protection standards.

In 1929 an Advisory Committee on X-ray and Radium Protection was organized in the United States, which in 1946 became the National Committee on Radiation Protection (NCRP), with representation from professional medical societies, government agencies, and x-ray manufacturers. In 1956 the name of the committee was enlarged to National Committee on Radiation and Measurements (but still abbreviated as NCRP). In 1964 the committee was reorganized and expanded, and was chartered by the U.S. Congress as the National Council on Radiation Protection and Measurements (NCRP).

Thus, from the beginning, both the ICRP and NCRP have been nongovernmental, voluntary organizations with members selected on the basis of professional expertise. Both have greatly influenced the development of federal regulatory standards in this country, including those promulgated by the U.S. Nuclear Regulatory Commission in 10 CFR 20 (U.S. Nuclear Regulatory Commission, 1984) , and by the former Federal Radiation Council (FRC). FRC was created in 1959 to provide guidance to executive agencies for protection against radiation, and was required by statute to consult with the NCRP. The EPA has assumed the guidance role of the FRC, and is currently finalizing a proposed revision in its radiation protection guidance to federal agencies.

AR 40-14 requires the Commanding General, U.S. Army Materiel Development and Readiness Command, to provide personnel monitoring devices for the Army, and to establish a Central Dosimetry Record Repository that is to maintain an ionizing radiation exposure history

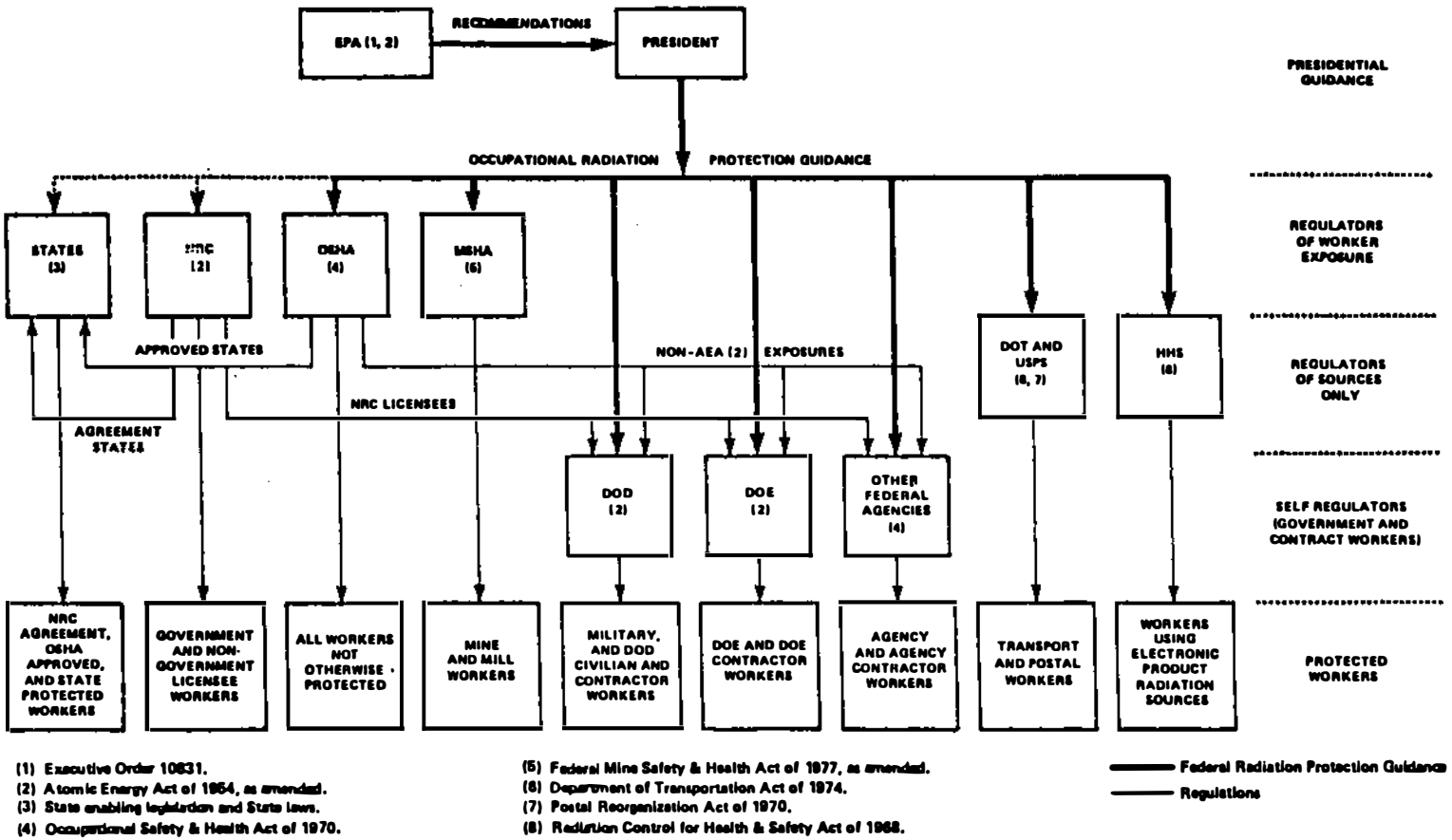

FIGURE 4-1 Authorities for radiation protection of U.S. workers.

SOURCE: EPA, 1984.

for each person who is employed in specified commands and is issued an Army personnel monitoring device.

The Central Dosimetry Record Repository, in turn, is to perform* the following operations:

1. Prepare separate automated annual consolidated statistical summary reports for the Department of the Army, Army National Guard, U.S. Army Reserve, and Defense Logistics Agency personnel occupationally exposed to ionizing radiation and radioactive material. Prepare a statistical summary report for each occupational code.
2. Prepare a separate annual personnel dosimetry report for each employee in the above categories.
3. Prepare requested histories for current or former employees.
4. Prepare a termination exposure history for each employee.
5. Provide a flexible computer program. It must be possible to separate total occupational exposure from medical (diagnostic and therapeutic) exposure. The computer program must provide for the following: (a) additional information such as outside employment (moonlighting), medical exposure, and other radiation exposures; (b) occupational codes; (c) the identity of radiation sources and other hazardous substances to which the worker is exposed.

A number of the requirements in items 1 and 5 above are not currently being met, e.g., recording of data on medical exposures, occupational codes, and identification of radiation sources and other hazardous substances. Except for the need to record occupational codes, the committee does not regard these areas of recording as appropriate activities for the U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC). For example, the main task of USAIRDC is to ascertain dose equivalent using all relevant information, rather than the routine recording of radiation sources and hazardous substances as required in 5(c) above.

AR 40-14 contains directives on the following items: radiation dose equivalent limits**; which personnel shall be monitored; the parts of the body to be monitored; the dose equivalents to be recorded; and (AR 40-14 13) the control procedure to be followed after an overexposure. The dose equivalent limits of AR 40-14 7 are generally consistent with those in Report 39, NCRP 1971 (revised 1978) and in the current version of 10 CFR 20. AR 40-14 8 provides that personnel monitoring devices are to be worn by each person "who may receive an accumulated dose

*As specified in AR 40-14 5c

**The committee prefers this usage; AR 40-14 uses "standards" rather than "limits".

equivalent in excess of 5 percent* of the applicable quarterly radiation exposure standard" specified in AR 40-14 7. These persons are those who are occupationally exposed and those who periodically enter a controlled (restricted) area.

In practice, this means that all such persons will be monitored, since 5 percent of the present quarterly whole-body dose equivalent limit of 1.25 rem (12.5 mSv) is a dose equivalent of 20 mrem (0.2 mSv) per month, which is close to the minimum detectable dose equivalent. AR 40-14 11 specifies certain information to be recorded on Form DD 1141. This form has provision for recording skin dose equivalent(soft), gamma and x-ray dose equivalent, and neutron dose equivalent in rem. Although the primary monitoring device is specified as the film badge (AR 40-14 8e), there is no specific mention of beta ray or neutron monitoring capability in the text of AR 40-14. Form DD 1141 does not include space for quarterly accumulated dose equivalents; however, these dose equivalents are on the USAIRDC computer-generated form. Form DD 1141 does include space to record the annual and total-lifetime-accumulated dose equivalents. The use of separate forms is specified to record localized dose equivalents other than those to the whole body, such as head and neck, thyroid, wrist, and fingers. Although the recorded dose equivalent data, including bioassay data, will be retained in the health records of military personnel or in the personnel file of civilian employees, there is no specific directive in AR 40-14 regarding their retention time.

AR 40-14 13 describes the control procedures following a report of a "radiation overexposure." This term refers to a dose equivalent greater than the radiation limit for either 1 month, 1 quarter or 1 year. The investigation reports are to be transmitted through command channels and to the NRC. Follow-up actions to be taken are described.

In 1977 the basic recommendations of the ICRP (1978) were significantly changed, and in 1986 NCRP recommendations are expected to change in similar ways (NCRP, in press). Moreover, the regulations of the NRC (10 CFR 20)--currently being revised--will implement those changes. In addition, new EPA guidelines for all federal workers--including similar changes--are in an advanced state of preparation in a draft document "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," which is pending approval and is likely to be promulgated in 1986. Of greatest significance for Army personnel monitoring are changes in basic standards that introduce new limits to specific organs for both stochastic (carcinogenic and genetic) effects and nonstochastic (clinically significant) effects. Also introduced in the EPA draft guidelines is the concept of "effective dose equivalent", calculated by combining organ dose equivalents using defined weighting factors. Presumably it will be desirable to revise AR 40-14, Section 7 to conform with these changes, once this new guidance to federal agencies becomes official.

*10 CFR20 states "in excess of 25 percent."

RADIATION GUIDELINES SUGGESTED BY LITIGATION EXPERIENCE

In addition to the limits established by regulatory and advisory bodies reviewed above, court decisions also could bear on the Army's radiation monitoring program. The Army could find its recordkeeping procedures at issue in a judicial* or administrative proceeding, for example, brought by a person alleging injury as a result of occupational exposure. While it is impossible to predict with certainty what judges may decide in the future, several general principles can be drawn from cases (summarized in Appendix C) decided in recent years. Several recent claimants** have not succeeded, largely because their employers were able to document that these claimants were exposed to only low levels of ionizing radiation. Thus, as a first general principle, good recordkeeping of dose equivalent is likely to reduce future liability.

Good recordkeeping is a function of quality as well as quantity. If all records are kept, although in such a way that they are inaccessible, they will be of little value. On the other hand, as a second general principle, records are persuasive in the adversarial atmosphere of a courtroom only to the extent that the recordkeeper is able to produce supporting evidence of their accuracy. The Federal Rules of Evidence (followed by all federal courts), for example, provide that courts will accept records of regularly conducted business activity "unless the source of information or the method of circumstances of preparation indicate lack of trustworthiness."*** Evidence of the trustworthiness of records of dose equivalents might include proof of the quality assurance steps that were routinely followed to ensure that the amount recorded on a particular date for a particular individual was indeed the dose equivalent measured for that individual. Documentation that the relevant quality assurance procedures were followed with respect to the particular records at issue in the case also would be of great value.

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*The Supreme Court in Feres v. United States, 340 U.S. 135 (1950), held that the Federal Tort Claims Act does not apply to injuries incurred by servicemen "aris[ing] out of or . . . in the course of activity incident to service." Veterans instead may seek compensation pursuant to a comprehensive claim system operated by the Veteran's Administration. (See 38 C.F.R. Secs. 3.150-160 [1984].) But whether claims are brought in federal court by civilian employees, or under the administrative program, they will inevitably force some external review of the monitoring program.

**See, e.g., Roberts v. United States, No. LV 1766 RDF (U.S. Dist. Ct.D. Nev.), filed June 14, 1984; Johnston v. United States, 597 F. Supp. 374 (D. Kan. 1984); Mahoney v. United States, 220 F. Supp. 823 (E.D. Tenn. 1963); contra Allen v. United States, 588 F. Supp. 247 (D. Utah 1984).

***Rule 803 (ANSI, 1972).

The American National Standards Institute (ANSI) Standard N13.6-1966 (1972) suggests on this very point what calibration and maintenance records should be kept in any radiation protection program:

> "Procedures, criteria, and schedules for calibration and maintenance of radiation measurement instruments and dosimeters are of value in demonstrating data dependability and reliability. For this purpose a records system should include:
>
> 1. procedures used for the calibration of the individually worn dosimeters and other radiation measurement instruments
> 2. descriptions of the calibration sources and of any data showing inter-comparisons with sources from other laboratories
> 3. data on the frequency of calibrations
> 4. results of the calibration tests
> 5. maintenance history of individual radiation measurement instruments."

Similarly, this ANSI standard provides that:

> ". . . changes that substantially revise procedures, methods of evaluation, or policies should be recorded. When pertinent, the reason for such changes also should be recorded."

REVIEW OF CURRENT ARMY PRACTICE

Many of the procedures--for example, recordkeeping procedures--in current use at USAIRDC apply to a personnel dosimetry program irrespective of the kind of dosimeter used. The following review is included to indicate the degree to which current Army practice conforms to the requirements of AR 40-14 in these more general respects.

A Central Dosimetry Record Repository was established at USAIRDC for the purpose of maintaining an ionizing radiation exposure history for each person utilizing the Army dosimetry service. Results of all dosimeters processed by USAIRDC are routinely (monthly) entered into the automated record repository. In the event that the installation using the dosimetry service determines that a reported dosimeter result is not a reasonable measurement of the dose equivalent received by an individual, the using organization reports the amended dose equivalent assignment to USAIRDC.

The computer presently being utilized is located at the Army's Redstone Arsenal in Huntsville, Alabama, but data input is from USAIRDC offices in Lexington, Kentucky. Programming support, maintenance, and data base management are provided by Redstone. A separate hard copy Administrative Dose file containing these data is maintained. That file is referenced by a code in the data base. Correspondence and source document files are maintained in hard copy format for each installation served by USAIRDC.

Results of all bioassay procedures are reported to the USAIRDC by the Radiological Protection Officer (RPO) at the using installation. AR 40-14 calls for such reports to be stated in units of individual organ dose equivalent, but in fact reports are currently being stated in units of activity (e.g., 10 μCi thyroid uptake). A reference code is placed in the repository indicating that this information is on file (hard copy) at USAIRDC.

USAIRDC provides on request--as mandated by AR 40-14--exposure histories for individuals who utilize the Army dosimetry service. USAIRDC also prepares separate annual consolidated summary reports for all personnel from the Department of the Army, Army National Guard, U.S. Army Reserve, and Defense Logistics Agency who have been occupationally exposed. These summaries are necessary to conform with requirements of 10 CFR 20 (NRC, 1984), and they give the number of persons monitored receiving stated ranges of penetrating, whole-body dose equivalent. A statistical summary report also is required by AR 40-14 for each occupational specialty code. This summary report is not currently being prepared, because no agreement has been reached regarding the occupational specialty codes to use. Individual, quarterly-to-date, and annual personnel dosimetry reports are prepared for each employee and transmitted to the installation RPOs in addition to the monthly listings of all personnel dosimetry results. Exposure histories are prepared for terminating employees upon request.

The repository is required by AR 40-14 to provide "a flexible computer program" separating total occupational exposure from medical exposure. However, medical exposures are presently not being reported to USAIRDC. The committee knows of no current or planned federal requirement to record medical exposures, nor of any federal agency that is maintaining this information. AR 40-14 also requires that there be provisions for recording via the computer system such additional information as outside employment, other radiation exposures, occupational codes, and identity of radiation sources and other hazardous substances to which the worker was exposed. Of these, only dose equivalent from outside employment is currently being recorded, in the form of a note code indicating that the data were obtained from a dosimeter other than that provided by USAIRDC, and that the dose equivalent so determined was added to the cumulative records.

Numbered and date-coded films are issued monthly by mail to using installations. These films are accompanied by a computer-generated form (replacing the manual DA Form 3484) in duplicate for each type of dosimeter issued (e.g., beta/gamma film, neutron film, and TL ring). The address of the installation and other pertinent data--including the names of persons at the installation for whom badges were issued in the preceding 3 months--are entered into the computer. The RPO at the installation records on the form the film number issued to each individual and to any additional persons (e.g., visitors), and deletes names for which badges were actually not issued. The RPO is requested to note the kind and energy of radiation to which the dosimeter was exposed (this notation is not often being made), the occupational

specialty code (this coding is not presently being done), and the appropriate transit control film number. One copy, signed by the RPO, is returned to USAIRDC with the exposed film packets.

After the films are processed at USAIRDC, net optical densities under the four filters are recorded in pencil on the form, and the computed dose equivalents are entered on the form. Microfilm copies of the form (which is the primary source document) are prepared annually, and a permanent microfilm file is maintained at USAIRDC. The original forms are then stored at the National Records Holding Center. Backup microfilm copies of data collected have been maintained since 1969. The film emulsion calibration set data sheets also are microfilmed and retained.

Data from the form are entered into the computer via an interactive computer terminal, then independently checked. An additional statistical check also is performed on a sampling of reports. The report so generated includes name, Social Security number, dose equivalents, film number, and use dates. Quarterly, annual, and lifetime doses are computed and entered on the report, which is returned to the installation by mail. Currently these data are manually transcribed by the RPO onto DD Form 1141, which is contained in each individual's medical folder. To avoid errors and save effort, USAIRDC advocates inserting the quarterly-to-date computer form into the folder instead of transcribing the data.

RECOMMENDATIONS ON PERSONNEL DOSIMETRY DATA THAT SHOULD BE OBTAINED, STORED AND ACCESSED

The following recommendations relate to several areas of data collection and recording, and to radiation protection practice, including: (a) kinds of dose equivalents to be measured, (b) frequency of measurement, (c) cumulative dose equivalents to be recorded, (d) retention of calibration and quality assurance data to validate recorded dose equivalents, and (e) primary dosimeter data that may be needed for subsequent reconsideration of personnel dose equivalents. The recommendations include proposed changes in current practice, both to accommodate the changeover in the monitoring device from film to TLD badges and the imminent changes in relevant NRC and EPA exposure limits and procedural philosophy.

Many of the types of dosimetry data now recorded will be the same with the new TL dosimetry system and the anticipated limits of radiation dose equivalent. Thus, for external radiation it will still be necessary to record:

(a) "whole body dose equivalents," both shallow and deep, in conformity with the protection limits for skin exposure and for whole body exposure to penetrating radiations, respectively;
(b) localized dose equivalents for parts of the body, such as the lens of the eye or the thyroid gland, where dose equivalents may

be higher than those recorded on the trunk of the body because of, for example, field nonuniformity or presence of protective clothing over the trunk; and

(c) dose equivalents to extremities.

The proposed new radiation limits will reduce the significance of eye exposure, because the annual limit will be raised to 15 rem (0.15 Sv), and of localized thyroid and some other single organ exposures, because of the small weighting factors (0.03) assigned by ICRP Publication 26 (ICRP, 1977) to those organs. On the other hand, the pending increase of the quality factor for fast neutrons from 10 to 20 will increase the significance of neutron exposure.

The introduction of weighting factors assigned to particular organs in the estimation of effective dose equivalent suggests that more information should be available regarding effective photon energy. For example, the algorithm could be modified so as to indicate one or two intermediate energies between 70 and 662 keV.

In order that dose equivalents received by specific organs of an individual can be calculated when necessary, the committee recommends that:

> Personnel records of dose equivalents be coded to indicate the known kinds of radiation--along with their associated energy ranges--to which the individual was exposed in his occupational environment.

The committee considered the frequency of badge readout, i.e., the wearing period. The committee supports the Army practice of initially monitoring individuals in a new operation on a weekly basis for the first 8 weeks*, but encourages the adoption of a monthly wearing period unless there is clear evidence of wide fluctuation of dose equivalent from week to week. In groups where the dose equivalents are low and stable, the committee recommends that:

> Serious consideration be given to instituting a 3-month wearing period, because this procedure would increase the accuracy of cumulative dose equivalent records by reducing the errors inherent in multiple readings of low dose equivalents, particularly when those readings fall below the minimum recordable level.

The increased fading (at moderate temperatures and low relative humidities) during 3-month periods is considered negligible at low dose equivalents, and substantial economies in labor could be effected.

Radiation-induced malignant disease may occur several decades after the period in which an individual was exposed, and deleterious effects of a genetic nature may occur during the lifetime of an offspring. As previously noted, experience with radiation litigation indicates that exposure records are highly significant. Yet there is at present little definitive guidance in federal regulations on radiation

*Army document SB11-206, May 31, 1983--Sections 3f and 6.

protection concerning the retention time of records. Standards for Protection Against Radiation (NRC, 1984) stipulates that records are to be maintained "until the [Nuclear Regulatory] Commission authorizes disposition." NCRP Report No. 57 (1978) recommends that personnel exposure records and supporting data be retained for at least 30 years, while ANSI N13.6-1966 (1972) recommends retention "until the year in which the individual would have reached the age of 75 years or until 10 years after the known death of the individual."

The committee endorses the NRC approach, and recommends indefinite retention of dosimetry records, pending promulgation of specific regulations.

There are several possible motivations for reviewing the accuracy of personnel exposures after the dosimeters have been processed. In the short term, these motivations include an "overexposure," as defined in AR 40-14, or an "unusual exposure," which may be unexpectedly lower or higher than the typical exposure of an individual in a particular working environment. Errors in each of these categories may result from a dosimeter failure, from a malfunction while reading the TLD badge, or during the computation process used to estimate dose equivalent. Also, one may wish to reconstruct dose equivalent to a specific tissue depth.

The committee recommends that:

All data concerning personnel dose equivalents be retained for at least a 1-year period following the processing of individual dosimeters, independent of their dose equivalent readings.

These data include the integral readings of each of the four dosimeter elements; the identity of the reader used; the associated digitized glow curves; the correction factors, including element correction factors, applied to the signal; and the quality assurance parameters of the reader, including glow curves, the batch correction factors for the photon and frequency counters, the switch-over point between photon and frequency counting, the correction factor for the response of $CaSO_4$ versus $Li_2B_4O_7$, percent coefficient of variation, and background responses from unirradiated controls with these elements; and equations used in the dosimetry algorithm.

Recent congressional interest in film badge dosimeters used during nuclear weapons tests suggests that data sources documenting dose equivalents should be retained "indefinitely" as discussed above. Although indefinite retention of all such data is clearly an option, the committee considered what economies in data storage could be effected without prejudice to the responsibilities of USAIRDC. One area where the committee concluded that certain TLD glow-curve records could be disposed of was the large amount of glow-curve data for the large number of workers receiving low dose equivalents.

The rationale for this conclusion assumes that if all associated calibration, processing, and quality assurance data relating to the reduction of those glow-curve data to dose equivalents are indefinitely retained, there would be no further need to retain the raw data once they are reduced. This rationale is also premised on the probable validity of those calculated dose equivalents in legal proceedings, in the absence of the raw glow-curve data, provided there is evidence of satisfactory quality control during the data-reduction process. Thus the committee concluded that certain glow-curve-related data that are indefinitely retained would suffice to demonstrate for the records of low dose equivalents that the equipment used to perform the glow-curve measurements and reductions had functioned properly. Accordingly, the committee recommends that:

> All of the above-listed data be so retained, except that in the case of the digitized glow curves, "indefinite" retention is recommended only in the following cases:
>
> (a) for individuals who during a particular year have a cumulative dose equivalent of penetrating radiation in excess of 500 mrem (5 mSv) (this would have included about 0.8 percent of the personnel monitored by USAIRDC in 1984);
> (b) for individuals with an annual cumulative extremity dose equivalent exceeding 7.5 rem (0.075 Sv);
> (c) for a particular badge that indicates a calculated dose . dose equivalent of penetrating radiation in excess of 100 mrem (1 mSv), or an extremity dose exceeding 1,500 mrem (15 mSv);
> (d) all glow curves of an unusual nature which are not explicable in terms of equipment problems (based upon a short-term review), along with the glow curves obtained by processing the badges immediately preceding and following the badges producing those curves. (If USAIRDC elects to retain records that resulted from an explicable equipment problem, those records should be accompanied by a statement identifying the experimental problem.);
> (e) all glow curves resulting from questioned dosimeter readings (e.g., in disagreement with other methods of dose estimation); and
> (f) all glow curves resulting from quality assurance procedures.
>
> The committee also recommends that:
>
> All data relating to the calibration of the reader throughout its history be retained "indefinitely", along with intercomparisons of dose equivalent evaluations (such as in the National Voluntary Laboratory Accreditation Program [NVLAP] of the National Bureau of Standards [NBS].)

At the present time, user installation RPOs are required to transcribe dosimetry data manually onto Form DD 1141 for insertion

into individual medical records. Although this practice may provide some assurance that the local RPO is aware of the latest dosimetry information, such manual transcription undoubtedly leads to errors and also represents (at least at the larger installations) a considerable expenditure of effort. USAIRDC has been advocating the direct insertion of the quarterly-to-date computer-generated reports into the medical records. The committee recommends that:

> The Army should require the various facilities to insert the quarterly-to-date computer-generated reports directly into individual medical records, rather than continue using manual transcription.

