**A Guide to the Selection, Training,
and Licensing or Certification
of Reprocessing Plant Operators**

(Volume I)

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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CHEMICAL TECHNOLOGY DIVISION

A GUIDE TO THE SELECTION, TRAINING, AND LICENSING OR
CERTIFICATION OF REPROCESSING PLANT OPERATORS

Volume I

Compiled by:

The Staff of the Pilot Plant Section

JUNE 1976

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A GUIDE TO THE SELECTION, TRAINING, AND LICENSING OR
CERTIFICATION OF REPROCESSING PLANT OPERATORS

FOREWORD

The Code of Federal Regulations, Title 10, Part 55, commonly referred to as 10 CFR 55, establishes procedures and criteria for the licensing of operators, including senior operators, in "Production and Utilization Facilities" that are themselves licensed under 10 CFR 50. Since production facilities are defined to include plants for reprocessing irradiated nuclear fuel and since several commercial fuel reprocessing plants are scheduled to go into operation during the next few years, considerable interest has been expressed in the nuclear industry concerning the need for guidance in training operators. The ERDA Division of Operational Safety, therefore, has supported a program at Oak Ridge National Laboratory (ORNL) to develop personnel guides that will assist the ERDA and the nuclear industry in this respect.

This first training guide proposes to facilitate the licensing of operators for nuclear reprocessing plants by offering generalized descriptions of the basic principles (theory) and the unit operations (mechanics) employed in reprocessing spent fuel. Hopefully, this generalized approach will assist in the writing of training manuals for operators in specific reprocessing plants and in preparing these individuals for their licensing examinations. The guide is written in two parts: Volume 1 supplies details about the portions of a training program that are of major interest to management, and Volume 2 presents a step-by-step description of typical fuel reprocessing operations together with controls and utility systems that support these operations. When the final draft for the present guide is complete, similar guides will be undertaken for fuel fabrication and other facets of nuclear fuel production.

The contributors to this training manual have all had long careers in their respective areas of radiochemical operations, and each brings a special expertise to this effort. Several have actively participated in the training of radiochemical operators at ORNL and in licensing operators at other facilities. It is appropriate here to acknowledge the most valuable contributions of R. E. Brooksbank, W. D. Box, F. N. Browder, J. M. Chandler, H. E. Cochran, M. F. Fair, R. W. Horton, Elizabeth B. Johnson, L. J. King, J. L. Matherne, W. T. McDuffee, C. H. Miller, R. G. Nicol, J. R. Parrott, R. H. Rainey, A. D. Ryon, L. B. Shappert, R. B. Waters, C. D. Watson, W. R. Whitson, O. O. Yarbrough, and E. L. Youngblood of ORNL; A. J. Hill, Jr. of Savannah River Laboratory; and H. J. Moe of Argonne National Laboratory.

A GUIDE TO THE SELECTION, TRAINING, AND LICENSING OR CERTIFICATION OF REPROCESSING PLANT OPERATORS

1. INTRODUCTION

The objective of this guide is to describe the recruiting, selection, and training actions found through experience to be necessary for providing competent operators and senior operators to perform the duties required in a present-day plant for reprocessing spent nuclear reactor fuel. This guide is intended to serve as a tool not merely for preparing applicants to pass "tests" but to operate complex and potentially hazardous processes with minimum danger to themselves and the public. Because a considerable investment goes into training operators, care must be taken in recruiting and selecting people with the proper qualifications that will make them competent operators. This guide presents some of the important qualifications to look for in operator candidates.

After candidates have been selected, the training needed to convert their potential into competence is of great importance. The dividends from proper training are manifold:

First, employees who are given a chance to improve their knowledge, skill, and attitude become more productive. The returns realized from this effort will usually far exceed the training cost.

Second, employees who receive proper training work more safely, thereby reducing lost-time accidents. This factor not only reduces costs but adds tremendously to the priceless commodities of the lives and health of all personnel in the plant and not just those involved directly in the radiochemical operations.

Third, proper training tends to reveal potential management capability in employees, making them even more valuable.

In addition to the advantages listed here, proper training will prepare operator candidates for licensing and/or certification. The Atomic Energy Act of 1954 as amended requires the Nuclear Regulatory Commission to:

1. Prescribe uniform conditions for licensing individuals as operators of licensed "production and utilization facilities";
2. Determine the qualifications of such individuals; and
3. Issue licenses to such individuals....and also to
4. Suspend licenses for violations of any provisions of the Act or any rule or regulation issued thereunder whenever the Commission deems such action desirable.

The basic Commission regulation which implements these operator licensing requirements of the Act is Title 10, Part 55, of the Code of Federal Regulations, commonly referred to as 10 CFR 55. The plants themselves are licensed under 10 CFR 50. Part 55 lists definitions and specifies conditions and content of operator licensing actions and calls out content and time scale for operator qualification testing. Nothing in this guide is intended to be a different interpretation of those requirements; rather, it is expected that this guide will be useful for study by candidates for operator and senior operator licenses and useful to those who prepare training manuals and conduct training classes that are specific in content for the facility being licensed. Responsibility for personnel training belongs to the facility licensee. The Commission provides guidance, specifies the requirements, and arranges for qualification testing of the operators and senior operators.

Basically the function of a reprocessing plant is to separate the uranium and plutonium values from spent nuclear fuel. On occasion, neptunium-237 may be recovered as a by-product of these operations. Compared with a nuclear reactor, whose operations are essentially the same day after day, the reprocessing plant may be regarded as a set of variable chemical and mechanical unit operations. Each plant startup may be different, and flowsheets and chemical conditions must be optimized to produce acceptable production rates. Decontamination from fission products and product losses must be kept within the demands made by conventional and nuclear safety. Because there are reprocessing plants in operation and under construction that employ slightly different flowsheets, a generalized approach has been taken in this document. For this reason, only broad descriptions of the basic principles (theory) and the unit operations (mechanics) employed in reprocessing spent fuel are offered in this guide.

2. SELECTION OF CANDIDATES

Since the training of an operator is a costly undertaking for the firms engaged in the reprocessing industry, the product of this training can be a valuable asset. As was emphasized in the previous section, operators in the reprocessing plant must have the competence to pass the NRC licensing examination required by Federal statutes. Although no cost figures on training radiochemical plant operators are available, the cost of preparing a nuclear reactor operator for licensing has been estimated at \$20,000 per individual. In view of this factor alone, operators must be selected with considerable care and forethought. Furthermore, a roster of able individuals, coupled with a well-rounded training program, can assure superior plant operation under normal conditions and will help assure that needed extra performance during abnormal conditions. Although each reprocessing plant organization has its own philosophy, it is agreed that highly qualified personnel provide that most desirable factor, "in-house" capability. Thus, the ability to select first-quality personnel is essential.

2.1 INITIAL SCREENING OF CANDIDATES

Once a qualified group of managers and supervisors has been selected, applicants for the operations, technical, and maintenance groups should be sought. Each applicant should be interviewed by the plant manager and the operations supervisor. Operator candidates should be evaluated for the following characteristics.

- A. Motivation. — A genuine desire to excel, characterized by a steady and continuing application of the required effort to reach above-average achievement. Experience has indicated that this characteristic cannot be determined by testing. Previous achievements and past employer references provide a measure of this trait.
- B. Technical Qualifications. — An applicant's participation in and completion of special courses and training show evidence of a desire to further his learning. The caliber of present job performance and job knowledge may be of assistance in evaluating his technical qualifications.
- C. Academic Achievement. — Formal education, including academic standing and scores on general intelligence tests. This skill is the best indication of the applicant's ability to study and achieve a good score on the written portion of the NRC license examination. Although not required, the completion of study in a professional two-year technical school or equal training in an accredited college provides adequate academic achievement.

- D. Stability. — Personal character, emotional stability, and sociability. Being accepted by his family, friends, and community as an honorable and respected citizen is a suitable indication of this trait.
- E. Adaptability. — Willingness and desire to relocate and establish himself and his family in a community close to the work site. In this regard, candidates who have their roots in the immediate plant area have an advantage over those who remain as transients not participating in community affairs.
- F. Medical History. — A preliminary medical examination before job offers are extended can prevent resentment among applicants. Evaluation and ratings for mental, physical, and over-all health should be coordinated with evaluations from the employment department.

2.2 TESTING

In prior years, selection of operator candidates was based on professionally prepared and scored aptitude tests. Because the use of such tests is now prohibited by law, operator candidate selection is now based on interviews with the person, recommendations from previous employers, education, training, health, and the general impression received from a review of the candidate's overall qualifications.

2.3 EDUCATIONAL BACKGROUND REQUIREMENTS

Recent experience¹ in the hiring of qualified radiochemical operators has indicated that the professional two-year technician school or equivalent training in a college or university provides an excellent source of such manpower. Applicants with this type of educational background have a reasonable understanding of physical and chemical terminology. Because the costs associated with a training program are necessarily high, this source of manpower should be considered. Operators working in government-sponsored reprocessing plants become available from time to time, and these people usually have training and experience in working with radioactivity. Also, some untrained and inexperienced individuals will probably be hired; these should be high school graduates whose records show a high degree of adaptability, the ability to absorb training rapidly, and a good sense of personal responsibility.

2.4 HUMAN FACTORS

One facet in selecting new employees for the nuclear industry concerns the role that human factors play in job performance. An employee who is hired to operate a left-handed widget machine may not need complete facility of his right hand, whereas a chemical operator should be dexterous enough to manipulate equipment inside a glove box, make up solutions, operate manipulators, and otherwise carry on the day-to-day operations of fuel recovery. Such items as sensitivity to solvents, acids, or detergents or the inability to wear gas masks, work in protective clothing, or climb to moderate heights above floor level should be investigated and noted before employment.

When a potential employee is given a medical examination, the staff examiner should have a thorough understanding of the requirements of the job. Any exceptions that might influence the performance of the applicant in his job functions should be noted on the medical certificates.

REFERENCES FOR SECTION 2

1. R. E. Brooksbank, W. H. Lewis, and D. J. Skovolt, *Licensing of Reprocessing Plant Operators*, ORNL-TM-2573 (June 1969).

3. LICENSING

This section of the guide describes the procedures and criteria necessary for the issuance of licenses to operators, including senior operators, of facilities licensed or authorized pursuant to the Atomic Energy Act of 1954 as amended.

3.1 REQUIREMENTS

The regulations contained in 10 CFR 55 apply to any individual who manipulates the controls of any facility, in this case a nuclear fuel reprocessing facility, that is licensed or authorized pursuant to Part 50 or 115 of that chapter and to any individual designated by a facility licensee or holder of an authorization to be responsible for directing the licensed activities of licensed operators. No person may perform the function of an operator or a senior operator as defined in 10 CFR Part 55 except as authorized by a license issued by the Nuclear Regulatory Commission. The Commission, however, specifically exempts an individual who is being trained and is under the direction and in the presence of a licensed operator or senior operator.

The contents of an application for licensing individuals who manipulate the controls of a properly licensed facility are set forth in Section 55.10 of Part 55, which states in part:

"Applications for licenses should be filed in triplicate, except for the report of the medical examination, and shall contain the following information:

- (1) The full name, citizenship, age, address, and present employment of the applicant;
- (2) The education and pertinent experience of the applicant, including detailed information on the extent and nature of responsibility;
- (3) Serial numbers of any operator and senior operator license issued by the Commission to the applicant and the expiration date of each;
- (4) The specific facility for which the applicant seeks an operator or senior operator license;
- (5) The written request of an authorized representative of the facility licensee or holder of an authorization that the operating test be administered to the applicant at the facility;

- (6) Evidence that the applicant has learned to operate the controls in a competent and safe manner and has need for an operator or a senior operator license in the performance of his duties. The Commission may accept as proof of this a certification of an authorized representative of the facility licensee or holder of an authorization where the applicant's service will be utilized. This certification shall include details on courses of instruction administered by the facility licensee, number of course hours, number of hours of training and nature of training received at the facility, and for reactors, the start-up and shut-down experience received.
- (7) A report of a medical examination by a licensed medical practitioner, in one copy in the form prescribed in Section 55.60."

In addition, the Commission may, at any time, request further information or impose additional requirements that it "deems appropriate or necessary to protect health and to minimize danger to life or property." Communications, reports, and applications should be addressed to the Director of Licensing, U.S. Nuclear Regulatory Commission, Washington, D.C. 20545, or may be delivered in person at the Commission's offices at 1716 H Street N.W., Washington, D.C.; at 7920 Norfolk Avenue, Bethesda, Maryland; or at Germantown, Maryland.

Full and accurate completion of NRC Form 396 (Certificate of Medical Examination, shown in Fig. 3.1.1) is essential to the expeditious processing of applications. Incomplete, illegible, or unclear medical reports will cause delay and requests for further information. When significant abnormalities exist, the detailed reporting of manifestations, diagnoses, and prognoses with supporting data may expedite the processing of applications and eliminate the need for additional correspondence. Special attention is directed to the following items in the Physical Examination section of the report form:

- A. Methods, where requested, must be indicated.
- B. Visual acuity (items 6-9) should be reported in a conventional manner. Near-point and far-point designations are not a satisfactory substitute for reports of acuity.
- C. If corrective lenses are not worn, there is no need to complete line 7 or 9. If corrective lenses are worn, all four items — 6, 7, 8, and 9 — must be completed.
- D. Visual fields (item 11) must be reported in degrees or as "full," "complete," or "normal" (or equivalent).

U. S. NUCLEAR REGULATORY COMMISSION

CERTIFICATE OF MEDICAL HISTORY

Facility Operator's or Senior Operator's License

Instructions: Applicant must complete all items on page 1. Typewrite or print in ink. Physician must complete all items on page 2.

1. Last Name First Name Middle Name 2. Date of Birth

3. Home Address 4. Sex

Have you ever had or do you now have any of the following? Give details of any condition answered in the affirmative under item 37.

	Yes	No		Yes	No
5. Rheumatic fever			16. Bone, joint, or other deformity		
6. Frequent or severe headaches			17. Painful or "trick" shoulder		
7. Dizziness or fainting spells			18. Painful or "trick" elbow		
8. Eye trouble			19. Paralysis		
9. Diabetes			20. Epilepsy or fits		
10. Tuberculosis			21. Depression or excessive worry		
11. Chronic shortness of breath			22. Loss of memory or amnesia		
12. Pain or pressure in chest or "heart attack"			23. Nervous condition which could impair judgment or reliability		
13. High blood pressure			24. Drug, narcotic habit or excessive drinking		
14. Low blood pressure			25. Do you normally wear eyeglasses?		
15. Peptic ulcer					

Complete each of the following. Give details of every affirmative answer under item 37.

	Yes	No
26. Has your work ever been limited or restricted for medical reasons?		
27. Have you ever been denied or rated up for life insurance for medical reasons?		
28. Have you ever been under observation or received care or treatment for any mental or nervous condition as a patient in a hospital, sanatorium, clinic, or other facility, or from a physician, clinical psychologist, etc.?		
29. Have you ever been rejected for or discharged from employment or military service for physical, mental, or nervous disorder reasons?		
30. Have you ever received, is there pending, have you applied for, or do you intend to apply for pension or compensation for existing disability?		
31. Have you ever seriously considered committing suicide?		
32. Have you ever been convicted of any violation of Federal law, State law, county or municipal law, regulations or ordinance? Do not include anything that happened before your 16th birthday. Do not include violations for which a fine of \$25 or less was imposed.		
33. Have you ever had any major illness or injury other than those already noted?		
34. How many jobs have you had in the last 3 years?		
35. What is the length of time in your present employment?		
36. Give a brief statement of your present health in your own words:		

37. Details of any items 5 through 33 answered in the affirmative. In addition, if your medical history includes any matter relating to physical, mental, or nervous condition, please describe the condition and set forth your explanation of why this matter would not affect your ability to function as a facility operator. Use additional sheet if more space is needed.

38. I certify that the foregoing information supplied by me is true to the best of my knowledge, and authorize the Nuclear Regulatory Commission to use any of the information in this certificate in the exercise of its authority over the licensing of operators.

(Date)

(Facility)

(Signature of applicant)

SIGN YOUR NAME IN INK AS IT APPEARS ON YOUR APPLICATION FOR OPERATOR'S OR SENIOR OPERATOR'S LICENSE

Fig. 3.1.1. Certificate of Medical History (Front)

MEDICAL EXAMINATION

39. Doctor: It is essential that each of the items on this page be completed. Sign the Certificate and mail to the Director, Division of Reactor Licensing, United States Nuclear Regulatory Commission, Washington, D.C. 20555 for reactor operator license applicants or to the Director, Division of Materials and Fuel Cycle Facility Licensing, United States Nuclear Regulatory Commission, Washington, D.C. 20555 for applicants for non-reactor licenses.

40. Physician's Summary and elaboration of the medical history on front of report. Use additional sheet if more space is needed.

Physical Examination. Give details of abnormal findings under item 20 below.

1. Date of examination	2. Height	3. Weight
4. Blood pressure	5. Pulse	
6. Distant visual acuity uncorrected	right left	method used
*7. Distant visual acuity corrected	right left	(data required only if corrective lenses are normally worn)
8. Near visual acuity uncorrected	right left	method used
*9. Near visual acuity corrected	right left	(data required only if corrective lenses are normally worn)
10. Color vision		method used
11. Gross visual fields		
12. Hearing	right left	method used
13. Eyes, general	14. Pupils	
15. Ophthalmoscopic		
16. Ears, general	17. Drums	
18. Heart	19. Vascular system	
20. Details and evaluation of any item 1 through 19, above, reported abnormal and summary evaluation of over-all condition.		

21. Did the foregoing examination reveal any mental or physical disability which might cause impaired judgment or motor coordination? ☐ YES ☐ NO

I understand that any of the information in this examination may be used by the Nuclear Regulatory Commission in the exercise of its authority over the licensing of operators.

(Date)

(Signature of examining physician)

DOCTOR: IT IS REQUIRED
THAT EVERY ITEM ON THIS
PAGE BE COMPLETED EX-
CEPT THOSE MARKED WITH *
WHEN NOT APPLICABLE.

Typed or printed name of examining physician

Address

State in which licensed

Fig. 3.1.1. Certificate of Medical History (Back)

- E. If hearing is not normal (item 12), audiometric data must be reported.
- F. An indication of "not applicable," "no significant information," or other similar notation should be entered for items where such a notation is appropriate, instead of merely failing to make an entry for such items.
- G. A chest x ray should have been performed within one year prior to the date of the medical examination. The date and evaluation of the x ray should be entered under item 40.
- H. Completion of all items is required, except as indicated in C above.

After the completed application and the medical report of an applicant have been satisfactorily reviewed by the NRC, the applicant is given a series of written and oral examinations that have been prepared by NRC and consulting examiners.

In addition to satisfying the regulatory function of the Atomic Energy Act, these examinations provide the management of a given facility with an appraisal of the effectiveness of the training at that facility.

3.2 CATEGORIES OF OPERATORS

For operating personnel of nuclear fuel reprocessing facilities, there is further classification of the operator and senior operator categories specified in 10 CFR Part 55. The exact number and titles of these categories are presently determined for an individual facility by mutual agreement between the Commission and the licensee. Operator categories in existing nuclear fuel reprocessing facilities include: Chemical Process Operator, Control Room Operator, Manipulator Operator, and Senior Operator. These categories may include operator and/or senior operator classifications, depending on need and level of certification. Each operator is tested and certified for his or her particular operational assignment and duties. For instance, a manipulator operator would perform predominantly mechanical (as opposed to chemical) operations encountered in the head-end portion of a nuclear fuel reprocessing facility, such as fuel receiving and storage; shipping-package decontamination, inspection, and servicing; broken fuel element handling and packaging; fuel segmentation; handling segmented fuel, storing it, and charging it to the feed preparation portion of the fuel process equipment train; and handling of scrap and waste from the above operations.

The chemical operator's responsibilities include the sampling of process streams for process control and nuclear material accountability, preparing nonradioactive process solutions, and packaging and handling of products. He is also responsible for the roving patrol duties necessary for process surveillance, for jetting in-cell process sumps, and for adjusting extraction column pulsers.

The control room operator plays an important role in the safe and efficient operation of a reprocessing plant since he has the responsibility for operating the controls for the chemical process. His duties include the operation of dissolvers and extraction columns; product purification and evaporation; and the managing of rework operations, acid recovery, waste treatment and storage, and off-gas systems.

The senior operator must be capable of performing the duties of all the aforementioned operators. A senior operator, however, should display a wider and more thorough knowledge of facility administrative controls and the provisions of applicable regulations. He should have an understanding about the theory of the process, know what are in the technical specifications for the plant, and demonstrate a higher degree of competence than the other operators. The shift supervisor is usually required to have a senior operator license. A senior operator may, on occasion, represent the facility management during the absence of the latter. In general, a senior operator is expected to serve as a "lead operator" and will often be expected to assume the duties and responsibilities of a foreman.

3.3 EXAMINATION AND CERTIFICATION OF OPERATORS

This section discusses the testing or examination of the candidates and the certification process used by the NRC to license operators. Basically, two tests are given each operator candidate: a written examination and an oral or walk-through examination of the candidate's knowledge of the facility and process flowsheets and of the safety features and safety procedures to be used during normal and abnormal conditions. The specific questions are changed for each examination period, but the general format of the testing remains the same year after year. According to 10 CFR Part 55.32, each operator and senior operator license shall expire two years after the date of issuance. Reexamination of the operators and senior operators may or may not be required by the Commission after this two-year interval. On August 17, 1973, an Appendix A was added to Part 55, which gives the requirements to be met to demonstrate continued competence every two years in order for a license to be renewed. Requalification Program requirements are also presented in 10 CFR Part 55 - Appendix A.

3.3.1 Written Examination of Candidates

When plant management is assured that an individual candidate for an operator license is sufficiently trained for the duties he or she is to perform, the NRC is requested to administer the written licensing examination.

The examinations are prepared specifically for each facility, using facility literature such as the Safety Analysis Report (SAR), training guides, etc., and are changed with each request to avoid "feed-back" of

answers from one examination to the next. The content of the written examination for nuclear fuel reprocessing facility operators is taken from 10 CFR 55.21 and 10 CRF 55.22 where applicable. Where some questions of Part 55.21 and 55.22 relate specifically to nuclear reactor operations, substitute questions on nuclear fuel reprocessing operations are provided. The examinations usually require three to six hours for completion, and a score of 70 is considered passing. Separate examinations are given to candidates for the respective operator categories described in Section 3.2. The walk-through examinations usually require two to four hours for completion.

The written examinations are divided into subparts, depending on the types and grouping of operators planned for the facility. For example, all examinations have questions on radiological safety, standard and emergency procedures, instrumentation and controls, chemistry, and equipment design and characteristics, whereas examinations for senior operators may have additional questions covering topics such as administrative procedural rules, physics, and power and auxiliary systems.

3.3.2 Sample Examination Questions

A comprehensive set of questions typical of those appearing in written examinations for operator and senior operator can be found in the Appendix to this chapter. The questions are grouped according to subject categories and according to operator or senior operator classification, and answers are provided for completeness.

3.3.3 Operator Certification

After it has been demonstrated to the Commission that the candidate's knowledge and understanding of the facility operations and administration are satisfactory and that he or she meets the requirements of the Atomic Energy Act and regulations of the Commission, the Commission will issue a license in such form and containing such conditions and limitations as it deems appropriate and necessary. The conditions of the license are stated in 10 CFR Part 55.31.

4. THE TRAINING PROGRAM

Effective training programs are those that wisely adapt and apply the basic principles of supervision, administration, and management. This process is never simple, and it must be nurtured from a deep understanding of the learning-teaching process that is influenced by the many factors in human development, learning, and the techniques of education and training.

4.1 MANAGEMENT FUNCTIONS

Present regulations and the increasing demand for training of nuclear reprocessing personnel have created a more critical requirement for skilled instructors, supervisors, managers, and administrators. In establishing a training program, management has five major functions: planning, organizing, directing, coordinating, and controlling.

Planning is the process of determining the specific requirements for training, the objectives, the barriers and bridges on the way to these objectives, and the staff and material resources needed.

Organizing is the process of staffing to achieve the objectives and assigning areas of responsibility and authority for the work to be done.

Directing and coordinating are processes that integrate all elements of the program and cause them to flow smoothly.

Controlling is the process of evaluating the results of training and taking action to improve the training program.

4.1.1 Planning the Training Program

In the planning function, management must accept the following responsibilities before a training program can be organized:

1. To determine the performance expected of graduates of their training programs.
2. To determine the exact requirements and objectives of the training program.
3. To survey the present employees' qualifications.
4. To inventory the resources available and list those needed to teach the program.
5. To develop standards for selection of instructors and other staff members concerned with the training program.

Each objective in a training program must be consistent with and must support the entire mission of the program. Constant tinkering with a training program without regard to these objectives will result in a weak training effort and a dissipation of resources. To reiterate, a course of action should be prepared and supported only after all the training information has been collected and digested. In obtaining this information, liberal use should be made of staff members to investigate and recommend action; but the management must make the decision and assume responsibility. Once the course of action is decided, the next step is to organize the resources.

4.1.2 Organizing the Training Program

Organizing is a primary responsibility of management. It can be defined as the process of assembling the procedures and structure for the training program.

Organization brings together all the functions, procedures, and resources necessary to form an effective training program. Some of the major concerns are: (1) lines of authority and responsibility, (2) regulations and procedures, (3) obtaining and assembling resources, (4) personnel assignments, and (5) combining all the elements into an operating program. A formal organization chart should be prepared so that the following responsibilities are delineated:

1. Prepare budget estimates for money and resources needed.
2. Recruit, select, and appoint instructors and other staff members.
3. Provide orientation and assign responsibilities to new instructors and staff.
4. Bring in outside specialists to assist in teaching.
5. Prepare and interpret regulations of an administrative nature.
6. Develop reporting procedures.
7. Establish a library of the most appropriate professional books, TV films, brochures, etc., on training methods.

Several principles of structural organization, although not inflexible laws, should be given serious consideration.

Responsibilities and Authority — The basic concept is that responsibility cannot be properly assigned without also assigning the authority to make decisions and to carry them out. Authority to make these decisions should be delegated as far down the line organization as possible without loss of essential control of the activities involved.

Homogeneous Assignment — Functions that are closely related should be assigned to one organizational unit. Whenever possible, the training program should not be administered by either the production department or the personnel department but should have a separate department of its own.

Unity of Control — The responsibility and authority of the training program should be assigned to one person who can be held responsible. Confusion often results from uncoordinated actions taken by staff people without regard to the lines of authority. These lines of authority should be written so that line personnel know the limits of their authority. Good judgment and experience rather than rigid rules are necessary in deciding how many people one man can supervise and how great a load he can carry.

4.1.3 Directing the Training Program

During the directing process, all the functions of the training program are put together and tested under the actual working conditions. This involves implementing, adjusting, and revising the procedures as experience warrants. Directing a training program includes the following:

1. Giving directions to put the training program into action.
2. Delineating to key personnel their levels of responsibility, the desired objectives, policies, plans, and detailed procedures to be followed.
3. Resolving any inconsistencies that arise after the program has begun to function.
4. Reviewing the program and modifying it where effective use of the resources can be improved.

Standard practice procedures should be established for activities of a recurring nature in order to get maximum use of time spent on the training program. Each person in the training program should know what is expected of him and the manner in which his efforts are to be synchronized with others. There is always the danger that the program will not move forward because everyone is waiting for someone else to do his part.

4.1.4 Coordinating the Training Program

Coordinating a training program involves influencing and bringing into agreement the various elements that affect the operation of the training program. Here the manager of training must work with managers of other departments to bring about harmonious adjustments for smooth operation.

The training manager may do this by (1) working with other supervisors on matters affecting the entire instructional program, (2) securing understanding and agreement among those with a common or related purpose, (3) arranging for visits from production supervisors to explain how the training program can benefit them, and (4) acting as a clearing-house for good ideas.

Good coordination and good communication go hand in hand. Enough time should be allowed so that each supervisor in the production department can still meet his deadlines while his workers are being trained.

4.1.5 Controlling the Training Program

Controlling involves constant evaluation of the work and the procedures by detailed comparisons with the objectives of the program. Controlling functions include (1) assessing work and progress and comparing them with established objectives, (2) taking positive and immediate action to bring the work within these established objectives, and (3) evaluating final results in terms of the established objectives and preparing reports on these findings.