5

RECOMMENDATIONS ON DATA PROCESSING AND ARCHIVING

This chapter reviews current data-handling techniques utilized at USAIRDC in connection with film badge dosimetry. Then, in accordance with Study Task 4, it considers desirable hardware and software capabilities to be employed for data storage, processing, and retrieval as a result of the transition to the new thermoluminescent dosimetry system of the U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC).* The scope of this study precludes detailed specification of the required system configuration and its cost.

BACKGROUND

Three hundred thousand individuals have been monitored by USAIRDC since 1954, resulting in 5.8 million dosimetry records that are periodically searched. In accordance with legal and regulatory requirements, the most recent records are continuously updated and cross-verified for accuracy. The film badge data base containing these records is stored at Redstone Arsenal, Huntsville, Alabama, on an IBM 4341 mainframe computer. Approximately 200,000 new records are added each year, using data obtained by processing film badges returned to USAIRDC.

The new USAIRDC TLD system is built around a Panasonic Model UD-710A automatic badge reader and a Hewlett-Packard (HP) Model 1000 minicomputer located at Lexington, Kentucky. The system will bring state-of-the-art monitoring and reporting capabilities to the dosimetry program.

To help define an optimum computer system configuration to carry out USAIRDC monitoring tasks in a cost-effective manner, several considerations are relevant:

1. Historical data, contained in some 5.8 million records, are currently stored in a computer located at Redstone Arsenal. Those records are remotely accessed by USAIRDC personnel.

*The committee acknowledges the assistance provided by RESCO Computer Services, Inc., in addressing this task.

2. A new computer and software system will be used with the TLD reader to automate determinations of dose equivalents.
3. Data-handling requirements for a TLD system are different than those for film dosimeters.
4. Certain desiderata identified by USAIRDC need to be achieved for satisfactory operation of its radiation monitoring program. These are:
   - o proper maintenance of DD Form 1141 (containing individual dose equivalent records),
   - o proper dosimeter documentation, and
   - o definition of dosimetry data retention requirements.

CURRENT SYSTEM SPECIFICATION

Source data on personnel dose equivalents are collected by a network of 775 stations, then transmitted to USAIRDC. Approximately 60 percent of those stations are located in the continental United States. Forms are periodically sent by USAIRDC to each station, listing individuals who should be issued film badges, along with an appropriate number of badges. On a monthly basis, the completed forms, listing the users, are returned to USAIRDC accompanied by the exposed film for analysis. Once the films have been processed at USAIRDC, readings of dose equivalent for each individual are manually transcribed onto the incoming form. These data are then entered into computer terminals at USAIRDC and transmitted via dedicated communication data lines to an IBM 4341 mainframe computer located at Redstone Arsenal.

Figure 5-1 is a schematic diagram of present USAIRDC procedures for handling and processing film badge dosimetry data. The dosimetry report form shown in Figure 5-2 substitutes for Department of the Army (DA) Form 3484, and is the form referred to above that is sent by USAIRDC to user locations. Other input documents are sometimes used in lieu of substitute DA Form 3484, without affecting the input information and data processing. Another form, shown in Figure 5-3, is used to control film badge shipments.

The quantities and kinds of badges requested by each station are also recorded on substitute DA Form 3484. An important field on the form is the user's Social Security number, which is the identifier that uniquely relates users to dose equivalents. USAIRDC data-entry personnel--operating from one of six terminals and during two shifts per day--update the dosimetry data bases using a menu-driven computer program. A photograph of the input-screen menu is shown in Figure 5-4.

All of the computer hardware (except terminals and printer) used to support the USAIRDC mission is physically located at the U.S. Army Missile Command at Redstone Arsenal. In addition to the dosimetry center requirements, 23 other applications are presently supported by the Redstone equipment. Forty terminals are currently connected to the Redstone mainframe computer. Table 5-1 is a listing of computer equipment presently used by USAIRDC to process data on dose equivalents.

The IBM 4341 computer is fast, capable of processing up to 1.8 million instructions per second. Even at that speed, actual processing

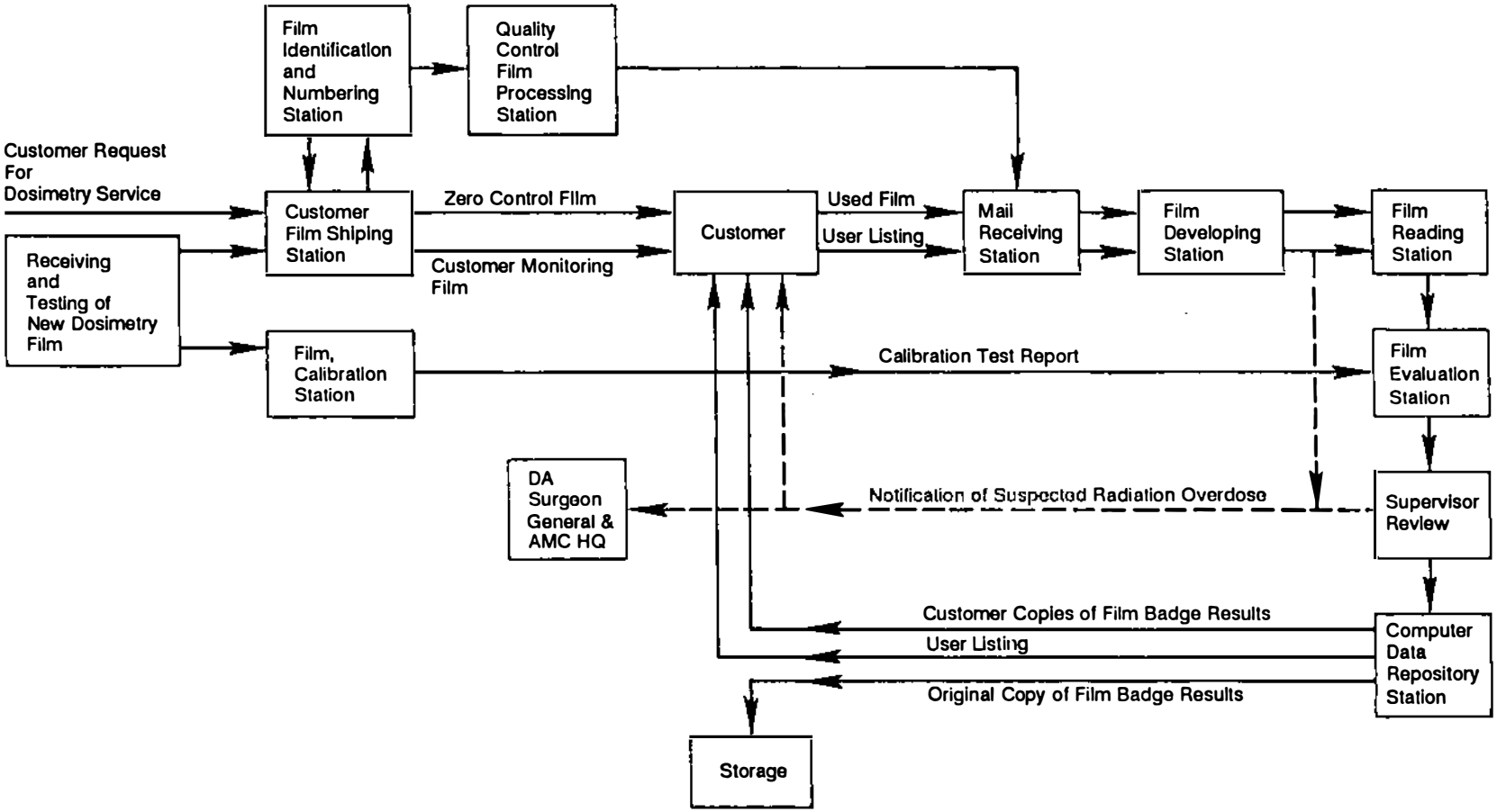
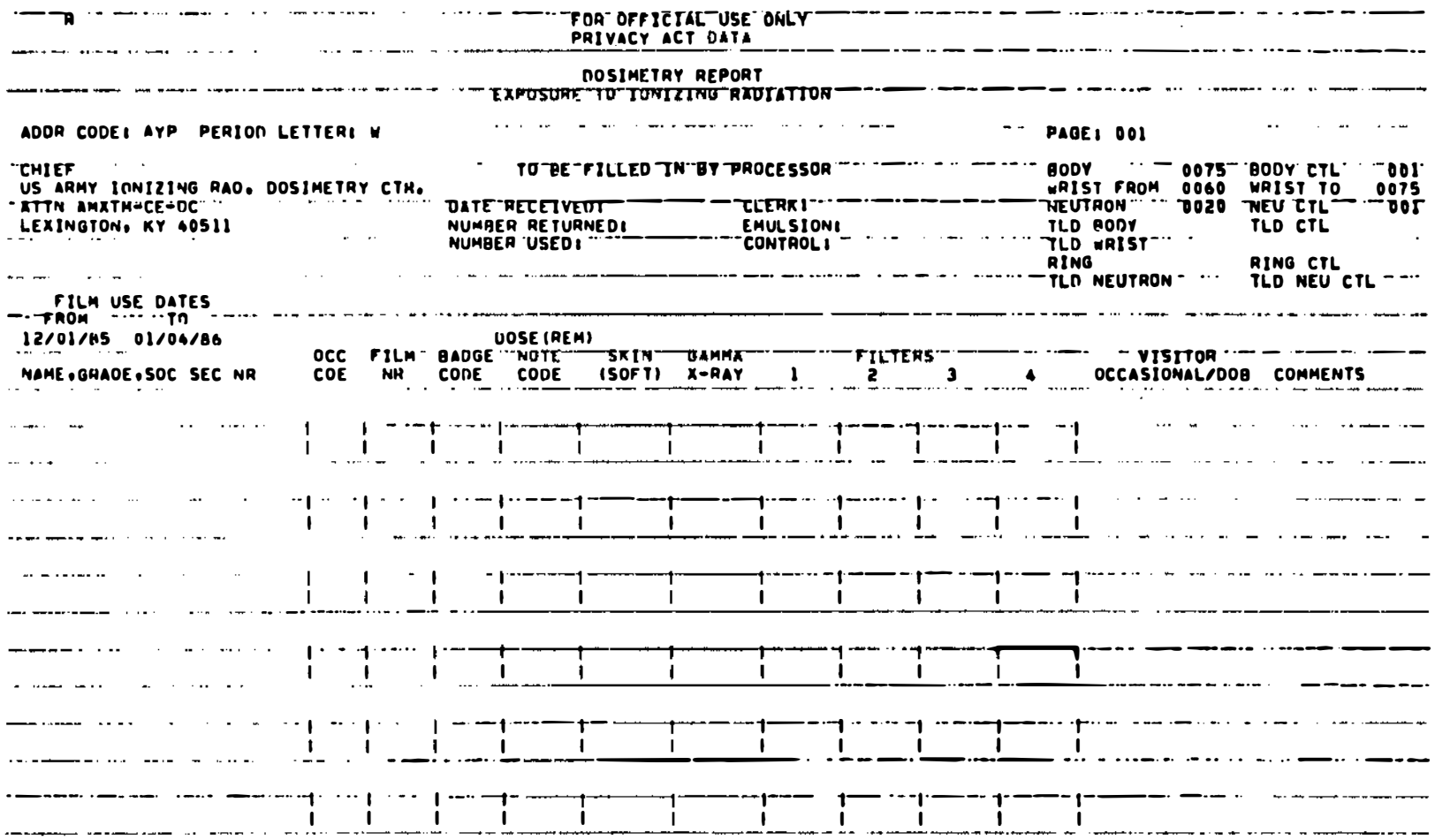


FIGURE 5-1 USAIRDC film badge processing flow diagram.

SOURCE: USAIRDC, 1986.



FOR OFFICIAL USE ONLY
PRIVACY ACT DATA

DOSIMETRY REPORT
EXPOSURE TO IONIZING RADIATION

ADDR CODE: AYP PERIOD LETTER: W PAGE: 001

CHIEF
US ARMY IONIZING RAD. DOSIMETRY CTR.
ATTN AMXTM-CE-DC
LEXINGTON, KY 40511

TO BE FILLED IN BY PROCESSOR

DATE RECEIVED: CLERK:
NUMBER RETURNED: EMULSION:
NUMBER USED: CONTROL:

BODY	0075	BODY CTL	001
WRIST FROM	0060	WRIST TO	0075
NEUTRON	0020	NEU CTL	001
TLD BODY		TLD CTL	
TLD WRIST			
RING		RING CTL	
TLD NEUTRON		TLD NEU CTL	

FILM USE DATES
FROM TO
12/01/85 01/04/86

NAME, GRADE, SOC SEC NR	OCC COE	FILM NR	DOSE (REM) BADGE CODE	NOTE CODE	SKIN (SOFT)	GAMMA X-RAY	FILTERS 1	2	3	4	VISITOR OCCASIONAL/DOB	COMMENTS

FIGURE 5-2 Dosimetry report--exposure to ionizing radiation (USAIRDC Form 3484).

FEB 14 1986

FILM SHIPMENT REQUIREMENT LIST
FOR WEEK 1

STATION CODE	WEAR CODE	BODY QTY	FILM CTL	WRIST FROM	FILM TO	WEAR CODE	NEUTRON QTY	FILM CTL	WEAR CODE	TLD BODY	TLD WRIST	TLD CTL	WEAR CODE	TLD RING QTY	TLD RING CTL	WEAR CODE	TLD NEUTRON QTY	TLD NEUTRON CTL
AAX	M	1151	8	76	105													
AAY	M	3701	26										M	381	8			
AR	M	1671	15	126	155	M	10	2					M	41	2			
ART	M	2601	19	205	260								M	81	1			
ACS	M	301	2															
ACX	M	31	1															
AD	M	61	1															
AFC	M	101	1															
AFH	M	4501	27	441	450								M	751	2			
AFJ	M	51	1															
AFN	M	31	1															
AFO	M	1651	13	146	165									71	1			
AFP	M	2121	20	193	212								M	401	1			
AFQ	M	301	4															
AFS	M	111	1															
AG	M	2351	15			M	32	2					M	151	1			
AH	M	241	3			M	14	3						31	3			
AHE	M	31	1															
AK	M	2401	1	201	240								M	61	1			

FIGURE 5-3 Film shipment requirements list--USAIRDC Form TBD.

PHOTODOSIMETRY REPORT SCREEN. NAME CX3MENU

EXPOSURE TO IONIZING RADIATION

ENTER TYPE OPTION -

1. ADD NEW PERSON.
2. ADD FILM DOSAGE TO EXISTING SSN.
3. NAME SEARCH (STRING 2000) > >
4. SSN SEARCH (STRING 2015) >
5. MODIFY FILM DOSAGE TO EXISTING SSN.
6. DELETE FILM DOSAGE FROM AN EXISTING SSN.
7. DEPART FILM DOSAGE FROM AN EXISTING SSN.
8. MODIFY SRO TO EXISTING SSN.
9. ALPHA REPORT : > >
10. END SESSION.

ENTER OPTION REQUESTED & HIT PF10**********TO CHANGE SCREENS HIT PF12

FIGURE 5-4 Film badge data input screen.

SOURCE: USAIRDC, 1986.

TABLE 5-1 U.S. Army Ionizing Radiation Dosimetry Center computer hardware located at Redstone and USAIRDC

Computer:	IBM 4341, 2 megabytes memory.
Data Storage:	IBM 3380 Mass Storage Drives (currently using 1 1/3 disk packs, or 600 megabytes of storage).
Terminal equipment:	6 Courier Model 270 terminals. 1 Northern Telecom Card Reader (Model 82816950). 1 Northern Telecom Remote Job Entry (RJE) Terminal (Model 82826065).
Printer:	Northern Telecom Model 402S, 800 lines per minute.
Communications:	Direct communications line (dedicated) 14,400 baud: 4,800 baud dedicated to each Courier terminal; 4,800 baud dedicated to the RJE; 4,800 baud dedicated to another application.

is slow for many USAIRDC output reports. Throughput is a function of the number of other users on the system, the speed of the mass storage drives, the transfer rate of the data lines, and printer capability. Redstone does not appear constrained to using existing equipment to meet the needs of its customers, and envisions even larger machines for the future. Indeed, Redstone plans to shift many of its customers to a newer computer--an IBM 4381--in fiscal year 1987.

Dosimetry data are stored at Redstone in three primary data bases, whose structures are shown in Figures 5-5, 5-6, and 5-7. The dosimetry data base was maintained manually for many years. Later, for entry into the computer, it was divided into three separate data base files: Dose Data, Historical Dose Data, and Backlog Data (historical data for which few Social Security numbers are available). When preparing individual dosimetry histories, USAIRDC staff must look at all three data files and (frequently) perform some detective work to verify that a particular individual is associated with a specific recorded dose equivalent. A fourth data base, the "Suspense" data base, whose structure is shown in Figure 5-8, is used to track badges being issued to individual stations.

Preparation of a dosimetry history of an individual can take hours. For example, if during a search multiple records are found corresponding to several persons having similar names, a comparison must be made of the relevant individual's employment history to determine whether he or she could properly be associated with each of the records. Sometimes, when records cannot be found in the computer

```
02/12/86 21:39:11 BEGIN SYSTEM 2000 RELEASE 11.0
 -556- OPENED.....CX14BL0                    26    8621  02/08/1986  00:19:34

DESCRIBE:
SYSTEM RELEASE NUMBER 11.0
DATA BASE NAME IS       CX14BL0
DEFINITION NUMBER                           26
DATA BASE CYCLE NUMBER      8621
   1*  BL-SSN (NON-KEY-CHAR X(9))
   2*  BL-NME (CHAR X(25) WITH SOME FUTURE OCCURRENCES )
   3*  BL-DOB (NON-KEY-DATE)
   4*  BL-REG (NON-KEY DATE)
   5*  BL-OCC (NON-KEY-CHAR X(5))
   6*  BL-CHK (NON-KEY DATE)
 100*  BL-STATION (RECORD)
 101*  BL-STA (CHAR XXX IN 100 WITH MANY FUTURE OCCURRENCES )
 200*  BL-EXPOSURE (RECORD IN 100)
 201*  BL-FILM (NON-KEY INTEGER NUMBER 9999 IN 200)
 202*  BL-BDG (NON-KEY-CHAR X IN 200)
 203*  BL-NOTE (NON-KEY CHAR X IN 200)
 204*  BL-FROM (NON-KEY-DATE IN 200)
 205*  BL-TO (NON-KEY DATE IN 200)
 206*  BL-SOFT (NON-KEY DECIMAL NUMBER 999.999 IN 200)
 207*  BL-HARD (NON-KEY DECIMAL NUMBER 999.999 IN 200)
 208*  BL-VIS (NON-KEY-CHAR X IN 200)
 209*  BL-MSG (NON-KEY CHAR X(6) IN 200)
```

FIGURE 5-5 Backlog data base file structure.

SOURCE: USAIRDC, 1986.

```
02/12/86  21:36:28  BEGIN SYSTEM 2000 - RELEASE 11.0
 -556- OPENED.....CX14HS0                24  13659  02/06/1986  12:50:36

DESCRIBE:
SYSTEM RELEASE NUMBER  11.0
DATA BASE NAME IS      CX14HS0
DEFINITION NUMBER      24
DATA BASE CYCLE NUMBER    13659
   1*  HIST-SSN (CHAR X(9))
   2*  HIST-NME (CHAR X(25))
   3*  HIST-DOB (NON-KEY DATE)
   4*  HIST-REG (NON-KEY DATE)
   5*  HIST-OCC (NON-KEY CHAR X(5))
   6*  HIST-CHK (NON-KEY DATE)
 100*  STATION (RECORD)
 101*    HIST-STA (CHAR XXX IN 100 WITH MANY FUTURE OCCURRENCES )
 200*  EXPOSURE (RECORD IN 100)
 201*    HIST-FILM (NON-KEY INTEGER NUMBER 9999 IN 200)
 202*  HIST-BDG (NON-KEY CHAR X IN 200)
 203*    HIST-NOTE (NON-KEY CHAR X IN 200)
 204*  HIST-FROM (NON-KEY DATE IN 200)
 205*    HIST-TO (NON-KEY DATE IN 200)
 206*  HIST-SOFT (NON-KEY DECIMAL NUMBER 999.999 IN 200)
 207*    HIST-HARD (NON-KEY DECIMAL NUMBER 999.999 IN 200)
 208*  HIST-VIS (NON-KEY CHAR X IN 200)
 209*    HIST-MSG (NON-KEY CHAR X(6) IN 200)
```

FIGURE 5-6 Historical data base file structure.

SOURCE: USAIRDC, 1986.

```
02/12/86  21:33:41  BEGIN SYSTEM 2000 - RELEASE 11.0
 -556- OPENED.....CX14DS0                33  95540  02/12/1986  21:22:41

DESCRIBE:
SYSTEM RELEASE NUMBER  11.0
DATA BASE NAME IS      CX14DS0
DEFINITION NUMBER ..... 33
DATA BASE CYCLE NUMBER    95540
   1*  ID NUMBER (CHAR X(9))
   2*  NAME (CHAR X(25))
   3*  DOB (NON-KEY DATE)
   4*  REG (NON-KEY DATE)
   5*  OCC (NON-KEY CHAR X(5))
   6*  DT-LST-CK (NON-KEY DATE)
 100*  JOB HISTORY (RECORD)
   101*  STA (CHAR XXX IN 100 WITH MANY FUTURE OCCURRENCES )
   200*  EXPOSURE DATA (RECORD IN 100)
     201*  FILM (NON-KEY INTEGER NUMBER 9999 IN 200)
     202*  BDG (CHAR X IN 200 WITH MANY FUTURE OCCURRENCES )
     203*  NT (NON-KEY CHAR X IN 200)
     204*  FROM (DATE IN 200)
     205*  TO (NON-KEY DATE IN 200)
     206*  SOFT (NON-KEY DECIMAL NUMBER 999.999 IN 200)
     207*  HARD (NON-KEY DECIMAL NUMBER 999.999 IN 200)
     208*  VISITOR (CHAR X IN 200)
     209*  MSG-NR (NON-KEY CHAR X(6) IN 200)
```

FIGURE 5-7 Dose equivalent data base file structure.

SOURCE: USAIRDC, 1986.

```
02/12/86  21:44:15  BEGIN SYSTEM 2000 -- RELEASE 11.0
 -556- OPENED.....CX14AD0                102   3273  02/12/1986  13:30:21

DESCRIBE:
SYSTEM RELEASE NUMBER 11.0
DATA BASE NAME IS       CX14AD0
DEFINITION NUMBER ------------ 102
DATA BASE CYCLE NUMBER      3273
    1*  STATION-NUMBER (CHAR XXX)
    2*  LINE1 (CHAR X(36))
    3*  LINE2 (CHAR X(36))
    4*  LINE3 (CHAR X(36))
    5*  LINE4 (CHAR X(36))
    6*  LINE5 (CHAR X(36))
    7*  LINE6 (CHAR X(36))
    8*  GROUP-CODE (INTEGER NUMBER 9)
    9*  WEAR-FILM (CHAR X)
   10*  PERIOD-CODE (CHAR X)
   11*  FILM-QTY-BODY (INTEGER NUMBER 9999)
   12*  FILM-QTY-CTL (INTEGER NUMBER 999)
   13*  WRIST-FROM (INTEGER NUMBER 9999)
   14*  WRIST-TO (INTEGER NUMBER 9999)
   15*  FILM-QTY-NEUTRON (INTEGER NUMBER 9999)
   16*  FILM-QTY-NEU-CTL (INTEGER NUMBER 999)
   17*  TLD-QTY-BODY (INTEGER NUMBER 9999)
   18*  TLD-QTY-WRIST (INTEGER NUMBER 9999)
   19*  TLD-QTY-CTL (INTEGER NUMBER 999)
   20*  TLD-QTY-RING (INTEGER NUMBER 9999)
   21*  TLD-QTY-RING-CTL (INTEGER NUMBE[illegible]
   22*  TLD-QTY-NEU (INTEGER NUMBER 9999)
   23*  TLD-QTY-NEU-CTL (INTEGER NUMBER 999)
   24*  WEAR-NEU (CHAR X)
   25*  WEAR-TLD-BDY (CHAR X)
   26*  WEAR-TLD-RNG (CHAR X)
   27*  WEAR-TLD-NEU (CHAR X)
   28*  POINT OF CONTACT (NON-KEY CHAR X(25))
   32*  DATE OF INITIATION (NON-KEY DATE)
   33*  DATE OF CANCELLATION (NON-KEY DATE)
   31*  COML (NON-KEY CHAR X(22))
   29*  AV (NON-KEY CHAR X(19))
   30*  FTS (NON-KEY CHAR X(19))
```

FIGURE 5-8 Suspense data base file structure.

data base, the USAIRDC staff must search through the original microfilm records to verify dosimetry data. USAIRDC receives about 2,000 requests for historical dosimetry searches each year. Each search requires 4 person-hours (on the average) to complete. Approximately one-half this time is for computer processing and one-half for manual research.