The process of controlling may lead to new planning or may merely be the constant job of removing obstacles in the path to the established objectives. Control can be initiated through personal contacts and direct observation. Control must also be based on complete records, reports, and cumulative information.

4.2 DETERMINING TRAINING REQUIREMENTS

The process whereby training needs or requirements are determined must be established by competent personnel using special care and having complete information. Determining training needs requires a high degree of good judgment about the learning and teaching concepts and sufficient practical experience in the design and guidance of the training program.

The process of determining the requirements of the training program is relatively easy:

1. Determine the skill and knowledge (performance) required for the job.
2. Determine the job-related qualifications of the available personnel, whether they be newly employed or veteran employees.
3. The difference between items 1 and 2 establishes the requirements of the training program.

4.2.1 Determining Performance Requirements

A detailed and valid assessment or inventory of the performance requirements for proficiency must be conducted. This assessment is called an occupational analysis and should not be confused with other techniques such as job classification, position description, or work schedules. It should be an analysis intended and designed specifically for use in the training program. To make an analysis, the first step is to identify and name the major segments, areas, or types of work to be covered by the training program. The second step is to list the specific skills, processes, and procedures found in these segments. This is a list of the operations, etc., that will remain basically the same day by day and are repeated over and over.

The next logical step is to list the theory and information necessary to perform step 2 with understanding and confidence.

When the three steps listed above have been completed, an outline should be prepared that will be detailed enough so that anyone using the analysis can easily determine the skills required for proficiency.

4.2.2 Determining Skills of Employees

When the performance requirements have been determined, the next step is to evaluate the skills possessed by the employees (present and potential). Many of the techniques for determining these skills are similar for each type of employee. Methods of determining skills of employees are: (1) personal interviews, (2) evaluation tests, (3) previous work experience, (4) direct day-to-day observations by supervisors, and (5) performance tests.

In evaluating the above methods, care must be taken to determine whether apparent deficiencies are due to lack of knowledge, insufficient skills, or poor attitudes. Well-trained and skilled employees may develop poor attitudes and lack motivation for a number of reasons, such as poor personal supervision, organizational changes, overlapping of responsibilities, or merely confusion as to what is expected of them. A training program will be of some help in alleviating poor attitudes, but corrections for this type of problem are outside the realm of this guide.

When the job requirements and the personnel skills have been evaluated, a comparison of the two will reveal the areas where training is needed.

4.3 DEVELOPMENT OF THE TRAINING PROGRAM

Now that the basic information that needs to be presented by a training program is known, the next step is to find qualified instructors to teach the classes. The selection of the best available instructors for the training program is essential for success. Where a specialty course is required, outside consultants should be considered.

The instructors are next given an outline that defines the objectives of the training program and are requested to prepare the detailed course contents and hours required for teaching. The training director then reviews these proposals with respect to the objectives and prepares a schedule of classes.

4.3.1 Typical Training Course at a National Laboratory

A recent training program conducted for chemical plant operators was designed to adapt these individuals to manufacture ceramic-grade uranium-233 dioxide for reactor fuel. Operations involved in this process include dissolution, solvent extraction, and ion exchange coupled with fuel preparation by a modified ammonium diuranate flowsheet to make the uranium-233 dioxide. Because of the attendant radiation problems associated with the uranium-232 isotope in the uranium-233, the purification operations are done remotely within biological shielding. The conversion of the uranyl nitrate solution to uranium dioxide is done in special glove box enclosures and employs operations similar to those of existing conversion plants. The hazards of handling this isotope include criticality, radiation, toxicity, flammability, and conventional chemical hazards.

Because the average experience level of the operators at the onset of the program was 25 years, they were well grounded in the basics of radiochemical processing. The training program included the presentation by videotape of all the plant operational specifics, theoretical information, and equipment design. The use of videotape as a training medium was selected for the following reasons:

1. It provides descriptions and explanations of the equipment by the designers of the equipment.
2. It provides pictorial representation of the equipment complete with the latest modifications prior to installation of the equipment behind 5 ft of biological shielding.
3. It provides a means of specifically relating remotely installed equipment to the control board.
4. Lecturers covering the theoretical aspects of the unit operations need to prepare a lecture only once. There is no need to present this same information in person by many groups.
5. Normal plant routine and in-plant testing and training may be done simultaneously with the videotape program.
6. The operators are allowed to view each subject as many times as necessary. Shift workers are instructed in the use of the machine and can view the tapes as their schedule permits.

In order to cover the plant operations satisfactorily, the following videotapes were prepared. In some cases, more than one tape was needed to cover the subject adequately. The average presentation time for a tape is 20 minutes.

<u>Category</u>	<u>Title</u>
General Program	LWBR Program Laboratory Participation Organization (no exam)
Plant Safety	Health Physics (1) Health Physics (2) Nuclear Safety Criticality Radiation Instruments Industrial Safety Industrial Hygiene Ventilation System - COG Ventilation System - VOG, DOG Ventilation System - Alpha EVS
Process Control	Quality Assurance Material Balance and Accountability Sample Preparation Preparation of Plant Records Analytical Requirements
Purification Systems Operation	IX Chemical Flowsheet IX Equipment Solution Unloading (no exam) Solids Unloading Solution Loading Solids Loading U-oxide Dissolution U-scrap Dissolution Solvent Extraction
	} Theory, Equipment, Operations
Conversion System Operation	Chemical Flowsheet Liquid Waste Handling Isotopic Dilution Precipitation and Centrifugation Microwave Drying Furnace Tray Loading Powder Weighing Equipment Powder Blending and Weighing Reduction and Stabilization
Plant Effluents	Solid Waste Handling

When an operator felt that he had a sufficient knowledge of a specific plant subject from viewing videotapes and in-plant training, he would request a tape in that subject. Upon receiving a passing grade (70%), it was felt that the man was qualified to operate in that area. In instances where an individual failed the examination, he was assigned for further instruction from the engineer responsible for that equipment. When the supervisor was convinced the individual had an in-depth knowledge of the subject, he would administer an additional test and personally certify the operator.

4.3.2 Typical Training Program at a Commercial Reprocessing Plant

At this commercial reprocessing facility, a newly hired chemical process operator is first assigned for a short period (40 hr) to the Health and Safety Department, where he becomes familiar with basic radiological safety and instrumentation. Following this initial training phase, he is assigned to work in the plant. Because the critical manipulation of the plant and the process involve the use of licensed operators, the new employee initially serves as a helper. After satisfactory performance has been demonstrated, usually within a two- to six-month period, formal classroom training is undertaken. Instruction is provided by key technical personnel and licensed senior operators. A breakdown of the current training program is presented in Table 4.3.1. In all, a chemical operator applicant can be expected to receive approximately 90 hr of formal training; the manipulator operator can expect 97 hr of formal training. The sequence of training and examining, from hiring to the granting of a license, is shown schematically in Fig. 4.3.1.

The method of training outlined above appears to be successful when one considers the testing experience in recent years. More than 80% of the applicants have been able to pass the licensing examinations; these results compare favorably with results of the reactor operator licensing experience.¹

Even though reactor operator training is not completely analogous to reprocessing plant training (e.g., many more reactor operators must be trained), the status of reactor operator training is of interest to management of a reprocessing plant. A study of reactor operator training² was made for the AEC in 1967. This study found that approximately 3100 people would have to be trained for reactor licensing in the succeeding ten years. Most of the current training is being done by reactor manufacturers. Even though some utilities plan to conduct their own programs in the future, most feel that they will need outside assistance with their training.

Table 4.3.1. Typical Training Program at a
Commercial Reprocessing Plant

Subject	Hours
<u>All Operators</u>	
Criticality	8
Health and Safety (total)	10
Industrial Safety	2
Contamination Control	2
Dressing and Undressing Procedures	1
Emergency Procedures	2
Plant Fire System	1
Radiation Instruments	2
Accountability	2
Mathematics (total)	12
Use of Calculator	1
Chemical Calculations	9
Use of Calibration Books	2
Chemistry	10
Physics	6
Instruments	2
Reading	2
<u>Additional for Chemical Operators</u>	
Flushing and Unplugging	1
Sampling	2
Systems (total)	14
Pulsers	1
Sumps	1
Interceptor	1
Makeup of Chemical Solutions	4
Ventilation and Off-Gas	2
Uranium Loadout	2
Plutonium Loadout	3
Dissolution	4
Column Operation	4
Uranium and Plutonium Product Purifications	4
Waste Evaporation and Acid Recovery	4
Plant Utilities	2
Solid Waste Handling, Packaging, and Disposal	1

Table 4.3.1 (Continued)

Additional for Mechanical Operators
(28 hr total)

General Purpose Cell — Chemical Process Cell

Theory of Operations in General Purpose Cell — Chemical Process Cell
Standard Operating Procedures — General Operations
Malfunctions

Process Mechanical Cell

Theory of Operations in the Process Mechanical Cell
General Operations
Malfunctions
Equipment Decontamination Procedures
Ventilation
Operating Experience in the Process Mechanical Cell

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Fig. 4.3.1. Training and Licensing Cycle for a Reprocessing Plant Operator

4.4 EVALUATION OF THE TRAINING PROGRAM

A training program must be evaluated on a routine basis, and this is the responsibility of the director of the program. Evaluation provides useful information for guiding and improving the training program. Some of the essential information used to evaluate the training program includes the following:

Motivation of the employee is an essential element in learning.

Guidance by an instructor to provide the application of principles to specific problems will give knowledge of results that can be compared with known standards. The trail and error method without guidance results in wasted time for both company and employee.

Standards should be set high but not so high as to be out of reach for the trainees. Each employee should be given some means of evaluating his own job performance after completing the formal training program. The evaluation of the training program should include the results of these self-evaluations.

Evidence of Creative Effort — The effective instructor conducts a never-ending search to evaluate and use updated media, to give credit for outstanding performance, and to strive toward more effective teamwork.

Tests and Examinations — The use of paper and pencil tests, performance tests, and direct observation as in a walk-through examination are excellent ways to evaluate employee achievement. It must be remembered that "achievement tests measure what the trainee knows; performance tests measure what he can do; and observation under work conditions measure what he will do."

4.5 SUMMARY

A training program that will contain the proper balance between the abilities resulting from the training and the abilities required by the job will result from use of the step-by-step procedures listed in this chapter. This is not to say that it is a guarantee for success but only that it is one method of organizing the training of employees. Equal results may be achieved by using existing programs or by altering a program presently in use.

REFERENCES FOR SECTION 4

1. R. E. Brooksbank, W. H. Lewis, and D. J. Skovolt, *Licensing of Reprocessing Plant Operators*, ORNL-TM-2573 (June 1969).
2. R. J. Bursey, *Reactor Personnel Training Study*, DIN-1617, Douglas United Nuclear Inc., Richland, Washington, June 1967.

5. ACCOUNTABILITY

The art of developing and maintaining an accurate knowledge and record of the identity, quantity, state or nature, and location of any material is called accountability. Within the scope of this training guide, however, and without any other modification, the term "accountability" will be limited to source and special materials, i.e., to materials that are fissile or that can be converted into fissile materials. Such materials include (but are not limited to) uranium, thorium, plutonium, and others having some intrinsic value for research or national defense. The quantity involved may vary from a few micrograms to several tons.

Possession of any of the accountable materials is restricted to licensed entities (individuals, companies, universities, etc.), which are responsible for keeping these materials safe at all times in whatever form, location, or process. According to the Code of Federal Regulations (10 CFR 70.1), a licensee is one authorized to "receive title to, own, acquire, deliver, receive, possess, use, transfer, import, and export special nuclear material."¹ No person subject to these regulations may conduct any of the above operations except as authorized in the license issued by the NRC.^{2,3} Furthermore, each licensee is required to "keep records showing the receipt, inventory (including location), disposal, acquisition, import, export, and transfer of all special nuclear material in his possession regardless of its origin or method of acquisition."⁴

To comply with these regulations, the licensee appoints an accountability officer, who heads an office or staff specifically charged with the responsibility of maintaining an accountability program. Included in the program are (1) the development of procedures to be used, (2) the organization and maintenance of the records that will be required, (3) the compilation of book inventories and measurement of physical inventories, (4) audits of the records, and (5) the conduct of a safeguards program.

With this somewhat lengthy introduction, we move into the part of an accountability program in which the operating personnel are directly involved. First, let us look at an example of a licensed operation, say a simplified version of a fuel reprocessing plant, and examine each area from the standpoint of accountability. Figure 5.1 shows the licensee's plant inside the dotted line. The plant area includes a receiving and unloading station, a disassembly and fuel storage facility, a processing facility, a finished-product storage facility, a finished-product packaging and shipping facility, and an on-site waste storage facility. The overall plant can be referred to as a Balance Area. Within this Balance Area all source and special materials that enter the area and those that leave it must be accounted for, and these quantities plus the material on hand must balance (equal) each other. Stated another way: From the beginning, this fundamental condition can be shown as:

$$\left[\begin{array}{c} \text{Material received} \\ \text{(entering)} \end{array} \right] = \left[\begin{array}{c} \text{Material sent out} \\ \text{(leaving)} \end{array} \right] + \left[\begin{array}{c} \text{Material on hand} \\ \text{(inventory)} \end{array} \right]$$

Fig. 5.1. Schematic Material Flow Diagram for a Reprocessing Plant

It should be borne in mind that the materials may exist in several forms (solids, liquids, and mixtures), and to satisfy the balance requirement the comparison must be made on some common basis. For example, if a plutonium balance is being made, the weights or volumes of the material measured must be converted to weight units of plutonium — that is, for solids such as plutonium dioxide,

$$(\text{wt plutonium oxide, g}) \times (\% \text{ Pu}) = \text{wt Pu, g} ;$$

or in solutions,

$$(\text{vol plutonium nitrate, liters}) \times (\text{g Pu/liter}) = \text{wt Pu, g} .$$

Also, at any time we can construct around the balance area a material balance that extends across an interval of time. This interval may cover all operations from the time the plant was constructed up to the present or any period in between. For a period in between, say, for example, a one-month period, the fundamental equation now looks like this:

Material on hand at first of month + (Beginning Inventory)	Receipts during month (Receipts)	=	Material on hand at end of month + (Ending Inventory)	Material leaving plant (Shipments Out)
--	---	---	---	---

Let us now look at the task of constructing a balance around the entire plant, remembering always that within the plant there may be and often are many subareas which are handled in exactly the same manner as the whole plant. To construct this overall balance, we use information gathered from many sources by many persons. Such information includes the following:

1. Shipping records which identify individual items (usually by serial numbers), the quantity of material, and some statement about the precision and accuracy of the measurement used in arriving at the estimate of special-material content.
2. Process records generated by operating personnel. These consist of piece counts, volume and weight measurements, and analytical data for converting the piece count and weight or volume data into quantities of special material to be accounted for.
3. Inventory records which include piece counts (of previously measured quantities of materials stored while awaiting shipment out or of items received and awaiting transfer to the process) and verification of the shipper's estimate of special-material content.
4. Material transfer forms executed by the accountability office staff.

The materials received, which will in this example consist of irradiated fuel assemblies, arrive in casks (Section 6.1.1) accompanied by shipping records (NRC Form 741 latest revision) listing the shipper and the receiver, the identity of the cask and its contents, the reactor operator's (shipper's) estimate of the quantity of source and special material, and such other data as required by the NRC, ICC, and DOT for safe transport and handling. Before the material enters the receiving area, the reprocessing plant operating personnel identify and record, on forms supplied by the plant management, information required by the plant, such as cask number (for verification), cask or coolant temperature data, and time of arrival.

If the cask is liquid-cooled, the liquid is sampled and analyzed for impurities and source-materials content. These data are used to determine the quantity that may be present and to take this value into account for accountability as well as for safety reasons. Copies of the recorded data are forwarded to the accountability office.

If the coolant is found to contain source or special materials, it is usually drained (or flushed) into a special vessel for later processing or disposal, depending on the degree of contamination. The cask is then transferred to the unloading station, where it is opened and the fuel assemblies are identified, removed from the cask, and stored temporarily in a facility designed for this purpose. The cask may need to be decontaminated, repaired, and tested before being returned to service (Sections 7.1.4 and 7.1.5).

As each assembly is identified (by serial number), a record (form or card) is started showing its identity, source- or special-material content (estimate), and the storage location. Copies of the card (form) are forwarded to the accountability office, where these data become the receiver's official records and may again be compared with those included in the shipping record (form). If a discrepancy is detected, the accountability office initiates action to confirm or disprove it. Should the discrepancy be confirmed, the shipper and the NRC are officially notified, and such other action as the NRC and regulatory agencies may direct is taken.

The aim here is to be sure that (1) some error was not made by the shipper, (2) source and special material was not diverted during transport, and (3) safety of the general public is maintained.

If no discrepancy is found, the cask contents are officially accepted as an item of plant input, and the quantity of source and special material stated on the shipping records is entered on the receiving record. Note that so far the actual source- and special-material content has not yet been determined; we have only verified the number of pieces that are present.

The fuel assemblies must be disassembled and as much hardware removed as possible to reduce the quantity of inert material to be handled in

the dissolvers. As each assembly is moved to the disassembly facility, the form started for it in the receiving area (above) moves to the new area also, and the transfer is noted. As the disassembly progresses, the storage location (bin, rack, etc.) where the active components of the assembly are stored is entered on the form.

The disassembled fuel is then loaded into a dissolver. A careful record is kept of the pieces of fuel loaded, usually noted on the check sheet, and the total is compared with data from the forms mentioned in the preceding paragraph. When the dissolution is completed, the quantity of source and special material is determined from volume measurements and chemical analyses of samples withdrawn from the dissolver solution. The amount of special material dissolved is compared with the amount loaded (based on the records mentioned above) to determine whether all of the material loaded has been dissolved. As a general rule, depending on policy, safety considerations, and license specifications, unless there is a large ($\pm 10\%$) difference, the operating personnel may proceed with the next dissolving; but the deficit is kept charged against the dissolver as an estimate of the undissolved heel, or it is considered real until the campaign (a group of sequential runs considered as a unit) is completed and one or more cleanout dissolvings are made in order to ensure absence of undissolved material.

Dissolvers used in fuel reprocessing facilities are necessarily complex pieces of equipment, often made in odd shapes and fitted with many internal baffles, mixing devices, heat transfer coils, etc., all of which limit the precision and accuracy of volume measurements. Also, deposits of undissolved material that introduce significant errors in volume measurements may remain (and accumulate) in dissolvers.

To deal with this problem of accumulating solids, it is now universal practice to transfer the dissolver solution to an accountability tank designed and equipped to provide accurate volume measurements of its contents and homogeneous solutions for sampling. Great pains are taken to employ the highest quality instrumentation in making these measurements. A strict calibration program is conducted to ensure that the instruments and the data obtained have minimum error associated with them.

Using these volumetric and analytical data, a precise measurement of the quantity of material present in the dissolver solution can be made. This quantity of material in the dissolver solution can now be used to confirm any deficit previously noted and to signal corrective action to be taken.

As an example, we might find that we account for all the uranium expected in a specific fuel but that the plutonium is too low. This leads to two possible conclusions:

1. A residue of difficult-to-dissolve plutonium sludge remains in the dissolver.

2. There was an error in the utility's (shipper's) estimate of burnup.

We would then quickly confirm or eliminate the presence of a plutonium sludge by extensive sampling procedures and/or cleanout dissolvings. If no sludge were found, then the utility would be notified, and a re-examination of its burnup measurements would begin.

Once the material content of the specific lot of dissolver solution has been determined, we have the data to complete a material balance around the dissolver, as mentioned, and also have obtained a very important item of data called the measured input to the system.

A great deal of care is exercised in the measurement of plant input since this quantity of source and special material represents a sizable investment by the utility as well as the basis, at least in part, for the fee which the reprocessor receives for his effort. Furthermore, a difference between the quantity measured by the reprocessor and that estimated by the utility can become the subject of negotiation or litigation should the difference be outside the limits of uncertainty of the measurements by each.

Accordingly, reprocessors take great pains in accounting for all items at each step of the disassembly, collecting scrap and breakage pieces and determining their source- and special-material content. The uncertainties in the measurements of volumes and weights, in calibration charts, and in corrections for temperature and the precision and accuracy of the analytical procedures used are carefully established and maintained so that the total uncertainty in the measured quantity of special material can be established. At this point, therefore, the comparison shown below is made.

Quantity received, as estimated by the utility	±	Uncertainty of utility's measurement	=	Quantity measured by reprocessor	±	Uncertainty of reprocessor's measurement
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If the difference between the quantities is greater than either of (or is not included in) the two, the reprocessor must initiate a detailed search for missing material and verify that his measurements and balances are correct. Should the new measured and verified quantities confirm the reprocessor's first quantities, the utility, along with the NRC, would, in the normal course of events, be notified. The utility, of course, would then reexamine its estimate for errors in the measurements and calculations used in arriving at this estimate and, in the normal course of events, would report to the reprocessor (and the NRC) whether the original estimate was in error or has been confirmed by the reexamination.

If the revised estimates (including uncertainties) of the quantities present in the fuel assemblies as made by the utility and the reprocessor are still in disagreement (and outside the range of uncertainty of each), there would be grounds for a most serious conclusion — namely, that a

high probability exists that a quantity of material has been diverted (lost, stolen, missent, etc.) during the movement of the fuel from the utility's site to the reprocessing site.

Although diversion of irradiated fuel during shipment is a highly unlikely occurrence because of the size of the bundles and assemblies, the high intensity of radiation associated with the fuel, and the stringent procedures that are followed in containing and packaging the fuel to ensure the safety of the public and the environment, nevertheless, the example serves to demonstrate the importance and use of balances to detect diversions of source and special material in any form whatever. It should be noted here that the first step in the verification by the reprocessor is confirmation of the number and identity of the assemblies. If these agree with the utility's count but a deficit in special material still exists, then the diversion may have occurred in the utility's area or perhaps in the fuel fabricator's shop, and the search for the missing material would be extended to include the fabrication operation.

The results of an accounting can be far reaching and are of extreme importance, since it is very expensive to conduct the train of events which can be set in motion in the event a discrepancy or a shortage (or overage) is found. The extreme care and attention to detail in assembling and conducting measurements are obviously justified.

Returning to the reprocessing plant (Fig. 5.1), let us continue with typical accounting procedures followed after the irradiated fuel has been dissolved and the quantity of source and special material measured. This quantity of material, the "measured input" to the plant, represents the amount of material that must be accounted for in the remaining processing operations necessary to recover a purified product.

The processing operations include some combination of most of the following (indicated schematically in Fig. 5.1 as A, B, etc.): the purification steps, such as solvent extraction and partitioning (to separate valuable products from each other); further purification steps, which may include additional solvent extraction and ion-exchange separation; and finished product recovery. Some reprocessing plant operations may utilize a fluoride volatility system in their processing scheme as well as denitrators, that is, a fluidized-bed system in place of some of the steps listed above.

In all of the processing schemes, however, it is necessary according to 10 CFR 70, 70.22, 70.51, and 70.52 to have some precise knowledge of the quantity of special material held up in the processing equipment. These regulations specify that adequate process records and run sheets be kept to identify the quantity and location of materials as well as the limits that the amount of material which is unaccounted for can reach. Furthermore, the regulations specify time limits within which material can be allowed to remain unaccounted for before corrective action must be taken, and they specify the corrective procedure to be followed.

Briefly summarized, these actions must be taken as directed in NRC Regulatory Guide 5.24.

1. The operating person must immediately (within 10 min) notify his foreman if a discrepancy (shortage or overage) is suspected, based on the posted records.
2. The foreman checks the run sheets and other records for errors in listing material holdup in the system.
3. He notifies his supervisor and the material balance area (MBA) custodian and continues further checking of the records such as run sheets, piece counts, tank-volume and analytical calculations, and transfer sheets (SNM) for material sent into and out of the area (waste streams, product transfers).
4. If the discrepancy continues, the process engineer is notified and begins an "earnest search, calling for special product-quality and measurement-control checks and verifying when last the contents of the process containers had been measured (such as transfer into the MBA, origination of the item, previous physical inventory, etc.)."
5. After another 4 hr, the process engineer notifies the plant shift supervisor and calls for an immediate physical inventory of all materials having passed that process step after the anomaly (discrepancy) was detected, a check and verification of the contents of all containers in the MBA, and a listing of all persons who may have had access to the material.
6. If the material is not found (accounted for) within 6 hr of his being notified, the shift supervisor calls for a shutdown inventory and notifies the plant manager and the NRC.

In order to implement compliance with the above regulations and to improve material control, a processing facility is normally divided into subareas (control areas), each encompassing some processing area or system. For example, Fig. 5.1 shows one subarea for dissolution, three for the purification system, and one for the finished-product area. Others shown include the finished-product storage facility, a packaging and shipping facility, and an on-site waste storage area. In each control area, material balances can be constructed from process, transfer, and inventory records, thus greatly facilitating material control.

Once more, referring to Fig. 5.1, we see that an overall material accounting across the plant involves the input measurements (and their verification) made on all material entering the reprocessor's facility plus similar measurements made on all materials leaving, with note being made of any changes in the "in-process inventory," that is, the total quantity of material held in the process equipment and in storage, including waste and scrap recycle. The balance now takes this form:

$$\begin{aligned} &(\text{Measured input}^a) + (\text{Beginning inventory}) = (\text{Measured output}^a) \\ &+ (\text{Ending inventory}^b) + (\text{Material unaccounted for}) . \end{aligned}$$

^a*Since the time that the beginning inventory was measured.
The output includes shipments and measured waste discharges
during the same interval of time.*

^b*Taken as the present time.*

While the above presentation is simple in appearance, in practice it is complex. For example, an inventory measurement will include the identification, location, and measurement of every item in storage (waste or product) or held up in equipment in the plant. These data are compared with the previous records and transfers to ensure that the present inventory measurement is in agreement with them. In conducting the present measurement, one also verifies that material in each control area is present in the quantities called for by the transactions that have taken place as reflected by processing records.

The quality of the measurements made is also taken into account to establish the uncertainties that are associated with the total quantities of material measured and to attach a value to the uncertainty of the material unaccounted for. The higher the quality of the measurements made in arriving at the total quantity of materials, the less uncertainty there will be associated with the "material unaccounted for."

In summary, an accountability program is dynamic and continuous. Data from every segment of the processor's operation are evaluated and used in controlling and protecting the special material from the time it enters the processing facility until the purified, refined product is returned to the utility and the quantity of unrecovered material in waste discharged to permanent waste storage is accounted for. All the care and expense involved in conducting such a program are easily justified by (1) the magnitude of the investment represented by the special material, (2) the safety of the operating personnel and the liability that might be incurred in the event of an accident (such as a nuclear excursion) or by an overt act by thieves using diverted (stolen) material, and (3) by the reprocessor's capital investment in facilities.

REFERENCES FOR SECTION 5

1. *Code of Federal Regulations*, Title 10, Part 70.1 (10 CFR 70.1).
2. *Code of Federal Regulations*, Title 10, Part 70.2 (10 CFR 70.2).
3. *Code of Federal Regulations*, Title 10, Part 70.42 (10 CFR 70.42).
4. *Code of Federal Regulations*, Title 10, Part 70.51b (10 CFR 70.51b).

6. PLANT SAFETY

Maintaining the health and safety of plant personnel is so important to the economics, labor relations, product quality, and the entire atmosphere of fuel reprocessing plants that all aspects of safety must be included in the basic training of operating personnel. New employees should be indoctrinated with the importance of safety as soon as possible after they have been hired and before they are sent into the operating areas of the plant. Every employee should be made constantly aware of the need to respect the safe way to conduct all his activities. Safety must be the business of everybody from the janitor to the plant manager. It requires both individual effort and team effort, since the members of the team — or staff — are dependent on each other for their individual and collective well-being.

The responsibility for enforcing safety regulations should be a function of line organization in the same manner and to the same degree as that for process operations. The people responsible for guiding safety, however, should be independent, insofar as practical, from the production line organization. They should have unimpeded communication with the production line organization and should report to a level of management high enough to guarantee enforcement of recommendations resulting from their analyses. Because of the variety of hazards in nuclear fuel reprocessing and the expertise required to assure proper safety in each of the major realms of personnel protection, the total responsibility for guiding plant safety is usually divided among several special groups, to each of which is assigned a particular aspect of safety; these may serve under one directorship or may be combined in any of several ways:

1. a health physics group,
2. a nuclear criticality safety group,
3. a group responsible for conventional safety,
4. a fire prevention and control group,
5. a plant security and nuclear safeguards group.

The members of these special safety groups should be familiar with the process operations, and they must thoroughly understand the particular hazards each operation presents in the realm of their special responsibility and the appropriate methods for controlling those hazards.

The remarks in the opening paragraph of this section, although apparently general, imply rather specific requirements. At the top of the overall line organization, there must be clear recognition of the need for safety and a willingness — even an eagerness — to achieve it. The attitude of management permeates the entire organization. The people at each level must be sufficiently trained, observant, and communicative to recognize areas of potential problems and must have the authority to correct deficiencies. In order that they may be able to perform their tasks safely and efficiently, those concerned at each step of the process must be aware of the limitations imposed on such factors as working times, operating conditions, batch size, geometry, and

concentrations; of the bases for these limitations; and of the consequences of violations. No one should take the attitude that if something seems not quite as it should be, someone else will take care of it.

In the final analysis, plant safety requires strong management support; personnel well trained in all aspects of their work assignments; adherence to carefully prepared procedures, including emergency procedures; and individual alertness, communicativeness, and sense of responsibility. But the ultimate and really effective responsibility for safety lies with the person actually performing each task. There is no substitute for trained, experienced, conscientious, certified operators.

6.1 HEALTH PHYSICS

Throughout his existence on earth, man has been bombarded by radiation: radiation from outer space (cosmic rays), from uranium and thorium deposits in the earth's crust, and from radioactive potassium and carbon within and outside his body. In spite of this exposure to natural background radiation, man has survived and evolved to his present state.

But man has learned to separate and concentrate the natural sources of radiation and has built machines to produce radiation artificially. He has learned to unleash and control the energy locked in the nuclei of atoms. As a result, man now has the potential for radiation exposures hundreds and thousands of times his natural radiation background.

The harmful effects of large doses of radiation were first manifested in radium workers around 1920, and the need for preventive measures was recognized. Fortunately, much attention was given to radiation protection from the start of the atomic energy programs, and in 1942 at the University of Chicago the science of radiation protection was first called health physics. The health physicist is concerned with the mechanisms of radiation damage, with the evaluation of radiation hazards, and with providing protection for man and his environment from exposure to unwarranted radiation.

The success of any safety program depends on the cooperative effort of every person concerned. A radiation safety program is no exception. Radiation safety must be everybody's business. The individual employee is the focal point and the object of every safety effort. When the concept that safety is a shared responsibility is accepted, the goal of a safety program can be realized.

6.1.1 Radiation in a Reprocessing Facility

6.1.1.1 Sources of Radiation — In a fuel reprocessing plant the unfissioned portions of reactor fuel (uranium-235, plutonium-239, and/or uranium-233) remaining after a part has fissioned ("burned") are

separated and recovered from the fission products generated by the burning reaction. The reactor fuels (fissile materials) are radioactive, but most fission products are more intensely radioactive. The hazard each presents depends on the quantity present, the chemical and physical form, and the type and energy of radiation emitted.

The quantity of a radionuclide (radioactive element) may be expressed in curies (Ci). A curie is the quantity of a radionuclide that has 3.7×10^{10} atoms disintegrating per second (d/sec). The disintegration of atoms in this fashion causes them to emit particles and/or waves (rays) of matter and energy, a phenomenon called radioactive decay. Because a curie is a fairly large amount, fractions of a curie are often more conveniently used: a millicurie (mCi) is 10^{-3} Ci, or 3.7×10^7 d/sec; a microcurie (μ Ci) is 10^{-6} Ci, or 3.7×10^4 d/sec.

The quantity of a radionuclide remaining at a given time after removal from a reactor depends on the initial quantity present and its half-life, the time required for half the radionuclide to disintegrate. Each radionuclide has its own characteristic half-life.^{1,2} Some fission products have fairly long half-lives (examples: strontium-90, 29 years; cesium-137, 30 years). All the reactor fuels have half-lives of thousands of years. These long-lived fission products and fissile materials will present a significant hazard for many years. Some fission products have half-lives of only hours, days, or months. Many of these decay to stable nuclides, and the quantities of others are greatly reduced during "cooling" periods between their removal from the reactor and transfer to a fuel reprocessing plant. For example, iodine-131 has a half-life of about 8 days; thus for each 8 days of cooling time its quantity is reduced by half. During a cooling period of 90 days (approximately 11 half-lives for iodine-131), the quantity of iodine-131 would be reduced to $1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 = (1/2)^{11} = 1/2048$ of the initial quantity.

In spite of cooling periods of 90 days or longer, however, hundreds to hundreds of thousands of curies of various fission products remain, necessitating the use of massive shields and special handling and containment procedures to protect personnel from exposure to radiation during transportation, storage, and processing in the head end of the recovery process for spent reactor fuels.¹

In the tail end of the process, as the separation of the fissile materials from the fission products becomes more and more complete, the hazard from the long-lived fissile materials may be the primary concern. In addition, throughout the entire process, special facility design, special equipment, and special procedures are needed to prevent a nuclear chain reaction (criticality accident) because of the tendency of fissile material to react with itself when a large enough quantity (critical mass) is accumulated in one place.

6.1.1.2 Types of Radiation - The energy of the radiations emitted by the disintegration of radionuclides² is usually expressed in units of electron volts (eV), kilo-electron volts (keV) = 1000 eV, or mega-electron volts (MeV) = 1,000,000 eV. In a fuel reprocessing plant we will be concerned with the following types of radiation: alpha (α), beta (β), gamma (γ), and neutrons (n). These emissions are called ionizing radiation as opposed to heat, light, and radio waves, which are nonionizing forms of radiation. Ionizing radiations cause biological damage through the formation of ion pairs (positively and negatively charged fragments of matter) or chemically reactive radicals (charged groups of elements) as the energy is absorbed by the cells and tissues of the body. Radiations that lose energy very rapidly in passing through tissue are more effective in causing damage than those which lose energy more slowly. The energy loss per unit path length by radiation passing through matter is referred to as linear energy transfer (LET).² Radiations with very high LET generally have a short range and thus may constitute a hazard mainly when the radionuclide is taken inside the body. Radiations with lower LET generally are more penetrating and thus are hazardous even when their sources are outside the body.

Alpha particles are helium nuclei traveling at high velocity. Each consists of two neutrons and two protons and has a charge of plus 2. Alpha particles lose energy continuously in passing through matter, chiefly through interaction with the electric fields of other positively charged nuclei and negative electrons in the orbits of the atoms they encounter. They have a high LET and consequently a short range. Most alpha particles are easily absorbed by a few sheets of paper and can travel only a few centimeters in air. Most alphas are emitted with energies less than 7.5 MeV, the minimum necessary to penetrate the outer dead layer of skin.³ Thus, alpha emitters are primarily a hazard when deposited inside the body, where all the energy of the alpha particles will be absorbed in a small volume of tissue surrounding the deposition site. This fact makes alpha-emitting radionuclides a real concern when deposited inside the body.

All the reactor fuels (uranium-235, uranium-233, and plutonium-239) are alpha emitters. Other alpha emitters likely to be encountered are neptunium-237, uranium-234, uranium-232, americium-241, americium-243, curium-242, and curium-244. Each of these radionuclides emits alphas with energy characteristic of that nuclide. For example, plutonium-239 emits alpha particles with 5.1 MeV energy, and curium-244 emits 5.8 MeV alphas.

Beta particles (β) are high-speed electrons emitted from the nuclei of radionuclides.⁴ The term beta particles has come to include negative electrons (β^-) and positive electrons (positrons, β^+). Most fission products decay by beta emission. Beta particles lose energy continuously in much the same way as alpha particles. However, they have a lower LET and consequently are more penetrating. A 1-MeV beta particle will travel 10 to 12 ft in air, whereas a 5-MeV alpha has a range of

about 1.5 in. in air. Betas require energies of about 70 keV (0.07 MeV) to penetrate through the dead layer of skin to the underlying living tissue. Since most vital organs are at a depth of 5 cm or more, which is much greater than the range of the beta particles from most radionuclides in tissue,³ these organs will be unaffected by beta particles, even those with energies greater than 0.07 MeV. Thus, the energy absorbed in the live skin is the main hazard from beta sources external to the body.

Unlike alpha particles, betas emitted from a radionuclide do not all have the same energy. The energy will range from zero up to a maximum characteristic of the radionuclide. Beta emitters become an internal hazard when deposited inside the body. However, since betas have a lower LET than alpha particles, their energy is absorbed in a larger volume of tissue and is not as effective in producing localized damage.

Gamma rays (γ) are electromagnetic waves similar to radiowaves and light but with much shorter wavelengths and correspondingly higher frequencies.⁴ They have no mass or charge and travel at the speed of light. Gamma rays and X rays differ only in origin; gamma rays are emitted from the nuclei of radionuclides, while X rays originate outside the nuclei. Further discussions of the hazards of gamma rays will apply equally to X rays.

Gamma rays have relatively low LET and are highly penetrating. Having no charge, gamma rays do not lose energy continuously but only upon direct "collision" with the orbital electrons or nuclei of the absorbing medium. They therefore have no definite range, as alpha and beta particles have. Since gamma rays can travel great distances in air, a significant hazard may exist even at great distances from unshielded gamma sources. Organs and tissues throughout the body are subject to damage from gamma rays because of their high penetrating ability. Thus, gamma rays present a more significant external hazard than beta particles.

Gamma- and X-ray emission usually occur in conjunction with the alpha and beta decay of radionuclides, though some decay processes result in gamma- or X-ray emission without alpha or beta emissions. The more significant gamma-ray hazards are usually associated with the beta-emitting radionuclides. Some examples are cesium-137 (0.514-MeV β^- and 0.66-MeV gamma) and niobium-95 (0.159-MeV β^- and 0.76-MeV gamma). However, the X-ray and gamma-ray emission associated with the decay of some alpha emitters may constitute a significant hazard. This is particularly true in the handling of plutonium products⁵ containing plutonium-241 and uranium-237.

Neutrons have about the same mass as protons and, like gamma rays, have no charge and lose energy only by collision in passing through matter. Since interactions may be infrequent, neutrons may travel large distances in air and other substances before losing all their energy. Neutron sources are therefore significant hazards even when external to the body.

Neutrons are classified as thermal (0.025 eV), intermediate (0.5 eV to 10 keV), and fast (10 keV to 10 MeV) according to their energies. The types of interactions in which neutrons deposit energy in matter are highly dependent on their energies.⁶ Fast neutrons lose most energy in "billiard ball" collisions with light nuclei, especially hydrogen. Since the body contains much hydrogen, it is a most efficient absorber of energy from fast neutrons.

The harmful effects of neutrons are largely due to ionization by secondary radiations resulting from neutron interactions. Protons, for example, are ejected in fast-neutron collisions with hydrogen nuclei. Protons have one-fourth the mass and one-half the charge of alpha particles. The energy imparted to tissue by protons is less effective in producing damage than that by imparted alpha particles but more effective than that by beta particles.

Neutron radiation is usually associated with nuclear reactors rather than fuel reprocessing plants. However, potentially lethal quantities of neutron and gamma radiation are released in a criticality accident.⁷ Proper design of plants and equipment and strict adherence to approved operating procedures essentially prevent such accidents (see Sections 6.2, 7.1.4, 7.2.4, 7.5.5, and 7.10.4).

A number of radionuclides fission spontaneously, emitting neutrons. One such radionuclide is plutonium-239. However, plutonium-238, plutonium-240, and plutonium-242 are more significant sources of spontaneous-fission neutrons.⁵ The neutron hazard from plutonium-239 product increases as the percentages of these isotopes in the product increase. If certain transplutonium radionuclides, such as curium-242, curium-244, and californium-252 are present, the neutron hazard will be even more severe. Also, neutrons are sometimes emitted when alpha particles of certain energies interact with the nuclei of light elements such as boron, beryllium, lithium, sodium, fluorine, and oxygen.^{1,5}

6.1.1.3 Radiation Units — The radiation damage to body cells and tissue depends, in part, on the total amount of energy absorbed, which is called the radiation absorbed dose. The rad, a unit for measuring radiation absorbed dose,³ will deposit 100 ergs* of energy in one gram of material being irradiated. If one's whole body receives a dose of 1 rad, this means that 100 ergs of energy have been absorbed in each gram of the body (the average man weighs about 70,000 grams). A whole-body absorbed dose of 5 rads means that $5 \times 100 \text{ ergs} = 500 \text{ ergs}$ of energy have been absorbed in each gram of the body. A millirad (mrad) = $1/1000 \text{ rad}$ is the unit often used. Since rad units do not take into account the relative effectiveness of the different radiations in producing biological damage, 1 rad of neutrons = 1 rad of alphas =

* An erg is another unit of energy equal to about 624,000 MeV.

1 rad of betas = 1 rad of gammas = 100 ergs per gram of material irradiated. The effectiveness of the various radiations in producing harmful effects in living tissue is related to the energy loss per unit path length (LET).² The greater the linear energy transfer (LET) the more effective the radiation in producing damage. For radiation protection purposes, the various types of radiation are assigned quality factors which are indications of their effectiveness in producing damage as compared with 250-keV X rays.⁸ Most beta particles, X rays, and gamma rays are assigned a quality factor of 1. Alphas and fast neutrons are assigned a quality factor of 10. This indicates that a rad of fast-neutron or alpha radiation is about 10 times as damaging as 1 rad of beta, X, or gamma radiation.

When the absorbed dose in rads is multiplied by the appropriate quality factor for the radiation involved, the resulting quantity is called the dose equivalent.³ The rem is a unit of dose equivalent (dose in rems = dose in rads factor). A millirem (mrem) = 1/1000 rem.

Examples:

1. The dose equivalent from 2 rads of fast neutrons is
 $2 \text{ rads} \times 10 = 20 \text{ rems}.$
2. The dose equivalent from 1 rad of alpha radiation is
 $1 \text{ rad} \times 10 = 10 \text{ rems}.$
3. The dose equivalent from 200 mrad of gamma or beta radiation is
 $200 \text{ mrad} \times 1 = 200 \text{ mrem}.$

Dose equivalents from different radiations can be added to obtain the total dose equivalent, which is representative of the total potential damage to the body or part of the body irradiated. Example: 150 mrem of neutrons + 25 mrem of gamma + 25 mrem of beta = 200 mrem total dose equivalent.

6.1.2 Radiation Detection and Monitoring Equipment

It is not the intent of this section to produce experts in making radiation measurements and evaluating radiation hazards. Usually health physics personnel who have made this their specialty are available. They have had extensive training in the operation and use of radiation instrumentation and know the applications and limitations of individual instruments. They are also conversant with the various radiation protection guides on which to base their estimate of the hazard and their recommendations after having made the appropriate measurements.

However, operators are expected to do limited self-monitoring and should have a working knowledge of the radiation-detection and measuring instruments that are available. They work in areas where radiation

monitors are operating continuously and should know the meaning of their alarms and what response is expected. Details regarding the use and operation of specific instruments are best learned on the job with instrument in hand. It is necessary to receive training and become "qualified" before attempting to make radiation measurements with any instrument.

Detection and measurement of radiation is necessary to determine personnel exposures to radiation, to aid in keeping personnel exposures within recommended limits, and to determine whether radioactive materials are adequately contained and shielded. Radiation monitoring equipment is needed to measure radiation fields (often mixtures of beta, gamma, and neutrons) in which personnel must work, to measure the total doses accumulated by personnel over a period of time, and to measure the quantities of radioactive materials on surfaces and in the air.

Before going into detail about instrumentation and detection devices for specific applications, let us present the following general considerations:

1. Selecting the proper instrument is important. Many instruments are designed to detect a certain type of radiation and to discriminate against (not respond to) other radiations present.
2. Electronic instruments must be turned on, and most of them require a warm-up time before they will operate properly.
3. The operation of an instrument should be tested with a source before it is used.
4. An instrument may detect only a fraction of the radiation of concern. Part may completely miss the detector (geometry). Part may be absorbed before reaching the detector. Part entering the detector may not be registered (counter efficiency).
5. All instruments and devices for measuring radiation must be calibrated with standard sources of the radiation they are expected to measure. Adjustments in readings by "counter factors" or efficiency factors may be necessary to correct for losses mentioned in item 4. Instrument calibration is a function of the health physics group.
6. To extend battery life, battery-powered instruments should be turned off when not in use.
7. Damaged or contaminated instruments should be reported to the health physics group. Operators should not attempt to use, repair, or decontaminate such instruments.

8. Damage to monitoring equipment should be avoided. It must be protected from unnecessary exposure to radioactive contamination, corrosive atmospheres and materials, excessive moisture, temperature extremes, and rough handling.
9. High readings and monitor alarms should be assumed to be the result of excessive radiation until proven otherwise.

Since radiation cannot be detected with the unaided senses, a substance that responds to the radiation in some manner (the detector) and a system to measure the extent of the response (the measuring apparatus) are required.

One group of gas-filled detectors uses the ionization that radiation produces in them. This group includes ion chambers, proportional counters, and Geiger-Mueller (G-M) counters.

A number of solids are used for detectors because of their response to radiation. Photographic film is darkened in proportion to the radiation dose it receives. Certain phosphors and crystals, when irradiated, emit light flashes which can be counted (scintillation detectors). Special types of glass undergo a color change or optical density change related to the radiation dose. Some types of glass, after being irradiated, give off fluorescent light when exposed to ultraviolet light (radiophotoluminescence). Some solids, after being irradiated, give off light upon being heated (thermoluminescence). The light can be measured, and the absorbed dose can be related to the light intensity.

To select the proper detection and monitoring equipment for a job, one must first decide what is to be measured (dose, dose rate, surface contamination, air contamination) and then select equipment that will respond to the radiation (alpha, beta, gamma, neutrons) to be detected or measured.^{9,10}

6.1.2.1 Detection and Measurement of Alpha Radiation — We are not concerned with dose or dose rates from alpha emitters outside the body. Our main concern is to keep the quantities of alpha emitters in the air and on the skin, clothing, floors, benches, walls, etc., as low as possible and within established limits so that the amounts of these substances taken into the body will not result in a significant internal dose. The limits for surface contamination (Table 6.1.1) are generally expressed in disintegrations per minute per 100 square centimeters ($d/m/100 \text{ cm}^2$), and the limits for air contamination in microcuries per cubic centimeter of air ($\mu\text{Ci/cc}$). For detection of alpha radiation proportional counters or scintillation counters are usually used with their voltage and discriminator settings such that they do not respond appreciably to other types of radiation (Figs. 6.1.1-6.1.4).

These may be battery-powered portable survey meters or stationary units powered with alternating current (AC). Such instruments are usually

Fig. 6.1.1. Alpha Survey Meter, Scintillation

The portable scintillation alpha survey meter is a battery-powered, transistorized amplifier with a high-voltage supply especially designed for use with an alpha scintillation probe. A register range is provided, thus obviating the difficulty of reading low counting rates on the meter. An output for earphone operation is also provided. The power is supplied by nickel-cadmium cells. The probe employs a 2-in. photomultiplier, a zinc sulfide phosphor, and a lighttight window.

Fig. 6.1.2. Alpha Survey Meter, Gas Proportional

The portable alpha gas proportional counter has a propane gas-flow chamber. The circuitry is transistorized and operated by dry cell batteries. Pulses from the counter are indicated by a rate meter and an earphone. The gas-flow counter is superior to an air proportional counter in regions of high relative humidity.

Fig. 6.1.3. Alpha Survey Meter, Air Proportional

The portable alpha air proportional counter has transistorized circuitry and a lightweight probe. It may be used in regions where the relative humidity is moderate to low. Pulses from the counter are indicated by a rate meter and an earphone. The power is supplied by nickel-cadmium cells, which are charged by a plug-in trickle charger operated from 110 V, 60 cycles.

Fig. 6.1.4. Lab Monitor, Alpha or Beta

This monitor consists of a versatile counting-rate meter, ac powered, and either a zinc sulfide scintillation probe for alpha detection or a G-M counter probe for beta-gamma detection.

equipped with a rate meter calibrated in counts per minute (c/m). However, to determine the actual alpha disintegration rate in disintegrations per minute (d/m) on the surface under the detector, we must multiply the counting rate by the counter factor to correct for losses due to geometry, absorption, and counter inefficiency:

$$\text{disintegration rate (d/m)} = \text{counting rate (c/m)} \times \text{counter factor.}$$

Counter factors will vary and should be posted on each instrument.

Usually, one is concerned with whether or not alpha emitters are present on the skin, shoes, clothing, equipment, etc., and not in determining the precise quantities present. Some instruments are designed for use with earphones or are equipped with speakers. If an accurate meter reading is not needed, it is easier to detect radiation by listening for "pops" in the earphone or from the speaker. The audible response may be used to locate "hot" spots, and then meter readings can be taken with the detector held stationary over the hot spot.

Since alpha particles travel only a few centimeters in air, the detector must be almost in contact with the surface and must be moved slowly across the surface. Also, a thin film of oil or water, a layer of dust, a coating of paint, etc., on an alpha-contaminated surface can completely absorb the alpha particles, and a serious hazard may not be detected.

The "windows" of alpha detectors must be very thin in order for alpha particles to enter the detector and be counted. Since these windows are easily damaged, special care is necessary to prevent objects from touching them. The window of a scintillation counter must also prevent light from entering the detector. If the window is damaged, the counter may not respond to alpha particles and may respond to light entering through the damaged window (become light-sensitive). Even small pinholes may cause this response. Though proportional counters are not light-sensitive, they usually contain special gases. Damage to their windows may allow the gas to leak out or air to diffuse in, so that the counters do not respond properly to alpha radiation.

The potential for alpha emitters (or beta emitters) to enter the body is related to how easily they can be removed (transferred) from surfaces. A direct reading with a detector gives an indication of the total quantity on the surface but not its degree of attachment to the surface. To determine how readily alpha or beta emitters transfer, smears or swipes (disks of filter paper, paper towels, sometimes masking tape) are rubbed over a representative portion of the surface and then are counted to determine the quantity transferred to the smears. Scintillation or proportional counters are used to determine the alpha count rate from smear samples (Figs. 6.1.5, 6.1.6). Proportional counters or thin-window G-M counters are used to determine the beta count rate from smears (Figs. 6.1.6, 6.1.7).

Fig. 6.1.5. Alpha Sample Counter (Scintillation)

These counters, used for the assay of alpha emitters in various types of samples, consist of a lighttight sample holder, a zinc sulfide phosphor, and a photomultiplier. They may be housed in a separate unit or be included as an integral part of the associated scaler and power supply.

PHOTO 45072

Fig. 6.1.6. Sample Counter (Gas Flow, Proportional)

The gas-flow proportional counter is a very efficient alpha and beta analyzer. It has a low alpha background and a 2π geometry. It discriminates between alpha and beta-gamma radiation in combination. It requires, as accessories, a timer and a scaler that are capable of supplying the necessary power.

Fig. 6.1.7. G-M Counter (End-Window Type)

This G-M counter has a thin mica window at one end. A cylindrical lead or iron shield houses the counter, which is usually mounted in the upper part of the cylinder, and the mica window is aimed downward. Located under the counter window is a slotted sample carrier, accessible through a hinged door. An absorber can be interposed in the slot between the sample and the counter window.

The counter background (c/m with no smear sample in the counter) is subtracted from the gross counting rate (c/m from the smear plus background c/m) and the counter factor is applied to the net counting rate (c/m from the smear only) to obtain the actual disintegration rate from the smear. Usually smear data and transferable contamination limits are expressed in d/m/100 cm², 100 square centimeters being the approximate area over which the smear is rubbed (Table 6.1.1). Usually at least one representative smear of approximately 100 square centimeters is taken from each square meter of surface area.

Table 6.1.1. Guide for Establishment of Contamination Zones

Type of radiation	Airborne contamination (μCi/cc air)	Direct reading surface contamination	Transferable surface contamination (d/m/100 cm ²)
Alpha	2×10^{-12}	300 d/m/100 cm ²	30
Beta-Gamma	3×10^{-10}	0.25 mrad/hr	1000

NOTE: The alpha surface contamination levels given above are maximum values and are derived primarily to serve as a guide where the contamination involves a small area such as a single room or cell. When the contamination is extensive and involves radionuclides such as ²³⁹Pu or some other long-lived alpha emitter of comparable toxicity, the alpha levels permitted should average no more than 1/10 of the above values.

6.1.2.2 Detection and Monitoring Equipment for Beta-Gamma^{*} Radiation — with beta-gamma emitters we are concerned with the dose rate from sources outside the body as well as with limiting their intake into the body by controlling quantities on surface and in the air. A general class of detectors called ion chambers is usually used to measure the gamma dose rate in air and to approximate the dose rate from beta radiation.⁹ The ion pairs formed by radiation in the ion chamber produce an electric current which can be measured to indicate the rate at which the energy is being absorbed in the chamber walls and gas. If the ion-pair production in the chamber walls and gas is the same as in air, the detector is said to be "air equivalent" and the instrument is usually calibrated to read in rads per hour or millirads per hour. If the ion-pair production in the chamber gas and walls is the same as in the tissue, the detector is said to be "tissue equivalent" and may be calibrated to read in rems per hour or millirems per hour.

* Indicates a mixture of beta and gamma radiation. Any x rays are considered to be included also.

A variety of ion chamber instruments are available commercially. Figures 6.1.8-6.1.11 show several types used at ORNL. The "cutie pie" is perhaps the most widely used portable survey meter for measuring dose rates of mixed beta-gamma radiations. Standard cutie pies have three manually selected ranges with corresponding full-scale readings of 100 mrad/hr, 1000 mrad/hr (1 rad/hr), and 10,000 mrad/hr (10 rads/hr). Cutie pie models with other ranges are available.

Cutie pies are usually calibrated with gamma sources but can be used to approximate the dose rate from beta radiation¹⁰ when equipped with thin chamber walls ($\leq 7 \text{ mg/cm}^2$).

Features of some other ion-chamber devices can be found in references 9-11.

Several points should be remembered when portable survey meters are used to measure dose rates from beta-gamma emitters. First, the reading may be inaccurate except when the instrument is used to measure radiation of the same type and energy as that used to calibrate the instrument. Second, a serious beta hazard may go undetected if thick-walled detectors are used. Third, the instruments are calibrated for uniform gamma-radiation fields; so readings very near to intense small-dimension beta sources and in highly collimated radiation beams may seriously underestimate the actual dose rate. Fourth, the measurement is actually made at the collecting electrode (usually centered in the chamber) and not at the outer wall of the detector; so the actual dose rate at the surface of a source or container may be considerably higher.

AC-powered ion-chamber instruments such as the Monitron (Fig. 6.1.12) indicate the gamma dose rate at fixed locations.¹⁰ An alarm is sounded when the dose rate exceeds a preset level. Such continuous monitors are used in areas where changing process conditions may result in an unexpectedly high radiation level. When the alarm sounds, one should leave the immediate area until dose rates can be determined.

One is also concerned with detecting beta-gamma emitters (beta-gamma contamination) that may be present on the skin, shoes, clothing, equipment, etc. Ion-chamber-type detectors are not suitable for detecting low levels of beta-gamma contamination, which may be of concern on these surfaces. Geiger-Mueller (G-M) counters are better suited for this application, though beta- and/or gamma-sensitive scintillation detectors are sometimes used. Figures 6.1.13 and 6.1.14 show several types of instruments used for detection of beta- or gamma-emitting contaminants.¹⁰

Each ionizing event in a G-M counter causes the same response regardless of the amount of energy deposited by the radiation in the detector. For this reason, G-M counters should be used only as detectors or to indicate relative radiation levels. They should not be used to measure dose rates. If a G-M counter is calibrated in millirads per hour with a specific gamma source such as radium-226, it may be used to measure absorbed doses from a similar radium gamma source.

Fig. 6.1.8. Cutie Pie (Standard Model)

This is a relatively small, lightweight, portable survey instrument used for the measurement of gamma air absorbed dose rates. It is used also for the indication of beta radiation.

Fig. 6.1.9. Extended Probe Cutie Pie

The Extended Probe Cutie Pie is similar to the Standard Cutie Pie (p 33) except that the chamber is smaller in volume and remotely affixed by means of a two-foot length of rigid tubing. The full-scale ranges are 1, 10, and 100 rads/hr.

Fig. 6.1.10. Hi-Range Cutie Pie

The hi-range cutie pie is similar to the standard cutie pie except that the chamber volume and the electrometer input resistors are adjusted to provide full-scale ranges of 10, 100, and 1000 rads/hr.