Typical output reports (such as Figure 5-9) include information on each individual being monitored, including the dose equivalent he or she received: (a) during a given period of time (usually a month), and (b) during the monitored portion of his or her lifetime. Figures 5-9, 10, and 11 are examples of some of the reports that are most frequently requested. These summary reports are for official use only and contain data covered by the Privacy Act. Information is taken from them, then transferred to the appropriate federal reporting forms for submission to monitoring agencies. Additional output reports--in the form of statistical summaries of personnel dose equivalents--are also available, on request, from USAIRDC.

Figure 5-9 is an example of a summary report provided to all monitoring installations each quarter of the calendar year. This report lists the year-to-date itemized dosimetry record for every monitored individual. The fourth-quarter reports will be maintained in the individual's medical file, in lieu of DD Form 1141 (U.S. Nuclear Regulatory Commission [NRC] Form 5). A copy of the fourth-quarter report will be provided to each individual each year, in compliance with reporting requirements stated in 10 CFR 20 and 29 CFR 1910.

Figure 5-10 is a typical quarterly output report that communicates to the user the results obtained from processing his or her film badges. In addition to containing current data from film badges, the output report also includes cumulative dose equivalents for the current quarter, the calendar year, and the individual's monitored lifetime.

Figure 5-11 exemplifies the output reports supplied to individuals who have requested a record of their cumulative dose equivalent corresponding to their monitored lifetime. Figure 5-12 is a schematic diagram of dosimetry data information flows in the current USAIRDC system.

The most frequently used data base is the active file--the Dose Data Base file. It currently contains approximately 1.6 million records, and has been growing at the rate of 200,000 records per year. Based upon the anticipated growth in dosimetry records, approximately 10 megabytes (Mb), or 10 million characters, of additional computer storage would be needed to meet this growth each year, assuming no significant qualitative changes in the dosimetry data that must be collected. Changes such as adding glow curves could well augment data processing and storage requirements. Some implications of continued growth in the number of dosimetry records are analyzed in the following sections.

Software support for the IBM 4341 computer is provided by the Army Missile Command. An Intel System 2000 (S2K) software development

PCN V60QD10034A

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PRIVACY ACT DATA

DATE 12/14/88 ANNUAL/QUARTERLY HISTORY OF EXPOSURE TO IONIZING RADIATION PAGE 001

NAME
SOC SEC NR
DATE OF BIRTH 10231945
OCCUPATION CODE 0
PERMISSIBLE LIFETIME DSGE 110.000

PERIOD WORN FROM	TO	STA NR	FILM NR	BDG CD	NOTE CD	DOSE THIS PERIOD SOFT	X-GAMMA	NEUTRON	DOSE THIS QTR SOFT	HARD	DOSE THIS YEAR SOFT	HARD	DOSE LIFETIME HARD
TOTAL OF WHOLE BODY HARD DOSE PRIOR TO			1985										000.052
01/27/85	02/23/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	
01/27/85	02/23/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
02/24/85	03/23/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	
02/24/85	03/23/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
03/24/85	04/27/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	
03/24/85	04/27/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
04/28/85	05/25/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	
04/28/85	05/25/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
05/26/85	06/22/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	
05/26/85	06/22/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
06/23/85	07/27/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	
06/23/85	07/27/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
07/28/85	08/24/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	
07/28/85	08/24/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
08/25/85	09/21/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	
08/25/85	09/21/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
09/22/85	10/20/85	JXQ	0005	A		000.000	000.000		000.000	000.000	000.000	000.000	000.052
09/22/85	10/20/85	JXQ	0022	C		000.000	000.000		000.000	000.000	000.000	000.000	

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JXQ COMMANDER
ALABAMA ST MILITARY DEPT
OFFICE OF THE ADJUTANT GENERAL
ATTN CSMS-1
P.O. BOX 3711
MONTGOMERY, AL 36109

FIGURE 5-9 Annual quarterly history of exposure to ionizing radiation.

SOURCE: USAIRDC, 1986.

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PRIVACY ACT DATA

DATE: 02/13/86 RECORD OF OCCUPATIONAL EXPOSURE TO IONIZING RADIATION ADDR CODE: AYP PAGE: 002

FROM 12/01/85 TO 01/04/86

EXPOSURE TRANSACTION

FILM NR	B C	SSN	NAME	N C	DOSE THIS PERIOD SOFT	DOSE THIS PERIOD X-GAMMA	DOSE THIS PERIOD NEUTRON	DOSE THIS QTR SOFT	DOSE THIS QTR HARD	DOSE THIS YEAR SOFT	DOSE THIS YEAR HARD	DOSE LIFETIME SOFT	DOSE LIFETIME HARD
0021	A				000,000	000,000		000,000	000,000	000,000	000,000	000,000	000,000
0015	A				000,000	000,000		000,000	000,000	000,000	000,000	000,004	000,159

THIS REPORT PREPARED BY:

CHIEF
US ARMY IONIZING RADIATION
DOSIMETRY CENTER
ATTN: AMXTM-CE-DCA
LEXINGTON, KY 40511-5102

FIGURE 5-10 Record of occupational exposure to ionizing radiation--exposure transaction (USAIRDC Form 1141).

DATE 02/13/86 HISTORY OF EXPOSURE TO IONIZING RADIATION PAGE 001

DATE OF REGISTRATION 03/20/75

NAME
SOC SEC NH
DATE OF BIRTH 05/07/42
OCCUPATION CODE
PERMISSIBLE LIFETIME DSGE 125.000

PREVIOUS EXPOSURE INFORMATION

	FROM	TO	DOSE	HOW DETERMINED
WHOLE BODY SOFT			000.000	
WHOLE BODY HARD			000.000	
EXTREMITY SOFT			000.000	
EXTREMITY HARD			000.000	

PERIOD WORN FROM	TO	FILM NH	BDG CD	STA NR	NOTE CD	DOSE THIS PERIOD SOFT	X-GAMMA	NEUTRON	DOSE THIS QTR SOFT	HARD	DOSE THIS YEAR SOFT	HARD	PERMISSIBLE LFE TME DSG
08/30/64	10/03/64	0037	A	AA		000.000	000.000		000.000	000.000	000.000	000.000	020.000
10/04/64	10/31/64	0015	A	AA		000.000	000.018		000.000	000.018	000.000	000.018	020.000
11/01/64	11/28/64	0015	A	AA		000.014	000.051		000.014	000.069	000.014	000.069	020.000
12/01/64	12/31/64	0015	A	AA		000.000	000.024		000.014	000.093	000.014	000.093	020.000
01/03/65	02/06/65	0015	A	AA	J				000.000	000.000	000.000	000.000	020.000
01/05/65	02/07/65	0015	A	AA		000.000	000.018		000.000	000.018	000.000	000.018	020.000
02/07/65	03/07/65	0015	A	AA		000.000	000.000		000.000	000.018	000.000	000.018	020.000
03/07/65	04/03/65	0015	A	AA		000.000	000.006		000.000	000.024	000.000	000.024	020.000
03/07/65	04/03/65	0002	B	AA				000.000	000.000	000.024	000.000	000.024	020.000
04/04/65	05/02/65	0003	B	AA				000.000	000.000	000.000	000.000	000.024	020.000
04/04/65	05/02/65	0015	A	AA		000.000	000.016		000.000	000.016	000.000	000.040	020.000
05/02/65	06/07/65	0015	A	AA		000.000	000.021		000.000	000.037	000.000	000.061	025.000
06/06/65	07/03/65	0015	A	AA		000.000	000.000		000.000	000.037	000.000	000.061	025.000
07/04/65	07/31/65	0015	A	AA		000.000	000.000		000.000	000.000	000.000	000.061	025.000
08/01/65	09/05/65	0015	A	AA		000.000	000.000		000.000	000.000	000.000	000.061	025.000
09/05/65	10/04/65	0015	A	AA		000.000	000.000		000.000	000.000	000.000	000.061	025.000
09/19/65	10/16/65	0114	A	HG		000.000	000.000		000.000	000.000	000.000	000.061	025.000
10/03/65	11/07/65	0015	A	AA		000.025	000.014		000.025	000.014	000.025	000.075	025.000
11/07/65	12/05/65	0015	A	AA		000.000	000.090		000.025	000.104	000.025	000.165	025.000
12/05/65	01/02/66	0015	A	AA		000.000	000.016		000.025	000.120	000.025	000.181	025.000
01/02/66	02/06/66	0015	A	AA		000.000	000.000		000.000	000.000	000.000	000.000	025.000
02/06/66	03/06/66	0015	A	AA		000.000	000.020		000.000	000.020	000.000	000.020	025.000
03/07/66	04/04/66	0015	A	AA		000.000	000.014		000.000	000.034	000.000	000.034	025.000
04/03/66	05/01/66	0015	A	AA		000.000	000.007		000.000	000.007	000.000	000.041	025.000
05/01/66	06/05/66	0015	A	AA		000.000	000.007		000.000	000.014	000.000	000.048	030.000
06/05/66	07/02/66	0015	A	AA		000.000	000.014		000.000	000.028	000.000	000.062	030.000
06/06/66	06/28/66	0002	B	AA				000.000	000.000	000.028	000.000	000.062	030.000
07/03/66	08/04/66	0015	A	AA		000.000	000.014		000.000	000.014	000.000	000.076	030.000
08/07/66	09/04/66	0015	A	AA		000.000	000.000		000.000	000.014	000.000	000.076	030.000
09/04/66	10/01/66	0015	A	AA		000.000	000.000		000.000	000.014	000.000	000.076	030.000

FIGURE 5-11 History of exposure to ionizing radiation.

SOURCE: USAIRDC, 1986.

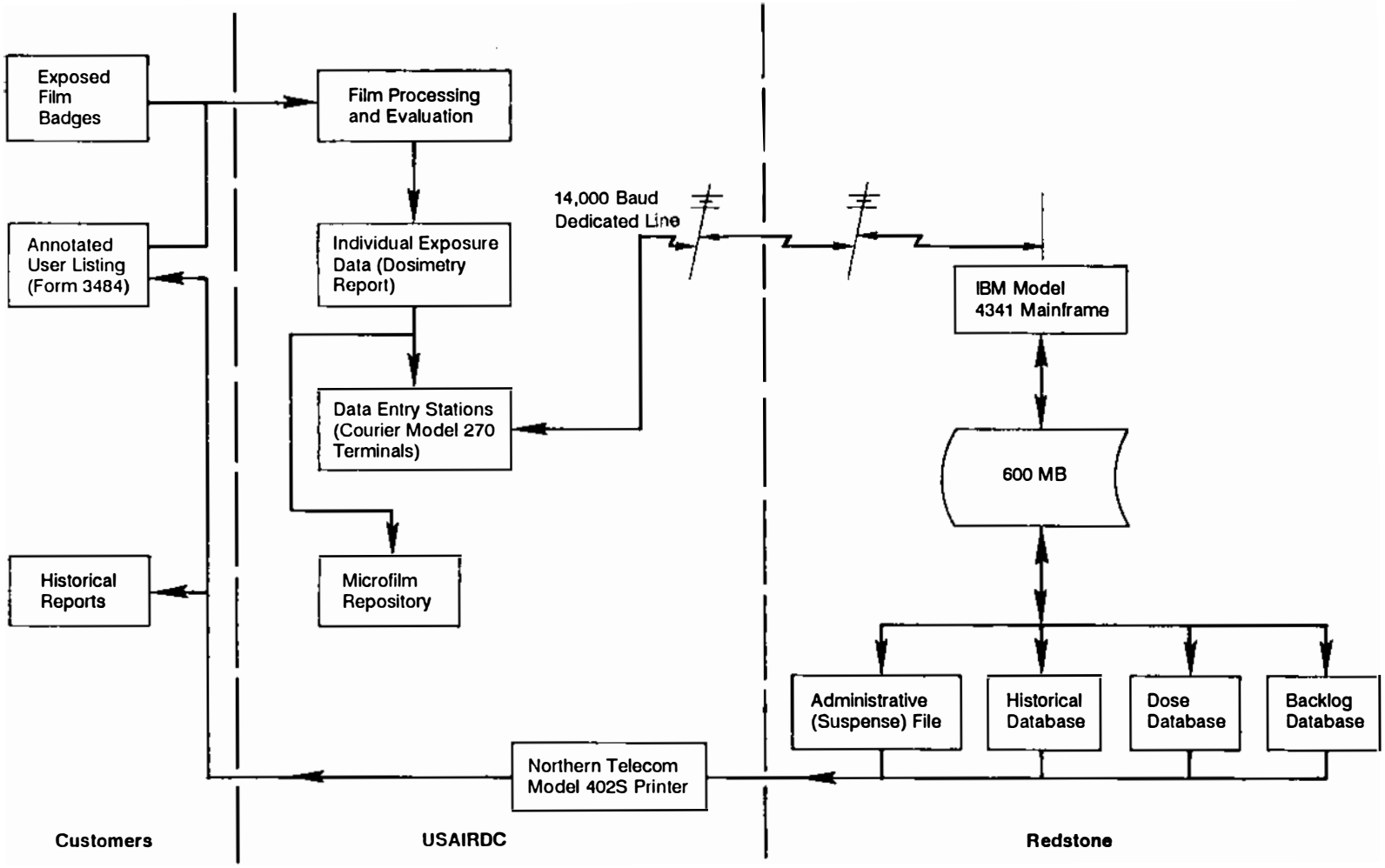

FIGURE 5-12 Film badge system flow chart.

SOURCE: RESCO Computer Services, Inc., 1986.

package is used, with custom programming and programming modifications provided by Redstone. Turn-around time for such programming has ranged from 3 to 9 months or more for new output reports.

INTERMEDIATE SYSTEM FUNCTIONS FOLLOWING CONVERSION TO A TLD SYSTEM

The existing process for collecting and analyzing personnel dosimetry data will soon be modified, when film dosimeters are replaced with TL dosimeters. To read and interpret the data from TLDs, an HP 1000 minicomputer system has been purchased and installed at USAIRDC. This section describes how this intermediate TLD system will operate, then discusses a proposed augmented TLD system planned to automate fully all dosimetry functions.

The recording and computer processing equipment to be used consists of a primary and backup system. The primary system includes an HP 1000 Model 6 processor, a 132 MB Winchester disk drive with tape backup (67 MB cartridge), 2 Hewlett-Packard graphics terminals with thermal printers, an HP2631B line printer, and two Panasonic 710A readers. Each reader has a custom interface with a device that converts the TLD analog data to digital data. These digital data are first stored on the Winchester drive, then interpreted by algorithm software on the HP 1000 to produce estimates of dose equivalents for each individual. Figure 5-13 is a flow chart of the planned TLD system, which has a backup computer/reader system virtually identical to the primary system except for having only one Panasonic 710A reader instead of two.

The process for obtaining radiation exposure data on individuals will be changed by the implementation of the HP 1000/Panasonic TLD reader system. Currently, using film badges, the USAIRDC must process dosimetry information as follows:

- Manually package film badges and a blank Form DA 3484 (photodosimetry report) for shipment to about 775 installations.
- Manually log badge numbers and their destinations.
- Manually read and record dose equivalents from film badges.
- Manually update the repository database (IBM 4341 at Redstone) with film badge readings from 6 remote terminals at Lexington.
- Manually add administrative dose equivalents to the repository data base.
- Manually retrieve raw data (developed negatives) from metal filing cabinets when backup information is required.
- Manually identify incidents of unusual dose equivalents.

As an intermediate step, the HP 1000/Panasonic TLD reader system will simplify the processing described above by introducing some automation. Approximately 114,000 TLD badges have been purchased. It is expected that about this number of badges will need to be calibrated each year. Thirty thousand TLD badges will be issued each month, of which 20,000 will actually be worn (the remaining badges are used for

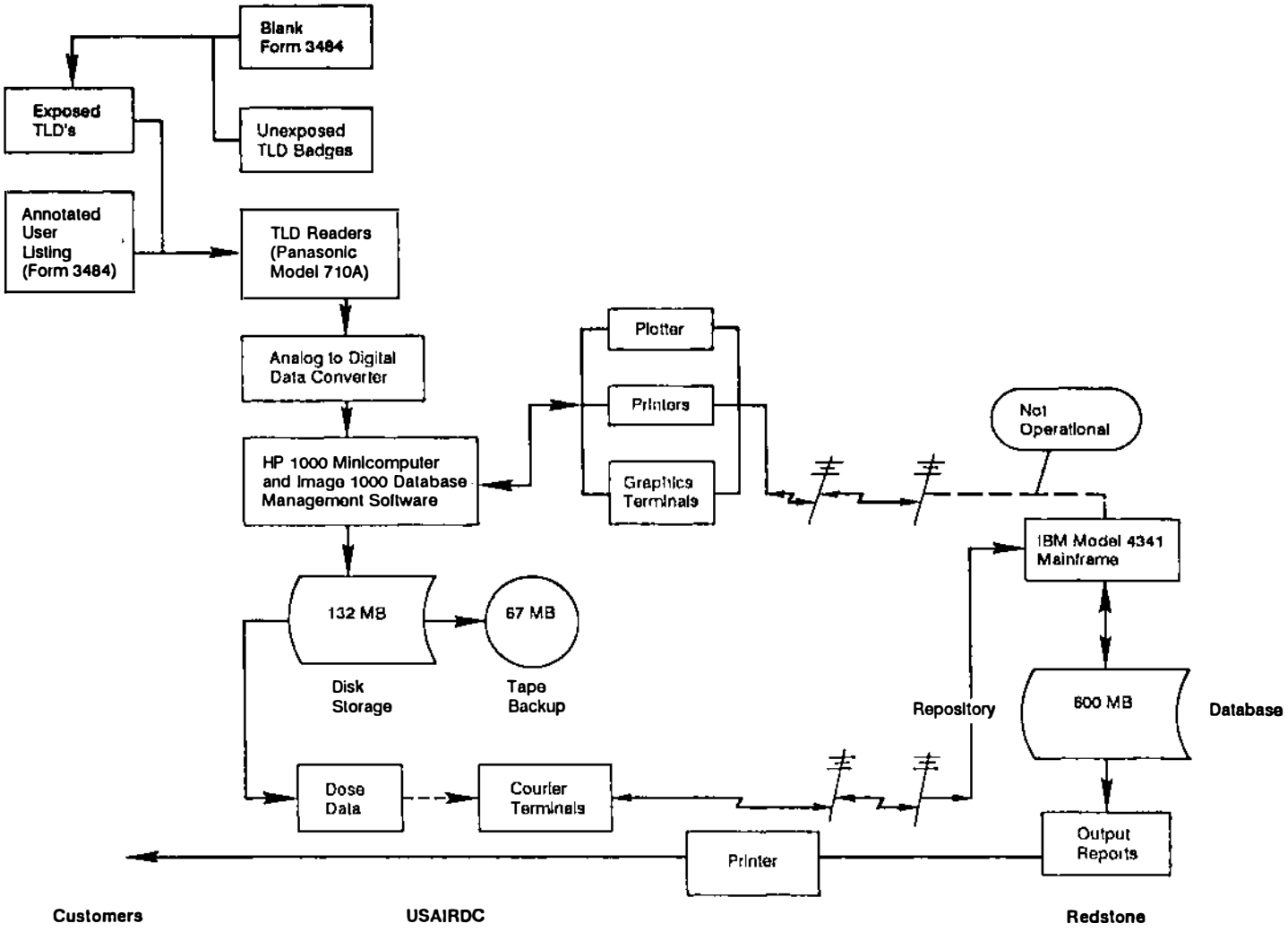

FIGURE 5-13 TLD system flow chart (USAIRDC).

visitors and to replace losses). An additional supply of badges--about 5,000 per month--will be used as quality controls and machine controls, for example. Implementation of the TLD system could begin within several months. According to USAIRDC, the complete transition from film badges to TLDs could be completed within 2 years.

Although the intermediate TLD system will permit USAIRDC to automate some of the manual procedures described above, when the intermediate system becomes operational TLDs will continue being manually packaged, together with a dosimetry report form, and sent to Army installations. The badge number, which is embedded in the TLD, will still be manually recorded. However, once the TLD is returned from the field, it will be read automatically to obtain dosimetry information.

In principle, this information could then be automatically uploaded to the IBM 4341. A modem exists, and software is available on the HP 1000 to accomplish the transfer; however, appropriate software has yet to be written for the IBM 4341. Presently, since this data link is not in place, the output of the TLD reader system has to be entered manually into the IBM 4341 data base using the Courier terminals, in the same way as film badge dosimeter data are now being entered.

The current HP 1000 configuration for TLD processing uses four data bases: special badge identifications; badge data; element and machine correction factors; and glow curve data. These files are supported by a general purpose data base management software system with query capability designed for HP 1000 systems (IMAGE 1000). The purpose of these files is to help manage the processing of badges, to store the raw data used by the dose algorithm, and to record both the correction (calibration) factors for TLD elements and the identity of the TLD reader used to calculate dose equivalent.

The USAIRDC has developed a concept for a TLD system upgrade (the Augmented Thermoluminescent Dosimetry System) to further automate TLD processing. The augmented system would utilize the Redstone IBM 4341 and the USAIRDC HP 1000 to accomplish the following:

1. Automatically assign badges and provide substitute Form 3484's for shipment.
2. Automatically track all in-service badges.
3. Automatically update the repository database.
4. Automatically determine requirements for administrative dose equivalents and update the repository data base.
5. Store raw digital data on the Redstone computer.
6. Automatically identify anomalous and high dose equivalent incidents.

This approach would download selected archival files from the IBM 4341, integrate the downloaded information with information from TLD files, and automatically generate TLD badge assignments for monitored personnel in each of the 775 Army sites. Once the TLDs are returned to USAIRDC for processing, badges would be automatically read and the calculated dose equivalent information transmitted from the HP 1000 to

Redstone to update the dosimetry data base. In addition, it is contemplated that raw data, such as glow curves and machine correction factors, would be preserved and possibly stored on the IBM 4341. Figure 5-14 shows the information flows projected for the Augmented TLD System. The expected cost of the upgrade is around $400,000, including hardware, software, training, and technical support, and is summarized in a proposed contract modification entitled, "The Augmented Thermoluminescent Dosimetry System Enhanced Software/Additional ADPE Procurement Requirements" (private communication from A. Edward Abney of USAIRDC, 1985).

SYSTEM REQUIREMENTS FOR CONVERSION TO TLD BADGES

USAIRDC mission requirements (as outlined in AR 40-14) applicable to both film and TLD badges, include: issue and track TLD badges; provide summaries of current dosimetry results to customers (including a report of unusual dose equivalents); update and maintain dosimetry repository data; provide summary and statistical reports as required by law; and provide histories of dose equivalents upon request. Operational activities needed to meet these mission requirements are summarized below.

Issuing and Tracking TLD Badges

Tracking of TLDs is not a trivial matter. An individual TLD badge represents an investment of about $20. With some 114,000 badges constantly being circulated to individual Army installations or being processed by USAIRDC, close controls and accountability are important. Moreover, it is of paramount importance that a one-to-one correspondence be maintained between each individual and a specific badge to ensure proper accounting of dose equivalent. The following administrative and accounting functions need to be accomplished to meet these mission requirements:

- Procure TLDs.
- Maintain a list of individuals at a site to whom badges must be issued.
- Maintain a list of sites and their addresses.
- Issue a numbered badge to appropriate individuals at each of 775 sites.
- Associate each individual with a Social Security number.
- Associate each badge with a Social Security number.
- Periodically prepare for each individual the equivalent of a DA Form 3484, "Dosimetry Report--Exposure to Ionizing Radiation."
- Receive and process badges from the field after use.
- Keep track of badges that have been issued but not returned.
- Maintain throughout the reading process a one-to-one association between badge readings and individuals.