Fig. 6.1.11. Juno Survey Meter

This instrument utilizes an ionization chamber with a rate meter to measure the intensity of gamma radiation and to indicate the relative intensity of beta-particle emission rates. Two manually positioned shields are incorporated to aid in determining types of radiation measured.

Fig. 6.1.12. Monitron

The monitron employs a large ionization chamber and is used for the detection of gamma radiation. The ionization chamber is connected with an amplifier circuit and a count-rate meter which reads directly in milliroentgens per hour. A relay circuit, actuating an alarm, may be set to go off at predetermined gamma-radiation levels.

PHOTO 51684

Fig. 6.1.13. G-M Survey Meter

This survey meter is a medium-weight, portable, beta-gamma indicating survey instrument. Audible or visible indication of radiation is afforded by means of earphones and a count rate meter. The Q2092A survey meter (shown above) was designed to work in gamma-ray intensities up to and exceeding 500 r/hr.

**Fig. 6.1.14. End-Window G-M
Survey Meter**

This survey meter is a lightweight survey meter for low-energy beta radiation monitoring. The circuitry is transistorized and powered by a rechargeable cell.

For most applications, G-M counters indicate the intensity of radiation detected in counts per minute (c/m). G-M counters are useful in locating hot spots or high radiation fields, after which dose rates can be measured with ion-chamber-type instruments.

If equipped with a very thin window, a G-M counter will respond to high-energy alpha particles and to low-energy beta particles as well as to gamma radiation. Very low-energy beta particles, such as those from tritium (maximum energy, 0.019 MeV), will not be detected. Since these thin windows are very fragile, they must be used with care. If thicker-walled G-M detectors are used, alpha and low-energy beta particles will not be detected. Some detectors are equipped with sliding shields which can be used to shield the detector from most betas in order to determine the relative intensities of beta and gamma radiation. If the instrument is to detect betas, the thin window or open area in the sliding shield must be facing the source or surface being scanned. The detector should be held near and moved slowly across the surface being monitored.

The detector will respond to background radiation (radiation from sources other than from the surface being scanned). Therefore, contamination monitoring should be performed in areas free of extraneous beta-gamma sources when possible. Contamination is indicated by count-rate meter readings (c/m) greater than the reading due to background radiation. Most portable G-M survey meters are provided with earphones. The earphone response, since it reacts faster, is a better indication of changes in the radiation intensity than the count-rate meter. Also, the count-rate circuit may fail to function properly in some G-M counters when exposed to high radiation fields. The earphone response does not fail in a high field, even though the meter may be reading zero instead of "offscale." Thus, it is always better to use earphones with portable G-M survey meters.

G-M detectors may be connected to "fixed" AC-powered instruments (Fig. 6.1.15). A speaker is usually provided in addition to a count-rate meter as an aid in detecting beta-gamma radiation.

AC-powered beta-gamma monitors for hands and feet also employ G-M detectors (Fig. 6.1.16).¹⁰ These are semiautomatic devices for detecting beta-gamma contamination simultaneously on the hands and shoes. The counting interval is automatically timed, and counts from the G-M tubes are indicated by digital registers. The normal background counts for the registers are posted on the instrument. Counts that register significantly above the background for the hand or foot registers indicate contaminated hands or shoes. A movable probe can be used to scan the clothing and other body surfaces. Low-energy betas will not be detected unless a thin-window G-M detector is used in the movable probe.

Fig. 6.1.15. Lab Monitor, Alpha or Beta

This monitor consists of a versatile counting-rate meter, ac powered, and either a zinc sulfide scintillation probe for alpha detection or a G-M counter probe for beta-gamma detection.

Fig. 6.1.16. Hand and Foot Monitor

The hand and foot monitor is a semiautomatic device for detecting beta-gamma contamination of shoes and hands simultaneously. Counts obtained by G-M tubes during an automatically timed interval are indicated by registers. An auxiliary probe for monitoring other areas of the body or clothing is included.

6.1.2.3 Detection and Monitoring Equipment for Airborne Radionuclides —

The concentration of beta-gamma and alpha emitters in the air must be determined in some areas. When established maximum permissible concentrations (MPC) are exceeded, appropriate procedures (use of respiratory protection, evacuation of personnel, limiting occupancy times) must be initiated to limit intake of the hazardous materials by personnel.¹² Air concentration measurements also serve to indicate process leaks and the need for improved containment.

A continuous air monitor (CAM) consists of a pump to draw air through a filter paper which collects radioactive particulates (plus nonradioactive dust), a detector to recognize the alpha or beta particles among the particulates, a count-rate meter to indicate the counts per minute from the filter, and a strip-chart recorder to record the count rate. An alarm is sounded when the count rate exceeds a predetermined level, which may indicate air concentrations in excess of MPC. When the alarm sounds, one should don a mask or evacuate the area until the air concentration returns to safe levels.

CAM's for detection of airborne alpha emitters employ alpha detectors, such as alpha scintillation detectors (Fig. 6.1.17). Nonradioactive dust collected on the filter paper absorbs some of the alpha particles and reduces the detection efficiency. Also, dust restricts the flow of air through the filter and may reduce the rate at which air is sampled. Thus, areas where alpha emitters are of concern should be maintained as dust-free as possible.

CAM's for detection of airborne beta-gamma emitters usually use G-M tube detectors. The lowest-energy beta that a CAM detects will depend on the tube wall thickness but is 0.1 MeV for the ORNL model¹⁰ (Fig. 6.1.18). The detector and filter are enclosed in a shield to reduce the response to beta-gamma radiation other than that from the filter. However, elevated count rates may result if the CAM is used in high-intensity gamma radiation fields or if a gamma source is brought near the monitor. The monitor will also respond to beta-gamma-emitting gases passing by the detector, although gases will not be retained on the filter.

The naturally radioactive gases, radon and thoron, diffuse into the atmosphere from uranium and thorium deposits in the earth's crust. These alpha-emitting gases and their alpha- and beta-gamma-emitting particulate daughters add to the background count rate of air monitors and interfere with the determination of the airborne contamination from process plant sources.⁹ The contribution from these natural sources varies with time of day and with weather conditions.

Health physics personnel determine the average concentration of particulate alpha or beta-gamma emitters during a sampling period by removing the filter paper from the monitor or sampler, allowing time for the natural alpha and beta-gamma emitters to decay, and then recounting the filter in suitable alpha and beta counters to determine the number of microcuries of the long-lived radionuclides of interest.

Fig. 6.1.17. Air monitor (Continuous, Alpha)

This device monitors the quantity of particulate alpha radiation in the surrounding air. A vacuum pump draws air through a filter under a scintillation detector. The detector is connected to a count-rate meter which is connected to a strip-chart recorder, and the radiation level is continuously recorded. An associated relay-alarm system permits visible and audible alarms to be activated at predetermined levels.

PHOTO 92209

Fig. 6.1.18. Air Monitor (Continuous, Beta-Gamma)

This device monitors the quantity of particulate beta-gamma radiation in the surrounding air. A vacuum pump draws air through a filter over a G-M tube mounted in a lead or stainless steel shield. The tube is connected to a count-rate meter which is connected to a strip-chart recorder, and the radiation level is continuously recorded. An associated relay-alarm system permits visible and audible alarms to be activated at predetermined levels.

Dividing this result by the total volume (in cubic centimeters) of air drawn through the filter paper yields the average concentration in microcuries per cubic centimeter, which can be compared with the recommended maximum permissible concentrations.¹²

An air monitor or sampler gives an indication of the concentration of airborne contamination only at the sampling point. Concentrations could be much higher elsewhere, and one should respond promptly to alarms and other indications that airborne contamination has been released.

6.1.2.4 Neutron Monitoring and Detection Equipment — The selection of a neutron detector depends on the energy of the neutrons to be monitored. Boron trifluoride (BF_3) gas proportional counters¹⁰ are often used for monitoring thermal neutrons (0.025 eV) (Fig. 6.1.19). These counters utilize the ionization of boron trifluoride gas by alpha particles emitted when boron-10 absorbs a neutron. A boron trifluoride proportional counter can also be used to monitor intermediate (0.5 eV to 10 keV) and fast (10 keV to 10 MeV) neutrons when the counter is equipped with a suitable moderator to slow the neutrons to thermal energies¹⁰ (Fig. 6.1.20). Special design AC-powered instruments of this type may be used to trigger an evacuation alarm in the event of a criticality accident, which may result in a "burst" of neutrons of too short a duration for a rate meter to respond. Again, the area should be evacuated immediately if the alarm sounds.

A tissue-equivalent proportional counter can be used for direct measurement of the fast-neutron dose equivalent rate¹⁰ (rems per hour or millirems per hour) (Fig. 6.1.21). This instrument measures the ionization from proton recoils ejected in fast-neutron collisions in the counter gas and components.

When fast neutrons interact with a moderator, some are slowed to intermediate and thermal energies. A thorough evaluation of the hazard may require monitoring for gamma radiation as well as fast, intermediate, and thermal neutrons and should be left to health physics personnel with expertise in making such evaluations.

6.1.2.5 Personnel Monitoring Devices* — Personnel monitoring devices serve three main functions: (1) to integrate radiation doses over an extended period, (2) to aid in controlling radiation doses during specific jobs and on a day-to-day basis, and (3) to indicate who has been exposed and the extent of exposure in the event of radiation accidents.

* Monitoring devices worn on the person or his clothing.

Fig. 6.1.19. Thermal-Neutron Counter (Portable)

The portable counter measures thermal-neutron flux rates. All circuitry is transistorized, and power is provided by rechargeable nickel-cadmium cells. The detector is relatively insensitive to gamma radiation.

Fig. 6.1.20. Neutron Monitor

This monitor (ORNL Q-2296) is for indicating the dose equivalent rate and integrated dose equivalent of neutrons. The circuitry is transistorized; alarm relays and an output for a strip-chart recorder are provided.

Fig. 6.1.21. Fast-Neutron Survey Meter

This survey meter is a transistorized count-rate meter calibrated in terms of millirems per hour. The detector is a tissue-equivalent proportional counter. A register is provided for very low dose-rate measurement. Unique circuitry provides excellent discrimination against gamma radiation.

Film badge dosimeters are perhaps the most widely used personnel monitoring devices for recording the total dose received by an individual over a period of weeks or months.^{9,13} The film is generally contained in packets similar to those used for dental X rays. Radiation causes darkening of the film upon development. The degree of darkening can be measured by an optical densitometer and is related to the total dose to the film. Most film badges have one or more metallic filters over a portion of the film. A comparison of the darkening in the filtered and unfiltered portions of the film aids the health physicist in determining the dose from radiations (beta, gamma, X rays, neutrons) of different types and energies. Film badges may contain several film jackets (sensitive and less sensitive) to allow coverage of a dose range from a few millirems to several hundred rems. Special packets may be included where neutron monitoring is necessary. One model of the ORNL badge¹⁰ is shown in Fig. 6.1.22.

Other dosimeters: a number of other substances have been developed into suitable radiation dosimeters.⁹ Irradiated phosphors such as lithium fluoride (LiF) and manganese-activated calcium fluoride (CaF:Mn) give off light when heated. The light output can be measured with a photomultiplier tube and the total light intensity related to the radiation dose. Such dosimeters are called thermoluminescent dosimeters. These have been developed to have sensitivity to a few millirems of gammas and an upper range of more than 1000 rems. Whereas developed film can be stored as a "permanent" record of radiation dose, the reading process "erases" the dose record in thermoluminescent dosimeters.

Special types of glass, after being irradiated, will emit an orange fluorescent light when illuminated with ultraviolet light.⁹ The light output is measured by a fluorimeter, and the intensity of the fluorescence gives a measure of the radiation absorbed dose. Glass dosimeters have been developed with suitable dose ranges (less than 50 mrad to more than 1000 rads), and the dose is not erased by the reading process.

Sometimes it is necessary to measure the radiation dose to the extremities of the body and to the whole body separately, since the allowable dose to the extremities is somewhat higher (see Table 6.1.2).⁹ Film and thermoluminescent dosimeters have been adapted for use in finger-ring and wrist dosimeters.

The health physicist must cope with a number of problems in the use, calibration, processing, and interpretation of data from all types of dosimeters (film, thermoluminescent, glass, etc.). The following precautions will help minimize some of these problems and assure the best possible estimate of occupational radiation dose: (1) The dosimeter should be worn at all times when one is working in a radiation area. (2) A dosimeter should never be exposed to radiation unless it is being worn. (3) Contamination of a dosimeter should be avoided and should be reported promptly to the health physics group if it should occur. (4) A dosimeter should not be exposed to excess moisture, high temperature (as in a closed auto in the hot sun), or abuse of any kind.

Fig. 6.1.22. ORNL Badge-Meter, Model II

The ORNL Badge-Meter is a combination identification, routine monitoring, and radiation accident monitoring device for personal use. It is described in *The ORNL Badge Dosimeter and Its Personnel Monitoring Applications*, ORNL-3126.

Table 6.1.2. Radiation Protection Guides^a

Occupational exposure	Condition	Dose (rems)
1. Whole body, head and trunk, blood-forming organs, gonads, lens of the eye	Accumulated dose 13 weeks	5(N-18); N > 18 yr ^b 3
2. Skin and thyroid	Year 13 weeks	30 10
3. Hands and forearms, feet and ankles	Year 13 weeks	75 25
4. Bone	Body burden	1.1 μ g ²²⁶ Ra or its equivalent
5. Other organs	Year 13 weeks	15 5

^aAdapted from *Background Material for the Development of Radiation Protection Standards*, Report No. 1, Staff Report of the Federal Radiation Council (1960).

^bN = individual's age in years at his last birthday.

Possible damage should be reported promptly to the health physics group. (5) A dosimeter should never be tampered with. (6) A dosimeter should never be worn during medical X rays or other medical radiation treatments.

Pocket meters (small pencil-shaped dosimeters) are frequently used to indicate radiation doses during a specific job or on a daily basis and are used in conjunction with a film badge, etc. Records of an individual's cumulative pocket meter readings also serve to indicate when an individual is approaching his weekly or quarterly dose limit (Table 6.1.2). Pocket meters are of two types: direct-reading and indirect-reading. The direct-reading pocket dosimeter (sometimes called visual dosimeter or "peep" meter) contains a quartz-fiber electrometer unit in one end, which is viewed through a lens in the other end¹⁰ (Fig. 6.1.23). A separate charging unit is used to adjust the quartz fiber to the zero position. Radiation causes a displacement of this fiber, which can be viewed on a calibrated scale. Direct-reading pocket dosimeters for routine use usually have a range of zero to 200 mrad, though dosimeters with other ranges are available. Visual dosimeters should always be read with the fiber image vertical. The indirect-reading pocket meter is a small ionization chamber for measuring doses, usually in the range of 5 to 200 mrad¹⁰ (Fig. 6.1.24). A special instrument is used to charge these dosimeters; the same unit measures the charge remaining after exposure, which is related to dose.

Both the direct- and indirect-reading pocket meters are accurate for gamma radiation with energies of 0.1 to 3 MeV. Betas of less than 1 MeV will not be detected.¹⁰ For accurate comparison with weekly or

The pocket dosimeter is a small pencil-type ionization chamber containing a quartz-fiber electrometer unit. The fiber unit, mounted into one end of the instrument, is viewed through a lens from the opposite end. A rectifier circuit or battery supply is used to charge the dosimeter. After the dosimeter has been charged, the displacement of the fiber indicates the exposure to the meter.

ORNL-LR-DWG 49998

Fig. 6.1.23. Dosimeter (Fiber Type)

The pocket ionization chamber is an indirect-reading gamma dosimeter for the measurement of low-level personnel exposures in the 5- to 200-mrem range. The principal components are a cylindrical outer wall, a central-rod electrode, insulators, and a protective cap. The chamber is used in conjunction with a charger-reader (Minometer) for dose measurement.

ORNL-LR-DWG 50004

VICTOREEN POCKET METER, MODEL 352

A. LOW ATOMIC NUMBER WALL	E ₃ POLYETHYLENE INSULATING WASHER
B. GRAPHITE-COATED PAPER SHELL	E ₄ POLYSTYRENE FIXED BUSHING
C. ALUMINUM TERMINAL HEAD	E ₅ ELECTRODE CONTACT
D. ALUMINUM TERMINAL SLEEVE	F. RETAINING RING
E ₁ POLYSTYRENE SUPPORT BUSHING	G ₁ ALUMINUM BASE CAP
E ₂ CENTRAL ELECTRODE, GRAPHITE COATED	G ₂ POLYETHYLENE FRICTION BUSHING

Fig. 6.1.24. Pocket Ionization Chamber

quarterly doses from badge dosimeters, pocket meters should be worn near these dosimeters. Dropping or exposing to high humidity may cause pocket meters to discharge, resulting in higher readings than the actual dose received. One must be careful not to use discharged pocket meters.

Accident dosimeters: in addition to components for recording radiation doses, badge meters may also contain devices for recording and/or indicating exposures to large doses of gamma or neutron radiation that might result from a criticality accident. Low-sensitivity film, glass dosimeters, or thermoluminescent dosimeters may be used to indicate gamma dose up to hundreds of rems. Gold and/or indium foils will be made radioactive by large doses of neutron radiation. The beta-gamma radiation from these activated foils can be detected with G-M survey meters, enabling rapid separation of exposed persons from the unexposed.¹³

To determine neutron doses from a criticality accident, additional information is required from fixed dosimeters stationed in the area. These units contain "threshold" foils and other materials activated by neutrons of different energies. These enable determination of the neutron spectra. Samples of blood are counted to determine the neutron activation of sodium in the blood. With data from the badge and the above information along with knowledge of the person's orientation, the health physicist can calculate the approximate neutron dose.¹⁴

A Personal Radiation Monitor (PRM) is a device worn on the body to warn of unexpected high-intensity gamma radiation¹⁰ (Fig. 6.1.25). It is not sensitive to beta radiation and should not be used for dose-rate measurements. It indicates the relative intensity of gamma radiation by an audible signal ("chirps"). The more intense the radiation field, the more rapid the chirp rate. A continuous high-pitched signal is emitted at dose rates greater than about 1 rad/hr. This device aids in avoiding high-intensity radiation fields and also in locating lower radiation fields in which to do any standing by.

6.1.3 Radiation Exposure Limits for Personnel

Earlier we stated that absorption of radiation energy results in damage to cells and tissues of the body. This damage can be broadly classified into early effects and late effects. Early effects are the manifestation of damage from large absorbed doses delivered in a short period of time. These have been well documented from studies of accident cases and persons exposed to radiation from nuclear bomb explosions.^{15,16} Table 6.1.3, taken from Medical Aspects of Radiation Accidents, summarizes some of these early effects.¹⁷ Note that doses to the whole body in the range of 300 to 450 rems are expected to result in the eventual death (usually within 30 days) of 50% of the individuals exposed. The dose that results in death within 30 days of 50% of those exposed is referred to as the LD_{50}^{30} (lethal dose to 50% in 30 days).

Fig. 6.1.25. Personal Radiation Monitor

The Personal Radiation Monitor is a pocket-pen size instrument for warning the user of the relative intensity of a field of radiation by means of an audible signal. It is especially useful in operations where high levels of exposure may be reached unexpectedly.

Table 6.1.3. Summary of Effects Resulting From Acute Whole Body External Exposure of Radiation to Man^a

0-25 rems	25-100 rems	100-200 rems	200-300 rems	300-600 rems	600 or more
No detectable clinical effects. Delayed effects may occur.	Slight transient reductions in lymphocytes and neutrophils. Disabling sickness not common, exposed individuals should be able to proceed with usual duties. Delayed effects possible, but serious effects on average individual very improbable.	Nausea and fatigue, with possible vomiting above 125 rems. Reduction in lymphocytes and neutrophils with delayed recovery. Delayed effects may shorten life expectancy in the order of 1 percent.	Nausea and vomiting on first day. Latent period up to 2 weeks or perhaps longer. Following latent period symptoms appear but are not severe: loss of appetite, and general malaise, sore throat, pallor, petechiae, diarrhea, moderate emaciation. Recovery likely in about 3 months unless complicated by poor previous health, superimposed injuries or infections.	Nausea, vomiting and diarrhea in first few hours. Latent period with no definite symptoms, perhaps as long as 1 week. Epilation, loss of appetite, general malaise, and fever during second week, followed by hemorrhage, purpura, petechiae, inflammation of mouth and throat, diarrhea, and emaciation in the third week. Some deaths in 2 to 6 weeks. Possible eventual death to 50 percent of the exposed individuals for about 450 rems.	Nausea, vomiting and diarrhea in first few hours. Short latent period with no definite symptoms in some cases during first week. Diarrhea, hemorrhage, purpura, inflammation of mouth and throat, fever toward end of first week. Rapid emaciation and death as early as the second week with possible eventual death of up to 100 percent of exposed individuals.

^aTaken from *Medical Aspects of Radiation Accidents*, by Eugene L. Saenger, M.D., Editor, USAEC.

There are no observable early effects from low radiation doses or doses up to several hundred rems accumulated at low dose rates over many years. This does not mean, however, that there is no risk in such radiation exposures. Delayed or late effects have been observed in animal studies and in studies of humans exposed in uranium mines, in the radium dial industry, in radiation accidents, in the medical profession, and in nuclear bomb blasts.¹⁸ These late effects include hereditary effects; an increased incidence of tumors, leukemia, and other cancers; cataract formation; and life shortening. Hereditary effects refer to gene mutations, the results of which may show up in subsequent generations. Other effects may not show up for 5, 10, 15, or more years after exposure. Unless death can be directly attributed to radiation exposure (see Table 6.1.3), life-span shortening cannot be demonstrated on an individual basis.

Most late effects have been observed only at total doses and dose rates considerably higher than those permitted for occupational exposures. In addition, it is difficult to assign radiation as the cause of a specific effect, since there are many other factors (chemicals, diseases, smoking, etc.) that also lead to the same effects. In fact, it would take a statistical analysis of thousands of radiation workers to discern any damage from radiation doses within the levels of permissible occupational exposure.

Since there is considerable uncertainty, yet to be resolved, regarding the risks of damage from low doses of radiation, it seems prudent to plan and perform our work so as to avoid any unnecessary radiation exposure.

Radiation protection guides (RPG) or maximum permissible dose limits (MPD) have been recommended by agencies such as the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurement (NCRP), and the Federal Radiation Council (FRC). Table 6.1.2 is adapted from the recommendations of the FRC as they appear in the council's first report.¹⁹

From Table 6.1.2 we note that the occupational dose limit is lower when the exposure is to the whole body or to parts of the body containing certain "critical organs," which may be especially vulnerable to radiation damage and which are more vital to the overall function of the body. On the other hand, dose limits are less restrictive when other organs or any parts of the body not including the critical organs are exposed. The quarterly dose limits for the whole body (including critical organs), for the skin, and for the extremities (hands, forearm, feet, and ankles) are 3 rems, 10 rems, and 25 rems respectively.

The whole-body or critical-organ dose accumulated to an individual's present age, N , must not exceed $5(N-18)$ rems. Example: at age 30 the maximum accumulated dose could be $5(30-18) = 5 \times 12 = 60$ rems. This means that from age 18 the average annual dose must not exceed 5 rems. The annual dose limits for the skin and extremities are somewhat larger at 30 rems and 75 rems respectively.

In applying the occupational dose limits to the whole body, to an organ, or to a part of the body, the total dose contributions from external and internal sources must be considered.

Maximum permissible concentrations in air, $(MPC)_a$, and water, $(MPC)_w$, have been established for various radionuclides.¹² These concentrations are not "permissible" in the usual sense, and every effort should be made to keep concentrations in the air breathed and the water ingested as low as possible. Continuous intakes (40 hours per week) of a radionuclide at the MPC level would eventually lead to a maximum permissible body burden or organ burden of that nuclide — the burden which would deliver the maximum dose permitted to the body or to the organ where the nuclide concentrates.

Internally deposited radionuclides irradiate the body or organs 24 hours a day until the nuclides decay to stable states or are excreted from the body. The time required for one-half of an element to be eliminated from the body is called the biological half-life. Some radionuclides (plutonium-239, for example) have both long radioactive and long biological half-lives and thus may contribute to the internal dose over a period of many years. Some radionuclides contribute doses primarily to specific organs where they tend to concentrate (examples: strontium and plutonium in bone; iodine in the thyroid).

Assessment of doses from internal sources is considerably more difficult than measurement of external doses. The quantities of various radionuclides excreted in urine and fecal samples serve as indications of the quantities deposited inside the body. For some radionuclides, X and gamma rays emitted from internally deposited radionuclides can be measured in a whole-body counter to yield estimates of the organ or body burdens. If the dose to the body or parts of the body from internal sources becomes significant, reductions in the dose permitted from external sources may be necessary so that the total dose limits are not exceeded.

6.1.4 Radiation Exposure Control Procedures

In Sect. 6.1.3 we discussed the radiation dose limits that should not be exceeded. Doses above these limits can be avoided by following proven control measures in the handling of radionuclides. The main objectives of such control measures are:

1. to maintain exposure to external radiation as low as feasible
2. to minimize the intake of radionuclides into the body.

Accomplishment of these goals requires positive planning and diligent execution of work procedures beyond the actions necessary for work with nonradioactive materials. The hazards of each job must be analyzed in advance and appropriate safeguards provided. It is necessary to plan against foreseeable accidents and to use protective devices and planned emergency procedures in accidents that do occur.

The health physicist maintains an intimate knowledge of the radiation safety aspects of the operations being conducted. He must accurately and currently determine the radiation hazards existing in the various work areas of the plant and advise the operating supervision accordingly. He assists the operating supervision in establishing radiation control zones where significant potential radiation hazards exist and where control measures are necessary to minimize external or internal exposures of personnel.

Entry into these radiation control zones is through specified portals and is controlled by the operating supervision. The zones are marked by signs or tags bearing the standard radiation symbol in magenta or purple on a yellow background²⁰ (Figs. 6.1.26-6.1-28). The general requirements for entrance to and exit from the zones are also posted at the zone portals. Sometimes very small areas or even pieces of equipment or containers may require zoning. Zones may be permanent or temporary in nature, and restrictions should be removed when the hazard no longer exists.

A Radiation zone is an area where control measures are established to prevent or minimize external radiation exposure of personnel. Table 6.1.4 may be used as a guide in establishing radiation zones.²⁰

Persons entering radiation zones must wear their integrating badge dosimeters as well as any other supplementary dosimeters required, such as pocket meters or wrist and finger dosimeters. Where the dose rate is sufficiently high, special administrative approvals may be required²⁰ (Table 6.1.5).

One's total dose from an external source of radiation can be controlled by limiting one's exposure time and by reducing the dose rate.

The total dose received is equal to the dose rate times the exposure time. Example: If one spends 1 hour in a radiation field where the dose rate is 200 mrem/hr he will receive a dose of 200 mrem/hr x 1 hr = 200 mrem. If his exposure time is reduced to half an hour, his total dose is reduced in direct proportion (200 mrem/hr x 1/2 hr = 100 mrem).

Where it is not feasible to reduce the dose rate, a working time limit may be necessary:

$$\text{working time} = \frac{\text{allowed dose}}{\text{dose rate}}$$

For example, if one is allowed to receive a dose of 60 mrem on a job where the dose rate is 300 mrem/hr, his

$$\text{working time} = \frac{60 \text{ mrem}}{300 \text{ mrem/hr}} = 1/5 \text{ hr} = 12 \text{ min.}$$

On jobs involving variable dose rates, pocket electrometers (visual dosimeters) are especially useful in indicating when the allowed dose has been received and one should leave the area.

Fig. 6.1.26. Zoned Areas for Radiation Hazard and Exposure Control.

Radiation Zone Sign (metal or cardboard)

Radiation Zone Tape Sign (available with or without adhesive backing)

Fig. 6.1.27. Radiation Zone Markers

Contamination Zone Sign (metal or cardboard)

Contamination Zone Tape Sign (available with or without adhesive backing)

Fig. 6.1.28. Contamination Zone Markers

Table 6.1.4. Guide for Establishment of Radiation Zones

Dose-rate range (rems/hr)	Immediate action	Follow-up action
0.003-0.006	Post low-level tags if the accumulated daily dose to personnel may be 20 mrem	Periodic review
0.006-1	Post warning signs or tags	Rope off the area if the accumulated weekly dose may be 1 rem
1-3	Post warning signs or tags; rope off	Erect a barricade which provides absolute exclusion of personnel. If the accumulated weekly dose in the area may be 12 rems, lock or block entrance
Over 3	Post warning signs and tags and erect barricades; lock and/or block all entries	

The dose rate to which an individual is exposed can be reduced by increasing the distance between him and the source and/or by placing a shield between him and the source.