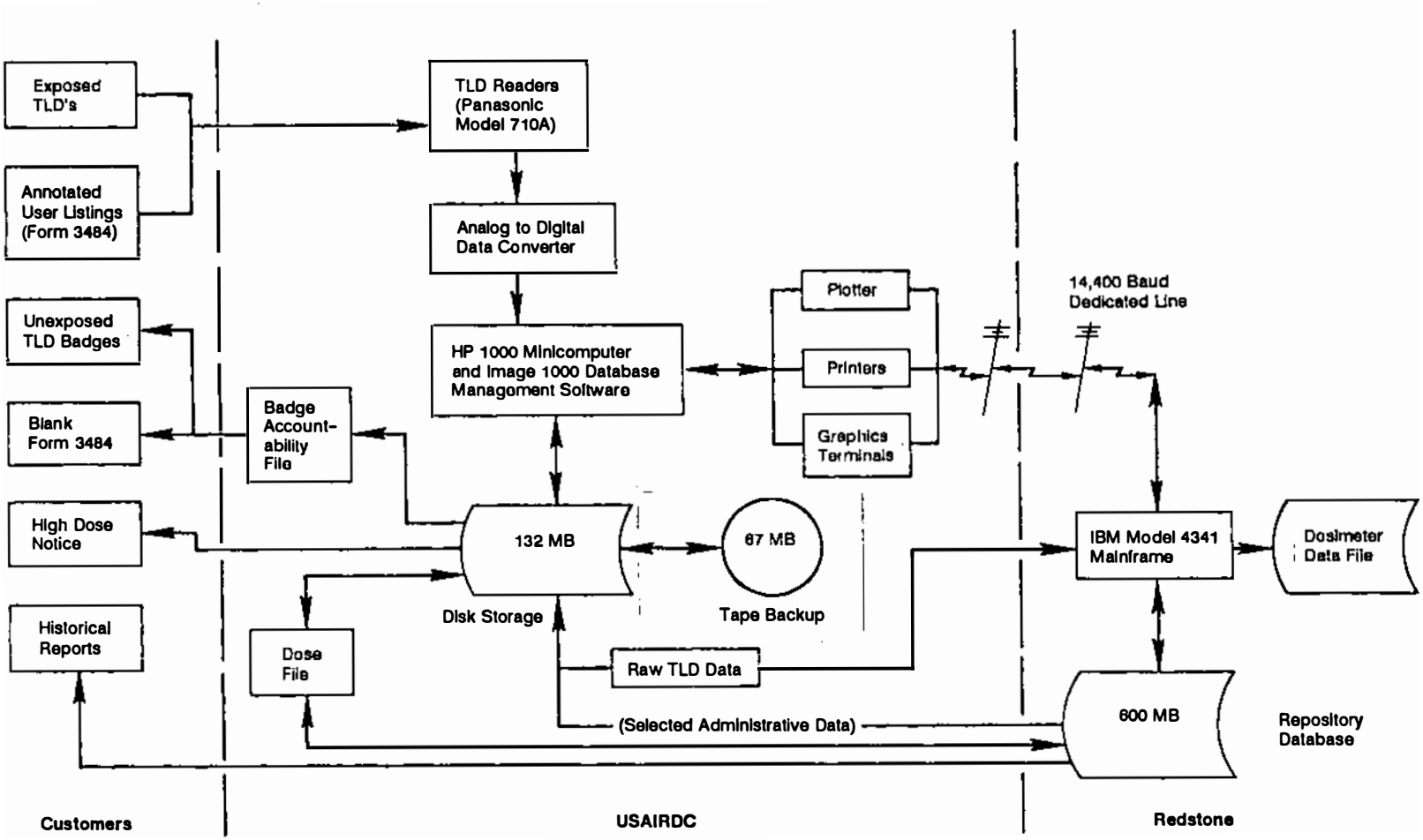

FIGURE 5-14 Augmented TLD System flow chart.

SOURCE: USAIRDC, 1986.

- Record element correction factors (ECFs).
- Maintain badge histories.

Evaluating TLD Data and Providing Dosimetry Results

After TLD badges are returned to USAIRDC, they must be processed to determine whether an individual has been exposed to radiation and to quantify and record any measurable dose equivalent. Subsequently, a report must be issued--for each individual and for each site--indicating occupational dose equivalents. The following functions must continually be performed to satisfy this mission requirement:

- Receive badges from the field.
- Match badge with individual's name and Social Security number.
- Read the TLD badge.
- Use an evaluation routine (computer algorithm) to interpret data from each dosimeter, applying correction factors to ensure accurate results.
- Notify customers, Army personnel and reporting agencies of dose equivalents, giving special attention to any unusual ones.
- Store dosimetry data in a permanent file.

Updating and Maintaining Dose Equivalent Files

After monthly dosimetry data are collected from all sites, and individuals have been informed of their resulting dose equivalents, these data must be permanently stored to enable information on all monitored individuals to be subsequently retrieved to provide the following:

- Automated Dosimetry Record--DD Form TBD (to substitute for DD Form 1141, "Record of Occupational Exposure to Ionizing Radiations"); and
- Termination dose equivalent histories for each departing employee (upon his departure from a specific site where he may have been exposed to ionizing radiation).

To accomplish this requirement, a data base must be maintained that contains all dose equivalent data for each monitored individual.

Providing Summary Dosimetry Reports

AR 40-14 requires that the USAIRDC prepare separate annual consolidated statistical summary reports (for the Army and for the Defense Logistics Agency) of dose equivalents from ionizing radiation and radioactive material. In addition, USAIRDC must prepare a statistical summary report corresponding to each occupational code. This information is maintained in the data file that contains individual dosimetry data.

Preparation of these reports requires retrieval of all records for all monitored individuals, aggregation of the dose equivalents received by each individual, and production of a printout of the resulting cumulative dose equivalents for all monitored personnel.

Providing Dosimetry Histories Upon Request

To meet the requirement of providing individual dosimetry histories upon request, the USAIRDC must retain and continually update all dosimetry data recorded by the Army for all persons employed at sites falling under the definition of AR 40-14. Functions that must be performed to satisfy these needs include searching the Dose, Historical, and Backlog files for individual records, combining the records encountered for a given individual, and printing out the resulting aggregate records.

POTENTIAL IMPACTS ON DATA HANDLING OF THE ACCEPTANCE OF THE COMMITTEE'S RECOMMENDATIONS IN CHAPTER 4

The following analysis considers whether there would be any major potential impacts on USAIRDC data processing and storage requirements if USAIRDC were to adopt the committee's recommendations (stated in Chapter 4) that respond to Study Task 3 on data policy. This analysis concludes that such adoption would indeed result in no major impacts, based upon the following considerations:

1. The committee is recommending (page 66) that personnel source document dose equivalent records be coded to indicate known kinds of radiation--along with their associated energy ranges--to which the individual was exposed.

This recommendation--which would be applicable to new records only--would require the implementation of a slightly modified record structure for the Dose file. Although that size increase would increase the size of the individual record, it would not be large enough to have a significant effect on storage requirements. Some additional effort would be required to implement this recommendation and to code output reports to reflect the additional information.

2. The committee is recommending (page 66) that a monthly wearing period for badges should be continued, except in groups where dose equivalents are low and stable, for which a 3-month wearing period could be instituted.

Implementing this recommendation could cause a significant reduction in the rate of growth of the Dose Data file, which currently grows at the rate of 200,000 records per year (assuming monthly monitoring).

For film dosimetry, that growth rate is equivalent to 10 million characters per year of storage. According to Army statistics for 1984 (Private communication from USAIRDC, 1984), approximately 77 percent of all individuals monitored were in an environment where dose equivalents were low and stable. Adoption of this recommendation would result in a reduction of about 50 percent per year in the yearly data storage requirement.

3. The committee is recommending (page 67) that dosimetry records be retained indefinitely.

Presently, all dosimetry records are kept on-line on the IBM 4341, i.e., every record is immediately accessible to authorized users. These files--which occupy a total of 500 million characters of storage and are expected to grow at the rate of about 10 million characters per year (depending upon the frequency of monitoring)--contain information on some 300,000 individuals, some of whom have retired or died.

A major reason for keeping the Dose files on-line is to permit USAIRDC to efficiently satisfy requests for dosimetry histories. As mentioned in the preceding, there are about 2,000 requests for searches annually; 75 percent of these requests are for dosimetry histories of individuals currently employed by the Army. Before a person may be employed at a site where he or she may be exposed to radiation, the individual's medical history must be updated to show his or her cumulative dose equivalent. Another 20 percent of the historical searches result from requests by former Army employees who are being employed as radiation workers by other organizations. The remaining 5 percent of the requests come from individuals inquiring about their dosimetry history, or from Veterans Administration or other hospitals seeking information about persons who may be suffering from radiation-related illnesses.

The USAIRDC has sought--so far unsuccessfully--to improve the quality of the Dose files by obtaining help from the Social Security Administration in verifying Social Security numbers. Apparently certain legal restrictions prevent the Social Security Administration from allowing their files to be used for this purpose. One consequence of this policy is that USAIRDC is unable to identify the names of persons who have died. Lacking such information, USAIRDC cannot move the corresponding records to off-line storage.

Inasmuch as USAIRDC data files will continue to grow at about 10 million characters per year, and since the NRC has yet to authorize disposing of any of USAIRDC's existing dosimetry records, it appears that little can be done to eliminate certain records from current on-line files in order to facilitate efficient historical searches. However, to the extent that computer storage costs per megabyte continue to decrease, the relatively modest annual growth in storage requirements will not be a significant consideration, but management of USAIRDC's dosimetry records will progressively become more cumbersome.

One way to cope with some of these problems is to try to reduce the need to do historical searches. This could be accomplished by going to the Automated Dosimetry Record (Substitute for DD Form 1141). Since about 75 percent of the requests for dosimetry histories correspond to individuals within the Army who have lost their dosimetry records, this approach would ultimately eliminate many of these requests. If records for all individuals are converted to this automated record system, then eventually the Current Dose files containing records for people who worked in a radiation environment in the 1950s will no longer be needed on-line. Those records can then be archived on tape and accessed on the rare occasions when they are needed.

4. The committee is recommending (page 67) the retention for at least 1 year of all data concerning dose equivalents. (These data would include: the integral readings of the four dosimeter elements, the identity of the reader used, the associated digitized glow curves, the correction factors [including the individual ECFs applied to the signal], and the quality assurance parameters of the reader.)

Adoption of this recommendation will have a significant impact on short-term storage requirements. The glow curve and ancillary raw data are currently estimated to require 3,200 characters of storage per TLD. This estimate is based upon an assumed need for about 200 data channels to process four glow curves in their entirety, using 4 bytes per channel. Thus, if 200,000 TLDs are read each year, the resulting storage requirements become formidably large: 640 million characters. However, there is some prospect of reducing these storage requirements from this estimate, since it may be possible to demonstrate that fewer data channels and/or smaller portions of the glow curves will suffice to perform the required function adequately.

Of course, much of this information could be stored off-line for use as needed, employing, for example, optical-character storage media. If, at the end of a year or of some other predefined period, there are no questions about TL dosimeter readings, a large fraction of these intermediate data could be erased.

5. The committee is recommending (page 68) that digitized glow curves should be stored indefinitely in the following cases:

(a) for individuals who during a particular year have a cumulative dose equivalent of penetrating radiation to the "whole body" (including head and neck) in excess of 500 mrem (5 mSv).

Adopting this recommendation would significantly reduce the amount of storage required, compared to storing all glow curves obtained each year. Moreover, the information could probably be stored off-line on tape until needed. Using 1984 experience as a guide, this would result

in reducing the annual glow curve storage requirement from 640 million to 5 million characters.

(b) for individuals with an annual cumulative extremity dose equivalent exceeding 7.5 rem (75 mSv).

The number of individuals falling into this category appears to be extremely small, hence this recommendation would have a negligible effect on storage requirements. However, some programming would be necessary to assure that the appropriate glow curves were preserved, based upon a cumulative dose equivalent criterion.

(c) for a particular badge indicating a calculated whole body dose equivalent of penetrating radiation in excess of 100 mrem (1 mSv), or where an extremity dose equivalent exceeding 1.5 rem (15 mSv) is indicated.

Since the number of badges in this category is probably small, the storage requirements for glow curves would also be commensurately small. A program would be required to assure preservation of the glow curves for badges in this category.

(d) all glow curves of an unusual nature which are not explicable in terms of instrumental problems (based upon a short-term review), along with the glow curves obtained by processing the badges immediately preceding and following the badge producing those curves, providing that these curves have normal shapes.

This recommendation will probably not have a large impact on storage requirements. However, programming will be needed to permit marking the appropriate glow curves for off-line storage.

(e) all glow curves from questioned dosimeter readings (e.g., readings in disagreement with the results of other methods of estimating dose equivalent).

The storage implications of this recommendation require an estimation of the number of occurrences of questioned dosimeter readings in a given year. In any event, TLD reader operators will need to have the capability of marking glow curves for preservation.

(f) all glow curves resulting from quality assurance (QA) procedures.

Implementation of this recommendation could have storage implications, depending upon the procedures used. USAIRDC is planning to process some 30,000 badges per month, including quality control badges. While off-line storage for the glow curves from these badges would be feasible, these additional storage requirements could amount to several million characters per year.

(g) Indefinite retention of all data relating to the calibration of the reader throughout its history, along with intercomparisons of evaluations of dose equivalent.

Data processing, storage, and programming impacts of adopting this policy--assuming calibration once every year--are expected to be modest.

6. Insert the "Annual/Quarterly History of Exposure to Ionizing Radiation" computer-generated report into individual medical records in place of DD Form 1141.

Relying upon the Annual/Quarterly History report as the output document from the dosimetry monitoring process would eliminate the need for manually entering information onto DD Form 1141. This history report is currently being prepared, and the Army recently obtained NRC approval to use this computerized report in lieu of DD Form 1141. A switch to the new report would present no problem from a data processing standpoint.

Data Security Requirements

There are two major concerns related to the security of data in this system for dosimetry monitoring. The first concern is the need to conform with the Privacy Act, which limits unauthorized access to information about individuals, including information as to their dose equivalents. The second concern is to provide data security, so that modification of dosimetry records can be performed only by authorized persons. The greatest threats to the security of both TLD and film badge processing would probably be allowing unauthorized persons to gain access to dosimetry data and to make changes in them. A password system is currently used to ensure data confidentiality and to prevent tampering. The TLD system is advantageous in that raw glow-curve data are preserved and are accessible for verification. Thus, in cases where individuals receive dose equivalents that appear unusual, a check of the raw data can be made to validate the tentative estimate of dose equivalent.

COMPUTER SYSTEM OPTIONS FOR FUTURE TLD PROCESSING

Options for processing TLD dosimetry data fall into two broad categories: remote processing, characterized by the current method of operation in which data on dose equivalents are derived from film badges at USAIRDC in Lexington, then are entered into computer terminals for remote processing and storage by the computer at Redstone, and local processing, characterized by a system whereby these data would instead be computer-processed and stored by a local computer at Lexington. Figure 5-15 shows these two generic computer system

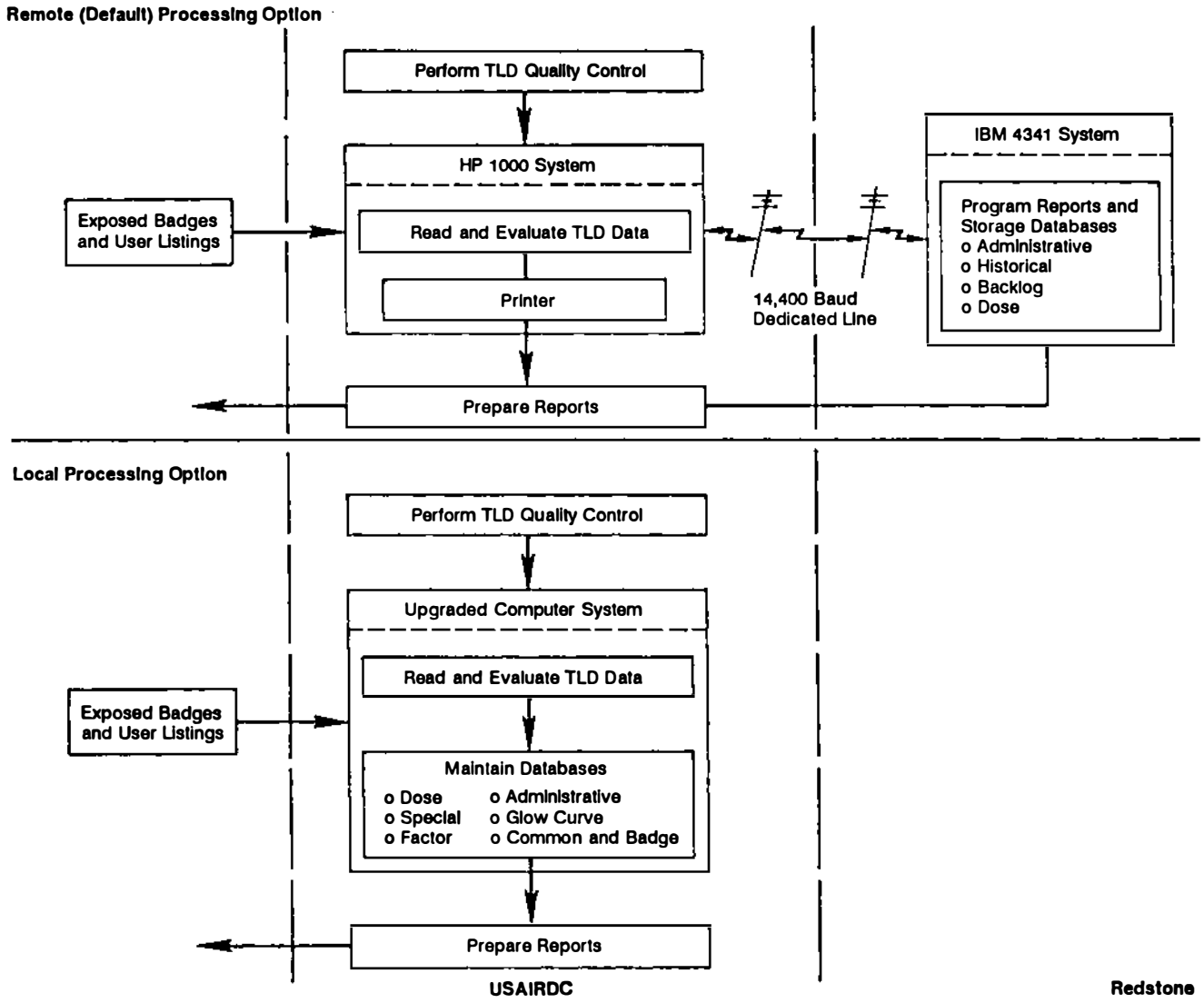

FIGURE 5-15 Computer system options using remote and local processing.

SOURCE: Analysis by this Committee.

options in flow diagram form. Within each option, various hardware and software combinations could be employed to accomplish the required processing.

This section describes and evaluates the computer hardware and software options available to USAIRDC. System options are evaluated technically and by comparing estimated marginal implementation costs. Evaluation factors include: hardware, software, custom programming (software development), personnel additions, and operating costs. Cost estimates are only approximate. More accurate estimates would require actual vendor quotes for new hardware and/or software options and analysis of U.S. Army allocation procedures for cost chargeback. Various ways in which the USAIRDC could accomplish its mission through automation are discussed in the following subsection.

Functional Performance Comparisons for the Local and Remote System Options

Here are some comparisons exploring the local and remote options insofar as their capabilities of performing several functions:

1. Prompt notification as to unusually large dose equivalent. It is important to notify promptly any individuals who receive an unusually large dose equivalent. This should be done soon after their badge has been read.

(a) Remote option: USAIRDC's present system configuration can perform the notification function, although film badge data must be keyed into the Redstone IBM 4341 before notification reports can be printed. Such notification can continue to be provided after conversion to TLDs. However, to accomplish this function--pending acquisition of additional peripherals for the HP 1000 and doing some additional computer programming--USAIRDC will have to manually enter the dosimetry information produced by the Panasonic readers/HP 1000 software into the IBM 4341, using computer terminals, as they are currently doing for film badges. Besides being tedious and expensive, manually entering HP 1000 data can introduce errors into an individual's dosimetry records.

Data may be interchanged between the IBM 4341 and the HP 1000 using modems and a data line (presently available), but some programming of both machines would be required to permit such data transfer. Using this approach, data on individuals could be downloaded to the HP 1000, integrated with the issuance of numbered TLDs, and--after the badges are read--results could be uploaded back to the IBM 4341. Thereafter, the requisite reports could be printed (using the IBM 4341) and the results sent to a remote printer at Lexington. The IBM 4341/HP 1000 link is in fact a significant option for USAIRDC.

(b) Local option: Another option that should be considered is to increase the local processing capabilities at USAIRDC to store and manipulate the Dose data base, presently residing on the IBM 4341. This file currently occupies about 100 million characters of storage and grows at an annual rate of 10 million characters. Besides transporting the data base to a machine at USAIRDC, new software would have to be written to perform the tasks of handling the badge-issuance process and of producing notifications regarding unusually large dose equivalents.

2. Updating and maintaining the repository data. The process of updating and maintaining the repository data can be accomplished either locally or remotely.

(a) Remote option: Individual dosimetry histories are maintained on the IBM 4341 for individuals actively employed by the Army and for whom radiation monitoring is required. Currently, Redstone has the capability to generate an automated version of DD Form 1141 for inclusion in an individual's medical records. With conversion to the use of TLDs, results from reading the TLDs would be entered manually via remote terminals--if the present system is unchanged-- using a process similar to that described in 1(a).

b) Local option: This application could be handled by a computer at USAIRDC by writing a program to generate the requisite individual dosimetry histories.

3. Providing summary dosimetry reports. USAIRDC is required to prepare separate annual consolidated statistical summary dosimetry reports.

(a) Remote option: The above information is contained in the Dose data base file on the Redstone IBM 4341, and there is an existing application program for preparing the requisite summary reports.

(b) Local option: The Redstone Dose data base files can be moved to a computer at USAIRDC. This would require writing an application program to prepare the requisite summary reports.

4. Providing dosimetry histories upon request. The capability of providing dosimetry histories of individuals upon request requires the use of three files currently located on the Redstone IBM 4341. These files are the Dose data base, the History data base, and the Backlog data base (see Figures 5-5, 5-6, and 5-7). These data bases contain, respectively, 97 million, 101 million, and 198 million characters.

There are two historical files, the History and Backlog files. Both are static. The History file contains dosimetry data on individuals (identified by Social Security number) who are no longer being monitored by the Army. The Backlog file, which contains information similar to that in the History file, identifies individuals by an assigned number since their Social Security numbers are not known to USAIRDC.

When there is a request to locate an individual's historical dose equivalent record (USAIRDC gets about 2,000 such requests each year), all three of these files may have to be searched. A typical search takes about 4 hours, about half of which is computer time. Records for individuals in the Backlog file, for example, frequently have to be checked against employment records to assure that proper dose equivalent information is assigned. When the current film badge system is converted to the TLD system, the Dose file could continue to be updated by rekeying the data (as is currently being done), or by electronic entry subsequent to computer processing.

(a) Remote option: The IBM 4341/HP 1000 interface could be utilized to transfer information between computers.

(b) Local option: With sufficient storage capability, the Dose file could be installed at USAIRDC.

5. Issuing and tracking TLDs. Presently, there is no automated process to track which Army installation will receive a particular TLD and to whom it will be issued. The augmented TLD system, described above, would automate the tracking function. Such a system would require input data from the IBM 4341 regarding individuals and their assigned stations, and badge number data from the HP 1000.

(a) Remote option: A program would need to be written to download the personnel information from the IBM 4341 and integrate this data file with badge information.

(b) Local option: This function could be performed at USAIRDC on its own computer.

6. Utilization of available computer systems. The overall data system utilized for satisfying USAIRDC requirements can be provided either remotely or locally, as described below.

(a) Remote Option: If current plans are implemented, the USAIRDC system for processing TLD data will consist of recorded data stored on an HP 1000 minicomputer, with provision for subsequently transferring these data to the Redstone IBM 4341 mainframe via a data-communication link. With the exception of the new "front-end" processing capability (i.e., the Panasonic

card reader and HP computer), and the addition of new data elements to record and store, the data processing system would function much as it does currently. However, remote operation introduces the difficulty and inconvenience of matching glow curves stored at Lexington with dosimetry records stored at Redstone. Redstone plans to switch to a more powerful mainframe computer--an IBM 4381--sometime in FY 1987. The 4381 uses the same operating system as the 4341 (which is no longer in production), but incorporates the following additional features: maximum of 32 Mb of internal memory, as compared to the usual 6 Mb for the 4341 (but only 2 megabytes for the current configuration, [summarized in Table 5-1 on page 76] of the Redstone 4341); a relative performance ratio of two to one, as measured by instructions processed per second; and a cycle time one-fourth faster. With these characteristics, the Model 4381 system would theoretically reduce processing times for USAIRDC and the other Redstone customers. Actual processing times for any customer will depend, however, upon many factors, including the number of users simultaneously on-line, the data-transfer speed of the communication lines, and the peripheral equipment connected to the 4381.

Whatever computer performs the processing at Redstone, the advisability of selecting the remote system option depends to a considerable extent upon (a) the cost of implementing and operating an adequate data-communication link between the HP 1000 and Redstone, and (b) the processing effectiveness of transferring information between the two locations. Table 5-2 summarizes the committee's rough estimate of the cost (in addition to the cost of the data link) to integrate the processing of TLDs at Lexington with remote storage of dosimetry data on the Redstone IBM 4341.

(b) Local Option: Several options are available for processing TLDs locally at the Lexington site. Besides hardware and software considerations, however, some additional factors would enter into arriving at a decision to move the data processing operations to Lexington. First, a new computer system may require an appropriately conditioned environment. The HP 1000 does not require such conditioning, but a mainframe computer does. Second, an organizational change may be necessary to assemble the correct combination (such as computer operators, programmers, and technicians) of staff needed to meet mission requirements. Special staff support considerations are more extensive for a mainframe system than for a minicomputer. While Redstone has not indicated any reluctance to continue servicing USAIRDC using the TLD system, a local repository has several advantages: most importantly, faster response time, local control, and simplified administration.