Increasing the distance from a source is frequently the most effective and economical means of reducing the dose rate and hence the total dose. The simplest source, geometrically, is a small "point source" which emits radiation in all directions. Envision a source at the center of a hollow sphere of radius r . The surface area of the sphere is $4\pi r^2$. If S represents the maximum dose rate at the source, the dose rate at a point on the surface of the sphere is $S/4\pi r^2$. The dose rates at points on spheres with radii of 1 ft, 2 ft, and 3 ft would be:

$$r = 1 \text{ ft: } S/4\pi(1)^2 = S/4\pi \times 1/1$$

$$r = 2 \text{ ft: } S/4\pi(2)^2 = S/4\pi \times 1/4$$

$$r = 3 \text{ ft: } S/4\pi(3)^2 = S/4\pi \times 1/9.$$

Example: if the dose rate at 1 ft is 80 mrem/hr and we double our distance from the source to 2 ft, the dose rate is reduced to $80 \text{ mrem/hr} \times 1/4 = 20 \text{ mrem/hr}$.

This principle is referred to as the inverse square law since the dose rate varies as the inverse of the square of the distance from the source. This applies only to point sources. A larger source may be treated as

Table 6.1.5. Guide for Planning and Authorizing External Exposure to Specified Dose Rates

I	II	III	IV	V	VI
Exposure level dose rate to whole body (rem/hr)	Direct reading and/or alarm-type monitoring instruments required	Health physics surveillance required	Special approvals required		
			Area division director	Health physics division director	Laboratory deputy director
0.003-5	X	X			
5-20	X	X	X		
20-50	X	X	X	X	
Over 50	X	X	X	X	X

Note: The above required approvals are to be noted on the Radiation Work Permit issued for the particular job assignment should doses >20 mrem in any one day be expected. In the dose-rate range of from 0.003 to 5 rem/hr, and where an individual's exposure time ensures that he will receive less than 100 mrem accumulated dose in one week (or the equivalent for individual organs), the requirements indicated in Columns II and III may be replaced by other safeguards in written procedures approved by the appropriate authorities indicated in Columns IV to VI.

a point source if the distance from the source to the detector is at least 2 or 3 times the maximum dimension of the source or the detector.

The dose rate from other types of sources, such as long process pipes or large contaminated surfaces, decreases more slowly with distance. Also, the inverse-square law disregards any absorption or scattering of the radiation between the source and the detector; so it applies primarily to X and gamma radiation. Since lower-energy beta radiation will be absorbed appreciably in the air surrounding the source, a beta-gamma reading at a distance could lead to a serious underestimate of the beta hazard near the source.

Increasing one's distance from a source may involve the use of tongs, forceps, or long-handled tools. Sources emitting significant levels of beta-gamma radiation should never be picked up directly with the fingers. Even short forceps provide a large reduction in dose rate from that delivered to the skin in direct contact with the source. Sources of radiation should be stored away from immediate work areas. Unnecessary lingering close to radiation sources such as drums, casks, glove boxes, process pipes, tanks, and equipment should be avoided. Any standing by should be done in the lowest radiation level available.

Shielding should be used where feasible and must be used when the dose rate is still excessive after time limits and distance factors are employed to the best advantage.

Shielding from alpha particles is not necessary because of their short range. Beta particles can penetrate the outer dead layer of skin and present mainly a skin exposure problem. But beta particles are easily absorbed by thin sheets of plastic, metal, etc. For example, a 1-MeV beta has a range of 0.079 in. in aluminum; so a sheet of aluminum 0.08 in. thick would completely stop all 1-MeV betas. A table giving ranges of betas of various energies in air, water, aluminum, and lead is found in reference 21. Often the walls of bottles, tanks, pipes, pumps, etc., containing beta emitters are effective beta shields. Thus, if beta emitters are spilled or leak from their containers, a serious beta hazard may result. A thin sheet of water and even the water containing a beta emitter in solution absorbs much of the beta energy. Thus, when the water evaporates or is drained away, a much more severe beta hazard may exist, and dose rates must be rechecked. A gamma shield would absorb all beta radiation. Removal of a gamma shield might expose an intense source of beta radiation also covered by the shield. Dose rates must be continuously monitored during removal of shielding or on any job where personnel might be subjected to significant unexpected increases in dose rates.

Protective clothing may absorb a large fraction of the energy of beta radiation. Safety eyeglasses significantly reduce the beta dose to the lens of the eye and should be worn when working with emitters of higher-energy betas.

X rays, gamma rays, and neutrons do not have a definite range and lose energy only upon interaction or collision with the nuclei or electrons of the absorbing material. Theoretically it is not possible to absorb 100% of these radiations. However, shields of sufficient thickness can be applied to reduce the intensity of the radiation penetrating the shield to safe levels. The thickness of a substance required to reduce an X- or gamma-ray beam to one-half its original intensity is called a half-value layer or half-thickness. A tenth-value layer will reduce a beam to one-tenth of its original value. Each additional half-value layer or tenth-value layer would yield an additional reduction by a factor of 2 or 10. For example, suppose a gamma-ray source results in a dose rate of 2000 mrem/hr at a point. If 3 half-value layers are interposed between the source and the point, the dose rate would be reduced to $2000 \text{ mrem/hr} \times 1/2 \times 1/2 \times 1/2 = 2000 \text{ mrem/hr} \times 1/8 = 250 \text{ mrem/hr}$. Three tenth-value layers would reduce the dose rate to $2000 \text{ mrem/hr} \times 1/10 \times 1/10 \times 1/10 = 2000 \text{ mrem/hr} \times 1/1000 = 2 \text{ mrem/hr}$.

The thickness of tenth- and half-value layers varies with the absorbing substance and the energy of the radiation. Dense materials such as iron and lead are best for X- and gamma-ray shields. The tenth-value layer of lead for 2-MeV gamma rays is about 1.8 in. For 0.1 MeV gamma rays the tenth-value layer of lead is only about 0.015 in.²¹

Hydrogen-containing compounds such as paraffin or water are frequently used to reduce the energy of fast neutrons. An outer layer of boron or cadmium is effective in absorbing low-energy neutrons. The appendix of reference 21 contains tables and graphs of attenuation factors for different substances for gamma rays and neutrons of various energies.

Secondary and scattered radiations are often important in the penetration of beta, gamma, and neutron radiations through shielding. Therefore, except in very simple situations, shields should be designed by trained people. The adequacy of a shield must always be tested by appropriate radiation surveys.

Contamination zones are established where control measures are necessary to prevent radionuclide contamination of personnel, the environs, and/or equipment and where there is the possibility that radionuclides may become deposited inside the body, leading to internal exposure. Table 6.1.1 may be used as a guide in establishing contamination zones.²⁰

The specific goals of contamination-zone procedures are to minimize internal and external contamination of personnel to prevent the spread of radioactive contamination outside the zone and to minimize the dissemination of radionuclides within the zone. A well-designed and constructed facility is a tremendous asset in achieving these goals. But 100% containment of radionuclides is an ideal situation rarely achieved. Leaks and spills of radioactive materials will occur occasionally. Maintenance will be necessary on process equipment with the attendant potential for release of radionuclides and exposure of

personnel. Protective clothing and equipment are essential for protection of personnel. But a neat, careful, conscientious worker, always alert and attentive to details, is a must also if these goals are to be realized.

Entrance to and exit from a contamination zone will be through specified portals where the general requirements are posted. The potential hazard within the zone may be due to radioactive substances deposited on surfaces as solids and/or liquids. Airborne radioactive gases or aerosols may also be present. A contamination zone may be posted as a radiation zone also if significant external hazards exist (see Table 6.1.1). Control procedures and protective equipment requirements vary with the nature and degree of the hazard. Before entering a contamination zone, one should be informed of the hazards involved, the protective equipment required, and the procedures to be followed.

The three main routes by which radioactive substances may enter the body are by inhalation, ingestion, and absorption through the skin or breaks in the skin.

Where airborne contaminants are present at concentrations exceeding permissible limits (MPC),¹² respiratory protection should be used to prevent inhalation of radionuclides. Selection of a respiratory device depends on whether the contaminant is an aerosol or gas and on the concentration (see Section 6.1.5).²² Before attempting to use a respirator in a contamination zone, a person should be tested for fit and be trained in its proper use. Filter-type respirators should never be used in oxygen-deficient atmospheres or other atmospheres immediately hazardous to life.

A good seal cannot be maintained over a heavy beard or the shanks of eyeglasses. If corrective lenses are required, eyeglasses can be modified for use in a mask designed for that purpose.

Since removal of other highly contaminated protective apparel may result in localized air contamination, the mask should be removed last and well away from areas of significant airborne contamination. Respiratory protection may be required because of the possibility that the operation itself may generate air contamination. This is especially true of welding, burning, grinding, or chipping on contaminated surfaces. Air contamination may also result when it is necessary to break connections to unvented and internally contaminated process equipment.

Ingestion, in general, refers to intake through the mouth by swallowing. Edibles of any kind — gum, food, candy, beverages — should not be brought into contaminated areas. Smoking should be prohibited in a contamination zone, since smoking materials may become contaminated, and the radioactive contamination may be transferred to the lips or inhaled as it is burned. Personal cleanliness is essential. Gloves should be worn to handle contaminated items, and hands should be washed after each work period in a contamination zone and before eating or

smoking. Personal items such as pens, pocketknives, handkerchiefs, lipstick, etc., should not be used in a contamination zone. Things that might be contaminated should not be put into the mouth. Of course, mouth pipetting of radioactive solutions should be forbidden.

The risk of absorption through the skin is increased when radioactive substances become deposited on the surface of the body. The intact skin serves as a barrier for many radionuclides, but if the skin is damaged the risk of intake via this route is greatly increased. Persons with cuts or wounds should not work in highly contaminated areas without medical approval and without waterproof coverings over their injuries. Also, the use of sharp or pointed tools or equipment in highly contaminated areas should be avoided. These may cut or puncture the skin, injecting radioactive materials beneath the skin. Should such an injury occur, immediately the wound should be flushed with water and reported to medical and health physics personnel for treatment and monitoring.

The use of prescribed protective clothing (caps, hoods, coveralls, laboratory coats, gloves, masks, etc.) reduces the potential for injury and contamination of the skin. If contamination levels in an area are excessive, multiple layers of protective clothing, with openings taped, may be required. When liquid or corrosive contaminants are encountered, air-supplied plastic suits may be necessary (see Section 6.1.5). Such suits are used also for high air concentrations of tritium, which is readily absorbed through the intact skin.

Special care is needed to avoid spread of contamination from clothing. Gloves and shoe covers should be monitored frequently and replaced as necessary to avoid spread to uncontaminated surfaces. This also helps reduce the dose to the hands from beta-gamma emitters on the gloves. Practices such as rubbing the nose or hair, adjusting glasses, or wiping the face on one's sleeve should be avoided. In donning protective clothing, the unsuiting procedure should also be considered. An unsuiting sequence should be followed which minimizes the risk of contaminating the skin or underclothing (personal clothing should be removed before suiting up for entry into areas of high-level contamination).

All contaminated clothing should be removed at the zone boundary and placed in receptacles provided (often more grossly contaminated outer protective clothing may be removed at the job site to avoid spread of contamination within the zone). Special care should be exercised to prevent spread of contamination across the boundary. Before leaving the zone portal, all personnel should scan their clothing and exposed body surfaces with contamination monitors (Section 6.1.2). Tools and equipment likewise should be monitored and any contamination removed or contained before they are removed from the zone. If contamination is detected on the clothing or on the skin, it should be removed or made nontransferable by tape or additional protective clothing until it can be removed in a more suitable location. Skin contamination should be removed as soon as possible. The health physics group should be contacted for assistance and monitoring (see Section 6.1.6).

Other techniques for radioactive contamination control are discussed in Section 6.1.5.

Radiation Work Permits are required by the company in advance of jobs where

1. an individual may receive a whole-body dose greater than 20 mrem during the work shift, or
2. an individual may receive a dose greater than 300 mrem to the extremities during a work shift, or
3. an individual will be exposed to a whole-body dose rate in excess of 5 rems/hr, or
4. an individual will encounter airborne radioactivity greater than the (MPC)_a for a 40-hour week.

The purpose of the Radiation Work Permit (RWP) is to assure that the job has been well planned, that the radiation hazards of the job have been thoroughly evaluated, and that the protective equipment and monitoring devices required are agreed upon. The permit also documents the participants in the job along with their planned exposure, planned working time limit, actual time worked, and estimated exposure (from pocket meters). The permit should be completed before the job is started and certified by the health physics group and the operating supervision. Ordinarily, the permit is issued to cover one work shift but when properly approved may be extended to the following shift.

Figures 6.1.29 and 6.1.30 show the front and back of a Radiation Work Permit used at the Oak Ridge National Laboratory.²⁰

6.1.5 Contamination Control

6.1.5.1 Protection of Personnel — Preventing contamination of the person is of fundamental importance to everyone working with radioactive materials. Providing the means for immediate detection and effective control of contamination should be given the same degree of importance as the design of equipment or the development of process details when construction of a new facility is being considered. The failure of a process component that is costly to replace can be insignificant compared with the loss of a highly trained technician or scientist because he has received a body burden of an isotope such as plutonium.

The highest risk of personnel contamination occurs in glove box work. This statement is based on the fact that, although personnel must occasionally work in areas of high air contamination, in those circumstances the wearing of protective clothing and other preventive measures are enforced, which result in a lower probability of contaminating the skin or of ingesting or inhaling radioactive material.

RADIATION WORK PERMIT (RWP)		DATE AND TIME FROM _____ AM _____ PM TO _____ AM _____ PM		EXTENDED BY _____ TO _____ AM _____ PM		WORK PERMIT NO. R-		
LOCATION & JOB DESCRIPTION _____ _____								
RADIATION SURVEY DATA (To be filled in by Health Physics)								
LOC. CODE	SPECIFIC LOCATION AND DISTANCE FROM SOURCE	TYPE OF RADIATION	mrem/hr.	WORKING TIME FOR _____ mrem	CONTAMINATION		RADIATION SURVEY	
					TYPE	MEASUREMENT	BY	DATE AND TIME
A								
B								
C								
D								
INSTRUCTIONS*								
HEALTH PHYSICS MONITORING REQUIRED: ☐ START OF JOB ☐ INTERMITTENT ☐ CONTINUOUS ☐ END OF JOB								
CONTACT HP FOR SURVEY BEFORE STARTING WORK IN A NEW LOCATION		PROVIDE ASSISTANCE FOR REMOVAL OF PROTECTIVE CLOTHING		PROTECTIVE EQUIPMENT AND MONITORING INSTRUMENTS				
TAPE COVERALLS TO GLOVES AND FOOTWEAR		MONITOR BREATHING ZONE		CAP	COVERALLS (1 PR.)	SHOE COVERS	POCKET METERS	
CHECK TOOLS AT END OF JOB		NASAL SMEAR REQUIRED		CANVAS HOOD	COVERALLS (2 PR.)	C-ZONE SHOES	DOSIMETER	
CHECK PERSONNEL AT END OF JOB		BIOASSAY SAMPLE REQUIRED		SAFETY GLASSES	GLOVES	CANVAS	RUBBERS	
TIMEKEEPING REQUIRED		DO NOT WORK ALONE - STANDBY OBSERVER REQUIRED		EYE SHIELD		LEATHER	RUBBER BOOTS	
REMARKS _____ _____ _____ _____ _____				HALF MASK		SURGEON'S	PLASTIC BOOTEES	DOSE ALARM
				ASSAULT MASK		PLASTIC	LAB COAT	CUTIE PIE
				CHEMOX MASK		RUBBERIZED CANVAS	SPECIAL FILM METER	GMS METER
				AIR-LINE HOOD	HOUSEHOLD RUBBER			
				AIR-LINE SUIT				
				REGULAR APPROVALS		SPECIAL APPROVALS		
				HEALTH PHYSICS CERTIFICATION		DIVISION DIRECTOR		
				SUPERVISION		H.P. DIVISION DIRECTOR		
				SUPERVISION		DEPUTY LAS DIRECTOR		

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* Only items checked (✓) apply.

(OVER)

Fig. 6.1.29. Radiation Work Permit (Front)

1. Health Physics shall be present for line breaks or removal of shielding.

2. Notify Health Physics of any deviations from instructions and changes in working conditions. TIMEKEEPING BY _____

3. Personnel survey is required when leaving contamination zones.

4. Return work permit to Health Physics† upon completion of job or expiration of permit. DEPT. _____

PERSONNEL AND EXTERNAL EXPOSURE CONTROLS						PLANNED EXPOSURE (mrem)	TIME RECORD							ESTIMATED EXPOSURE (mrem)
NAME	DEPT	P.R. NO.	LOCATION CODE	DOSE RATE USED	WORKING TIME		BEGIN	END	BEG N	END	BEGIN	END	TOTAL TIME	

1. Radiation Work Permit is required* when:

- (a) expected dose is > 20 mrem to the body or 300 mrem to extremities for an individual during a single work assignment;
- (b) dose rate > 5 rem/hr (total body);
- (c) airborne radioactivity is $> (MPC)_a$ for a 40-hr week;
- (d) specified by divisional operating rules and procedures or by posted regulations.

2. Supplementary Time Sheet

To be used if extra space is needed for the timing of individuals into and out of an area, etc.

3. Special Approvals

- (a) Dose Rate rem/hr (total body)

> 5 Division Director in charge of work area

Oral or written; noted and initialed on the permit by the person obtaining the approvals.

> 20 Above and Health Physics Division Director.

> 50 Above and Laboratory Deputy Director.

(b) Dose (total body)

> 60 mrem/day for nonoperating personnel, or > 300 mrem/wk for operating individual

personnel

> 1 rem Above and Laboratory Deputy Director

4. Copies

- (a) The RWP must be posted or available at work site.
- (b) Health Physics maintains a copy for record and reference purposes.
- (c) A copy must be distributed to appropriate line supervision.

*Posted regulations may be used in lieu of an RWP for operating personnel under specified conditions. (See Regulation 1, Procedure No. 26, ORNL Health Physics Manual.)

Fig. 6.1.30. Radiation Work Permit (Back)

The possibility of contaminating the hands while working in a glove box can be kept to a minimum, if not entirely eliminated, by establishing a few simple standard operating procedures and strictly enforcing them. These procedures can be listed as follows:

1. Latex rubber gloves or surgeon's gloves should be worn inside glove box gloves. This precaution provides an additional line of containment between a radioactive source and the skin.
2. The hands should be monitored, with gloves on, after each withdrawal from the glove box gloves. The monitoring instrument should be attached to or located near the glove box station so that the operator need take no more than two or three steps to reach it and need not touch the monitor with his gloves.
3. Personnel should be instructed to summon help in the event contamination is detected. Any movement by a contaminated person can result in spreading contamination.
4. Contaminated gloves should be removed by inserting the thumb of the contamination-free hand (in the event both gloves are contaminated, a co-worker should perform this task) inside the glove at the wrist and peeling the glove off, turning it wrong side out to contain the contamination.
5. The outer wear on the person should then be thoroughly monitored for contamination before resumption of work or movement to another area.
6. Most incidents of skin contamination can be attributed to using the hands before monitoring them. Examples are: scratching the nose, adjusting eyeglasses, touching the head, etc. A good policy is always to treat the hands or gloves as contaminated until proven otherwise and never to touch another part of the body while wearing gloves.
7. A point that must be stressed is that skin contamination can be of minor consequence compared with ingestion or inhalation of a toxic isotope. Therefore, if one suspects the presence of airborne contamination, he should immediately don a fresh air mask or assault mask even though the act may result in contaminating the head. A clean mask should be available at all times in a prefitted condition and should be donned by touching only the straps that cross the back of the head. This will eliminate the possibility of contaminating the face or ingestion or inhalation of a contaminated particle in the event the hands are contaminated.
8. The work areas, glove box faces, and glove box gloves must be checked at least once per day for contamination as well as for

radiation. The detection of contamination above the allowable level ($30 \text{ d/min/100 cm}^2$ for a swipe or $300 \text{ d/min/100 cm}^2$ for a direct reading) requires immediate action to reduce the level to below tolerance.

9. Where a number of isotopes with widely varying toxicities are handled in the same facility, the contamination levels allowed should be based on the most hazardous isotope handled. For example, the allowable contamination level for natural uranium alpha is many times that for plutonium. Since it is impractical to analyze for the isotope producing the contamination, however, the only alternative when handling both isotopes is to maintain cleanliness to the permissible level for plutonium alpha contamination.
10. Operating personnel should be taught the proper use of monitoring devices and should be able to correlate meter readings with contamination levels. The importance of proper use, testing, and maintenance of health physics instrumentation (discussed in Section 6.1.2) cannot be overemphasized.

It is often necessary for radiochemical plant operating personnel to work in an area in which the air contamination is high enough to require a respirator, assault mask, fresh air supply, or a complete air suit. The decision as to the degree of protective clothing needed should rest with the operations supervisor after consultation with health physics personnel.

Although an air suit which provides ventilation air for the body as well as breathing air is the most comfortable and perhaps the most protective, some locations and work requirements make handling the air line a major chore. For routine jobs where the operator does not have to maneuver in and out of tight places, such as decontaminating surfaces with a high-pressure spray (Fig. 6.1.31), the air suit is ideal, and one can work for up to 4 hours in comfort. The use of a small venturi in the air line to cool the air can contribute greatly to the comfort of the operator.

The most formidable task associated with the use of an air suit is removing the contaminated suit without contaminating the skin of the person wearing the suit or the one helping to remove it. The most effective and successful technique is to let the person exit into a man-sized glove box equipped with a filtered air inlet and an exhaust into the more contaminated area. This box should be equipped with a shower operated from outside the box and a floor drain connected to the radioactive liquid waste system. The first step would be to wash the suit down thoroughly with water to remove loose radioactive dust and particles, then, by means of gloves from outside the box and using long-handled brushes, scrub it thoroughly with a mild detergent. After rinsing it free of soap, an assistant working through the gloves should remove the suit by cutting it free. The suit should be peeled off the

Fig. 6.1.31. A Fresh Air Supplied Suit in Use

person by essentially turning it inside out as it is removed. The person wearing the suit must not touch anything with his gloves while the suit is being removed.

Following removal of the suit, the person should step through the door onto blotter paper for a final thorough monitoring of his undergarments, hands, face, shoes, etc. The used air suit should be bagged out of the air lock and disposed of in the same manner that contaminated waste is removed from a glove box. ORNL experience has shown that it is not economically feasible to salvage and decontaminate air suits after use in a highly contaminated area. Of course, this would not be true after use in a suspect or low-contamination area.

Although a pressurized air suit fed from a Mine Safety Appliances Company approved air supply can be considered the ultimate in prevention of both internal and external contamination of the worker, some circumstances make its use either impractical or impossible. An example would be work in a radiochemical processing cell where as much as 50 ft of air hose and as many as three or more people would be needed to perform tasks. A kink in the air hose or a fellow worker stepping on an air hose could result in loss of air, leading to a catastrophe unless the air supply could be restored immediately. It is very difficult for a person to remove his own air suit; therefore, he should be provided with a means of cutting a hole in the suit if necessary. Although this would result in his inhaling contaminated air, the consequences are less severe than suffocation or "mere" unconsciousness in the area described.

The alternative to an air suit is an approved full-face assault mask along with the proper protective clothing. A method commonly used at Oak Ridge National Laboratory (ORNL) for adequately dressing to work in highly contaminated areas is demonstrated by Figs. 6.1.32-6.1.35. The worker is shown in normal work attire in Fig. 6.1.32. He dons shoe covers and a second pair of coveralls (Fig. 6.1.33). He then puts on high-top shoe covers and gloves, then tapes the outer coveralls at the ankles and wrists, up the front, and across the neck to essentially seal any opening to the atmosphere (Fig. 6.1.34). (IMPORTANT - note the tabs left in the tape to permit easy removal.) The next step is to don a second pair of gloves, sealed by tape to the outer coveralls, and an assault mask (Fig. 6.1.35). After the assault mask is tested, a hood is applied and taped to seal it to the mask as well as to the coveralls at the shoulders and back (Figs. 6.1.36, 6.1.37). (Again, note the tabs left for easy removal of the tape.)

In circumstances where liquids might be encountered, it is wise to use a plastic suit over the outer coveralls. A two-piece suit, shown in Fig. 6.1.38, is inexpensive and affords good protection. Suits of this sort should contain elastic at the top of the pants, at the ankles, and at the bottom of the blouse and sleeves.

PHOTO 079074

Fig. 6.1.32. Technician in Normal Work Attire

Fig. 6.1.33. Technician Dressed in Shoe Covers and 2nd Pair of Coveralls

Fig. 6.1.34. Technician with 2nd Pair of Coveralls and 2nd Pair of Shoe covers. All Openings are Sealed with Tape. Note Tabs on the Tape to Facilitate Removal.

Fig. 6.1.35. Technician Donning 2nd Pair of Gloves and Assault Mask

PIIOTO 0793 74

Fig. 6.1.36. Technician Completely Dressed for Work in Highly Contaminated Area

Fig. 6.1.37. Technician Completely Dressed for Work in Highly Contaminated Area

Fig. 6.1.38. Use of a Two-piece Suit for Protection Against Liquids

It should be pointed out that the majority of cases of contamination to the skin result during the removal of protective clothing upon completion of the work rather than from the actual work itself. The removal must be performed by a second person, who is free of contamination. The contaminated person must not touch anything or attempt to remove any of his own clothing. The undressing operation must be performed in an area having a positive stream of fresh air flowing toward the contaminated area, and the second person must also wear a mask and have on hand an adequate supply of rubber gloves. A health physics surveyor must be present to monitor constantly for contamination.

A good detailed procedure for the removal of clothing is as follows:

1. While wearing a mask and gloves, the helper should grasp the tab on the tape around the wrists and carefully remove the tape.
2. Have the health physics surveyor monitor the gloves of the helper; change if necessary.
3. Carefully, with thumb and forefinger, the helper should grasp the gloves at the top and carefully remove them while turning wrong side out. Dispose of gloves in a plastic bag.
4. Have the health physicist monitor the worker's as well as the helper's gloves. It may be necessary to change the helper's gloves; however, do not remove the worker's gloves until outer coveralls are off.
5. Repeat steps 1 through 4 to remove outer shoe covers from worker. Have worker step on clean blotter paper as shoe covers are removed.
6. Remove hood, using same precautions as above.
7. Remove outer coveralls very carefully, turning wrong side out as they are removed.
8. After surveying carefully, using new gloves, the helper should grasp the worker's mask by the snout and remove mask in an upward motion. Do not attempt to release the snap around lower part of hood.
9. A thorough survey of all the worker's inner clothing, shoes, neck, and head should follow. It may be necessary to require a complete change of clothing before permitting the worker to proceed to the shower.
10. The worker and helper should then wash thoroughly in a shower and be surveyed again before dressing.

The above procedure, as the reader has undoubtedly concluded, is for work in an area of extremely high air and surface contamination. It must be pointed out that, although this elaborate method is desirable to prevent contamination of the skin, even a high level of contamination is not of major consequence unless the skin is punctured. Inhalation or ingestion of contaminated material is of major consequence.

One must use a logical approach in deciding the degree of protection needed. It is possible to protect to such a degree that the worker has no freedom of movement and is thus subject to injury, or he may be clothed to such an extent as to hinder breathing and cause sweating, which could lead to exhaustion or a heart attack. This is pointed out to show that overprotection can cause a much more serious problem than the original hazard.

6.1.5.2 Protection of Equipment — Effective control against contamination of equipment rests more with the designer than the operator. The designer must envision widespread contamination of the primary containment system (glove box, hot cell, cubicle, processing cell, etc.) as well as the secondary containment system (the alpha laboratory housing the glove box or other areas surrounding or immediately adjacent to the primary system). Each piece of equipment or apparatus installed in an area of possible contamination must be evaluated in relation to cost in money and man-hours and detriment to the health and safety of personnel in the event it becomes highly contaminated. The assumption must be made in both the design and operation of a facility that if an undesirable event is possible, it will happen ("Murphy's law").