TABLE 5-2 Estimated marginal cost to implement TLD remote processing

	No Augmented TLD System	With Augmented TLD System
Hardware[a]	$0	$400,000
Software	0	0
Development	0	100,000
Staff[b]	0	0
Operating[c]	0	100 (per month)

[a]Includes complete hardware/software system.
[b]Custom programming at Redstone and for the HP 1000/IBM @ $50/hour.
[c]Estimate for a contract to maintain additional hardware used by the augmented system.

One approach within the local option is to upgrade the HP-1000 system. That system is part of a family of related computers, systems, software, and peripherals designed to provide a complete framework for linking computers and controlling the flow of computer-generated information throughout an organization. The HP 1000 uses an open-system strategy to allow the user to select the right combination of products for the desired applications. For example, three levels of computing power are available (Series A, E, or F), along with an array of optional peripherals that result in a total of nine system configurations.

The current system installed at USAIRDC is a Model 6, the smallest of the integrated HP 1000 line. This model is based upon an A600 central processing unit (CPU) with the following characteristics: 1 Mb of memory, a 1-132 Mb storage disk, a 1-67 Mb tape backup, a dot matrix printer, several graphics terminals, a color terminal, and a high-speed printer. This computer system, provided under the Panasonic TLD contract, is connected to two Panasonic badge readers with magazine changers. A backup computer system--similar to the primary system except that it uses two terminals and one badge reader/changer--is also located on-site.

The HP 1000 is designed for applications where data access speed is of prime importance. Approximately 100,000 units are in operation worldwide, and the models have been in existence for about 10 years. IMAGE 1000, a data-base management software package, can accommodate data bases containing up to 3.2 gigabytes (Gb) of data.

The potential for upgrading the HP 1000 (A600) is constrained by practical limits on memory and storage. Parity-checking internal memory can be increased to 4 Mb, and error-correcting memory to 8 Mb, while storage is, in practice, limited to 1.2 Gb (1,200 Mb). However, upgrading the current HP 1000 system to meet future requirements is technically feasible either by replacing the Central Processing Unit (CPU) and using the existing peripheral equipment, or by adding another CPU to perform the tasks currently accomplished by the IBM 4341. This would enable USAIRDC to process, store, and retrieve the necessary data on-site.

Replacing the HP 1000 Model 6 by a Model 29, i.e., replacing the A600 CPU by an A900 unit, would boost performance significantly to a base of 3 million instructions per second (MIPS) (compared to 1 MIPS for the current Model 6 and 2 MIPS for the IBM 4341 at Redstone). The Model 29 has a maximum memory of 21 Mb, close to the level of the planned Redstone IBM 4381, and well above the 4 Mb of the Model 6. Besides using the same peripherals employed by the Model 6, the Model 29 uses the same interface cards, simplifying problems of interconnections with communications and other equipment. Table 5-3 summarizes the committee's rough estimate of costs for this option.

TABLE 5-3 Estimated marginal cost to implement local processing with an Augmented TLD System using an HP 1000 Model 29

Hardware[a]	$500,000	
Software	0	
Development	100,000	
Staff[b]	40,000	(per year)
Operating[c]	210	(per year)

[a]Including installation costs for A900 with 3 Mb memory and 260 Mb storage (total system storage of 400 Mb).
[b]Net after transfer of functions from Redstone to Lexington.
[c]Additional cost of maintenance agreement for A900 system. Does not include savings from elimination of time-sharing fees billed by Redstone, nor savings from eliminating the data link between Lexington and Redstone.

Another approach within the local option is a series of microcomputers in a network arrangement. In this configuration, networked personal computers (PCs), consisting of modules such as the IBM, model PC/AT, would replace the Courier terminals used at Lexington. Although the potential for this particular choice of network module is constrained by the computing capacity of this 16-bit machine and by the limited storage currently available for its processing unit, new technology is rapidly expanding PC use for a variety of new applications. For example, new optical storage units are becoming available that upgrade PC memory capability into the hundreds-of-megabyte range, and at least one manufacturer is offering "write-once," "read-mostly" storage of 500 Mb and above. However, because of limitations on processor speed and the fact that the Army has other, more powerful hardware already installed, this option may not be cost effective.

Summary of Equipment Options

Table 5-4 summarizes selected operating characteristics and estimated costs of the options considered by the committee and discussed in this section.

An additional approach within the local option is to specify USAIRDC's functional computer system requirements in a competitive offering to vendors who, in turn, will provide bids for equipment to satisfy those requirements.

STAFFING CONSIDERATIONS FOR AN AUTOMATED TLD SYSTEM

Transition from the well-established, mostly manual film badge technology to a new, fully automated TLD system necessitates a careful appraisal of the personnel capabilities needed to operate it. Consideration has already been given (see pp. 55-56) to staffing requirements of this transition relating to TLD specialists.

In the information processing and programming area, the services of an experienced systems manager/programmer are required. Software developed by the TLD vendor will need modifications, and the entire records system, software and hardware, both new and old, will require development and maintenance. Although consulting services are a convenient way to get started, permanent staff will probably be needed for the long run.

RECOMMENDATIONS

Previous sections of this chapter described the current and proposed dosimetry monitoring programs and the data-processing implications of various scenarios of future growth. This section summarizes

TABLE 5-4 Computer system intercomparison

Option	Main Memory Capacity (Mb)	Number of terminals	Maximum Practical Storage (Gb)	Maximum Instructions Processed (MIPS*)	Approximate Hardware Purchase Price
Remote processing					
IBM 4341	1-16	4 to 150	80	1.5	$450,000
IBM 4381	4-32	Up to 1,600	320	4.8	1,000,000
Local processing					
HP 1000 (A600)	0.5-8	2 to 32	1.6	1.0	16,000
HP 1000 (A900)	6-21	33 to 64	1.6	3.0	500,000
IBM PC/AT	0.5-2	2 to 20	0.5	0.5	48,000‡

*MIPS are defined as millions of instructions per second.
‡Assuming eight personal computer units costing $6,000 each.

recommendations for hardware and software systems needed to meet USAIRDC mission requirements.

Issuing and Tracking TLD Badges

Badge issuance, badge accountability, and associating each dose equivalent with the proper individual are central to USAIRDC's radiation monitoring responsibility. The Augmented TLD System will help ensure that these responsibilities are met. Therefore, the committee recommends that:

> USAIRDC implement the Augmented TLD System for either the local or remote processing option.

Selecting a Data-Processing Option

In this chapter, the costs of the local and remote processing options have been evaluated to the limited extent that information was readily available within the scope of the study. Before accurate cost estimates can be prepared for the data processing options available to the Army, firm price quotes would need to be obtained for Army-specified system configurations (i.e., system hardware, software, installation, training, maintenance, and follow-up support) and/or for satisfying specified functional system-performance requirements. The committee recommends that:

> USAIRDC conduct a detailed data-processing cost-benefit analysis, and if results of that analysis validate the estimates developed in this chapter, that USAIRDC implement the local processing option. The committee further recommends that this analysis include actual costs relating to the computer services that USAIRDC is presently obtaining--or might obtain in the future--from Redstone, such as the costs of leasing the 14,400-baud data link between Lexington and Redstone.

Since they are internalized within the Army, these costs are difficult for the committee to assess, but they would be eliminated by local processing. They include capital and operating costs of the IBM 4341 at Redstone that are not directly charged to USAIRDC. Redstone is simply providing computer services to USAIRDC at costs reflected in an Army chargeback system. but the committee could not obtain detailed information about it.

The above-recommended cost-benefit analysis should include the intangible benefits associated with the relative simplicity of the local processing option: such benefits as convenience, control over use of resources, and avoidance of the need to transmit data over long distances on sometimes noisy data lines. This kind of local control is

important for an application such as this one, which will continue as long as Army personnel are in proximity to sources of radiation.

On the cost side, local processing could require that USAIRDC add additional staff, such as a programmer to maintain and create the programs necessary to accomplish the processing tasks now being performed (and programmed) on the IBM 4341. Alternatively, a support contractor could be used for special applications when needed.

Updating and Maintaining Dosimetry Files and Providing Dosimetry Histories upon Request

The committee recommends that:

The Army convert to the Automated Dosimetry Report in place of DD Form 1141.

The Automated Dosimetry Report assures that individual dosimetry histories are maintained for individuals currently employed by the Army, and will obviate the need to do historical searches. Inasmuch as 75 percent of all requests for searches come from individuals who are in the Army's employ, this conversion will ultimately result in allowing much of the historical data to be archived off-line.

During the conversion to the Automated Dosimetry Report (DD Form 1952), it also would be advantageous to break up the existing dosimetry data bases presently on the mainframe computer. This Automated Dosimetry Report would allow comparison of information--presently on existing DD Form 1141's in individual personnel files--with information in the data base for the 20,000-25,000 Army personnel currently being monitored. If the local processing option were chosen, only this subset of the main data base would have to be moved to the HP 1000. The remaining data could reside on the 4341 at Redstone in an on-line mode until historical searches became so infrequent that this information could be archived off-line.

Storage of Digitized Glow Curves

The committee recommends that glow curves and other raw data be stored off-line whenever possible.

There does not appear to be a need for on-line storage of glow curve information following initial TLD processing. Data may be loaded back to on-line storage when a question arises about a particular reading. Having a local processor handle this, rather than relying upon a remote mainframe, would help simplify operations.

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APPENDIX A

COMMITTEE QUESTIONNAIRE ENTITLED:

"SURVEY OF IONIZING RADIATIONS BEING MONITORED"

Sent to about 775 Army installations monitored by USAIRDC, October 2, 1985.

NATIONAL RESEARCH COUNCIL
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
2101 Constitution Avenue Washington, D.C. 20418

Committee on Radiological Monitoring

October 1, 1985

Dear Colleague:

The U.S. Army is sponsoring a study by the National Academy of Sciences--National Research Council of the Army's proposed new personnel dosimetry system. To conduct that study, the National Research Council has established a Committee on Radiological Monitoring, composed of nationally known experts in related areas. I am writing you on behalf of Dr. John R. Cameron, chairman of that committee.

One of the key tasks of the study is to "review the characteristics of ionizing radiations to which Army military and civilian personnel are exposed occupationally." Also, the Army has already invested a large sum in dosimeters and related equipment, and desires to deploy the new system based upon the results of the study, which will be completed in a few months. Accordingly, it is now important that the Committee obtain from you and your colleagues some essential information on the kinds and amounts of radiation exposure that the new dosimeter will be called upon to measure. For that purpose we have obtained your name from the U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC).

We ask your prompt assistance in providing the information requested on the enclosure. Our need for your participation is urgent, in order to ensure effective deployment of the new dosimetry network. Please respond by mailing to me the relevant information within seven days of your receipt of this letter. Enclosed is a return mailing label for your convenience.

Please be assured of the confidentiality of this survey. Your identity as a respondent will by safeguarded by the National Research Council and by the Committee, and only statistical tabulations of your responses will be provided to the USAIRDC. Thank you for your cooperation.

Sincerely yours,

John M. Richardson
Principal Staff Officer

Enclosures

c: Professor John Cameron, University of Wisconsin, CRM

Committee on Radiologial Monitoring
SURVEY OF IONIZING RADIATIONS BEING MONITORED

Date mailed: October 1, 1985
Please return within 7 days of receipt

This is a confidential survey. Your identity as a respondent will be safeguarded by the National Research Council and by its Committee on Radiological Monitoring. Only statistical tabulations of your responses will be provided to the Army.

THE FOLLOWING INFORMATION IS REQUIRED FOR A STUDY BY THE COMMITTEE ON RADIOLOGICAL MONITORING OF THE NATIONAL ACADEMY OF SCIENCES--NATIONAL RESEARCH COUNCIL ON BEHALF OF THE U.S. ARMY IONIZING RADIATION DOSIMETRY CENTER (USAIRDC).

Please type or print all information except your signature. Please do not include any classified information. The information requested here is to be provided only by personnel utilizing the services of USAIRDC.

1) Name and address of your facility or monitoring location:

_____

_____

_____

_____

2) Check and describe the kinds of radiation sources at your facility or monitoring location (use a supplemental sheet if necessary):

Kind of source	✓	Types or energies (for each kind)	Comments or description
X-ray units:			
Dental	____		
Diagnostic	____		
Radiotherapy	____		
Other	____		
Gamma	____		
Beta	____		
Neutron	____		
Radionuclides	____		
Fissionable material	____		
Fission products:			
Old	____		
New	____		
Other (describe in "comments" column)	____		
	____		

- Over

3) State the number of film-badge wearers at your facility or monitoring location who are issued the following kinds of badges:

Type of badge	Number of wearers
Standard	_____
Ring	_____
Neutron	_____
Other: _____	_____
_____ (description)	_____

4) State the approximate number of personnel at your facility or monitoring location who are annually exposed to penetrating radiation (as monitored by USAIRDC) at the following dose levels:

Dose	Number	Percent of total personnel
Below 100 mrem/year	_____	_____
From 100 to 1000 mrem/year	_____	_____
Above 1000 mrem/year	_____	_____
Total personnel at your installation:	_____	100%

5) Estimate the current number of your film-badge wearers who potentially or accidentally could be exposed to the following kinds of radiation:

Radiation source	Number of people
X-rays or gamma rays	_____
Beta rays	_____
Neutrons	_____

6) Please provide whatever comments you may have regarding the present Army film badge capability:

7) Person completing this form (for Committee reference, and in the event of any need for clarification):

Signature:_____ Title(s):_____
Name: _____ Date: _____
Telephone No.: _____

Please mail the completed form promptly, using the enclosed mailing label, to

Dr. John M. Richardson
National Academy of Sciences, JH424
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Thank you for your cooperation.

APPENDIX B

*AR 40–14
*DLAR 1000.28

ARMY REGULATION
No. 40–14
DEFENSE LOGISTICS
AGENCY REGULATION
No. 1000.28

DEPARTMENT OF THE ARMY AND
DEFENSE LOGISTICS AGENCY
WASHINGTON, DC, *15 March 1982*

MEDICAL SERVICES

CONTROL AND RECORDING PROCEDURES FOR EXPOSURE TO IONIZING RADIATION AND RADIOACTIVE MATERIALS

This revision requires that the Radiation Control Committee, Radiation Protection Officers, and individuals who maintain DD Forms 1141 and DD Forms 1952 will be designated in writing. It also includes the requirements for the investigation and evaluation of alleged or actual overexposures to ionizing radiation.

Local limited supplementation of this regulation is permitted but is not required. If supplements are issued, HQDA agencies and major Army commands will furnish two copies of each supplement to HQDA(DASG-PSP), WASH DC 20310; other commands will furnish one copy of each to their next higher headquarters.

Interim changes to this regulation are not official unless they are authenticated by The Adjutant General. Users will destroy interim changes on their expiration dates unless sooner superseded or rescinded.

The words "he," "his," and "him," when used in this regulation, represent both the masculine and feminine genders unless otherwise specifically stated.

This publication may be released to foreign governments (sec 1719, title 44, US Code).

* This regulation supersedes AR 40–14/DLAR 4145.24, 20 May 1975, including all changes.

1. Purpose. This regulation prescribes procedures and responsibilities for the control and recording of exposures to ionizing radiation from radiation producing devices and radioactive materials. It implements the rules and regulations set forth in Title 10, Code of Federal Regulations (CFR), Parts 19 and 20; 29 CFR 570.57; and 29 CFR 1910.96.

2. Applicability. *a.* This regulation applies to the Active Army, Army National Guard (ARNG), the US Army Reserve (USAR), persons employed by the Department of the Army (DA), and the Defense Logistics Agency (DLA). Except as specified by formal written agreement, it also applies to Federal and non-Federal agencies, including civilian contractors, whose personnel are occupationally exposed to ionizing radiation on an Army or DLA installation or activity.

b. This regulation does not apply to the following:

(1) Personnel exposed to ionizing radiation and radioactive materials resulting from the use of nuclear or thermonuclear weapons in combat military operations.

(2) Personnel exposed to ionizing radiation while being examined or treated for medical or dental purposes.

c. For DA and DLA installations or activities holding US Nuclear Regulatory Commission (NRC) licenses, the appropriate provisions of 10 CFR apply. However, the DD Form 1141 (Record of Occupational Exposure to Ionizing Radiation) and DD Form 1952 (Dosimeter Application and Record of Occupational Radiation Exposure) will be used in lieu of Form NRC-4 (Occupational External Radiation Exposure History) and Form NRC-5 (Current Occupational External Radiation Exposure).

3. Explanation of terms. *a. Absorbed Dose (D).* The amount of energy imparted by ionizing radiation to the matter in a volume element divided by the mass of the matter in that volume element. It is commonly expressed in rads. One rad equals 0.01 joule per kilogram (J/kg) or 100 ergs per gram. (In the International System of Units (SI), the unit for absorbed dose is the gray (Gy). One Gy is equal to 1 J/kg which is equal to 100 rad.) See rem and roentgen.

b. Bioassay. The determination of kinds, amounts or concentrations, and locations of radioactive materials in the human body. This may be by in vivo counting (e.g., whole-body counting, selected organ counting) or by analysis of materials excreted or removed from the human body.

c. Calendar quarter. A period of not less than 12 consecutive weeks nor more than 14 consecutive weeks. The first calendar quarter of each year will begin in January. Subsequent calendar quarters will be such that no day is included in more than one calendar quarter or omitted from a calendar quarter (10 CFR 20.3).

d. Controlled (restricted) area. Any area to which access is controlled for the purpose of protecting persons from exposure to ionizing radiation or radioactive materials. This means that a controlled (restricted) area requires control of access, occupancy, working conditions, and egress. Areas not included are those used as residential quarters or areas where food is stored, prepared, or served. However, a separate room or rooms in a residential building or a building in which food is stored, prepared, or served may be set apart as a controlled (restricted) area. This does not apply to facilities which use ionizing radiation sources for food preservation.

e. Critical organ. That organ which will receive the greatest exposure and whose damage by a radionuclide entering the human body will result in the greatest potential impairment to the body.

f. Curie. A unit of activity, or degree of radioactivity, of a radioactive substance. One curie (Ci) equals 3.70×10^{10} nuclear transformations per second.

g. Dose (D). A general term denoting the quantity of radiation absorbed, or energy absorbed per unit of mass, by the body or any portion of the body. For special purposes, it must be appropriately qualified. The special unit of absorbed dose is the rad. See absorbed dose.

h. Dose commitment.

(1) *Individual dose commitment.* The total dose equivalent to a part of the human body that results from radioactive material having entered the human body. In estimating the dose commitment, the period of exposure to retained radioactive material is assumed not to exceed 50 years from the time of intake (10 CFR 32.2).

(2) *Environmental dose commitment.* The sum of all radiation dose equivalents to persons over the entire time period the radioactive material can adversely affect humans. The unit of measure for this total population dose is the person-rem.

i. Dose equivalent (H). The product of absorbed dose (D), quality factor (Q), and other modifying factors (N). It is a measure of the effects of radiation

received by exposed persons, taking into account different radiation characteristics and external and internal exposure. The special name for the unit of dose equivalent is the sievert (Sv). The special unit of dose equivalent, rem, may be used temporarily. (One Sv is equal to 1 *J/kg* which is equal to 100 rem.)

j. Dose to whole-body. The dose equivalent to the whole-body, gonads, active blood-forming organs, head and trunk, or lens of the eye.

k. Dosimeter. A device for measuring exposure to radiation.

l. Exposure.

(1) A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all of the ions of one sign produced in air when all electrons liberated by photons (x or gamma radiation) in a suitably small element of volume of air are completely stopped in air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen (R).

(2) The condition of being irradiated by ionizing radiation.

m. High radiation area. Any area, accessible to personnel, where ionizing radiation exists at such levels that a major portion of the body could receive in any 1 hour a dose equivalent in excess of 100 millirems (mrem).

n. Investigation level. The amount of radioactive material incorporated into the human body which justifies further investigation or inquiry. This may be a review of the circumstances or the assessment of the consequences.

o. Ionizing radiation. Electromagnetic or particulate radiation capable of producing ions as it passes through matter. Alpha and beta particles, gamma rays, X-rays, and neutrons are examples of ionizing radiation.

p. Ionizing radiation Protection Program. The management effort by command that includes monitoring the use of ionizing radiation producing devices and radioactive materials. The purpose of this program is to ensure that the exposure to persons from ionizing radiation and the release of radioactive effluents to the environment is as low as is reasonably achievable (ALARA) (as far below specified radiation exposure standards as is practicable).

q. Occasionally exposed individual. An individual whose work is not normally performed in a controlled (restricted) area and whose duties do not normally involve exposure to ionizing radiation or radioactive material. However, such individuals may have reason to enter a controlled (restricted) area in the performance of their duties. Examples are messengers, deliverymen, and maintenance workers. These individuals will not be permitted to receive an exposure to ionizing radiation in excess of that allowed to any individual in the population at large. See paragraph 7*b*.

r. Occupational exposure to ionizing radiation. Exposure to ionizing radiation that is incurred as a result of an individual's (military or civilian) employment or duties which are in direct support of the use of radioactive materials or equipment capable of producing ionizing radiation. Occupational exposure does not include the exposure of an individual, as a patient, to sources of ionizing radiation or radioactive material for the purpose of medical or dental diagnosis or therapy of that person. Occupational exposure does not include exposure to naturally occurring ionizing radiation.

s. Occupationally exposed individual (radiation worker). An individual whose work is performed in a controlled (restricted) area and who might be exposed to more than 10 percent of the radiation exposure standards in paragaph 7*a*(1) as a result of employment or duties in a controlled (restricted) area. The term "occupationally exposed individual" is synonymous with the term "radiation worker."

t. Person-rem. The product of the mean individual whole-body dose equivalent in a population times the number of individuals in the population. The term "person-rem" is synonymous with the term "man-rem."

u. Quality factor (Q). A number by which the absorbed dose is multiplied to obtain the dose equivalent. The magnitude of this number is determined by the effect on the body of different kinds of radiation. For beta particles, gamma rays, and X-rays, the quality factor is 1. For neutrons and protons having energies up to 10 million electron volts (MeV), the quality factor is 10. For alpha particles and other particles heavier than protons, the quality factor is 20.

v. Personnel monitoring device. A device designed to be worn or carried by a person for measuring radiation exposure. Examples are film badges, thermoluminescent dosimeters (TLD), self-reading pocket dosimeters, pocket chambers, and finger dosimeters. The term "personnel monitoring device" is synonymous with the term "personnel dosi-

meter."

w. Rad. The special unit of absorbed dose. One rad equals 0.01 J/kg or 100 ergs per gram. See rem and roentgen.

x. Radiation area. Any area, accessible to personnel, where radiation exists at such levels that a major portion of the body could receive in any 1 hour a dose equivalent in excess of 5 millirems (mrem), or in any 5 consecutive days a dose equivalent in excess of 100 mrem. Practically, this would be any area in which the exposure rate is greater than 2 milliroentgens per hour (mR/hr) but less than 100 mR/hr. See also "high radiation area."

y. Radiation sources. These are materiel, equipment, or devices which generate or are capable of generating ionizing radiation. They include the following:

(1) Nuclear reactors.

(2) Radiographic or fluoroscopic x-ray systems.

(3) Particle generators and accelerators.

(4) Klystron, magnetron, rectifier, cold-cathode, and other electron tubes operating at potentials above 10 kilovolts (kV).

(5) X-ray diffraction and spectrographic equipment.

(6) Electron microscopes.

(7) Electron-beam welding, melting, and cutting equipment.

(8) Radioactive materials.

(*a*) Natural or accelerator produced radioactive materials.

(*b*) Byproduct materials.

(*c*) Source materials.

(*d*) Special nuclear materials.

(*e*) Fission products.

(*f*) Materials containing induced or deposited radioactivity.

(*g*) Radioactive commodities.

z. Radiation Work Permit (RWP). A locally developed form completed by the area supervisor and countersigned by the Radiation Protection Officer (RPO) prior to the start of any work in a controlled (restricted) area. It describes the potential radiation hazards and protective clothing and equipment requirements for a given work assignment. It also provides a record of radiation exposures received by persons during a given work assignment. The RWP will be initiated by the area supervisor or the RPO when required to minimize the exposure of the radiation worker.

aa. Radiation worker. The term "radiation worker" is synonymous with the term "occupationally exposed individual."

ab. Radiation Protection Officer (RPO). A person designated by the commander and tasked with the supervision of the radiation protection program. The RPO ensures compliance with current directives for radiation protection. This person will be technically qualified by education, training, and professional experience commensurate with the responsibilities of the assignment. The RPO will provide consultation and advice on the degree of hazards associated with radiation and the effectiveness of measures to control these hazards. The term "radiation protection officer" is not intended to denote a commissioned status. The RPO may be military or civilian of any grade.

ac. Rem. The special unit of dose equivalent. The dose equivalent (H) in rems is numerically equal to the absorbed dose (D) in rads multiplied by the quality factor (Q) and other modifying factors (N). For the purposes of this regulation, N equals 1. One rem is equal to 0.01 Sv.

ad. Roentgen (R). The special unit of exposure. One roentgen (R) equals 2.58×10^{-4} coulombs per kilogram of air. See "exposure."

ae. Termination. The end of employment with DA, ARNG, USAR or DLA; also, the end of a work assignment in a controlled (restricted) area. The expectation or specific scheduling of reentry into a controlled (restricted) area would not be permitted during the remainder of the terminating calendar quarter (10 CFR 20.3).

af. User. A person who has been delegated the authority for the use, operation, or storage of radiation sources.

4. Regulatory authority. *a.* The concepts in this regulation are based in part on the recommendations of the following:

(1) The National Council on Radiation Protection and Measurements (NCRP) Report No. 39, Basic Radiation Protection Criteria.

(2) The International Commission on Radiological Protection (ICRP) Report No. 9, Recommendations of the ICRP.

(3) ICRP Report No. 12, General Principles of Monitoring for Radiation Protection for Workers.

(4) Federal Radiation Council Report No. 1, Background Material for the Development of Radiation Protection Standards.

b. Where more precise definitions are required, those provided in the following will be used:

(1) The International Commission on Radiation Units and Measurements (ICRU) Report No. 19, Radiation Quantities and Units.

(2) Supplement to ICUR Report No. 19, Dose Equivalent.

(3) ICRU Report No. 25, Conceptual Basis for the Determination of Dose Equivalent.

5. Responsibilities. *a. The Surgeon General (TSG).*

(1) Approve all Army radiation exposure standards less restrictive than those in paragraph 7 before implementation of such standards.

(2) Provide information resulting from the investigation of alleged or actual overexposure of a person to ionizing radiation and radioactive materials. This information and appropriate recommendations are sent to the following:

(*a*) The Central Dosimetry Record Repository (SB 11-206).

(*b*) The commander of the installation or activity to which the person is assigned or attached.

(*c*) The commander of the organization possessing either the NRC license or DA radiation authorization (DARA) for the radioactive material or ionizing radiation producing device which caused the alleged overexposure.

(3) Provide DA staff supervision on the medical aspects of the personnel dosimetry program.

b. The Commanding General, US Army Materiel Development and Readiness Command (CG, DARCOM).

(1) Provide personnel monitoring devices for the Army.

(2) Establish a Central Dosimetry Record Repository. This office will maintain an ionizing radiation exposure history for each person employed by DA, ARNG, USAR, and DLA who is issued an Army personnel monitoring device.

c. The Central Dosimetry Record Repository.

(1) Prepare separate automated annual consolidated statistical summary reports (RCS NRC-1007) for DA, ARNG, USAR and DLA personnel occupationally exposed to ionizing radiation and radioactive material. Prepare a statistical summary report for each occupational code. These summary reports will contain the information specified in paragraph 15. A copy of these reports will be forwarded through command channels to HQDA (DASG-PSP), WASH DC 20310, by 1 March of each calendar year.

(2) Prepare a separate annual personnel dosimetry report for each employee of DA, ARNG, USAR, and DLA.

(3) Prepare requested histories from current or former employees.

(4) Prepare termination exposure history for each employee.

(5) Provide a flexible computer program. It must be possible to separate total occupational exposure from medical (diagnostic and therapeutic) exposure. The computer program must provide for the following:

(*a*) Additional information such as outside employment (moonlighting), medical exposure, and other radiation exposures.

(*b*) Occupational codes.

(*c*) The identity of radiation sources and other hazardous substances to which the worker is exposed.

Note. The Automated Dosimetry Record will be consistent with the requirements of the Form NRC-5 and DD Form 1141.

d. Director, DLA (DLA-WH).

(1) Approve all DLA radiation exposure standards less restrictive than those in paragraph 7 before such standards are implemented.

(2) Provide information based on the results of investigations of alleged overexposure of persons to ionizing radiation and radioactive materials. This requirement is exempt in accordance with paragraph 7-2*k*, AR 335-15. This information and appropriate recommendations are sent to the following:

(*a*) The Central Dosimetry Record Repository (SB 11-206).

(*b*) The commander of the installation or activity to which the person is assigned or attached.

(*c*) The commander of the organization possessing either the NRC license or DARA for the radioactive material or ionizing radiation producing device causing the alleged overexposure.

e. Commanders of installations or activities which possess or use a radiation source.

(1) Establish appropriate and adequate measures to control ionizing radiation so that the total radiation exposure of each person will be maintained as low as is reasonably achievable. This will be as far below the radiation exposure standards in paragraph 7 as is practicable.

Note. In applying the term "as low as is reasonably achievable," the current state of technology and the economics of improvements in relation to the benefits to safety and health of per-

sonnel, the utilization of nuclear (atomic) energy in the public interest, and other societal and socioeconomic considerations, must be taken into account. (See NRC Regulatory Guides 8.8, 8.10, and 8.18, which are available from USNRC, ATTN: Publications Sales Manager, WASH DC 20555.)

(2) Ensure that personnel radiation exposure is monitored and recorded.

(3) Ensure that when there are operations involving occupational exposure to radiation sources, an adequately trained and qualified RPO and an alternate RPO are designated in writing. The RPO or the alternate will supervise the radiation protection program and advise on the control of hazards to health and safety. If the assignment as RPO is an additional duty, then adequate time will be given to perform these duties.

Note. When a civilian employee is performing the duties of RPO, his job description should be appropriately modified to reflect this additional duty for that time period in which the duty is performed. The job description will be returned to its normal state following termination of the individual's assignment as the RPO.

(4) When an installation or activity possesses radioactive material under a specific NRC license or DARA, designate a Radiation Control Committee (RCC) in writing (unless otherwise specifically exempt). The RCC will review proposals for the use of ionizing radiation sources and recommend protective measures to the commander. An RCC is not required for the use of radioactive check sources or smoke detectors or for in vitro studies. The committee will not exercise the functions of a clinical board or any function in nuclear reactor or nuclear weapons programs administered by DA or DLA. Specific responsibilities of the RCC for US Army Medical Center/Medical Department Activities (MEDCEN/MEDDAC) are given in AR 40-37.

The RCC will include the following:

(*a*) The commander/director or his designated representative, who will serve as chairperson.

(*b*) The RPO.

(*c*) The staff medical officer or his designated representative.

(*d*) The safety manager or his designated representative.

(*e*) Other technically qualified persons as necessary.

(5) Insure that all persons working in or frequenting a controlled (restricted) area are informed of the presence of radioactive materials or equipment capable of producing ionizing radiation. These persons will be instructed in the following:

(*a*) Safety precautions and procedures needed to minimize their exposure.

(*b*) Safety precautions and procedures needed to minimize the exposure of the general public. Purposes and functions of protective clothing and equipment. The extent of these instructions will be commensurate with the potential radiological health protection problem in the controlled (restricted) area (10 CFR 19.12 and 29 CFR 1910.96).

Note. When provided instruction about health protection problems associated with ionizing radiation exposure, female employees who are radiation workers will be given specific instruction about prenatal exposure risks to the developing embryo and fetus. (See NRC Regulatory Guide 8.13, and NCRP Report No. 53.)

(6) Establish procedures for the centralized issue and control of personnel monitoring devices.

(7) Provide adequate resources to implement an effective radiation protection program.

(8) Designate in writing a person responsible for preparing and maintaining DD Forms 1141 and DD Forms 1952.

(9) Forward the results of bioassay procedures or other dosimetry data quarterly to the Central Dosimetry Record Repository. This data will be included in the proper person's exposure history (SB 11-206). If the results or data indicate that a person has exceeded applicable guidelines for exposure, dose, or intake of radionuclides, the appropriate dose equivalent for the whole-body and critical organ(s) will also be included.

(10) Investigate abnormal or alleged overexposures to ionizing radiation or radioactive materials.

Note. The investigation conducted in accordance with the requirements of this regulation will be used for the medical evaluation of abnormal or alleged overexposures to ionizing radiation or radioactive materials. Other investigations may be required under the provisions of AR 385-40.

6. Medical surveillance. *a.* Preplacement and termination medical examinations will be given to all radiation workers (military and civilian) by the supporting medical treatment facility. These medical examinations should include a review of prior occupational radiation exposure. They should also include a description of any unusual radiation exposure resulting from previous occupations, accidents/incidents, or therapeutic procedures. Baseline blood counts (white cell count with differential, platelet count, and hemoglobin) will be performed during the preplacement medical examination. Pre-

placement and termination ophthalmic examinations should be performed on employees working in areas of potential exposure to neutrons, high energy beta particles, and heavy particles. Examinations related to ocular surveillance of ionizing radiation workers may be performed by ophthalmologists, optometrists, or physicians competent in funduscopy and biomicroscopy of the eye. Designated individuals will be appropriately credentialed by the Medical Treatment Facility commander.

b. Periodic medical and ophthalmic examinations, when required, should be performed at a frequency determined by the medical commander or staff medical officer in coordination with the RPO. The frequency and thoroughness of these examinations should be commensurate with potential radiation hazards and the circumstances in which the work is performed. Periodic ophthalmic examinations are required for persons occupationally exposed to high linear energy transfer (LET) ionizing radiation when their exposures exceed 70 percent of the annual limit stated in paragraph 7*a*(1). At such examinations, special attention should be given to changes in the lenses of the eyes. Radiation workers occupationally exposed to more than 1.5 rem to the whole-body within 1 calendar quarter will need more detailed supervision by their immediate supervisor and the RPO. This is required to provide background information which might be useful in the event of an overexposure. It is also needed to detect any condition that would require termination of occupational exposure or employment.

Note. For information concerning medical examinations, see AR 40-501, Standards for Medical Fitness, for DA organizations; and DLAM 1000.1, DLA Safety and Health Program, for DLA organizations.

c. Persons suspected of having received excessive exposure will be referred to a physician. They will receive whatever examination determined appropriate by the local medical authority in consultation with the RPO. When appropriate, this examination should include tests and bioassay procedures to evaluate any potential health hazard or injury and to plan appropriate medical care.

d. A reported overexposure does not necessarily indicate the need for a physical examination. The background related to this reported overexposure must be evaluated. This evaluation should help determine the need for such an examination and the tests that are required. Factors to be considered are as follows:

(1) Total reported dose.

(2) Type and energy of ionizing radiation.

(3) Portion of the body exposed.

(4) Critical/significant organ dose.

(5) Length of wearing period for personnel monitoring devices used to measure this radiation.

(6) Time elapsed between exposure and notification, and other appropriate factors.

7. Radiation exposure standards. Every effort will be made to keep the total radiation dose equivalent and the dose commitment to each person as far below the following radiation exposure standards as is reasonably achievable. The necessity for exposures will be weighed against the benefits expected.

a. Radiation exposure standards adopted by DA, ARNG, USAR, and DLA for the control of total occupational exposure to ionizing radiation and radioactive material include the following:

(1) The accumulated dose equivalent of radiation to the whole-body, head and trunk, active blood-forming organs, gonads, or lens of the eye will not exceed—

(*a*) 1.25 rem in any calendar quarter, nor

(*b*) 5 rem in any 1 calendar year.

Note. During the entire gestation period, the maximum dose equivalent to the embryo-fetus from occupational exposure of the expectant mother should not exceed 0.5 rem (NCRP Reports No. 39 and 53).

(2) The accumulated dose equivalent of radiation to the skin of the whole-body (other than hands, wrists, feet or ankles), and forearms, or cornea of the eye, will not exceed—

(*a*) 7.50 rem in any calendar quarter, nor

(*b*) 30 rem in any 1 calendar year.

(3) The accumulated dose equivalent of radiation to the hands and wrists or the feet and ankles will not exceed—

(*a*) 18.75 rem in any calendar quarter, nor

(*b*) 75 rem in any 1 calendar year.

(4) The accumulated dose equivalent of radiation to the bone, thyroid, and other organs, tissues, and organ systems will not exceed—

(*a*) 5 rem in any calendar quarter, nor

(*b*) 15 rem in any 1 calendar year.

b. Persons entering a controlled (restricted) area but who are not classified as radiation workers or minors will not be exposed to a whole-body dose equivalent of more than—

(1) 2 mrem in any 1 hour.

(2) 100 mrem in any 7 consecutive days.

(3) 500 mrem in any 1 calendar year.

(4) 10 percent of the values in *a*(2), (3), and (4) above for other areas of the body.

c. Persons over 18 years of age, but who have not yet reached their 19th birthday, may be occupationally exposed to ionizing radiation if they do not exceed a dose equivalent of 1.25 rem to the whole-body in any calendar quarter. Persons under 18 years of age will not be exposed to more than 10 percent of the values in *a* above.

d. When a pregnant woman is occupationally exposed to ionizing radiation, the embryo-fetus enters the radiation environment involuntarily. Therefore, the female employee is responsible for advising her employer of the fact that she is pregnant. Special consideration may be necessary to insure that her dose does not exceed the radiation exposure standards in *a* above and that her exposure is kept as low as is reasonably achievable.

e. Radiation exposure standards adopted by DA, ARNG, USAR, and DLA for the control of planned occupational exposures under emergency situations are as follows:

(1) *Life saving situation*. This applies to search for and removal of seriously injured persons, or entry to prevent conditions that may injure a number of people. The following exposure standards then apply:

(*a*) Any person's accumulated total absorbed dose of ionizing radiation to the whole-body should not exceed 100 rad.

(*b*) Any person's accumulated total absorbed dose of ionizing radiation to the hands and forearms should not exceed 300 rad.

(2) *Less severe situation*. This applies when it is desirable to enter a hazardous area to protect property, minimize the release of effluents, or to control fires. The following exposure standards then apply:

(*a*) Any person's accumulated total absorbed dose of ionizing radiation to the whole-body should not exceed 25 rad.

(*b*) Any person's accumulated total absorbed dose of ionizing radiation to the hands and forearms should not exceed 100 rad.

f. Guidelines for selecting personnel to participate in emergency operations are shown below:

(1) Rescue personnel should be professionally trained in rescue operations and techniques. If professional rescue personnel are not available, then only volunteers who have received proper instruction should be allowed to participate in emergency operations.

(2) Rescue personnel will be informed of the potential consequences of exposure to ionizing radiation or radioactive material as well as other hazards associated with the rescue mission.

(3) Rescue personnel will be informed as to the proper use of protective clothing and equipment.

(4) Women capable of reproduction should not be occupationally exposed during a rescue mission to more than the limits set forth in *a* above if other personnel are available for the mission.

g. Radiation exposures incurred under an emergency situation, as stated in *c* above, will not be allowed to occur more than once in the lifetime of a person. The record of such exposures will become part of the person's health record or civilian employee medical file.

h. Radiation exposure standards for nonoccupational exposures to ionizing radiation include limiting the use of sources of ionizing radiation such that:

(1) The accumulated dose equivalent of radiation to the whole-body for a person in the general population will not exceed 0.5 rem in any 1 calendar year. This excludes natural background radiation and medical and dental exposures.

(2) The accumulated dose equivalent of radiation to the whole-body for a suitable sample of the exposed population or for the whole exposed population will not exceed a yearly average of 0.170 rem per person from all sources of ionizing radiation. This excludes natural background radiation and medical and dental exposures.

i. Radiation exposure standards less restrictive than those prescribed above may be used in special circumstances only when approved by TSG (DASG-PSP) or Director, DLA (DLA-WH), as appropriate.

(1) Proposals for the use of alternate radiation exposure standards will contain complete justification. They will describe the procedures by which the alternate standards will be implemented.

(2) Less restrictive radiation exposure standards will not be considered for the following:

(*a*) Persons under 19 years of age.

(*b*) Females known to be pregnant.

(*c*) Occasionally exposed persons.

(*d*) Members of the general public for whom the exposure is considered to be a nonoccupational exposure to ionizing radiation.

8. Personnel Monitoring. *a*. Consideration will be taken of all external and internal occupational expo-

sures a person may receive during each quarter. Each person who may receive an accumulated dose equivalent in excess of 5 percent of the applicable quarterly radiation exposure standard specified in paragraph 7 will wear a personnel monitoring device. This is a person who—

(1) Is occupationally exposed to ionizing radiation.

(2) Periodically enters a controlled (restricted) area.

b. The monitoring of personnel who work only with soft beta emitters (e.g., tritium, carbon-14, calcium-45, and sulfur-35) and alpha emitters will be by bioassay as prescribed by the RPO. In general, requirements for bioassays will be based on considerations of the following:

(1) Chemical and physical forms of the radionuclides involved.

(2) Procedures and equipment which would permit radioactive material to be ingested, inhaled or absorbed into the body.

c. Bioassay measurements should be performed when it is possible for a person to acquire 5 percent or more of the annual radiation exposure standard for a specific radionuclide as established by the NCRP/ICRP. (See NRC Regulatory Guides 8.9, 8.11, 8.15, 8.20, and 8.22.)

Note. The laboratory performing the bioassay analysis should be accredited by either the Center for Disease Control, US Health and Human Service Department, or the American Industrial Hygiene Association.

d. Each person under 18 years of age who enters a controlled (restricted) area and for whom the potential exists to receive an accumulated dose equivalent excess of 5 percent of the applicable quarterly radiation exposure standard in paragraph 7*c* will wear a personnel monitoring device.

e. Each person who enters a high radiation area will wear, in addition to a film badge, one of the following near the film badge to monitor the whole-body exposure:

(1) A pocket chamber.

(2) A self-reading pocket dosimeter.

(3) A TLD.

f. An RWP will be prepared to control ingress and egress from a high radiation area or other controlled (restricted) areas that have been so designated by the RPO. The RWP will include the following:

(1) The person's name and social security number.

(2) Identification (e.g., serial number, badge number) of the assigned dosimeter.

(3) The time of entrance and time of exit.

(4) The initial reading of the dosimeter upon entrance and final reading of the dosimeter upon exit from the controlled (restricted) area, if appropriate.

Note. An RWP is not required for the routine entry into or use of a diagnostic medical or dental X-ray facility or a radiation therapy facility.

g. The RPO will review entries on the RWP periodically to ensure that complete exposure records are maintained for all persons using personnel monitoring devices issued by him.

h. The person designated in writing by the commander to be responsible for preparing and maintaining the exposure records may be one of the following:

(1) The custodian of the health records.

(2) The custodian of the civilian employee medical files.

(3) The person who prepares the DA Form 3484 Photodosimetry Report (Exposure to Ionizing Radiation), and normally controls the issuance and recovery of the personnel monitoring devices.

(4) The RPO.

i. The person responsible for the exposure records will annotate them in accordance with instructions on the reverse side of DD Form 1141 at least once each calendar quarter. The results of each wearing period for the personnel monitoring device will be annotated separately on this record. The normal wearing period for the personnel monitoring device will not exceed the wearing period schedule set by the organization furnishing the dosimetry service.

j. Personnel who may be occupationally exposed to ionizing radiation will wear a personnel monitoring device issued specifically for that purpose. The commander will ensure that the results for monitored visitors for whom personnel monitoring is required (para 8*a*) are forwarded to the custodian of the person's health record, radiation exposure record, or the custodian of the civilian employee medical files.

k. Personnel who may be exposed to ionizing radiation at other installations or activities may wear a personnel monitoring device issued for that specific purpose by the RPO at their duty station. This is in addition to the personnel monitoring device that may be provided by the installation or

activity being visited. However, only the highest value will be recorded.

l. Any person governed by this regulation who is exposed to ionizing radiation at an activity outside the jurisdiction of DA, ARNG, USAR, or DLA will ensure that the required exposure information is furnished to the individual who maintains DD Form 1141 for that person.

m. Separate requirements of DA, ARNG, USAR, and DLA with respect to personnel dosimetry are as follows:

(1) *Department of the Army, ARNG and USAR.* The primary whole-body dosimetric device will be the film badge. Exceptions to this will be when the low-energy (18 kiloelectron-volt (keV) to 1.2 MeV) direct reading personnel dosimeter (0-200 mR range) or TLD has been so designated by TSG as the primary dosimetric device. TLDs will be used to measure localized exposure to the fingers and other parts of the body, except the wrist, in accordance with paragraph 9. All personnel (military, civilian, or contractor) working within DA, ARNG, and USAR will use the dosimetry service provided by DA. The dosimetry service for Army installations and activities is provided by DARCOM. This service will be used solely for personnel dosimetry, except in unusual cases as approved by DARCOM. This requirement in no way precludes the use of supplemental or additional personnel monitoring devices when a particular operation makes such use desirable.

(2) *Defense Logistics Agency.* The primary whole-body dosimetric device will be the film badge. All DLA field activities will use the dosimetry service provided by DA, as outlined in SB 11-206. Exceptions are those DLA activities that have tenant status at a military installation, activity, or base with a personnel monitoring program, in which case they will be included in that program. Government-furnished personnel dosimetry service will be employed exclusively, as approved by the Director, DLA (DLA-WH). This requirement in no way precludes the use of supplemental or additional personnel monitoring devices when a particular operation makes such use desirable.

9. Wearing of personnel monitoring devices. *a.* When monitoring of external whole-body radiation exposure is the critical assessment, the personnel monitoring device will be worn below the shoulders, above the hips, and on the outside of clothing. During certain operations it may be appropriate to protect the film badge from environmental factors such as high humidity, temperature, or radioactive contamination. The film badge window must face outward from the body. Any procedure used will be approved by the RPO prior to initiation.

b. When a lead apron or similar protective garment is worn, the whole-body personnel monitoring device will be worn on the outside of the basic clothing but beneath the protective garment.

c. In certain situations (e.g., fluoroscopy, veterinary radiography, nuclear medicine, and radiation therapy) it is desirable to measure localized exposure to ionizing radiation. Examples are instances of exposure of the head and neck, hands, fingers, or forearms. In these situations, personnel monitoring devices should be worn in each location to assess the localized exposure. This assessment will be in addition to, but never in lieu of, routine personnel monitoring procedures (i.e., assessment of whole-body exposure). A person's regular whole-body personnel monitoring device will never be used on other areas of the body. Conversely, a personnel monitoring device used to record a specific localized exposure will never be used to record exposures at other body sites. (See para 11 for recording procedures.)

d. The wrist or finger dosimeter will be worn when a person could possibly receive an accumulated dose equivalent of radiation to the wrist or finger in excess of 10 percent of the radiation exposure standard in paragraph 7*a*(3). A wrist or finger dosimeter will be worn on the wrist or finger closest to the radiation source and under the protective glove. The wrist or finger dosimeter will be oriented toward the radiation source.

10. Care and handling of personnel monitoring devices. *a.* When personnel monitoring devices are not being worn, they will be stored in locations approved in writing by the RPO. The devices will be located conveniently close to, but outside of, any radiation area. They will be adequately shielded from ionizing radiation produced within the area. A control dosimeter will be stored in each approved personnel dosimeter storage location. To assure that persons wear only their own dosimeter, personnel monitoring devices will display some individual identification. Under *no* circumstances will the personnel monitoring device be permanently inscribed with a name, number, or other identifying symbol. The recommended procedure is to type the persons name on embossing tape or on a small strip of paper which is attached to the front or back of the per-

sonnel monitoring device with transparent tape. The small window on the front of the film badge *will never* be covered with tape or any other material except when authorized in writing by the RPO. This may be required to protect the film badge from environmental factors.

b. A person's immediate supervisor and the RPO will ensure that the personnel monitoring device issued to or used by one person will not be issued to or used by another person during the same wearing period.

c. When persons leave the controlled (restricted) area at the end of the work day or the installation or activity, they will ensure that their personnel monitoring devices are left in a location approved by the RPO.

d. Stocks of unissued dosimeter film should be stored at temperatures below 70° F (21° C), preferably between 35° F (2° C) and 46° F (8° C). Film packets should never be subjected to pressure or other physical stress that could result in sensitization of the film. The storage area for unissued film and TLDs will be as remote from ionizing radiation sources as practical. It will never be near chemical fumes since certain chemicals, such as mercury and formaldehyde, can cause fogging or sensitization.

11. Recording procedures. DD Form 1141 or Automated Dosimetry Record will be prepared and maintained for each person occupationally exposed to ionizing radiation. It may be prepared and maintained by a person other than the custodian of the health records or custodian of the civilian employee medical files. (See para 8*h*.) When the DD Form 1141 or Automated Dosimetry Record is maintained separately from the health record or civilian employee medical file, a Chargeout Record (OF 23) will be placed in each record. (See AR 40-66 for DA procedures.)

a. When a person other than the custodian of the health record or civilian employee medical file prepares DD Form 1141, he will advise the custodian of this fact and furnish the OF 23.

b. Upon notification of the transfer of a radiation worker, the RPO, in coordination with the custodian of DD Forms 1141, will perform the following:

(1) Insure completeness and accuracy of DD Form 1141 and the results of bioassay procedures.

(2) Insure that the Chargeout Record (OF 23) has been removed and that DD Form 1141 or Automated Dosimetry Records, and the results of bioassay procedures are placed in the health record or civilian employee medical file.

(3) Prepare a copy of DD Form 1141 or Automated Dosimetry Records, DD Form 1952, and results of bioassay procedures to be retained at the installation activity (10 CFR 20.401(*c*)(1)).

(4) Maintain the address of the gaining organization to which the person has been assigned to insure proper forwarding of dosimetry information. This information may be recorded on the retained copy of DD Form 1952.