Equipment installed in a contamination glove box or cell will undoubtedly become contaminated and must be classified as a "repair" or "replace" item in the event of its failure. This decision must be based on the cost of replacement versus the costs of decontamination plus repair. However, in the case of a facility containing specialized or expensive equipment, where decontamination with harsh liquids is not advisable or is impossible, a separate maintenance cubicle should be installed to which the equipment can be transported for repair. This cubicle should be provided with at least a water-wash system to reduce the contamination level or with shielding and manipulators for repairing equipment if beta-gamma contamination would cause higher than permissible exposure to radiation. One must never overlook the possibility of repairing contaminated items in situ; however appropriate tools and techniques should be worked out before the equipment is used. Photographs of the equipment and surroundings have been found useful and beneficial in clarifying maintenance procedures.

Perhaps the job that causes most concern in alpha facilities is repairing or replacing a viewing window. In a glove box the window is safety plate glass; in a shielded facility it may be a massive section of laminated layers of glass, each lamination having a different density, or it may be a glass box filled with a clear but dense liquid. In any case,

the glass surface inside the box or cell will undoubtedly be highly contaminated and the outside relatively clean. It is advisable first to wash down the inside glass surface with a mild detergent and to dry it thoroughly before attempting to remove the window from the glove box or cell. If the cleaning cannot be done with the gloves, a soft brush and squeegee usually work well. The next step is to build an air lock (plastic sheeting and wooden framing) to provide containment against the spread of contamination as the window is removed. A filtered air supply should be provided through the containment enclosure, exhausting into the glove box or cell, once the window is unsealed. Of course, the workmen should be provided with maximum protection, as previously discussed. The window should be removed directly into a plastic bag and the inside surface of the glass covered with plastic tape to trap contaminated particles as soon as the glass is removed. After the window frame is decontaminated, the window may be replaced.

The replacement of massive shielding windows requires considerably more effort. Radioactive materials should be removed from the cell containing the defective window, and the cell should be decontaminated to a permissible level before the work is performed. The details for replacing the wide variety of shielding windows now in existence will not be described here; however, one particular technique for changing a window composed of a massive section of laminated glass and a light-weight alpha seal is documented.²³ It is highly recommended that either a similar technique be demonstrated before starting radioactive operations in a new facility or a detailed plan be formulated before attempting to replace a window in a facility that is operating.

The maintenance of manipulators is a formidable task in the operation of any facility utilizing them. Obviously, manipulators are required constantly and must be decontaminated and repaired for reuse because of the high cost of replacements. It is wise to keep spare manipulators on hand where failure of one would interrupt operations. Then the defective manipulator can be replaced by a spare. Of course, this requires a facility where the failed manipulators can be decontaminated and repaired. Normally, decontamination can be effectively accomplished in an enclosure equipped with a high-pressure spray nozzle utilizing a mild, warm detergent. Decontamination is discussed in more detail in Section 6.1.6.

One can assume that electric motors and miscellaneous small equipment can be replaced much more cheaply than they can be repaired. However, a sufficient number of high-maintenance items may make feasible the construction of a "contained" repair facility (one capable of keeping all radioactive matter inside it). Complete decontamination of electrical equipment such as motors is possible, but it is not possible to adequately check the interior of a motor for contamination. Therefore, a repair facility for such items would have to be contained in a manner similar to that for any other contamination facility.

Perhaps the best rule to follow is to keep only the minimum equipment needed in a contamination zone and to store other equipment elsewhere. Immediately after use in a contaminated area, equipment such as shipping containers, tools, vacuum pumps, drum carts, etc., should be monitored for contamination, decontaminated if necessary, and removed from the area. This practice can eliminate many hours of decontamination effort in the event of a widespread release of contamination.

6.1.6 Decontamination Procedures

Research and development investigators as well as radiochemical plant operators who work with radioactive materials are confronted ultimately with the problem of removing and disposing of them. Decontamination is the practice or art of removing radioactive smudges, chemical compounds and solutions, metal fines, reaction products, etc., from valuable surfaces in order to

1. render such surfaces ("hot" cells, buildings, areas) harmless or safe for occupancy by unprotected operators and to prevent the spread of contamination to the surroundings;
2. restore valuable production, research, and development facilities and equipment to a condition suitable for reuse; or to
3. aid in safely removing unwanted radioactive matter and/or contaminated materials and equipment from an undesirable location to a more desirable one.

Generally, decontamination is considered to be an expensive cleaning process and a necessary evil that is best managed by avoiding it or by working around it. It is generally accepted that contamination of a surface by radionuclides occurs chemically by exchange of their ions with free surface ions and by physical adhesion. All this is accompanied by migration of the nuclides into cracks and crevices. Only a few minutes is required for radioactive ions to become attached to the surfaces of metal and other structural materials. Experience has shown that radioactive ions are fixed by the visible and invisible oxide films on metals and that after extended contact times the contaminants diffuse into the parent metal and interact between the oxide films.²⁴

Decontamination processes likewise include chemical and physical mechanisms. The radioactive atoms that have combined with nonradioactive ones are dissolved chemically by contacting them with strong solvent while simultaneously preventing them from redepositing on the surface being cleaned. This is usually done with solutions of strong acids or alkalis that also contain complexing or chelating agents.

The physical methods include the removal of loosely adhering surface scales, soils, salts, and particulate matter and the abrading away of oxides and a surface layer of the material itself. Examples of these

methods are vacuum cleaning, swabbing, brushing, high-impact jet cleaning, sandblasting, and grinding. The ideal method would leave a surface in its original condition of smoothness and utility, but this is rarely achieved. It should be noted that a smooth nonporous surface is much easier to decontaminate than a porous surface like skin, concrete, or unpolished stainless steel. One should seriously consider coating concrete and stainless steel surfaces with a good paint (Amercoat is a good example) before placing a facility in operation.

6.1.6.1 Decontamination of Processing Cells — In general, the designs of radiochemical processing plants follow philosophies that permit maintenance to be performed in one or a combination of the three following categories:

1. Remote maintenance. Equipment is repaired or replaced from outside the cell, using manipulators or an in-cell crane. Very little decontamination is necessary, but the equipment removed requires shielding for transport to a burial ground or to a decontamination facility. Some facilities are constructed with equipment decontamination areas and enclosed maintenance areas that permit equipment repair using gloved hands without removing the equipment from a contained environment.
2. Direct maintenance after complete decontamination. This philosophy requires complete decontamination of all the equipment and surfaces within a cell, followed by personnel entry to perform the required maintenance.
3. Direct maintenance using cubicle or "unit" shielding. This philosophy permits repair of a system component after decontamination of that component only. Each vessel or system is shielded from every other component, so that one can enter a cell without excessive exposure to radiation and can gain access to one particular item or system by removing only the shielding around it.

An example of Class 1 design for maintenance is the Transuranium Processing Plant (TRU) at Oak Ridge National Laboratory. All equipment, including the piping, may be disconnected and replaced by in-cell manipulators. Normally, complete decontamination of a cell for entry by workers should never be required at this facility. The cell bank is designed so that all operations can be isolated and transfers between the nine cells can be made in a sealed conveyor. This helps ensure that even a serious spill in one cell will have little effect on adjacent cells. Another example of Class 1 design is the processing canyons at the Hanford processing plants. These utilize shielded in-cell cranes, with which operators can change system components by use of mirrors and ingenious disconnects.

Class 2 plants are rare, since those in existence now utilize some combination of Classes 2 and 3. Normally the highly radioactive head-end and first-cycle systems are unit shielded and the second- and third-cycle equipment is not, since more than 90% of the radioactive matter is removed in the head-end and first-cycle steps.

Before beginning any decontamination program, the operations supervisor must first verify the quantities of both fissile and fertile materials held up in the plant systems and must provide sufficient flushing with liquids (water, nitric acid, etc.) compatible with these systems to recover essentially all such materials. The valuable materials can be concentrated and stored for future recovery. The operators should then begin to decontaminate the vessels and piping. However, before the start of decontamination, radiation and contamination levels should be charted as thoroughly as possible without causing excessive exposure to the persons performing the monitoring. These data will aid in establishing the effectiveness of the decontaminating solutions being used.

Effective decontamination has been achieved with a minimum volume of reagent when in-cell vessels are equipped as shown in Fig. 6.1.39. The in-cell Thorex Pilot Plant vessels at Oak Ridge National Laboratory were equipped with jackets for heating or cooling and internal spray jets for contacting the vessel interiors with the solution. The reverse-dished bottoms leave a minimum heel after emptying the vessels. This plant, consisting of a dissolver, feed-adjustment tank, feed system, and two solvent-extraction cycles, each with an evaporator, was decontaminated after two years of operation using alternate passes of 30% nitric acid and 20% caustic soda - 2% tartaric acid, each recirculation 1 hour at 60-70°C. Between 5 and 10 cycles were necessary to reduce radiation levels enough to permit direct access. However, the dissolver required treatment with 3% hydrofluoric acid - 20% nitric acid to reduce its radiation to a satisfactory level.

A study of various decontaminating reagents is not considered appropriate in this guide. Sufficient documentation is readily available to provide the plant supervisor sufficient data to select the most effective reagent for a particular application.

After internal decontamination, the walls and equipment surfaces should be spray-washed to reduce the external contamination level. A very effective way for performing this chore is by use of a Sellers injector,²⁵ using a mild detergent. Figure 6.1.31 illustrates the use of such a device.

It should be noted that as a plant ages, decontamination becomes increasingly difficult. This is due to activity buildup in inaccessible places, to deeper penetration of radioactive materials into the surfaces of the equipment, and to surface contamination of cubicle walls and equipment supports. The use of harsh reagents during routine operations will cause poor results during subsequent decontamination programs, as a result of corrosion.

ORNL DWG. 6199R3

**THOREX PILOT PLANT
TYPICAL CELL TANK**

Fig. 6.1.39. Decontamination Scheme Used in ORNL Thorex Pilot Plant

6.1.6.2 Decontamination of Laboratories, Offices, etc. — Once contamination is detected in an office or laboratory area, all normal work of personnel in that area should be halted and the area evacuated. The only access permitted should be that by the health physics surveyors attempting to locate the source and extent of the contamination. Since in the majority of cases contamination is a result of someone's wearing contaminated shoes, each person in the area should be monitored and should don shoe covers before being allowed to move into uncontaminated areas.

It is of utmost importance that the extent of the contamination be determined as quickly as possible and the affected areas isolated. One should not begin massive cleanup without first knowing the degree and intensity of the contamination. It is wise to begin decontaminating only the areas detected to be contaminated and to move the isolation barriers in as cleaning reduces the readings of contamination level to a point below tolerance. However, in the event a contaminant has become airborne and general contamination is involved, work should begin on the ceiling and progress down the walls to the floor.

If the presence of solid particles is suspected, decontamination by vacuuming or with sticky tape can be most effective, because in such a case the use of a liquid may spread the contamination or, at best, move it to a less accessible location. After vacuuming, swabbing with a mild liquid detergent and wet mop or cheesecloth can be quite effective. However, one must avoid spreading material. It should be pointed out that spreading an intense source such as a 100-cm² area reading 10,000 d/min to an area of 10,000 cm² reading 100 d/min is a zero reduction in contamination.

Applying water to some surfaces, such as tile floors, should be avoided, since a liquid can drive contaminants through the cracks between tiles and contaminate the base floor beneath. It is better to simply vacuum the area and replace a section of tile.

The decontamination effort required after a widespread plutonium release incident in 1959 is referenced²⁶ to permit the reader to study in detail each of the items discussed in this section.

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6.2 CRITICALITY

Nuclear criticality is, in many respects, quite similar to such natural phenomena as fire and electricity, to name two with which we are all familiar. Uncontrolled, all three can be dangerous or lethal; controlled, they are useful servants capable of performing a number of desirable tasks. The margin between control and lack of control of each can be very narrow. The safe, nondestructive application of each depends on recognition and knowledge of and strict adherence to the appropriate rules that govern their behavior. In general, these rules are the result of an accumulation of experience and of careful experimentation; they are not imposed arbitrarily or whimsically but have as their purpose the protection of people and property. The goal of this discussion is to give some background information on the reasons for many procedures that must be followed to assure freedom from criticality. Freedom from criticality is called nuclear criticality safety.

There have been numerous demonstrations of planned but uncontrolled criticality, of a type that requires knowledgeable and premeditated effort to produce. Nuclear reactors represent criticality that is also intentional but is deliberately and carefully controlled. Criticality is the normal state of a nuclear reactor, whether it is used for research, for producing radioisotopes, or for generating electric power. In fuel fabrication and reprocessing plants, however, nuclear criticality is a condition to be avoided for several excellent reasons. Since any criticality in such plants would be inadvertent and therefore uncontrolled, the consequences could be severe, particularly to people. Criticality releases tremendous energy in the form of kinetic energy and penetrating radiations. The kinetic energy can damage equipment and spread contamination; the radiations can be lethal. These effects are partially isolated in shielded cells, but in work areas where people are not shielded, criticality can result in fatalities or injuries as well as long-term contamination and cleanup problems that can be quite expensive. It is important, therefore, that we understand the fundamentals by which nuclear criticality can be produced, to specify the conditions that must be avoided and those that must be maintained in order to assure a comfortable level of subcriticality, and to learn proper responses to abnormal and emergency conditions.

6.2.1 Administration of Nuclear Criticality Safety

Because of the great variety of situations that can occur, control of nuclear criticality in a fuel reprocessing plant is a complex subject. Extensive experimental work has been performed and methods of calculation developed by experts in neutron physics in order to predict potentially critical conditions and to establish criteria for maintaining subcriticality.* A plant handling fissile material* either must have

* See Section 6.2.3 for definition.

a nuclear safety group as a part of the plant organization or must have readily available access to nuclear experts on a consulting basis. It must be the policy of the plant management that nuclear criticality safety will not be compromised for expediency in operations and that rules and regulations formulated by the nuclear experts will be followed at all times. The nuclear safety group should maintain direct contact with all departments of the plant at every level of management. This approach permits immediate access to problem areas and permits solution of problems at the lowest management levels. The nuclear safety people must be familiar with plant operations but should not be a part of the operations organization; they should report directly to the plant manager.

The nuclear safety program often uses a variety of administrative tools. These may include formal reviews and approvals of the design of the equipment and the processes, written procedures for the entire operation as well as for any alterations in certain areas, and detailed procedures for each step of the several operations. Criticality safety analyses are fundamental. Work Permits (Section 6.3) may be required for specific operations. All these administrative tools are means of clearly establishing responsibilities. Specifically, the nuclear safety group should be responsible for the following functions:¹

1. Advise operating supervision on the design, installation, alteration, operation, and maintenance of equipment and facilities that handle fissile material.
2. Establish nuclear safety limits and procedures, working with line supervision.
3. Review all sources of relevant data and maintain contact with facilities where criticality data are being obtained.
4. Maintain calculational capability to apply and extend applicable experimental data.
5. Assist in the investigation of nonroutine incidents, such as near misses and infractions of criticality rules, and suggest possible methods of eliminating such incidents in the future.
6. Assist supervision in the selection and placement of instruments for detecting radiation from a criticality accident, should one occur.
7. Assist in a program of nuclear safety lectures and demonstrations.

Operating groups, also, should have general and specific responsibilities relating to nuclear safety and adherence to the plant safety policy in operations involving fissile materials. The prime responsibility for enforcing safety should be placed on line management instead of on the safety groups. Experience has shown that placing this responsibility

on the operating groups has resulted in their taking an active role in safety programs, for example, participation in nuclear safety training programs, posting of limits, and performance of audits.

In the final analysis, nuclear criticality safety requires strong management support; personnel well educated in all aspects of their work assignments; adherence to carefully prepared procedures, including emergency procedures; and individual alertness, communicativeness, and sense of responsibility. The ultimate and really effective responsibility for safety lies with the man actually performing each task. There is no substitute for trained, experienced, conscientious, certified operators. In such an environment, even though the potential hazards may be great, the risks should be small.

6.2.2 Atomic Structure

More than 2000 years ago the Greek philosophers gave us the first concept of an atom as the smallest indivisible unit of which all material things are formed. Today we define the atom slightly differently, as the smallest particle of an element that retains the identity of the element. An atom, we now know, consists of still smaller particles assembled in precise numbers that identify the element. For our purposes we can limit consideration of these smaller particles to protons, electrons, and neutrons.

A proton is a positively charged particle of mass number 1 on the scale we use; the nucleus of the hydrogen atom is a proton. Since all things in nature have no net electrical charge, it is not surprising to find a negatively charged particle, called the electron, also a part of the hydrogen atom, "in orbit" around the proton nucleus; this combination results in an uncharged atom. The electron, although its electrical charge is of the same magnitude as that of the proton, is very much smaller in mass; 1836 electrons have the same mass as a single proton! There are, then, two regions in an atom: the core, or nucleus, and its surrounding cloud of electrons, called orbital electrons. The number of protons in a nucleus is called the atomic number, Z , and is the distinguishing characteristic of an element. For instance, every boron atom has 5 protons in its nucleus, every aluminum atom has 13, every oxygen has 8, uranium has 92, and plutonium has 94. In a neutral atom the number of electrons is always the same as the number of protons, resulting in an electrically neutral particle. The usual manner of briefly indicating the atomic number is to combine it in a specific location with the symbol for the name of the element. The elements just mentioned are thus symbolized: ${}^5\text{B}$, ${}^{13}\text{Al}$, ${}^8\text{O}$, ${}^{92}\text{U}$, and ${}^{94}\text{Pu}$.

For many years it was believed that atoms were made up only of protons and electrons. Much experimental work was being done around the turn of the century in this new and fascinating field of physics, but we shall mention only a few of the highlights particularly important to our understanding of nuclear criticality. In 1895 Roentgen discovered

X rays, which are electromagnetic radiations, like light, but of much shorter wavelength. The next year, Becquerel found that uranium salts give off highly penetrating rays that also produce electrical conductivity in gases, a phenomenon designated as radioactivity; and the Curies in 1898 identified two more radioactive elements, radium and polonium. Further investigations showed that the rays coming from these elements were of three kinds: gamma rays (electromagnetic radiation), which are not deflected by a magnetic field, alpha particles, which exhibit a positive charge, and beta particles, which have a negative charge. We now know that all three of these radiations are not emitted simultaneously by all radioactive substances and that the radioactivity of a particular element is not changed by temperature or by chemical combination with other elements. Very careful and precise measurements of the charge and mass of alpha particles and of beta particles showed that the former are helium nuclei (helium atoms with the orbital electrons stripped off) and that the latter have the mass and charge of electrons. Additional work demonstrated that both the alpha and beta particles come from the nucleus of the atom, thereby modifying it significantly. Elements that occur in nature emitting these radiations spontaneously are known as naturally radioactive elements.

Early models of the nucleus were based on the assumption that it was an electrically neutral sphere consisting of equal numbers of protons and electrons. This concept failed to explain the behavior of the subatomic particles in their interaction with atoms. The new model of the atom, devised by Rutherford in 1911 and sketched in Fig. 6.2.1 for neon, has provided satisfactory explanations for atomic phenomena and has been changed even today only to the extent of amplifying the details of the nucleus and the behavior of the orbital electrons. These details have a profound influence on the interactions among and between subatomic particles and atoms. But even Rutherford's atom, which defined the nucleus as the center of the atom and located the electrons outside the positively charged volume occupied by the protons, left unanswered questions. In 1932 a British physicist, Sir James Chadwick, discovered another particle, which proved to be the key to the puzzle. This particle has a mass essentially the same as that of the proton and is also located in the nucleus. Since it has no electrical charge (neutral), it was named a neutron.

The atomic weight of an element is approximately equal to the total number of protons and neutrons in its nucleus. A nucleon is a constituent of a nucleus, either a proton or a neutron. There are several reasons why the atomic weight is not an integer (whole number), even on the mass scale we are using.* A proton and a neutron have

*The basis of the scale used for atomic masses is the atomic weight (or mass) of the most abundant carbon isotope, ^{12}C , exactly 12.000 units. The unit of atomic masses, the atomic mass unit (amu), is thus one-twelfth of the mass of the ^{12}C isotope; in more familiar units an amu is 1.67×10^{-24} g.

Fig. 6.2.1. Representation of an atom (of neon) with a nucleus carrying 10 positive charges surrounded by 10 electrons

From "Inner Space: The Structure of the Atom," by Samuel Glasstone (The World of the Atom Series, U.S. Atomic Energy Commission, 1972).

approximately but not identically the same mass (they are different by about 1 part in 1000; that is, by about 2×10^{-27} g), and the mass of neither is precisely unity. Also, although the electron is quite light when compared with either of the two heavier particles, it does have a finite and measurable mass (about 5.5×10^{-4} amu, or 9.1×10^{-28} g).

In addition, all atoms having the same atomic number do not have the same atomic weight, because, although every atom of oxygen, for instance, has eight protons in its nucleus, it may also have either eight, nine, or ten neutrons, resulting in three different nuclides. A nuclide is the name given to a species of atom characterized by the numbers of protons and neutrons it contains. A more familiar term is isotope, which is one of a group of two or more nuclides having the same number of protons (the same atomic number) but different masses because of the different numbers of neutrons. Only 20 of the stable (not radioactive) elements occurring in nature have only one nuclide, or a single species. Tin (atomic number 50) has the greatest number of isotopes, 10.

All the isotopes of an element exhibit the same chemical behavior, because they all have the same number of orbital electrons, but each isotope shows its own characteristic response to physical forces, because each has a nucleus of different mass. Each isotope has a specific number of protons and neutrons in its nucleus, the sum of which is called the mass number, A . The number of neutrons is the difference between the mass number and the atomic number, or $A-Z$. If we consider the same elements mentioned above, the isotopes are designated as $^{10}_5\text{B}$, $^{11}_5\text{B}$, $^{27}_{13}\text{Al}$ (all naturally occurring aluminium atoms contain 14 neutrons), $^{16}_8\text{O}$, $^{17}_8\text{O}$, $^{18}_8\text{O}$, $^{234}_{92}\text{U}$, $^{235}_{92}\text{U}$, $^{238}_{92}\text{U}$, etc. Since the symbol for the element and the atomic number convey essentially the same information, it is customary to omit the atomic number and write simply ^{235}U , for example.

6.2.3 Nuclear Reactions

We have seen that the nucleus of each isotope is made up of a specific number of nucleons. The precise masses of a proton and a neutron are 1.007593 and 1.008982 amu, respectively, so that the sum of the masses of the nucleons is significantly larger than the mass number. However, the masses of nuclei are less than the sum of the masses of the constituent nucleons, and in the case of the lighter nuclei the sum is less than the mass number. Thus, on a mass scale, the whole is not equal to the sum of its parts. In 1906 Einstein postulated that mass and energy are related and interchangeable according to the famous equation

$$E = mc^2,$$

where E is energy in ergs, m is mass in grams, and c is the velocity of light in centimeters per second. The mass difference mentioned just above is directly related to the binding energy that holds the nucleons together. The binding energy of a nucleus is the energy that would be released if Z protons and $A-Z$ neutrons could be combined to form a nucleus; it is also the energy that would have to be supplied to break the nucleus into its component nucleons.

Instead of the familiar units of energy in ergs and mass in grams, it is more convenient to use the atomic mass unit (amu) for mass and the electron volt* (eV) for energies. Since the binding energies and nuclear energies associated with nuclear reactions are in general large, it is more convenient to talk about millions of electron volts (MeV); by using the appropriate conversion factors, we find that 1 amu = 931 MeV and that 1 g = 5.61×10^{26} MeV (the energy conversion factor is 1 eV = 1.602×10^{-12} erg).

* The electron volt is the energy acquired by a unit electric charge when it is accelerated by a potential of one volt.

We have seen that unstable (radioactive) nuclei, such as radium and uranium, occur in nature. Radioactivity can also be induced by artificial means. The nucleus of an aluminum atom ($^{27}_{13}\text{Al}$) may capture a proton (^1_1H), thereby producing the unstable nuclide $^{28}_{14}\text{Si}$, which decays to $^{24}_{12}\text{Mg}$ by the emission of an alpha particle, ^4_2He . The equation for this reaction may be written in a form comparable to that for chemical reactions:

or even more briefly as

In this example, a proton was the projectile, an aluminum nucleus the target, and an alpha particle and a magnesium nucleus the products. If aluminum is bombarded with neutrons, the following reaction occurs:

and the $^{24}_{11}\text{Na}$ nucleus, being unstable, decays to $^{24}_{12}\text{Mg}$ by beta-particle emission. There are innumerable reactions of these types, where the bombarding particles may be neutrons, protons, alpha particles, etc. In all cases energy is involved in the reaction, as the energy of the bombarding particles and the energy of the resultant particles. In some reactions, energy becomes mass, and in others mass is transformed into energy.

6.2.3.1 Nuclear Fission — Fission is really a special case of radioactivity, in which two or more heavy particles as well as a number of light particles are produced. Of the naturally occurring uranium isotopes, uranium-235 is the one in which fission can be most easily produced. When uranium-235 is bombarded with neutrons, one of three things can happen:

1. A neutron can be scattered by the uranium nucleus.
2. A neutron can also be absorbed into the nucleus to produce uranium-236, which does not fission but releases a gamma ray to lose its excess energy (a process called radiative capture).
3. A neutron absorbed into the nucleus can cause the nucleus to divide into two or more relatively heavy particles called fission products or fission fragments. This splitting of the nucleus is called nuclear fission, and nuclides that exhibit this behavior are known as fissionable material.

For this discussion, only the third reaction, that producing fission, is immediately relevant.

Each of the above reactions is a statistically occurring event, whose probability is stated in terms of cross sections. For instance, the probability of radiative capture compared with that of fission is about one in six: on the average, for every neutron that enters a uranium-235 nucleus to form uranium-236, six neutrons will cause fission of the compound nucleus. A cross section is a measure of the probability that a specific reaction will occur. It is expressed as an area, which may be thought of as the size of the target. The common unit designating a cross section is the barn (b), equal to 10^{-24} square centimeter. The numerical value of a cross section depends on the nuclear event that occurs, on the target nucleus, and on the energy and identity of the bombarding particle.

One example of nuclear fission is illustrated in Fig. 6.2.2, which shows a neutron entering a nucleus and causing it to split into five separate particles: two fission fragments and three free neutrons in this case. Gamma rays are also emitted. These neutrons and gamma rays are called prompt neutrons and prompt gamma rays because they appear at effectively the same time that fission occurs. Using the customary notation for nuclear reactions, this one might be

where the asterisk indicates an excited (unstable) state.

Fig. 6.2.2. A Fission Reaction

From "Nuclear Reactors," by John F. Hagerton (Understanding the Atom Series, U.S. Atomic Energy Commission, 1970).

There are approximately 30 known ways in which the uranium-235 nucleus splits under neutron bombardment. Although as many as seven neutrons may be emitted from a single fission, the "average" number for uranium-235 is 2.43. Most fissions produce two "heavy" nuclei, but about five out of a million produce three. Each fission results in the release of a fairly large amount of energy, about 200 MeV ($1 \text{ MeV} = 1.6 \times 10^{-6} \text{ erg}$), of which approximately 168 MeV (90%) appears as the kinetic energy of the fission products, which generally is converted into heat at or near the point of fission and can be used to produce electric power commercially. The kinetic energy of the prompt neutrons is about 5 MeV total, and the energy of the prompt gamma rays is also about 5 MeV. The remaining roughly 20 MeV appears in the energy of other radiations, including the radiations from the decay of the fission products. The fission of a gram of uranium-235 per day would result in a power production of roughly 1 megawatt (MW), equal to the output of an electric power plant burning several tons of coal per day.

Now let us come back to the consideration of cross sections, the measure of the probability that a specific reaction will occur. A cross section is a function of the energy of the projectile particle and in general decreases as the energy of the particle increases. For instance, the cross section for fission of uranium-235 by thermal neutrons* is about 580 barns. The cross section for radiative capture of thermal neutrons in uranium-235 is about 107 barns, giving a total thermal absorption cross section of 687 barns. These facts are the basis for the statement above that the probability of fission is about six times that of capture.

In general, the relatively massive fission fragments are themselves radioactive and, like naturally radioactive nuclei, emit particles and radiation. These delayed neutrons and delayed gamma rays are of particular interest. Delayed gamma rays are important because they constitute a continuing release of energy long after the termination of fission, as exemplified by the radiation and thermal properties of irradiated fuel removed from a nuclear reactor. The delayed neutrons are most important because, although they represent only about 0.6% of all neutrons produced in the fission of uranium-235, this small number of neutrons, which appear within minutes after fission, make possible the application of the fission process in a controlled manner, as in nuclear reactors.

In addition to the naturally occurring uranium isotope of mass 235, there are two other nuclides that are readily fissionable by neutrons of thermal energy* and that are important in the nuclear energy program at this time. Neither of these nuclides is found in nature in more than trace amounts if at all, but they may be produced in commercial

* Thermal neutrons are in thermal equilibrium with their environment; that is, their energy corresponds to 20°C , or 0.025 eV (electron volts).

quantities by nuclear reactions. One of these nuclides, plutonium-239, results from the interaction of high-energy neutrons with the naturally abundant uranium isotope of mass number 238; the other, uranium-233, results from the interaction of neutrons with the thorium isotope of mass number 232. Both plutonium-239 and uranium-233 are fissile* in a manner basically similar to uranium-235, although some of their fundamental properties, such as the yield of fission neutrons and the fraction thereof that are delayed, vary from nuclide to nuclide.

Further, this discussion thus far has emphasized neutrons of thermal energy as the cause of fission, because the current nuclear power reactor program utilizes the fission of uranium-235 by low-energy neutrons and because the presence of hydrogenous materials in nuclear fuel preparation and reprocessing establishes an environment in which any neutrons present probably have energies in the thermal region. However, fission of many elements can be induced by particles other than low-energy neutrons, although cross sections for such processes are generally lower than those with thermal neutrons. For example, uranium-238 fissions only after interaction with a neutron or energy greater than about 1 MeV; that is, the fission cross section is said to have a threshold at 1 MeV. The nuclear power program under intensive development at the time of this writing will utilize fission by high-energy (fast) neutrons in devices known as fast reactors. Fission of heavy elements can be produced by alpha particles, protons, and gamma rays (photons), but further consideration of these phenomena is beyond the scope of this discussion. In addition, some nuclides are sufficiently unstable in nature that they fission without provocation. This process is called spontaneous fission, and uranium-238 is an example of an element having this property.

6.2.3.2 Chain Reactions — We have seen that one or more neutrons (including prompt and delayed) are produced each time a uranium-235 nucleus splits. If one of these neutrons is captured by another uranium-235 nucleus and causes it to split, producing still more neutrons, one of which causes another fission, and so on indefinitely, a nuclear chain reaction has been produced (see Fig. 6.2.3). Fire is a familiar example of a chain reaction.

Certain conditions must be met in order to establish a chain reaction: the product of an event within the chain must be that required to initiate the next event; the number of products of the event must be equal to or greater than the number required to cause the next one; and the quality of the product must be that necessary to initiate the next event. For example, in the case of fire, the temperature of the flame must exceed the kindling point of the unburned material; in the case of a row of tipping dominoes, the length of each domino must be equal to or greater than the separation of adjacent dominoes; in

* A fissile isotope will fission with thermal neutrons.

ITS JUST LIKE FALLING DOMINOES!

Fig. 6.2.3. Chain Reaction

nuclear chain reactions the energy of fission neutrons must be equal to or greater than that required to produce fission.

When each fission is followed by one and only one additional fission, the system is critical; that is, a self-sustaining chain reaction has been produced, and the neutron population is constant with time. If, however, every fission does not cause another fission, the neutron population will decrease with time, a chain reaction has not been produced, and the system is subcritical. When more than one new fission follows each initial fission, the system is supercritical. Control of criticality depends, as we noted above, on delayed neutrons. Since the delayed neutrons, on the average, may be emitted as much as a minute after fission and since these neutrons are necessary to maintain the chain reaction, there is opportunity for adjustments necessary to control the rate of reaction, and the system may be delayed critical or delayed supercritical. By contrast, a system in which the prompt neutron population is constant in time is said to be prompt critical. It is evident, however, that, because of the presence of delayed neutrons and their participation in the process, the total neutron population increases with time. Further, because of the exceedingly short interval between fission and the production of the prompt neutrons, the system cannot be controlled. It can be shown that in any supercritical system the time behavior of the neutron population is

exponential. This means that, once initiated, the neutron population in a supercritical system increases exceedingly rapidly with time, particularly when the neutron lifetime is as short as that of the prompt neutrons. In a slightly supercritical system with delayed neutrons, after one second the neutron population has increased 5%; in the absence of delayed neutrons, after one second the neutron population will be 150 times as large.

Since significant quantities of energy as heat and radiations are produced as products of fission, it is abundantly clear that the fission phenomenon is to be avoided in all processes with fissile materials outside operating nuclear reactors. The amounts of energy released are potentially lethal to personnel and can cause damage to and radioactive contamination of equipment and the environment. Since less than 1% of all neutrons produced in fission are delayed in their emission, the margin between subcriticality and an uncontrolled chain reaction is small when measured in terms of amounts of fissile material.

6.2.4 Methods of Control

Nuclear reactors depend upon the establishment of a chain reaction for their function. Some reactors, in fact, are designed to operate in the superprompt-critical mode. All reactors are provided with shielding to protect personnel from radiation and are equipped with means of automatically controlling and terminating the chain reaction. Insofar as chemical processing, reprocessing, and fuel fabrication are concerned, however, the problems of nuclear criticality safety center around accumulations of fissile materials in which criticality must be prevented. Since many conventional chemical and metallurgical operations are not provided with radiation shielding or with automatic means of controlling criticality, it is necessary to maintain subcriticality by the proper design of processes and process equipment and by administrative controls.*

In order to better understand how to prevent criticality, it is necessary to know the conditions under which it can be produced. We mentioned above in Section 6.2.3 that, on the average, 2.43 neutrons are produced when a uranium-235 nucleus splits under bombardment with thermal neutrons and that only one neutron is necessary to induce a succeeding fission in a critical system. A natural question is what happens to the rest of the neutrons. Some may be absorbed in uranium-235 to produce uranium-236. Others may be absorbed by associated nonfissile materials and also be lost to the fission chain. Others may escape from the volume containing

* Radiation shielding is necessary for the handling of some process materials because of their history.

fissile material and therefore be lost from the system (leakage). If a system is critical, the net result of the fates of all the neutrons must be a balance such that the rate of production is equal to the sum of the rates of absorption and leakage, or

$$\text{production} = \text{loss}$$

$$= \text{absorption} + \text{leakage} .$$

This equation states that, in a critical or chain-reacting system in steady state, the neutron population remains constant in time.

Consider now the properties of the system that relate to these three factors:

1. The production of fission neutrons depends upon the fissile material, its quantity and density or concentration, and the energy of the initiating neutrons.
2. Absorption depends on the presence of other elements that can capture neutrons.
3. Leakage depends on the shape of the fissile unit and on the presence of surrounding materials that can scatter neutrons back into the unit.

Since the production is a volume phenomenon and the leakage is a surface phenomenon, it follows that the most reactive configuration for a given quantity of material is a sphere, which has the minimum surface-to-volume ratio.

6.2.4.1 Mass and Volume Control — It is apparent that a quantity of fissile material is necessary for the production of a nuclear chain reaction. If the nuclei are compacted, that is, if the material density is high, the quantity required for a chain reaction is, in general, less than if the nuclei are more widely separated. Similarly, it is necessary that the volume occupied by the fissile material be greater than some minimum value in order that the leakage not be excessive.

6.2.4.2 Neutron Moderators — If the energy of the neutrons initiating the events in a chain reaction is that for which the fission cross section is high, the required quantity of fissile material is less. Since the neutrons produced in fission have an energy of about 2 MeV and since neutrons having an energy of about 0.025 eV are most effective in producing fission, the presence of light nuclei, such as hydrogen, mixed with the fissile nuclei reduces the quantity necessary for a chain reaction. This reduction in energy or slowing down of neutrons is referred to as moderation; and the material, such as hydrogen, with which the neutrons interact is called a moderator.

The fewer collisions a neutron must make with nuclei of moderator materials in order to lose most of its energy, the more effective the moderator is said to be. That hydrogen is the most effective moderator, because its nucleus and the neutron have essentially the same mass and generally only one collision is necessary, can be illustrated by observing the collision of two billiard balls, one of which is initially at rest; the moving ball will impart essentially all its kinetic energy to the initially stationary ball. It follows that materials containing hydrogen, such as water, oil, many plastics, and hydrocarbons, are excellent moderators. Carbon, with a mass of 12, is a fair moderator, although a fast neutron must collide with more carbon atoms than with hydrogen in order to reach thermal energy. An illustration is the collision between a billiard ball and a stationary bowling ball; the billiard ball will bounce back with little loss of energy, and more collisions are required in order to slow the smaller ball.

We conclude, then, that the presence of moderating materials along with fissile nuclei increases the efficiency of the fission process and causes less mass of fissile material to be required for criticality. This is the basis for the fact that the critical masses of aqueous solutions of fissile isotopes are dramatically less than the critical mass of metal or of dry oxide.

6.2.4.3 Neutron Absorbers — The presence of nuclei of other elements that have relatively high neutron absorption cross sections will increase the quantity of fissile material necessary for a chain reaction. Such elements may be necessarily present in the process stream or may compose the equipment structure. Nitrogen present in uranyl nitrate, a common chemical form of fissile material, and even the hydrogen in the water in which uranyl nitrate is dissolved are examples of the former. Iron in the process piping is a simple example of the latter. The nuclei of certain elements, such as boron, gadolinium, cadmium, and others, have unusually high absorption cross sections for thermal neutrons. These materials are sometimes called nuclear poisons because of their ability to remove neutrons and thus prevent them from reaching fissile nuclei. Any of these neutron absorbers can be added to a process solution if the absorber is chemically compatible with the solution. For example, in some fuel reprocessing plants, boric acid, cadmium nitrate, or gadolinium nitrate may be mixed with the nitric acid solution in a dissolver, thereby increasing the mass of fissile material that can be charged and the efficiency of the operation without compromising nuclear criticality safety. Stainless steel impregnated with boron may be used as the plates in a pulse column, which may allow the diameter of the column to be increased to improve process efficiency. Pyrex glass or stainless steel Raschig rings may be placed in storage tanks that would otherwise be too large for subcriticality to be guaranteed under all foreseeable conditions. Raschig rings are also used in pans beneath tanks or other process equipment in order to ensure that any quantity of material that leaks into the pans will remain

subcritical. Whenever criticality control depends on neutron absorbers, it is mandatory that their presence in the desired concentration be assured at all times. This is as much a part of process control as any other operation and is of at least equal importance.

6.2.4.4 Geometry — In the consideration of leakage, one can see the obvious advantage of making the surface-to-volume ratio high, as in the case of long skinny pipes and thin slabs as opposed to spheres, cylinders whose height and diameter are approximately equal, and thick slabs. Of the neutrons produced, a relatively greater number escape from small-diameter cylinders or pipes and from thin slabs than from large diameters or thicknesses. In fact, subcriticality can be ensured by limiting diameters or thicknesses to dimensions that are safe for any concentration and material. Controls of this type, referred to as geometry controls, are built into the system and are considered more reliable than those, such as mass limitations, that depend on administrative procedures for their effectiveness. Should it be desirable from an engineering standpoint to use a large diameter container, either its height must be rigidly controlled or it must at all times contain sufficient neutron absorbers, such as Raschig rings to guarantee subcriticality.

6.2.4.5 Concentration Control — Still another means of increasing neutron leakage is to decrease the concentration of fissile isotopes in solution. In addition, the presence of absorbers like the hydrogen or nitrate ions in the solvent also removes neutrons. The actual solution concentration below which criticality is not possible, called the limiting critical concentration, depends on the fissile isotope and on the solution composition (aqueous, organic, etc.). This also is a common method of criticality control.

6.2.4.6 Neutron Reflectors — Surrounding the fissile unit by a reflector will also reduce the quantity of fissile material needed to establish a chain reaction, because the return to the unit of neutrons that would otherwise be lost gives these neutrons another chance to produce fission. If the reflector is a material of low atomic number, its effectiveness is increased because not only are the neutrons returned but they are returned at a lower and more effective energy. Thus the interaction of a reflector results in a decrease in leakage (escaping) neutrons and in an increase in moderation (energy loss). Although any material can be a reflector, the ones most usually encountered are water, concrete, plastics, the materials of which containers and pipes and columns are made, insulation — and people. In establishing limits for a process, the presence and types of reflectors must be considered, even the workers around equipment and those entering storage areas.

A very simple example of the interrelation of several types of control is shown in Fig. 6.2.4. It is a practical application of safe sizes and shapes for particular uranium solutions that result from hand cleaning of small equipment items contaminated by uranium-235.

Fig. 6.2.4. Example of Limits Used to Control Criticality

6.2.4.7 Some Numerical Values for Criticality Control — We have discussed at some length how criticality is influenced by a number of conditions such as mass, shape, and moderation. A few actual values of critical dimensions of single simple units may be interesting for illustration. For example, an unreflected uranium-235 metal sphere requires about 45 kg for criticality, but the addition of a water reflector reduces the critical mass to 22 kg. The minimum critical mass of a sphere of aqueous uranyl fluoride solution is 1400 g of uranium-235 unreflected; when this same solution is reflected by water, only 820 g of uranium-235 is critical. The critical volume of an unreflected uranium-235 metal sphere is 2.44 liters, but with water reflector, 1.16 liters. The minimum critical volumes of the uranium solution spheres mentioned above, reflected and not, are 6.1 and 12 liters, respectively. A water-reflected metal slab 1.49 cm thick is critical, and a water-reflected solution slab 4.8 cm thick is critical (the cross section of the slabs is effectively infinite).

These values indicate that the critical dimensions depend on the physical form and moderation of the fissile material and on the reflector condition.

In contrast to the 22 kg required for uranium-235 metal, a 5.5-kg water-reflected sphere of plutonium-239 metal will be critical; the corresponding value for uranium-233 metal is 7.6 kg. The critical masses of mixtures of nuclides depend on the composition of the mixture as well as on other parameters. The limiting critical concentrations of uranium-235, uranium-233, and plutonium-239 in aqueous solutions are 12.3, 11.2, and 7.2 g/liter, respectively. Table 6.2.1 lists the values of basic nuclear parameters.

Table 6.2.1. Minimum Critical Values of Basic Nuclear Parameters*

	Infinite water reflector		
	²³⁵ U	²³³ U	²³⁹ Pu
Mass, kg:			
Solution	0.82	0.59	0.51
Metal	22.8	7.5	5.6
Diameter of infinite cylinder, in.:			
Solution	5.4	4.4	4.9
Metal	3.1	1.9	1.7
Thickness of infinite slab, in.:			
Solution	1.7	1.2	1.3
Metal	0.6	0.3	0.24
Solution volume, liters	6.3	3.3	4.5
Chemical concentration of aqueous solution, g (of isotope)/liter	12.1	11.2	7.8

*These values are from "Nuclear Safety Guide," TID-7016, Rev. 1, 1961, and thus 15 years old; they are intended as examples to roughly indicate the magnitude of the basic nuclear parameters and should not be used for design or operating purposes.

A very small decrease in any of the above critical values will result in subcriticality of that unit. With water reflector, a uranium-235 metal slab 1.3 cm thick or a slab of aqueous uranium-235 solution 4.6 cm thick will be subcritical. It is seldom that values so close to the critical values can be permitted in process operations without other controls also being imposed on other conditions, such as the spacing between units and the proximity of materials that may be better

reflectors than water. Even so, once process conditions are established, it is practical and customary to use geometry limitations for criticality control. It is obvious from the few examples given above that a geometry (or size) that is "safe" for one material will not necessarily be safe for another. Several criticality accidents in chemical processes have been caused by solutions being transferred from vessels of safe dimensions to others that were not safe for those solutions. In many cases, safety must depend on the alertness of the operator: for example, should a column upset occur, to take corrective action before the solution is transferred into unsafe geometry; to label bottles correctly; to read labels carefully; and to manipulate valves properly. It is poor practice, to say the least, to permit containers such as mop buckets, beakers, drums, etc., in areas where someone might use them to catch solution leaking from a part of a system — criticality could be the result.

6.2.4.8 Control of Interaction — Thus far we have limited our discussion to individual units or containers of fissile material, each of which must be kept subcritical. In practical situations, however, it is much more common to find multiple units in the same area. These units may be containers in storage vaults, components of process equipment, fuel in various stages of fabrication, or units in transit from one area to another. It is no less important that these multiple units also remain subcritical. The means of preventing their criticality is the deliberate and specific spacing of the individually subcritical units so that the neutrons produced by fission in one unit or container do not reach another unit in sufficient numbers to produce criticality by interaction between the fissile contents of the units. The units may be drums, bottles, beakers, pipes, pumps, tanks, columns, and so on. The separation necessary to prevent interaction will influence the design of processes, the location of equipment, material transfer procedures, permissible storage patterns, even the proximity of fissile material to nonfissile materials that are potential neutron reflectors.

6.2.4.9 Administrative Controls — It is very seldom that an entire process can be controlled throughout by limiting only one, or even two, of the factors that influence criticality, although it is practical in many cases to establish a limit on the value of one of them at a particular step of a process. For example, the mass of material that may be charged into a dissolver may be limited, the magnitude of the limit depending on (1) the physical and chemical form of the charge material; (2) the size, type, and operation of the dissolver; and (3) the possibility of the limit being exceeded. This latter point is particularly important in recovery operations, where precise compositions may not be known. In like manner, the content of a furnace may be limited on the basis of how the furnace is cooled, because of the possibility that water or steam coils could conceivably rupture. There are, of course, many other examples. Each step of each process must be examined very carefully in order to determine what is safe under normal operating conditions and also under realistic abnormal conditions.

Everything that we have discussed in this section (6.2.4) is related to the neutron balance equation, which says that criticality will occur when the rate of neutron production is equal to the rate of neutron loss through absorption and leakage. It should be evident that the establishment of the design and process limits that will give reasonable assurance that there will be no criticality can be rather complex. The interrelationships between the various factors that govern criticality and between the several parts of the process are very real and must be taken seriously by all concerned, from the operators up through the plant manager. Although we cannot detect these subatomic particles with any of our five senses, these particles can, through the energy they can cause to be released, cause injury and even death. As long as we respect the phenomena with which we are working and observe the rules of the game, there is little danger.

6.2.5 Monitoring Equipment

The equipment necessary to monitor process operations where nuclear criticality must be prevented supplements that required for conventional monitoring of operations and sometimes allows conventional monitoring equipment and procedures to serve dual purposes. Since monitoring equipment is discussed in Sections 6.1.2.4 and 6.1.2.5 and conventional process instrumentation both in Section 8.1 and also in descriptions of specific operations in Section 7, they will not be treated here except to emphasize their importance. The use of sampling methods and analyses (Section 8.2), for instance, to establish solution concentrations at the several stages of a process takes on added significance when the control (prevention) of criticality as well as of the process depends on the maintenance of established concentration limits.

In the preceding discussions we have seen that both gamma rays and neutrons are emitted as a consequence of fission. In addition to these radiations, alpha and beta particles appear in the decay of radioactive nuclei such as uranium, fission products, plutonium, and associated materials in the process streams that may have become activated. All these radiations are important to the safety of personnel involved in the handling and reprocessing of nuclear fuels. In general, the alpha and beta particles are a hazard only if the parent nuclides are allowed to enter the body by ingestion, by inhalation, or through a wound, which they may do as radioactive contaminants of equipment and personnel and as airborne contamination. Since they can be absorbed by very thin material, they generally cause little external bodily damage. Neutrons and gamma rays, however, are penetrating radiations that can enter the body through undamaged skin and cause severe internal damage, as discussed in the Section 6.1 on health physics. Although personnel must be shielded from the effects of all these radiations, it is often possible and desirable to use the presence of neutrons and gamma rays to monitor various stages of the process.

Particularly in chemical processes, neutron or gamma-ray detectors may be used to monitor parts of the process where material may be held up for any reason such as poor circulation, pockets in the equipment, or deposits of process materials on the walls of equipment. The actual detectors and their locations are a part of the process and its specifications; not only may different processes use different detectors, but the several stages of the same processes may also. For this reason, our remarks must be general.

Radiation detectors depend on the ionization produced in them by the incident neutrons or gamma rays. The signal from the detector is fed into an electronic circuit, whose output is displayed in some manner, perhaps as a meter reading or as an audible or visual signal. The output signal may also be used to sound an alarm. Part of the training of an operator, therefore, consists in learning the instrumentation that is used in the particular process, the meaning of the indications it can and should give, and his proper response. It should never be assumed that an instrument that is indicating an undesirable or unsafe condition is not working properly; it is wise to take the most pessimistic view and act accordingly.

One of the more important process instruments in use is the criticality accident alarm system. Although the detectors in these systems may also be sensitive to either neutrons or gamma rays, most systems now in use are activated by gamma rays. Detectors are appropriately located to detect criticality in any area where it could reasonably occur. The response of the entire system is sufficiently fast to initiate an alarm at essentially the same time that criticality occurs. The alarm is usually a distinctive audible sound, although lights or other visible alarms may be more appropriate in some cases. In addition, the response of the entire system, including the alarm, must be tested at intervals. The ability of the system to respond as intended must be monitored continuously and any indication of malfunction promptly remedied. A scheduled sounding of the alarm for test purposes should always be announced. If one hears no announcement of a test, he should assume that the alarm is real and respond accordingly. Emergency procedures are described in Section 6.6.

REFERENCES FOR SECTION 6.2

1. C. L. Schuske and J. D. McCarthy, "The Nuclear Safety Program at Dow Chemical Company's Rocky Flats Plant - Part I," *Nuclear Safety Journal* Vol. 15, No. 5 (Sept.-Oct. 1974).

Additional information can be found in American National Standards for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, N16.1-1975, sponsored by the American Nuclear Society.

6.3 STANDARD OPERATING PROCEDURES

6.3.1 Purpose and Description

The Standard Operating Procedure (SOP), sometimes referred to as an operating manual, is a written, management-approved device which clearly designates responsibility and safety requirements for any routine operation. The operation could be the replacement of an electrical component, the start-up and shutdown of an air conditioning unit, the preparation of a specified concentration of nitric acid, or a host of miscellaneous tasks. The SOP is differentiated from so-called run sheets, check sheets, etc., in that it specifically relates to routine operations, whereas run sheets normally may be altered immediately prior to or even during an operation.

The SOP normally is not expected to require almost constant revision as is the case with very detailed run sheets do. For example, one might have a SOP for mixing water and nitric acid. This procedure would simply state the protective clothing required and the manner of mixing, regardless of the final concentration or intended use of the material. However, a run sheet would first give the specifications, then lead the plant operator through the necessary calculations to add the required volumes of acid and water to reach the specifications. It is wise to refer the operator to the proper SOP number as Step No. 1 in the run sheet. This practice eliminates the need for incorporating SOP's in each revised run sheet.

The SOP (see example in Section 6.3.2) should clearly state the policy of plant management, the responsibilities for each division or section involved, and the use of standard forms such as the hazards work permit presented in Section 6.3.2.

A set of SOP's under one cover should be readily available to all personnel and must be kept current with the latest revised edition. It is wise to circulate new procedures among operating supervisors, craft foreman, etc., and to require the signature of each attesting to the fact that he and all personnel under his supervision have read and understand the procedure.

6.3.2 Typical Example of a Standard Operating Procedure

USE OF WORK PERMITS, LOCKS, AND TAGS

A. Policy

It is the policy of the Laboratory to require that necessary safety precautions be exercised in connection with maintenance work, and, in certain instances, to require that applicable

approvals, permits, locking, and tagging be completed prior to performance of the work.*†

B. Responsibilities

1. Operating Supervisor — The operating supervisor must anticipate the hazards connected with the work to be performed and see that adequate safeguards are provided.
2. Foreman-in-Charge — The foreman-in-charge must see that work does not commence until the required permits have been properly authorized, the operating supervisor has tagged out all necessary equipment, and that the individual craftsmen, if applicable, have attached locks to insure that the equipment is inoperable.
3. Health Physics and Safety Section — The Health Physics and Safety Section of the Health Physics Division will assist supervisors in defining hazardous operations and evaluating the necessary safeguards.
4. Laboratory Protection Division — The Fire Prevention and Control Section of the Laboratory Protection Division will assist supervisors in defining fire and explosion hazards and will approve areas exempt from welding and burning permit requirements.
5. Industrial Hygiene Department — The Industrial Hygiene Department of the Health Division will assist supervisors in defining the hazards and evaluating the safeguards associated with the use of toxic, corrosive, or poisonous chemicals and related industrial hygiene problems.

C. Hazards Work Permit

1. A hazards work permit (form UCN 3694A) is required where service personnel[‡] are exposed to environmental hazards arising out of

*Where significant quantities of ionizing radiation and/or fissionable materials are involved, see the applicable procedures of the Health Physics Manual.

†Where components of the electrical distribution system operating at 2.4 kV and above are involved, see Plant and Equipment Division Procedure M.3.3.

‡Although this procedure has been written specifically to cover the activities of the craft workers of the Plant and Equipment Division, the principles are applicable to and should be used for the protection of any personnel exposed to conditions outlined in part C-1.

work in an area, or on equipment, or with materials of which they do not have complete knowledge and/or over which they do not exercise complete control. Situations requiring permits, but not limited to these are:

- a. Any welding or burning operation outside approved areas.
 - b. Where ignition of flammable gases and liquids is possible.
 - c. Where release of toxic, corrosive, or highly reactive chemicals is possible.
 - d. Work to be performed in the presence of mechanical or physical hazards, such as moving machinery, dangerous heights, high pressures, etc.
 - e. Any change in status of equipment, facilities, or system which would create additional hazards or eliminate any safeguards against hazards.
 - f. Work to be performed on electrical circuits or electrically controlled equipment where inadvertent activation could create a hazard.
2. Hazards work permits are valid for a maximum of the shift on which they are issued and must be displayed or available at the work area involved.
 3. When valves, electrical circuits, gates, etc., are to be tagged, the standard "DO NOT OPERATE" tag (form UCN-3981, stores stock item number 10-991-9905) shall be used.
 4. The operating supervisor shall insure that:
 - a. Appropriate safety work permits are issued when required.
 - b. All necessary valves are closed and tagged, necessary equipment is drained and cleaned, tests for presence of toxic or flammable material are made if required.
 - c. Appropriate electrical circuits are de-energized and tagged.
 - d. Work performed is completed in accordance with required permits.
 5. The foreman-in-charge shall insure that:
 - a. Work is not begun until required permits have been issued and the operating supervisor has tagged out all necessary equipment.

- b. A safety work permit is requested when none has been issued and he believes one is necessary.
 - c. Craftsmen attach chains and locks to insure that equipment and/or switches are inoperable. Whenever practical, the line should be disconnected and blanked rather than depend on closed valves, particularly for an extended period. Likewise, pumps feeding into a line must be shut down and locked out. Where the above precaution cannot be obtained by switches, valves, or blanking, the area superintendent will approve the work method to be utilized.
 - d. Each workman removes his lock upon completion of his particular assignment or permanently leaves the work area. Under no circumstances may the craft supervisor or his craftsman remove the operating supervisor's "DO NOT OPERATE" tag.
6. The Fire Prevention and Control Section will inspect welding and burning operations for violations of this procedure and report such to the Division Director concerned, with a copy to the Superintendent of the Plant and Equipment Division.

With approval of the Fire Prevention and Control Section, major construction areas where extensive welding and burning operations are to be performed, and welding shops, will not be subject to the requirements of obtaining a safety work permit. These areas will be approved by memorandum from the Laboratory Protection Division to supervision concerned.

A typical example of a Hazards Work Permit is shown in Fig. 6.3.1(front) and (back).

D. Lockout Procedure

- 1. Best Mfg. Co. padlocks combined in the 3-I series, with a single key, will be designated as safety locks and will be issued to the Plant and Equipment work centers.
- 2. Authorized personnel working on equipment or electrical circuits requiring a lockout shall obtain a safety lock and key from their work center. The employee's name and badge number shall be placed on the lock with vinyl embossing tape at the time of issue. Upon completion of the assignment the lock shall be returned to the same work center and the vinyl tape removed.
- 3. Before starting work the craftsman should place his lock on the designated electrical switches and/or valves and retain the key in his possession.