(5) Submit a report to the NRC when required by 10 CFR 20.407. Also comply with paragraphs 13, 14, and 15 of this regulation.

c. Upon transfer, if DD Form 1141 or Automated Dosimetry Records, DD Form 1952, and results of bioassay procedures are not present in the person's health record or civilian employee medical file, the custodian of these records at the gaining organization will write to the installation or activity RPO identified on OF 23. He will request that these records be forwarded for inclusion into the person's health record or civilian employee medical file. DD Form 877 (Request for Medical/Dental Records or Information) may be used to request these records from the MEDCEN/MEDDAC. (For DA, see AR 40-3 and AR 340-1.)

d. In the initial preparation of DD Form 1141, the custodian shall try to obtain complete reports of all previous occupational exposures based on recorded personnel dosimetry. DD Form 1952 will be used to record the occupational exposure history and relevant health physics information. A sample DD Form 1952 is at figure 1.

(1) For each period where occupational exposure was probable and no record (or an incomplete record) is available, it shall be assumed that 1.25 rem was incurred per quarter of each calendar year or 00.416 rem was incurred per calendar month. When the person was potentially exposed to ionizing radiation at more than one facility, the cumulative exposures will be calculated and recorded in items 7 through 12 of DD Form 1141, as appropriate. (See fig. 2.) The sum of these whole-body exposures will be entered in item 13 of DD Form 1141. A statement regarding the source of this information will be entered in item 16.

(2) If there were no previous occupational exposures, the statement "no previous occupational exposure" will be entered on the first line of DD Form 1141. A copy of all previous occupational

exposure data obtained from outside employment or administrative doses will be forwarded to the Central Dosimetry Record Repository for proper posting to the person's record (SB 11-206).

Note. When an occupationally exposed individual is reassigned, the gaining organization will initiate a new DD Form 1952 and transpose previous exposure history information to the new form.

e. A separate DD Form 1141 or Automated Dosimetry Record will be maintained to record other than whole-body or skin of the whole-body exposures. Appropriate descriptions shall be made under item 16 of DD Form 1141. Examples are the thyroid, head and neck, wrist, and fingers. These records will be cross-referenced with the whole-body record. Results of bioassay procedures are considered as laboratory studies and should be filed accordingly. Reference to the results of such studies will also be entered under item 16. (See AR 40-66.)

f. The dose equivalent determined by bioassay will be entered on the appropriate DD Form 1141 or Automated Dosimetry Record when it exceeds investigational levels as defined in ICRP Report No. 10 or 10A. A case will be investigated when the amount and distribution of the radionuclide in the human body could deliver in 50 years to the critical organ more than 10 percent of the quarterly exposure standard or 5 percent of the annual exposure standard.

g. A sample DD Form 1141 at figure 2 shows the proper posting and maintenance of a whole-body exposure record. Figure 3 shows the proper posting and maintenance of a partial body (e.g., wrist, finger, etc.) exposure record. Entries in items 9 and 11 may include the abbreviation NU (not used) and NR (none reported).

h. When RWP are used, exposures recorded on supplemental monitoring devices will be recorded on the permits. (For DA, these records will be retained in accordance with AR 340-18-6.) The results from the primary dosimeter device (film badge) will be recorded on the DD Form 1141 or Automated Dosimetry Record unless this device has been lost or damaged beyond usefulness. (See para 13*g*.)

i. At the request of any employee, the RPO, in coordination with the Central Dosimetry Record Repository or custodian of DD Forms 1141, will advise the employee, in writing, annually of his exposure to ionizing radiation or radioactive material. This information will be obtained from the records maintained by the Central Dosimetry Record Repository or installation or activity (see para 5*c*).

12. Retention and disposition of DD Form 1141 or Automated Dosimetry Records, DD Form 1952, and results of bioassay procedures.

a. DD Form 1141 or Automated Dosimetry Records, and results of bioassay procedures are permanent parts of the person's health record or civilian employee medical file. (See AR 40-66 and AR 340-18-9 for Army procedures.) All previous copies of these records will be retained in the person's health record or civilian employee medical file or with the custodian of the person's DD Form 1141.

(1) Commanders will authorize inspecting officials to review exposure records and the results of bioassay procedures. If the above records are being maintained in the health record or civilian employee medical file of the person concerned, then the custodian will provide them.

(2) For policies and procedures on the confidentiality and/or release of medical information, see chapter 2, AR 40-66, AR 50-5, AR 340-1, and AR 340-17.

b. When a civilian employee of the DA, ARNG, USAR, or DLA is not included in a Federal civilian employee health service, his DD Form 1141 or Automated Dosimetry Records, and results of bioassay procedures will be kept as a permanent document in his SF 66 (Official Personnel Folder). For a non-Federal employee, a copy of such records will be retained by the RPO and copies of the results will be forwarded to the person for his personal and employer's files. DD Form 1141 or Automated Dosimetry Records, and results of bioassay procedures will be subject to review by authorized inspecting officials (*a* above).

c. The DD Form 1141 or Automated Dosimetry Records, and results of bioassay procedures will be retained in the health record of any military member retired from DA, ARNG, USAR, or DLA who has been occupationally exposed to ionizing radiation during his service. Disposition of these records for retired or separated civilian personnel will be in accordance with governing civilian personnel directives.

d. If any member of DA, ARNG, USAR, or DLA is released from active duty, or if a civilian employee terminates employment with these agencies, he will, upon request, be furnished information concerning his radiation exposure history. This

information will be requested from the RPO at the employee's last duty station in accordance with paragraph 14.

e. The disposition of "stray" DD Forms 1141 or Automated Dosimetry Records, and results of bioassay procedures for military personnel and DA civilian personnel will be in accordance with AR 40-66 and Civil Service regulations.

13. Control procedures. The RPO will review and evaluate, at intervals not to exceed a calendar quarter, DD Form 1141 or Automated Dosimetry Records and results of bioassay procedures for each person occupationally exposed to ionizing radiation. This review and evaluation will be noted on DD Form 1141 or Automated Dosimetry Records. The RPO will establish procedures to inform and advise the person, his commander, his supervisor, and the responsible medical officer when action is necessary to limit a person's exposure to ionizing radiation. When a person is reassigned or terminates his employment at an installation or activity, the custodian of the health record or civilian employee medical file will insure that all appropriate DD Form 1141's or Automated Dosimetry Records, and results of bioassay procedures are included in the person's health record or civilian employee medical file.

a. When a person has been reported to have received an exposure to ionizing radiation or radioactive materials which exceeds the radiation exposure standards in paragraph 7, the exposure will be classified as a radiation overexposure. Overexposures are classified as follows:

(1) *Type I.* An excessive rate of radiation accumulation to one or more of the following:

(*a*) Whole-body, head and trunk, gonads or lens of the eyes greater than 400 mrem in a calendar month but less than 1.25 rem in a calendar quarter.

(*b*) Skin of the whole-body (other than hands, wrists, feet or ankles), forearms, or cornea of the eye greater than 3 rem in a calendar month but less than 7.5 rem in a calendar quarter.

(*c*) Hands and wrists, or the feet and ankles greater than 6 rem in a calendar month but less than 18.75 rem in a calendar quarter.

(*d*) Other organs including bone, thyroid, tissue, and organ system greater than 1 rem in a calendar month but less than 5 rem in a calendar quarter.

(2) *Type II.* Overexposure exceeding the quarterly radiation exposure standard but less than the annual radiation exposure standard shown in paragraph 7*a*.

(3) *Type III.* Overexposure exceeding the annual radiation exposure standard shown in paragraph 7*a*.

b. When notified of a Type I exposure, the immediate commander will conduct an informal investigation. This will determine if the apparent or actual excessive exposure is the result of a violation of approved operating procedures or indicates the existence of faulty equipment. The commander will take appropriate action to prevent recurrence. If this was in fact an exposure to a person, then the proper data will be entered on the DD Form 1141 or Automated Dosimetry Record. If the investigation reveals that this was not in fact an exposure to a person, then the RPO in coordination with the local medical authority will record the dose which most accurately assesses the dose the individual could have received. The dose assessment data will be forwarded through command channels to the Central Dosimetry Record Repository for posting to the person's record (SB 11-206).

c. When notified of a Type II exposure, the immediate commander will take the following actions:

(1) Promptly remove the person concerned from any duty involving potential exposure to ionizing radiation pending completion of an investigation of the overexposure.

(2) Conduct an investigation to determine if the apparent or actual excessive radiation exposure is the result of a violation of approved operating procedures or indicates the existence of faulty equipment.

(3) Take appropriate action to preclude recurrence.

(4) Forward a report of the investigation, along with corrective actions taken, through command channels to HQDA(DASG-PSP), WASH DC 20310.

(5) Upon completion of the investigation, return the person to duties involving potential exposure to ionizing radiation. This is allowed if the expected dose, when added to the accumulated occupational dose, will not exceed the annual radiation exposure standard shown in paragraph 7*a*. If the exposure was not in fact an exposure to the person, then a recommendation in the investigative report will be made by the RPO in coordination with local medical authority which most accurately assesses

the dose the person received.

a. The action below will be taken when notified of a Type III exposure.

(1) The immediate commander will take the actions prescribed in *c* above, except that the person will not be returned to normal duties involving potential exposure to ionizing radiation without written concurrence of OTSG (DASG-PSP).

(2) The report of investigation will include a copy of the person's DD Forms 1141 or Automated Dosimetry Records, results of bioassay procedures, if applicable, and signed statements from the person and his immediate supervisor similar to the following: "To the best of my knowledge and belief, I (did) (did not) receive this exposure because _____."

(3) If the investigation reveals that the exposure was not in fact an exposure to the person, then a recommendation in the investigative report will be made by the RPO in coordination with local medical authority which most accurately assesses the dose the person received.

(4) TSG will inform the immediate commander additional medical evaluations, bioassay procedures, or treatment required. TSG will also state when the exposed person may be returned to duties involving potential exposure to ionizing radiation.

e. Reports of alleged or actual overexposures to ionizing radiation or radioactive material which exceed the radiation exposure standards shown herein will be made in accordance with applicable DA or DLA directives. All abnormal exposures or alleged overexposures to ionizing radiation will be investigated as stated above. An information copy of such investigations concerning NRC-licensed or DA-authorized operations or radioactive commodities will be furnished to the licensee or to the command having logistical responsibility for the radioactive commodity.

f. In addition to the above reporting requirements, the following NRC reporting requirements also apply to installations or activities possessing radioactive material under a specific NRC license. A copy of any correspondence submitted to the NRC will be provided to the appropriate MACOM and TSG (HQDA(DASG-PSP) WASH DC 20310) or Director of DLA. (DLA-WH).

(1) *Immediate notification.* Immediate notification of the Director of the appropriate NRC Regional Office listed in appendix D of 10 CFR 20 shall be made by telephone and telegraph, mailgram, or facsimile of any incident involving NRC licensed material which may have caused or threatens to cause the following:

(*a*) Exposure of the whole-body of any person to 25 rem or more of radiation.

(*b*) Exposure of the skin of the whole-body of any person to 150 rem or more of radiation.

(*c*) Exposure of the feet, ankles, hands or forearms of any person to 375 rem or more of radiation.

(2) *Twenty-four hour notification.* Notification of the Director of the appropriate NRC Regional Office listed in appendix D of 10 CFR 20 shall be made by telephone and telegraph, mailgram, or facsimile within 24 hours of any incident involving NRC-licensed material which may have caused or threatens to cause the following:

(*a*) Exposure of the whole-body of any person to 5 rem or more of radiation.

(*b*) Exposure of the skin of the whole-body of any person to 30 rem or more of radiation.

(*c*) Exposure of the feet, ankles, hands, or forearms to 75 rem or more of radiation.

(3) Thirty-day report.

(*a*) In addition to any notification required by paragraph 15, the following will be submitted within 30 days:

1. A written report to the appropriate NRC Regional office listed in appendix D of 10 CFR 20.

2. A copy of the above report to the Director of Inspection and Enforcement, US Nuclear Regulatory Commission, Washington, DC 20555.

3. An information copy to the appropriate MACOM and to HQDA (DASG-PSP), Washington, DC 20310.

(*b*) The above report and copies will be submitted for the following:

1. Each exposure of a person to radiation in excess of the applicable limits in 10 CFR 20.101 or 10 CFR 20.104(a) or the NRC license.

2. Each exposure of a person to airborne concentrations of radioactive material in excess of the applicable limits in 10 CFR 20.103(a)(1), 10 CFR 20.103(a)(2), 10 CFR 20.104(b), or the NRC license.

3. Levels of radiation of concentrations of radioactive material in a controlled (restricted) area in excess of any other applicable limit in the NRC license.

4. Any incident for which notification is required by paragraph 13(c)(1) and (2), or 10 CFR

20.403.

g. Any report filed with the NRC and HQDA(DASG-PSP) shall be prepared so that names of persons who have received exposure to radiation will be stated in a separate part of the report. For each individual exposed, this will include, the name, social security number, date of birth, and an estimate of the person's exposure.

h. When a person's dose equivalent cannot be determined because his primary dosimetric device has been lost or damaged, he will be assigned an administrative dose by the RPO for each month the device was used. Use any of the following methods to determine the administrative dose:

(1) Calculate the person's exposure based on occupancy information and exposure levels.

(2) Assign the dose measured by a supplemental monitoring device if one was worn during this period.

(3) Average the person's previous occupational exposure over the preceding calendar year. This value may be used if the radiation exposure during the period in question is not likely to have been significantly different from that of a similar period the previous year.

(4) Assign 00.416 rem for each month during the period in question. This is the monthly average of the whole-body limit of 5 rem over 12 months.

i. The RPO should select the method, in *h* above, which will determine the most accurate assessment. The method of determining the administrative dose will be noted in the REMARKS section of the DD Form 1141. The Form will also be annotated to indicate an "administrative dose." The RPO will forward this information to the Central Dosimetry Record Repository for proper posting to the individual's record (SB 11-206).

14. Report of personnel exposure on termination of employment or work assignment.

a. When a person who has been occupationally exposed to ionizing radiation terminates employment, he will be provided, at his request, with a report of his exposure to ionizing radiation. This report will be provided by the RPO in coordination with the custodian of DD Forms 1141 or Automated Dosimetry Records. The information will be obtained from the records maintained by the Central Dosimetry Record Repository or the installation or activity (see para 5c). Such reports will be furnished within 30 days from the time the request is made and will cover each quarter of the person's employment involving exposure to ionizing radiation or a lesser monitored period if requested by the employee. The report will also include the results of any calculations and analyses of radioactive material deposited in the body of the employee.

b. The former employee's request will include appropriate identifying data, such as social security number and dates and location of employment.

c. The report furnished the employee will be in writing and contain the following statement:

"This report is furnished to you under the provisions of the US Nuclear Regulatory Commission Regulations (10 CFR 19) or the Department of Labor Regulations (29 CFR 1910). You should preserve this report for future reference."

15. Personnel radiation exposure RCS NRC–1007. *a.* A yearly report must be filed by NRC licensees which conduct industrial activities requiring substantial quantities of radioactive material (10 CFR 20.407 and 20.408). These include the following:

(1) Operators of Army nuclear reactors designed to produce electrical or heat energy, or used as research and testing facilities. Their reports normally are included in their annual operating report in accordance with AR 385-80.

(2) Installations or activities that use or possess byproduct materials for radiographic purposes (10 CFR 34).

(3) Installations or activities that possess or use at any one time, for the purposes of fuel processing, fabrication or reprocessing, special nuclear material in quantities exceeding 5,000 grams of contained uranium-235, uranium-233, plutonium, or any combination of these.

(4) Installations or activities that possess or use at any one time, for processing or manufacturing for distribution pursuant to 10 CFR 30, 32 or 33, byproduct material whose activity exceeds any of the following:

Radionuclide	*Activity in Curies*
Cesium-137	1
Cobalt-60	1
Gold-198	100
Iodine-131	1
Iridium-192	10
Krypton-85	1,000
Promethium-147	10
Technetium-99m	1,000

b. Each NRC licensee described in *a* above, will, within the first quarter of each calendar year, sub-

mit a Personnel Radiation Exposure report (RCS NRC-1007) for the previous calendar year. This report will be sent to the Director of Management and Program Analysis, US Nuclear Regulatory Commission, Washington, DC 20555. DA licensees will forward information copies to HQDA(DASG-PSP), WASH DC 20310.

c. The report will contain the following information:

(1) Either the total number of persons for whom personnel monitoring was required or the total number for whom personnel monitoring was furnished during the calendar year. This total must include at least the number of persons required to wear personnel monitoring devices.

(2) A statistical summary report of personnel monitoring information recorded for persons for whom personnel monitoring was required. It shall indicate the number of persons whose total whole-body exposure recorded during the previous calendar year was in each of the dose equivalent ranges shown below.

Estimated whole-body dose equivalent range (rem)	*Number of individuals*
No measurable dose	
Measurable, less than 0.10	
0.10 to 0.25	
0.25 to 0.50	
0 50 to 1.00	
1.00 to 2.00	
2.00 to 3.00	
3.00 to 4.00	
4.00 to 5.00	
5.00 to 6.00	
6.00 to 7.00	
7.00 to 8.00	
8.00 to 9.00	
9 00 to 10.00	
10.00 to 11.00	
11.00 to 12.00	
12.00 or greater	

Note. Individual values exactly equal to the values separating dose equivalent ranges will be reported in the next higher range.

d. When a person terminates employment with an NRC licensee or work assignment in an NRC licensee's facility as described in *a* above, the NRC licensee will furnish the Director of Management and Program Analysis, US Nuclear Regulatory Commission, Washington, DC 20555, a report of the person's exposure to radiation and radioactive materials incurred during the period of employment or work assignment in the NRC licensee's facility. An information copy of this report for each DA licensee will be forwarded through the appropriate MACOM to HQDA (DASG-PSP), WASH DC 20310. Such report will be furnished within 30 days after exposure of the person has been determined or 90 days after the date of termination of employment or work assignment, whichever is earlier. A copy of this report will also be provided to the person concerned.

16. Careless and intentional exposure of the personnel dosimeter to ionizing radiation.

a. The personnel dosimeter is a device used to measure how much radiation a person has been exposed to such that his accumulated dose equivalent will not exceed the radiation exposure standards. These data may be used for "medical-legal" purposes. All reported overexposures will be investigated to ensure that unsafe practices and improper procedures are corrected and that overexposed persons are provided suitable medical care (see para 13). Improper use of the personnel dosimeter may result in misleading reports and unnecessary expenditure of resources to conduct an investigation.

b. It is incumbent upon each commander, supervisor, and person issued a personnel dosimeter to ensure that it is used correctly.

17. Privacy Act Statements. The following statements implement the Privacy Act of 1974 (PL 93-579). (See AR 340-21 for Army requirements.)

a. The Privacy Act statement for the DD Form 1141 or Automated Dosimetry Record is DD Form 2005 (Privacy Act Statement—Health Care Records)

b. The Privacy Act statement for the DD Form 1952 will be found on the reverse side of the form. See figure 1.

DOSIMETER APPLICATION AND RECORD OF OCCUPATIONAL RADIATION EXPOSURE

Print legibly or type all information requested. See Privacy Act Statement on reverse.

1. FULL NAME (Last, First, Middle)	2. DATE OF BIRTH (YYMMDD)	3. SOCIAL SECURITY NO.
JARVIS, Whitney N.	42-04-15	777-07-3000

4. DUTY SECTION (Dept., Ward, Unit, etc.)	5. JOB TITLE	6. DUTY PHONE
Research Laboratory	Chemist	283-1814

7. PAY GRADE		8. HAVE YOU WORN A DOSIMETER ISSUED BY THIS COMMAND IN THE PAST	9. DATE OF RADIATION PHYSICAL (YYMMDD)
CIVILIAN	MILITARY	☐ YES ☒ NO	81-05-01
GS-12			

10. DUTY STATUS	11. IF TRANSIENT SHOW MAILING ADDRESS (street address, city, state, zip code) OF LOCATION OF HEALTH RECORDS
☒ PERMANENT ☐ TRANSIENT 8 WEEKS OR LESS	

EXPOSURE INFORMATION *(ITEMS 11 THROUGH 20 FOR HEALTH PHYSICS USE ONLY)*

11. CLASSIFICATION OF EXPOSURE
☒ EXTERNAL ☐ NEUTRON ☐ INTERNAL

12. BADGES REQUIRED			13. TLD REQUIRED		
☐ WRIST	☒ WHOLE-BODY	☐ NEUTRON	☐ WRIST	☐ WHOLE-BODY	☐ INGER

14. BIOASSAYS REQUIRED

WHOLE-BODY COUNT		THYROID UPTAKE		URINALYSIS			FREQUENCY	
☐ YES	☐ NO	☐ YES	☐ NO	☐ α	☐ β	☐ β-γ	☐ QUARTERLY	☐ MONTHLY ☐ ANNUALLY

GIVE DATES FOR ITEMS 15 THROUGH 20 (YYMMDD)

15. DOSIMETER(S) ISSUED	16. DD FORM(S) 1141 INITIATED	17. DOSIMETER(S) DISCONTINUED
81-05-03	81-05-03	

18. LAST DOSIMETER(S) RETURNED	19. LOCATOR CARD TO HEALTH RECORD	20. DD FORM(S) 1141 TO MEDICAL RECORDS
	81-05-03	

OCCUPATIONAL EXPOSURE HISTORY

NOTE: This section only applies to the individual who has worked with radiation-producing devices or radioisotopes in a permanent status. List only those employers for whom you worked with radiation.

NAME OF EMPLOYER	ADDRESS (Street address, city, state, zip code)	FROM YR	FROM MO	TO YR	TO MO	Do not write in this space
Nuclear Services, Inc	Shickshinny, PA	78	08	80	04	
Rosewater University	Portland, OR	80	04	81	04	
	TOTAL EXPOSURE DATA					

REMARKS

DD FORM 1 NOV 81 1952 EDITION OF 1 SEP 74 IS OBSOLETE. (See reverse)

SAMPLE

Figure 1. Sample DD Form 1952.

PRIVACY ACT STATEMENT
DATA REQUIRED BY THE PRIVACY ACT OF 1974
(5 USC 552a)

1. TITLE OF FORM: Dosimeter Application and Record of Occupational Radiation Exposure.

2. PRESCRIBING DIRECTIVE: AR 40-14 and DLAR 4145.24.

3. AUTHORITY: 5 USC 301-Departmental Regulation; 10 USC 1071, Medical and Dental Care, Purposes; 42 USC 2073, 2093, 2095, 2111, 2133, 2134, 2201(b), and 2201(o). The authority for soliciting the social security number is 10 CFR 20; 44 USC 3101-Record Management by Agency Heads, General Duties.

4. PRINCIPAL PURPOSE(S): To establish qualification of personnel monitoring and document previous exposure history. The information is used in the evaluation of risk of exposure to ionizing radiation or radioactive materials. The data permits meaningful comparison of both current (short-term) and long-term exposure to ionizing radiation or radioactive material. Data on your exposure to ionizing radiation or radioactive materials is available to you upon request.

5. ROUTINE USES: The information may be used to provide data to other Federal agencies, academic institutions, and non-governmental agencies, such as the National Council on Radiation Protection and Measurement and the National Research Council, involved in monitoring/evaluating exposures of individuals to ionizing radiation or radioactive materials who are employed as radiation workers on a permanent or temporary basis and exposure received by monitored visitors. The information may also be disclosed to appropriate authorities in the event the information indicates a violation or potential violation of law and in the course of an administrative or judicial proceeding.

6. MANDATORY OR VOLUNTARY DISCLOSURE AND EFFECT ON INDIVIDUAL NOT PROVIDING INFORMATION: It is voluntary that you furnish the requested information, including social security number; however, the installation or activity must maintain a completed DD Form 1141 on each individual occupationally exposed to ionizing radiation or radioactive material as required by 10 CFR 20, 29 CFR 1910.96 and AR 40-14/DLAR 4145.24. If information is not furnished, individual may not become a radiation worker. The social security number is used to assure that the Army/Agency has accurate identifier not subject to the coincidence of similar names or birthdates among the large number of persons on whom exposure data is maintained.

STATEMENT

Under the provisions of 10 CFR 19.13, 29 CFR 1910.96 and the Privacy Act of 1974, I hereby authorize the release of, and request that all of my radiation exposure records be furnished appropriate authorities in accordance with the "Routine Uses" portion of the above Privacy Act Statement. As a radiation worker, I have been provided instructions in radiation protection as required by 10 CFR 19.12 and 29 CFR 1910.96. As a female radiation worker, I have been informed of the biological effects and the risks from ionizing radiation on the embro-fetus and received a copy of NRC (Nuclear Regulatory Commission) Guide 8.13. I will contact my supervisor or the radiation protection officer if I have any questions. I hereby certify that the exposure history listed on the obverse is correct and complete, to the best of my knowledge and belief. I have read and understand the above Privacy Act Statement.

81-04-25
Date (YYMMDD)

Whitney M. Brown
Signature of Applicant

Figure 1. Sample DD Form 1952—Continued.

RECORD OF OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

FOR INSTRUCTIONS, SEE REVERSE OF SHEET.

1. IDENTIFICATION NUMBER	2. NAME (Last, first, middle initial)	3. SOCIAL SECURITY NUMBER	4. RANK/RATE TITLE OF POSITION	5. DATE OF BIRTH (Day, month, year)
074	JARVIS, WHITNEY N.	777-07-3000	TDR	15 Apr 42

6. PLACE WHERE EXPOSURE OCCURRED	7. PERIOD OF EXPOSURE FROM (Day-Mo-Yr)	8. PERIOD OF EXPOSURE TO (Day-Mo-Yr)	9. DOSE THIS PERIOD (rem) SKIN DOSE (Self)	10. GAMMA AND X-RAY	11. NEUTRON	12. TOTAL THIS PERIOD	13. ACCUMULATED DOSE (rem) TOTAL LIFETIME	14. PERMISSIBLE LIFETIME (N-18)	15. INITIAL PERSON MAKING ENTRY
WHOLE BODY									
Previous Exposure[1]	Aug66	Apr68	NR	00.107	NU	00.107	00.107	-	CED
Admin Dose[2]	Apr68	Apr69	-	-	-	05.000	05.107	45.000	CED
APG-EA, MD	3May69	4Jun69	NR	00.000	NU	00.000	05.107	45.000	CED
do	6Jun69	6Jun69	Quarterly Review by RPO				-	-	JER
do	5Jun69	4Jul69	00.003	00.010	NU	00.010	05.117	45.000	CED
do	5Jul69	7Aug69	NR	00.078	NU	00.078	05.195	45.000	CED
do	8Aug69	6Sep69	Film Badge Lost[3]		NU	00.416	05.611	45.000	CED
do	8Sep69	8Sep69	Quarterly Review by RPO				-	-	JER
do	7Sep69	4Oct69	NR	00.064	NU	00.064	05.675	45.000	CED
do	5Oct69	4Nov69	NR	00.075	NU	00.075	05.750	45.000	WLW
do	5Nov69	6Dec69	00.016	00.070	NU	00.070	05.820	45.000	WLW
do	Film Badge Service Discontinued 6 Dec 69						-	-	WLW
do	6Dec69	6Dec69	Quarterly Review by RPO				-	-	JER
Fort Plunkett	2Jan70	3Feb70	NR	00.000	00.000	00.000	05.820	45.000	RKO
do	4Feb70	3Mar70	NR	00.178	00.062	00.240	06.060	45.000	RKO
do	4Mar70	2Apr70	00.052	02.504	00.126	02.630	08.690	45.000	RKO
do	22Mar70	22Mar70	Quarterly Review by RPO				-	-	MJM
do	3Apr70	4May70	Relieved From Duties				08.690	50.000	RKO
do	5May70	3Jun70	Involving Exposure to RAD[5]				08.690	50.000	RKO
do	4Jun70	2Jul70	00.017	00.100	00.043	00.143	08.833	50.000	RKO
Fort Smith, CA	Aug70	Jul71	No Film Badge Worn Or Exposure Received				08.833	55.000	GML
			SAMPLE						

16. REMARKS (Continue on additional sheet if necessary)

1. Nuclear Services, Inc., Shickshinny, PA
2. Rosewater University, Portland, OR
   No film badge records (AR 40-14).
3. Admin Dose = $\frac{5 \text{ rem}}{12 \text{ months}}$ = 00.416 rem
4. Alleged overexposure.
5. Pending investigation IAW AR 40-5.

NR - none reported; NU - not used
Has wrist badge No. 086.

TO BE RETAINED PERMANENTLY IN INDIVIDUAL'S MEDICAL RECORD

DD FORM 1141 PREVIOUS EDITIONS ARE OBSOLETE.

Figure 2. Sample DD Form 1141 for whole-body exposure.

RECORD OF OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

FOR INSTRUCTIONS, SEE REVERSE OF SHEET.

1. IDENTIFICATION NUMBER	2. NAME (Last, first, middle initial)	3. SOCIAL SECURITY NUMBER	4. RANK/RATE TITLE OF POSITION	5. DATE OF BIRTH (Day, month, year)
086	JARVIS, WHITNEY N.	777-07-3000	TDR	15 Apr 42

PLACE WHERE EXPOSURE OCCURRED	PERIOD OF EXPOSURE		DOSE THIS PERIOD (rem) 1. Method of monitoring is assumed to be film badge reading unless otherwise specified under Item 16, "REMARKS."				ACCUMULATED DOSE (rem)		INITIAL
ACTIVITY	FROM (Day-Mo-Yr)	TO (Day-Mo-Yr)	SKIN DOSE (Soft)	GAMMA AND X-RAY	NEUTRON	TOTAL THIS PERIOD	TOTAL LIFETIME	PERMISSIBLE LIFETIME 5(N-18)	PERSON MAKING ENTRY
6	7	8	9	10	11	12	13	14	15
Previous Exposure[2]	Aug66	Apr68	-	-	-	00.204	00.204	NA	CED
Admin Dose[3]	Apr68	Apr69	-	-	-	75.000	75.204	NA	CED
APG-EA, MD	3May69	4Jun69	NR	00.009	NU	00.009	75.213	NA	CED
do	6Jun69	6Jun69	Quarterly Review by RPO				-	NA	JER
do	5Jun69	4Jul69	00.007	00.018	NU	00.018	75.231	NA	CED
do	5Jul69	7Aug69	NR	00.159	NU	00.159	75.390	NA	CED
do	8Aug69	6Sep69	Film Badge Lost[4]		NU	06.250	81.640	NA	CED
do	8Sep69	8Sep69	Quarterly Review by RPO				-	NA	JER
do	7Sep69	4Oct69	NR	00.143	NU	00.143	81.783	NA	CED
do	5Oct69	4Nov69	NR	00.162	NU	00.162	81.945	NA	WLW
do	5Nov69	6Dec69	00.032	00.150	NU	00.150	82.095	NA	WLW
do	Film Badge Service Discontinued 6 Dec 69						-	NA	WLW
do	6Dec69	6Dec69	Quarterly Review by RPO				-	NA	JER
Fort Plunkett	2Jan70	3Feb70	NR	00.015	NU	00.015	82.110	NA	RKO
do	4Feb70	3Mar70	NR	00.420	NU	00.420	82.530	NA	RKO
do	4Mar70	2Apr70	00.140	18.125[5]	NU	18.125	100.655	NA	RKO
do	22Mar70	22Mar70	Quarterly Review by RPO				-	NA	MJM
do	3Apr70	4May70	Relieved From Duties[6]				100.655	NA	RKO
do	5May70	3Jun70	Involving Exposure to RAD				100.655	NA	RKO
do	4Jun70	2Jul70	00.025	00.200	NU	00.200	100.855	NA	RKO
Fort Smith, CA	Aug70	Jul71	No Film Badge Worn or Exposure Received				100.855	NA	GML
			SAMPLE						

16. REMARKS (Continue on additional sheet if necessary)

1. Wrist Record (WB Record 074)
2. Nuclear Services, Inc., Shickshinny, PA
3. Rosewater University, Portland, OR
   No film badge records (AR 40-14)
   NR - none reported; NU - not used.
4. Admin Dose = $\frac{75 \text{ rem}}{12 \text{ months}}$ = 06.250
5. Accidental Exposure. Case documented IAW AR 40-5.
6. Necessary to avoid exceeding quarterly limit

TO BE RETAINED PERMANENTLY IN INDIVIDUAL'S MEDICAL RECORD

DD FORM 1141 PREVIOUS EDITIONS ARE OBSOLETE.

Figure 3. Sample DD Form 1141 for wrist exposure.

15 March 1982 AR 40–14/DLAR 1000.28

The Army office of primary interest in this joint regulation is the Office of The Surgeon General. Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) direct to HQDA (DASG–PSP–E) WASH DC 20310.

By Order of the Secretary of the Army and Director, Defense Logistics Agency:

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APPENDIX C

RELEVANT LEGAL CASES

1. Allen v. United States, 588 F. Supp. 247 (D. Utah 1984) (nuclear weapons testing) (appeal pending)

2. Begay v. United States, 591 F. Supp. 991 (D. Ariz. 1984) aff'd (9th Cir. Aug. 13, 1985)

3. Brafford v. Susequehanna Corporation, 586 F. Supp. 14 (D. Colo. 1984) (uranium mill tailings)

4. Bulloch v. United States (Bulloch I), 145 F. Supp. 824 (D. Utah 1956) (sheep/fallout case - causation)

5. Bulloch v. United States (Bulloch II), 721 F. 2d 713 (10th Cir. 1983) (subsequent proceeding)

6. Crowther v. Seaborg, 312 F. Supp. 1205 (D. Col. 1970) (injunctive relief sought)

7. Employers Mutual Liability Insurance Co. of Wisconsin v. Parker, 418 S.W. 2d 570 (Ct.Civ.App.Tex. 1967) (workmen's compensation)

8. Ferrara v. Galluchio, 152 N.E. 2d 249 (N.Y. 1958) (X-ray therapy)

9. Garner v. Hecla Mining Company, 431 P. 2d 794 (S. Ct. Utah 1967) (uranium miner)

10. Greenberg v. Michael Reese Hospital, 83 Ill. 2d 282, 415 N.E. 2d 390 (1980) (X-ray therapy)

11. Johnston v. United States, 597 F. Supp. 374 (D. Kan. 1984 (radium dial workers)

12. Kuhne v. United States, 267 F. Supp. 649 (E.D. Tenn. 1967) (occupational exposure)

13. Krumback v. Dow Chemical, 676 P. 2d 1215 (Colo. 1983) (workmen's compensation)

14. McVey v. Phillips Petroleum Company, 288 F. 2d 53 (5th Cir. 1961) (occupational exposure)

15. Mahoney v. United States, 220 F. Supp. 823 (E.D. Tenn. 1963) (occupational exposure)

16. Roberts v. United States, No. LV 1766 RDF (D. Nev., filed June 14, 1984) (failure to demonstrate causation)

17. Silkwood v. Kerr-McGee Corp., 485 F. Supp. 566 (W.D. Okla. 1979); 667 F. 2d 908 (10th Cir. 1981) rev'd (on punitive damages grounds) 104 S. Ct. 615 (1984) (remanded) (occupational exposure)

Synopses of Key Cases

A. Allen v. U.S., 588 F. Supp. 247 (D. Utah 1984).

The 1,192 named plaintiffs in this case were residents (or relatives of residents) of communities in southern Utah, northern Arizona or southeastern Nevada near the Nevada test site. They alleged loss due to radiation-caused cancer or leukemia. The court held:

1.) The discretionary function exception did not shield the government from liability in these cases. Had the government made a policy decision that some people would be injured and could not be warned, the exception would have applied. But the government policy was to warn surrounding communities and to promote their safety.

2.) The government failed to provide plaintiffs with adequate information about the risk of, or about ways to prevent, long-range biological consequences of exposure to fallout.

3.) Ten of twenty-four plaintiffs selected as "bell weather cases" established that fallout was a substantial factor causing their injuries. The rest did not.

In finding ten plaintiffs had proved causation, the court emphasized that the government's "negligent failure to adequately monitor and record the actual external and internal radiation exposures of off-site residents on a person-specific basis" was a factor in the decision to shift some of the proof burden to the government."

B. Begay v. United States, 591 F. Supp. 991 (1984) aff'd (9th Cir. Aug. 13, 1985).

Former Navajo uranium miners and survivors of Navajo uranium miners brought suit against the United States for cancers and injuries caused by exposure to radioactive gas, radon, in the uranium mines from the 1940's through the 1960's. The plaintiffs claimed that the United States was negligent under the Federal Tort Claims Act (FTCA) in the decisions its officials made during that period concerning safety and regulation of the uranium mines. Specifically, plaintiffs claimed that the federal government agencies involved (the AEC, the U.S. Bureau of Mines, and the HEW) and Congress had conducted studies on the injurious effects of radon gas on the uranium miners, but failed to establish safety guidelines within the mines. Instead, the federal agencies and Congress only suggested guidelines for the states to implement.

The court found the U.S. was not negligent under the FTCA because the decisions made from the 1940's to the 1960's to not establish standards were high level policy decisions, and thus protected under the discretionary function exception to the FTCA.

C. Brafford v. Susquehanna Corp., 586 F. Supp. 14 (D. Colo. 1984)

The plaintiffs in this case sued a corporation for injury to their cellular structure and their increased risk of cancer and other diseases that allegedly resulted from the defendant negligently exposing them to a considerable amount of radiation. The plaintiffs, five members of one family, lived in a house in Edgemont, South Dakota for over two years. The town had been the site of a uranium milling facility since 1956 and the mill was operated by a subsidiary of the defendant's corporation until 1972. The house was built in the 1960's, and the plaintiffs purchased it in 1977. Plaintiffs contended that uranium mill tailings (waste material produced from milling uranium ores known to contain radioactive residues) from the defendant's mill placed in and around the foundations of the plaintiff's home had exposed them to considerable quantities of radioactive material. The plaintiffs sought compensation for the loss of their home, for present and future medical costs, and the mental grief from their radiation exposure.

The court ruled that the plaintiff's claim raised at least a question of fact entitling them to bring their case forward. Plaintiffs presented experts who testified that with a reasonable degree of medical probability, damage can occur immediately to cellular structures from overexposure to radiation.

D. Bulloch v. United States (Bulloch I), 145 F. Supp. 824 (D. Utah 1956)

In 1953 the AEC conducted a series of nuclear tests in the Nevada proving ground called "Operation Upshot Knothole". At the time of the first test, the plaintiff's herd of sheep were about fifty miles northeast of the site. Following the first test, and continuing until the last test, the sheep and lambs of plaintiff's herd were dying at abnormally high rates and showed lesions and other signs simulating the effects of beta and gamma radiation exposure. Other herds nearby suffered similar losses and complications. Plaintiffs contended that exposure to radiation fallout from the testing caused the loss and damage to the herd. They further contended that government officials negligently failed to warn them of the impending blasts, thereby failing to provide them a greater opportunity to protect their herd.

The court held that the government's failure to adequately warn the plaintiffs of the blasts and the possible danger to their herd did not fall under the discretionary function exception to the FTCA because such failure was not based on policy decisions. The plaintiffs, however, failed to prove that the damage to their sheep was actually and proximately caused by the nuclear blast. Their claim for damages was therefore denied.

E. Bulloch v. U.S. (Bulloch II), 721 F. 2d 713 (10th Cer. 1983)

Twenty-five years after the first Bulloch case, plaintiffs made a motion to set aside the District Court's judgment on the grounds of fraud. The Court of Appeals denied the motion, stating that the plaintiffs failed to establish proof that a fraud was committed on the court. The court held the plaintiffs should not have waited so many years to reopen the case, and suggested they were merely attempting to retry their case on the crest of a wave of public and congressional attention to this subject.

F. Crowther v. Seaborg, 312 F. Supp. 1205 (D. Colo. 1970)

The plaintiffs, represented by a public non-profit corporation, were landowners in the area surrounding the site of a joint venture test of the AEC, the Department of the Interior, and Austral Oil Co. The test, Project Rulison, was aimed at creating a cavity in the Mesa Verde formation for the release of natural

gases in commercial quantities. The plaintiffs sought to enjoin the defendants from exploding the device. They alleged that the test would damage the plaintiffs' property and present a hazard to public health and natural resources in the area through the radiation released from the detonation of the nuclear device.

The court refused to grant the injunction because the evidence did not support the plaintiffs' claim that flaring the nuclear device would present a danger to the health, life, or property of those in the vicinity.

Specifically, the court noted that because the AEC planned to carefully monitor radiation levels in the soil, water, air, wind, and milk, in the area the dangers to anyone close to the blast were both well under control and probably avoidable. The chances of a "blowout", an escape of radioactive gases from the flaring, were so remote, moreover, that it did not pose a threat of undue harm to property, life, or health.

G. Employers Mutual Liability Insurance Co. of Wis. v. Parker 418 S.W. 2d 570 (Ct. Civ. App. Tex. 1967)

Employers Mutual appealed a lower court decision granting Parker, the plaintiff, permanent disability status for cancer in the cervical lymph node. The plaintiff had been an employee engaged in contract work for the U.S. government handling radioactive material in assembling and disassembling nuclear weapons. As a material handler, plaintiff was not furnished any protective clothing. After his promotion to production operator, the plaintiff was required to wear a leaded apron and gloves with a film badge always worn under either the gloves or the apron. The evidence revealed that the plaintiff had been exposed to well over 36 rems during his employment.

This court refused to grant the plaintiff permanent disability for his cancer. The court concluded that the expert testimony presented in court established that the exposure to radiation was not the probable cause of the plaintiff's cancer.

H. Ferrara v. Galluchio 152 N.E 2d 249 (N.Y. 1958)

The plaintiff sued her doctors for malpractice. While suffering from bursitis in her shoulder, the plaintiff went to the defendants for treatment. The defendants, specialists in X-ray therapy, exposed the plaintiff in a series of seven treatments to 1400 Roentgens of radiation. The plaintiff suffered nausea during the treatments, and the area of her shoulder where the rays had been concentrated blistered, peeled, and left scabs which took an inordinate amount of time to heal. The resulting area exhibited

telanglectasia, hyperpigmentation, depigmentation, and some atrophy. Two years after the treatments, the plaintiff went to another dermatologist who prescribed a salve for the shoulder, and advised the plaintiff have herself examined frequently for signs of cancer. Plaintiff developed a mental anxiety, cancerophobia, as a consequence of the advice.

The issue before the court was whether the defendants were liable for the plaintiff's mental anguish resulting proximately from their negligent treatment with X-rays.

The court affirmed the lower court's holding that the plaintiff could recover for her cancerophobia. The plaintiff's basis for mental anxiety was founded on reasonable facts and, under N.Y. tort law, the defendants are liable for any injuries, now including mental anguish, which are the proximate result (i.e., reasonably foreseeable) of the defendant's original negligence.

I. Garner v. Hecla Mining Co., 1967 431 P.2d 794 (S. Ct. Utah 1967)

The plaintiffs in this case, the widow and children of Douglas Garner, attacked the findings of the Industrial Commission denying benefits to the plaintiffs for Garner's death. Garner worked for the defendant's uranium mining company for four years, and had been a uranium miner since 1940. Garner developed cancer in the lungs, bronchus, preaortic nodes, liver, spleen, and adrenal glands. He died soon after. An autopsy revealed that Garner had thirty-four times as much lead-210 (the end product of radon gas) in his bones as the average for a non-miner. Moreover, defendant's mines contained about two and a half times as much radon gas as the recommended levels approved by the federal government.

The court affirmed the Commission's denial of benefits because the plaintiffs failed to produce evidence substantially forging a link between Garner's exposure to radiation and his subsequent cancer In other words, the plaintiffs failed to prove that Garner's cancer was proximately caused, for purposes of the Utah statutes, by his exposure to radiation in the defendant's uranium mines.

J. Johnston v. U.S., 597 F. supp. 374 (D.Kan. 1984)

The plaintiffs in this case were four employees of Aircraft Instrument and Development, Inc. (AID), of Wichita, Kansas who claim their concerns were caused by exposure to ionizing radiation from luminous dials and instrument parts the U. S. sent to the AID plant primarily for storage. The court held:

1.) the decision of the government to ship the radioactive parts was protected by the discretionary function exception of the F.T.C.A.

2.) In any event, the plaintiffs failed to prove their exposure to radioactive parts caused their injuries.

K. Kuhne v. United States 267 F. Supp. 649 (E.D. Tenn. 1967)

Plaintiff's decedent worked for an independent contractor to the government at the Oak Ridge atomic plant in eastern Tennessee from 1944 to 1945. Decedent worked as a supervisor over a portion of the project that broke down uranium, often exuding radioactive dust and particles Unlike the other personnel, the decedent, as a supervisor, was not required to wear and did not wear protective clothing. Several years later, the decedent developed myelofibrosis (a disease that attacks the bone marrow, reducing its production of red blood cells). Plaintiff sued the government for negligence under the FTCA, claiming that its officials at Oak Ridge failed to adequately warn her husband of the hazards involved in working with radiation, failed to provide protection, and failed to set appropriate safety standards.

The court ruled:

a. The discretionary function exception to the FTCA did not apply in this case because the government was well out of the planning and policy stage at Oak Ridge when the decedent began to work for them. They were in the operational stage of carrying out the policies of the government already decided upon.

b. The Feres doctrine did not apply because the decedent was a civilian engineer, not a soldier, or in any way connected to the armed forces or the military.

c. Plaintiff's testimony did not carry its burden of showing that decedent's disease was indeed the result of his exposure to radiation. The medical experts presented conflicting evidence, none of which was conclusive in the court's opinion.

L. Krumback v. Dow Chemical Co. 676 P.2d 1215 (Colo. 1983)

Plaintiff's husband worked from 1959 until 1973 at the Rocky Flats Nuclear Weapons Plant, a facility of the Dow Chemical Co. He was exposed to over 45 rems of external radiation and was involved in a number of industrial accidents resulting in internal

radiation contamination during the course of his employment. Plaintiff's husband died in 1974 of cancer of the colon. The plaintiff brought a claim to the Industrial Commission for benefits accruing from what she alleged was her husband's occupational disease, caused by overexposure to radiation.

The hearing examiner found that although the expert testimony was in conflict, the plaintiff had shouldered her burden of proof that overexposure to radiation at the defendant's facility caused her husband's disease. The Commission reversed the examiner and refused to permit the testimony of two of the plaintiff's key expert witnesses because they were not competent medical witnesses.

The court reversed the Commission for excluding the experts' testimony. The court then remanded the case for consideration in light of the evidence admitted by the plaintiff's two witnesses.

M. McVey v. Phillips Petroleum Co. 288 F.2d 53 (5th Cir. 1961)

The plaintiffs, two employees of the Kellogg Co., used the defendant Phillips' radioactive pellets to provide the X-rays for a device manufactured by Kellogg to detect cracks in welded pipes. While unpacking radioactive pellets shipped by the defendant, two of the pellets exploded, emitting radioactive dust and particles that irradiated the plaintiffs. Plaintiffs alleged they later developed fatal cancers as a result of their exposure. The plaintiffs dosimeter badges measured below the maximum permissible weekly exposure accumulation of 300 milliroentgens for the week of the explosion.

The court denied recovery, holding that plaintiffs had failed to prove their cancers resulted from exposure to the radiation.

N. Mahoney v. United States 220 F. Supp. 823 (E.D. Tenn 1963)

The plaintiffs worked for Union Carbide at the Oak Ridge nuclear facility in Tennessee. The majority of the plaintiffs were members of Union Carbide's maintenance crew working with noxious and radioactive gases and substances. Each of the plaintiffs was regularly exposed to and inhaled radioactive gases. On one particular occasion, plaintiff Mahoney had been exposed to noxious fumes and breathed radioactive gases during an explosion of one of the pipes. Mahoney and the other plaintiffs subsequently developed Hodgkin's disease or lukemia, both blood cancers.

The plaintiffs filed suit against the United States under the FTCA. The AEC had been in primary control of the facility, even though Union Carbide was an independent contractor. After a lengthy description of each of the plaintiff's exposures and surrounding circumstances, and a detailed analysis of the science and physics behind radiation and its exposure and effect on the human body, the court concluded that the plaintiffs did not prove, through a preponderance of the evidence, that the plaintiffs' injuries were caused by the amount of radiation exposure received.

O. Roberts v. U.S., No. LV 1766 RDF (D. Nev., filed June 14, 1984).

The plaintiffs in this case were widows of two men who worked for a private contractor in Area 12, some three and a half miles from the Banberry test site in Nevada. Banberry was exploded underground on December 18, 1970. Due to unforseen geographic and meteorologic circumstances, a fissure developed. Radioactive dust was released and the wind carried the dust over the campsite irradiating the plaintiffs. They later developed leukemia and died.

The court held:

1.) the decision to hold the test was a policy decision protected by the discretionary function exception to the FTCA.

2.) there was a duty, once a decision was made to evacuate the campsite, to do so properly. The government did not meet the standards set forth in the AEC handbook for evacuation and decontamination.

Specifically, there were no plans or procedures to insure that personnel in Area 12 were accounted for, monitored for radiation and promptly decontaminated. Once the venting occurred, the government failed to order the immediate evacuation of Area 12. It even permitted workers to proceed into the area. It also failed to promptly decontaminate the exposed workers. Roberts, for example, remained in contaminated clothes and in a contaminated vehicle for more than eight hours after his exposure

3.) Nonetheless, the plaintiffs did not prove that their injuries were directly and causally linked to their exposure to the Banberry cloud. First they presented no evidence confirming alpha radioactivity permeated Area 12. Roberts' film badge indicated an exposure of something less than 900 mrem gamma of which some 530-600 rem came from wearing a contaminated fur collar, "which resulted in a lower dose to the whole body." The court found a total internal dose to his red bone marrow of 420 mrem (0.42 rem). Relevant exposure standards for workers are 3 rem per quarter and 5 rem per year. Roberts' exposure, in short, was well within the standards. The court rejected claims by experts' for the plaintiffs that exposure to low doses causes an increase in the incidence of leukemia. Because the burden was on the plaintiffs to establish that the doses of radiation received did, to a reasonable degree of certainty, cause the leukemia from which Roberts died, the claim of his widow was denied.