HAZARDS WORK PERMIT

ISSUED TO: FOREMAN OR REPRESENTATIVE				BADGE NUMBER		DEPARTMENT		PHONE NUMBER	
FROM	SHIFT	DATE	TIME	TO	SHIFT	DATE	TIME	WORK ORDER NO.	
LOCATION OF WORK		BUILDING NUMBER		FLOOR		ROOM NUMBER			
DESCRIPTION OF WORK									

PRECAUTIONS TO BE TAKEN IN PREPARATION FOR WORK							
GENERAL PREPARATION		YES	NOT APP'D	FIRE PREVENTION		YES	NOT APP'D
VALVES CLOSED AND TAGGED VALVE NUMBERS				TEST FOR FLAMMABLE VAPORS			
EQUIPMENT DRAINED AND CLEANED				IGNITION SOURCES REMOVED			
PIPELINES BLANKED				WELDING AND BURNING REQUIRED			
MOVING MACHINERY GUARDED				INSTRUCTIONS ON REVERSE SIDE COMPLIED WITH			
AREA ROPED OFF				WELDER'S NAME			
SPECIFY VESSELS VENTED				FIRE WATCHER'S NAME			
OTHER				OBSERVERS			
HEALTH				ELECTRICAL			
TEST FOR TOXIC MATERIAL				NON-ELECTRICAL PERSONNEL EXPOSED TO			
SPECIAL VENTILATION REQUIRED				ELECTRICAL HAZARDS*			
PROTECTIVE EQUIPMENT REQUIRED				CIRCUITS DEENERGIZED, TAGGED, LOCKED OUT			
☐ RESPIRATOR ☐ GLOVES ☐ EYE PROTECTION ☐ GAS MASK ☐ CLOTHING				SPECIFY			
OTHER PRECAUTIONS							

I have personally inspected the work site and certify that the area is cleared for work and that conditions are safe for the work indicated.

SUPERVISOR REQUESTING WORK	PHONE NUMBER	ELECTRICAL DEPARTMENT FOREMAN*	PHONE NUMBER
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PERMIT TERMINATION				
WORK COMPLETED	PERMIT TERMINATED		WELDING AND BURNING	
	DATE	TIME	TIME STARTED	TIME FINISHED
SUPERVISOR REQUESTING WORK		MAINTENANCE FOREMAN		

COMPLIANCE WITH C-5 (ON REVERSE SIDE)
CHECKED BY:

Distribution: Original given to Maintenance Foreman for display at work site. Duplicate retained by issuing supervisor. Upon termination of the permit, duplicate is completed and maintained for division file. The original is completed by the Maintenance Foreman and forwarded to the Safety Department (to the Fire Department when welding and burning has been performed).

* Approval of Electrical Department Foreman is required when personnel other than electricians will be exposed to electrical hazards.

Fig. 6.3.1. Hazards Work Permit Form (Front)

- A. **A Hazards Work Permit** is required where service personnel are exposed to environmental hazards arising out of work in an area, or on equipment, or with materials of which they do not have complete knowledge, and over which they do not exercise complete control. Situations requiring permits, but not limited to these are:
1. Any welding or burning operation.
 2. Where ignition of flammable gases and liquids is possible.
 3. Where release of toxic, corrosive or highly reactive chemicals is possible.
 4. Work to be performed in the presence of mechanical or physical hazards such as: moving machinery, dangerous heights, high pressures, etc.
 5. Any change in status of equipment, facilities or system which would create additional hazards or eliminate any safeguards against hazards.
- B. **Workers Authorized by Permit** shall ensure that equipment being used is in good condition and that the manufacturer's instructions for maintenance are followed.
- C. **Necessary Precautions Against Fire** (Responsibility of Supervisor Requesting Work) when Welding and Burning is being performed.
1. Before welding, make sure sprinklers are in service. Call the Fire Department if in doubt.
 2. Before starting, sweep floors clean, wet down wooden floors, or cover them with sheet metal or equivalent. In outside work, don't let sparks enter doors or windows.
 3. Move combustible material 35 ft. away; cover what can't be moved with asbestos curtains or sheet metal, carefully and completely.
 4. Arranges for an employee or employees, equipped with hose, extinguishers, or fire pails to watch sparks and see that they do not start fire. Where fire hazard is slight, the authorizer may assign the task to the observer.
 5. After completion, watch scene of work a half hour for smoldering fires, and inspect adjoining rooms and floors above and below. (To be made by authorizer or his designated representative.)
 6. Don't use the equipment near flammable liquids or on closed tanks which have hold flammable liquids until properly purged and tested, so that formation of an explosive atmosphere inside is impossible. The Safety and/or Fire Department will advise in this matter. If work is to be done on pipes, ducts, etc., any combustible insulation or inside deposits shall be removed.

Fig. 6.3.1. Hazards Work Permit Form (Back)

4. If two or more men are working on a job, then each man shall attach his own lock so that the controls cannot be operated until all locks have been removed. At the completion of his assigned work, each man removes his own lock.
5. In case of emergency or lost key, the Laboratory Shift Supervisor may, after determining that conditions are safe, remove the lock with his grand master key.
6. If a key becomes lost, the lock shall be recombined to a new number and a new single key issued.

6.4 CHEMICAL SAFETY AND SAFETY EQUIPMENT

In the operation of a nuclear facility, the majority of occupational accidents are not the direct result of radiation. This can probably be explained by the fact that more emphasis is placed on (1) constantly reminding the worker of the dangers of radiation, (2) the use of physical safeguards to restrict entry into radioactive areas, and (3) the containment of radioactive materials within designated areas. Similar emphasis must be placed on conventional safety. Plant management must constantly remind employees to develop the ability habitually to recognize unsafe situations and equipment and to take appropriate action.

In radiation safety, there are principles, procedures, and practices that have been codified to result in safe working conditions. There are similar principles, procedures, and practices in industrial safety, which can be codified and learned and thus become habitual. The Company Safety Manual is such a codification of practices and criteria for conventional safety. New employees should be indoctrinated in the concepts of this manual, and all employees constantly encouraged to follow its practices. The importance of this is demonstrated by the fact that plants with strong industrial safety programs consistently have the best safety records. The Accident Prevention Manual for Industrial Operations* embodies experience from the nuclear industry and other industries and is an excellent guide to industrial safety.

The Occupational Safety and Health Act of 1970 (OSHA) was signed into law on December 29, 1970. The chemical process industries, including nuclear industry, must of course abide by OSHA standards for work areas, protective clothing, mechanical equipment, fire prevention, ventilation, air contaminants, handling hazardous materials, etc. In the prevention of accidents, however, there is no substitute for good

* *Accident Prevention Manual for Industrial Operations*, 4th Edition, National Safety Council, Chicago, Illinois (1959).

individual judgment and the constant practice of personal safety. The employee must be educated to know safety, think safety, act safely, and react safely to unusual events if he is to benefit from the safety program sponsored by the company.

The contents of a safety manual may contain the headings listed below. This list is not exhaustive but presents examples of topics included in a typical safety manual.

Foreword

- 1.1 Company XXX Safety Policy
- 1.2 Accident Investigation and Reporting
- 1.3 Eye Protection
- 1.4 Chemical Laboratory Safe Practices
- 1.5 Electrical Gas Cylinders and Regulators
- 1.7 Use of Work Permits, Locks, and Tags
- 1.8 Housekeeping and Safety
- 1.9 Disposal of Flammable Solvents
- 2.0 Conduct and Safety (Horseplay, Running, Use of Stimulants, Apathy)
- 3.0 Obey Rules and Signs (No Smoking, No Eating, Use Handrail, Load Limit, etc.)

6.5 FIRE PREVENTION AND CONTROL

Human safety, protection of the environment, and the prevention of personal injury and damage to and loss of property are very important considerations in the design and operation of all nuclear production and fuel reprocessing plants. Accidents such as a serious fire or explosion could potentially result in the release of radioactive materials in the plant or even to the environment if the primary containment is not maintained or if the protective ventilation systems are breached.

It is well known that accidents have been averted and the consequences of incidents that have occurred have been minimized by protective measures that had already been established and by well-trained personnel acting promptly and following these established procedures. As an additional safeguard, because such preventive measures cannot guarantee that an unforeseen incident or an operational error will not occur, protective equipment is installed, including fire extinguishers and automatic fire extinguishing systems.

This section of your manual presents some facts about fires, their causes, the types or classifications of fires, methods of extinguishment, means of preventing fires, and the individual's responsibilities.

6.5.1 Fires and Explosions

6.5.1.1 Combustion Process — By definition, a fire is a combustion or burning process that is intense enough to emit heat and light. Chemically this is called an oxidation reaction. The oxygen in the air plays a major role in most combustion processes. It is interesting to note that materials can burn in other oxidizing atmospheres, such as chlorine or fluorine gases. However, in discussing the types of fires that may be encountered in a fuel reprocessing plant, we can limit the oxidizing agent to oxygen and primarily to that contained in air.

For many years the three elements of fire, comprising fuel, air (oxygen), and temperature, have been represented by a triangle. When the triangle is complete, a fire can start. This is still true, but now we know that when the combustion reaction is accompanied by flame, there is a fourth factor that must be considered. This is a very fast chemical reaction that takes place in the envelope or hottest part of the flame. In this zone, fuel that is vaporized by the heat of the flame breaks down into highly reactive fragments (free radicals) which combine with oxygen in rather complex reactions, producing more heat and thus propagating the burning process. The reactions are known as chain reactions.

In contrast, a metal fire is a surface oxidation that does not involve a flame unless other volatile materials are present. Thus, metal fires require special techniques for extinguishment. This will be discussed later.

6.5.1.2 Classification of Fires — For the purposes of fire prevention and extinguishment, fires are generally grouped into four classifications according to the type of combustible material involved. The classifications were developed first by Underwriters' Laboratories, Inc., and later adopted by the National Fire Protection Association. Within these classifications, fires can also be typed by rate of burning as slow, fast, and ultrafast or supersonic.

The classes are as follows:

Class A: Ordinary combustible solid materials such as wood, rubber, paper, cloth, and plastics. The burning of these materials is characterized by glowing embers or incandescence plus the production of flammable gases that burn and propagate the fire and leave a carbonaceous residue like charcoal.

Class B: Flammable fluids such as solvents, gasoline, diesel oil, lubricants (oils and greases), hydraulic fluids, and paints.

Class C: Energized electrical equipment such as transformers, switches, motors, ovens, and computers. The hazard of electric shock

due to the conductivity of an extinguishing agent must be recognized. Electrical equipment that is deenergized can be in Class A or in A and B.

Class D: Combustible and reactive metals such as sodium (Na), potassium (K), sodium-potassium alloy (NaK), or magnesium (Mg). These materials may react with water or with air (water vapor or oxygen).

6.5.1.3 Causes of Fires — Basically, the causes of fires in nuclear facilities are not different from those encountered in industrial operations. They are: failure of electrical controls or of electrical equipment; ignition of combustible materials from hot surfaces of equipment such as furnaces, heaters, hot plates, or overheated vessels and from welding sparks and open flames; improper handling of flammable solvents and other flammable materials; and reaction of reactive metals with air, moisture, or organic materials. Some fires have also occurred spontaneously when anion exchange resins, used to separate or purify radioisotopes, have been exposed to air after extended use and consequent irradiation by exposure to the radioactive materials being processed.

Some fires have been caused, at least in part, by continuing an operation or running equipment when an instrument or control was known to be inoperable or was showing abnormal behavior. If any control or instrument vital to the safety of an operation is faulty it may be necessary to shut the equipment or the process down until the unit is replaced or the reason for the unusual behavior is determined. For example, fires have been caused by overheating of electrical heaters, such as those on off-gas systems, because the automatic controllers failed in the closed position. An unusual temperature increase should be an immediate warning that something is wrong. Other examples of critical controls are high or low liquid level sensors in vessels, high or low flow rate sensors in liquid or gas lines, and pressure sensors.

6.5.2 Fire Prevention

An important consideration in effective fire prevention is the identification of all aspects of the plant and the work that have a fire or explosion hazard potential or both. In general, fire and explosion hazards are determined by the following:

1. the potential consequences of a fire or explosion,
2. the quantity of flammable material,
3. ignition sources and the ease with which ignition can occur,

4. the speed with which corrective action can be taken, and
5. the effectiveness of the corrective action.

In nuclear power plants and fuel reprocessing facilities the fire prevention measures are directly related to the possible effects of loss of containment on both human and environmental safety. Because the hazard is high if containment is lost, fire resistance and explosion protection are important factors in the design and construction of the facilities. Nonflammable and low fire-risk materials are used extensively. The same degree of care must be taken in all aspects of operations within the facilities.

Thus, the potential for a fire can be minimized by elimination of flammable materials wherever practical and by replacing these with materials that are nonflammable or of lesser hazard. When it is not possible to replace the flammable material, the quantity should be kept to an absolute minimum to reduce the possible consequences of a fire, should one occur.

Sources of ignition can be limited by care in the use of electrical equipment and by being certain that all equipment is grounded, especially portable tools. Portable electrical equipment should be disconnected when not in use. Extra care should be taken to follow all regulations and restrictions with regard to the use of other ignition sources such as gas burners, torches, and soldering irons. Smoking and the use of matches or lighters should be regulated.

Housekeeping is equally important in fire prevention. Equipment and materials should be kept in their proper locations, and the storage of flammable materials such as kraft paper, plastic sheeting, and rubber gloves should be held to the minimum necessary for work in progress. Waste materials should be removed as soon as possible and should not be allowed to accumulate.

Finally, for your personal safety, all exits, stairways, corridors, and passageways should be lighted and clear of obstructions. Fire alarm boxes, fire extinguishers, gas masks, and other emergency equipment should be kept clear of obstructions. All personnel should know the locations and use of this equipment and the emergency exit procedures.

6.5.3 Extinguishing Methods and Agents

As described earlier, the elements of combustion are fuel, air (oxygen), temperature, and chemical reactions that propagate flame. Thus, it follows that some fires can be extinguished by removing or encasing the fuel; some by diluting, blanketing, or inerting the surrounding air; some by cooling the burning material below the ignition point; and some by terminating the chemical chain reaction in the flame. In many extinguishing agents, two or more of these factors are combined in the action on a fire.

6.5.3.1 Classes of Fires — Class A fires (symbol is "A" in a green triangle) can be extinguished by wetting and cooling with water or with preparations containing a large percentage of water, such as foams. The steam that is formed also has a blanketing effect that reduces the amount of air available to support the fire. Water is the best and most commonly used agent for Class A fires and generally has to be used to extinguish large deep-seated fires. However, it must be used with care in nuclear facilities to minimize the spread of contamination. Class A fires can also be extinguished by dry chemicals of the ordinary type that smother the fire or by special-purpose chemical mixtures that melt and form a coating on the burning material to exclude air.

Class B fires (symbol is "B" in a red square) can be extinguished by smothering or blanketing to exclude air. This can be done with carbon dioxide (CO_2) or dry-chemical extinguishers. The chemical reaction of the liquefied gas Halon 1301 to terminate the flame reactions is very effective on flammable-liquid fires.

Class C fires (symbol is "C" in a blue circle) require a nonconducting agent to prevent electric shock. Carbon dioxide, dry chemicals, and liquefied gases are suitable. When the equipment is known to be deenergized, the extinguishing agents for Class A fires are suitable unless flammable fluids (transformer oil, hydraulic fluid, etc.) may be involved which require the use of Class B agents. In general, it is safer to assume that electrical equipment is energized and to use only agents designated for Class C fires.

Where delicate electronic equipment such as a computer is involved in a fire, the liquefied gases Halon 1301 and carbon dioxide are more suitable than other agents that might render the equipment inoperative.

Class D fires (symbol is "D" in a yellow star) require special agents in granular or dry powder form. These are not the same as the dry chemical powders used for Class A or Class B and C fires. The agents for metal fires are usually proprietary formulations containing materials such as graphite, shredded asbestos, vermiculite, or sand. The inert material is frequently mixed with alkali metal salts or combinations of salts. The metal fire is extinguished by the smothering action of the inert material, which reduces the amount of air in contact with the metal, or by the melting of the salts, which forms a coating over the metal to exclude air. These extinguishing agents are generally approved for the control of fires involving specific metals.

6.5.3.2 Portable Extinguishers — Fire control and extinguishing methods can be classified broadly into two major categories: (1) manual or portable equipment for hand use and mobile equipment and (2) installed or fixed automatic systems. Large mobile equipment such as a fire truck is normally operated only by trained professional firemen. In large plants it is common practice to have auxiliary fire brigades made up of plant personnel who are specially trained and capable of controlling most fires that might occur in the plant.

Because time is a vital factor in preventing a small fire from becoming a large one, it is very important to have all operations personnel know how to use portable hand extinguishers. Instructions for the operation of hand extinguishers are always on the labels. In addition to these instructions, the labels indicate by the letters A, B, C, or D the type or types of fires on which the extinguishers can be used. The labels also indicate, by numerals in front of the letters, the relative extinguishing capability of the extinguisher as well as the approximate square-foot area of a fire which an average operator can extinguish. The numerical ratings are whole numbers starting with one (1); the higher the number the greater the ability of the extinguisher. For example, an extinguisher rated 8-B is most effective for Class B fires, and you can expect it to extinguish a flammable-liquid fire covering about twice the area that could be covered by one labeled 4-B. Extinguishers can have multiple numerical ratings as well as alphabetical, such as 2-A:10-B:C.

The numerical code does not apply to Class C (electrical) fires. The only requirement for a Class C extinguisher is that the agent must not conduct electricity.

6.5.4 Summary and General Rules

In summary, fire prevention is a function of the design of the facilities, the materials of construction, the work being done, and the flammable materials that are handled. The success of preventive measures and the prompt control of an accidental fire depend on the ability and training of all people in all work areas. Their ability to observe and be alert to what is going on in the work area and to recognize any unusual or abnormal conditions is vital. The supervisor, or whoever is in charge of the area or equipment, should be informed of such conditions.

The following rules are important points to remember:

1. Know the exact location of all fire-fighting equipment in your work area.
2. Know how to use each extinguisher, the fires on which you can use it, and those on which you should not.
3. Do not block any door, safety exit, or fire-fighting equipment with other equipment or materials.
4. Unplug all portable electrical equipment and tools when they are not in use.
5. Smoke only in designated and posted areas where smoking is permitted. Do not smoke in work areas where radioactive materials are handled or flammable materials may be stored.

6. In the event of a fire, leave immediately unless it is obvious that it is safe to remain.
7. Turn in an alarm or see that someone does before fighting a fire.
8. Do not reenter a room unless your presence is required.
9. Always be sure that you are safely between the fire and an exit.
10. Know the meaning of the alarm signals in any area in which you work and what action you are expected to take.
11. Know the emergency phone number(s) in your work area.
12. Know how and whom to call for help and how to give or send in an alarm if such action is necessary.
13. If it is necessary to telephone for help, be sure to tell the other person quickly and briefly what has happened, where it has happened, what help is needed, and who you are.

6.6 EMERGENCY PROCEDURES

Since each fuel reprocessing plant is unique in its details of arrangement and operation, this guide will not attempt to describe specific procedures for handling emergency situations but will attempt to set forth the basic premises from which specific fuel reprocessing plants may develop procedures for handling emergencies that may arise in their own operations. The recommendations made below have been tested in a number of emergency situations and found to be sound.

The most important factor in handling emergencies is to have a plan to follow and personnel previously trained and well versed in appropriate methods for coping with every situation that might conceivably arise in the plant and its environs. Of course, it is vital to know that an emergency has occurred or is about to occur, and it is assumed here that the plant is equipped with alarms and warning devices to alert operating personnel whenever abnormal conditions that might lead to an emergency are in prospect. The alarms must be distinctive in sound or other indications, and the personnel must be able to recognize their meaning and the location of the difficulty. In plants where there may be several types of warning signals, a sensible method to assure that people understand the meaning of various bells, sirens, horns, etc., is to provide a taped explanation of them which can be played to individuals when they dial a special plant telephone number. Drills and tests should be conducted from time to time to make certain that everyone in the plant knows what to do in an emergency. Most drills should be announced in advance, but it may be wise to have an occasional surprise drill to test the alertness of the personnel and the efficiency of the emergency procedures.

The emergency procedures should assign responsibilities to various key people (emergency supervisors, wardens, squad leaders) and should provide secondary assignments for others to follow in the event the key people are injured or otherwise unable to handle the situation. Each person should know his assignment thoroughly. One of the assignments should be to make sure that everyone (except those assigned to specific tasks) evacuates the plant when the evacuation signal is given. A search should then be made for any missing persons. Evacuation routes should be planned to conduct people out of every area of the plant without their having to pass areas where emergencies are most likely to occur. It is also important to designate assembly points for evacuees in order to account for all personnel quickly. Maps of these evacuation routes and assembly points should be posted in prominent locations for all personnel to be familiar with them.

APPENDIX

Appendix to Chapter 3

3.3.2.1 Senior Operator Classification — Typical Examination Questions with Answers.

RADIOLOGICAL SAFETY

- Q. 1. Name two of the three items surveyed by the continuous air monitor at the stack.
- A. 1. I-131, Kr-85, and particulate radioactivity (any two of these).
- Q. 2. (a) What is the maximum daily dose to penetrating radiation that an employee may receive without special approval?
(b) With approval by the Health and Safety Director, what is the limit on radiation exposure?
(c) With the written approval of the employee's Department Manager and the Health and Safety Director together, the limit on radiation exposure may be increased to what value?
- A. 2. (1) 0.1 rem
(2) 0.2 rem
(3) 1.0 rem
- Q. 3. (a) A "hot spot" is causing a radiation intensity of 100 mr/hr in a working area 6 ft away (assume no other radiation source) and is not shielded. What would the radiation intensity be 18 ft away instead of 6 ft?
(b) If, instead of a "spot" the radiation came from a 5-ft-diam by 7-ft-long tank, would the intensity at 10 ft be (greater than, equal to, or less than) the answer to part (a) of this question?
- A. 3. (a) approximately 11 mr/hr
(b) greater than
- Q. 4. (a) List three different types of radiation emitted by radioactive materials; for each, give an instrument type suitable for measuring the intensity.
(b) Approximately how close to the source would the instrument probe have to be to detect alpha particles given off by uranium?
- A. 4. (a) alpha, alpha survey meter
(b) beta, G-M survey meter, "cutie pie"
(c) gamma, G-M survey meter, ion-chamber, "cutie pie"
(d) within about 1 inch
- Q. 5. Give two precautions that are observed to prevent the possibility of a criticality incident in the dry chemical vault.
- A. 5. Discharges of plutonium from the NaF trap must be accompanied by a given amount of NaF. The spreading equipment must be in operation (or the Pu content less than 20 grams) before the fluorinator bed or the fluorine reactor bed can be discharged.

- Q. 6. Describe the methods used to prevent the possibility of a criticality incident in the fuel storage basin?
- A. 6. The elements are stored in special baskets and only one element or basket is handled at a time.
- Q. 7. Give two checks that are performed to make sure the UF_6 product cylinder will not contain an excessive amount of moderator when loaded.
- A. 7. The tare weight of the UF_6 cylinder is checked to make sure the heel is less than a certain value. The vapor pressure of the UF_6 is checked in the cold traps to make sure that there is not an excessive amount of HF present.

STANDARD AND SAFETY PROCEDURES

- Q. 1. (a) For what purposes are special work permits and radiation work permits used?
- (b) Who approves each type of permit?
- (c) For how long a period is each type valid?
- A. 1. (a) All work performed in exposure control areas is covered by either a RWP or SWP. The RWP covers repetitive work and the SWP is used for specific work.
- (b) Plant Safety and other groups performing work under the procedures (Production Supervisor).
- (c) A RWP is good until revoked by Supervision or Plant Safety. A SWP is valid for only one shift unless extended.
- Q. 2. List any 5 types of emergency procedures that are available for use at the facility. Where are these procedures located?
- A. 2. (a) Criticality Accident
- (b) Contamination Release
- (c) Fire
- (d) Equipment Failure or Operational Accident
- (e) Plant Prompt Shutdowns
- (f) Accidents from Natural Causes
- (g) Serious Injury or Illness
- The above procedures are available in the main control room.
- Q. 3. (a) What is the primary method used to control the formation of "red oil" at the facility?
- (b) What methods are used to prevent excessive pressures in the plutonium product bottles?
- A. 3. (a) Red oil is prevented by limiting the temperatures in the HCU and UNH concentrators to less than 135°C and by keeping TBP out of the concentrators.
- (b) The Pu product is reduced to Pu(IV) before loadout. Product is kept in strongly acid state (7 to 8 M HNO_3). Bottle caps are designed to vent and the bird cages are vented.

EQUIPMENT AND INSTRUMENTATION

- Q. 1. (a) What is the maximum height relative to the water surface that the crane in the fuel storage pool can be raised?
 (b) Why is this important?

- A. 1. (a) A limit switch on this crane prevents the fuel element from rising above a level 11 ft below the water surface.
 (b) To prevent over-exposure of personnel to radiation.

- Q. 2. Sketch, in schematic form, a typical control system for controlling the interface of an aqueous-continuous extraction column. Label all parts.

- A. 2.

TYPICAL AQUEOUS
 CONTINUOUS EXTRACTION
 COLUMN

Equipment and instrumentation
 (Fig. for problem 2)

Q. 3. The interface probes in a pulse column are as follows:

If the pressure difference between probes is 18 in. of water, what is the height of the interface above the lower probe (dimension "A" above)?

- A. 3. Distance between probes = 20 in.
Pressure difference between probes = 18 in. of water
Depth of aqueous phase = A
 $A(1.0) + (20-A)(0.8) = 18$
 $A + 16 - 0.8A = 18$
 $0.2A = 2$
 $A = 10$ inches

- Q. 4. During a dissolution, (a) What items are recorded continuously?
 (b) What alarms are associated with the dissolvers?
- A. 4. (a) liquid level, density, and temperature of the dissolver and system pressure in the off-gas line.
 (b) low solution level, temperature of the solution, and gas pressure.

- Q. 5. Typical instrumentation for measuring the level and density in a vessel by the use of pressure differential transmitters and air bubbler is shown in Fig. 3.3.1. The density indicator has a range of 0 to 20 in. H_2 and the liquid level indicator has a range of 0 to 100 in. H_2O . Using the dimensions given in Fig. 3.3.1 answer the following question?
- If the density instrument reads 70% of full scale, what is the density of the solution in the tank?
 - What would the liquid level instrument read (in percent of full scale) for the liquid depth shown?
 - What would you expect the effect on the liquid level and density readings to be if there were a partial restriction in line A somewhere inside the vessel?
- A. 5. (a) ΔP across density probes = $20 \times .7 = 14$ inches of water
 $\text{density} = \frac{14}{10} = 1.4$
- (b) Head above liquid level probe = $5 \times 12 \times 1.4 = 84$ in. H_2O
 $\frac{84}{100} \times 100 = 84\%$
- (c) Both the density indicator and liquid level indicator would indicate higher values than they should.

CHEMISTRY AND CHEMICAL ENGINEERING

- Q. 1. The attainable loading of the solvent in a TBP system is approximately 4 g of U/liter for each percent of TBP in the solvent mixture. (a) If the flow rates and concentrations of streams going to the extraction column were as follows, what is the minimum HAX flow rate needed if you want the uranium concentration in organic phase to reach no more than 70% of saturation? (b) What would you expect to happen if the U concentration reached saturation in organic phase?

<u>Stream</u>	<u>Rate (liters/hr)</u>	<u>Concentration</u>
HAF	25	320 g of U/liter
HAS	16	No U
HAX	?	30% TBP; no U

- A.1 (a) Feed rate (g of U/hr) = $25 \times 320 = 8,000$
 Solvent loading at 70% saturation (g of U/liter per percent TBP) = $\frac{70 \times 4.0}{100} = 2.8$
 Solvent loading for 30% TBP (g of U/liter) = $2.8 \times 30 = 84$
 Minimum HAX rate = $\frac{8,000}{84} = 83$ liters/hr
- (b) Some uranium would probably be lost to waste.

Fig. 3.3.1. Equipment and instrumentation
(For problem 6)

- Q. 2. List one undesirable effect of each of the following conditions in the facility chemical flowsheet.
- (a) For any given pulse frequency, too high a pulse amplitude to a solvent extraction column.
 - (b) Air sparger is cut off the feed adjustment and accountability tank.
 - (c) Incorrect cold chemical addition to the feed tank to partition cycle feed tank.
 - (d) Loss of HAX to HA column.
 - (e) Low air supply to partition cycle feed pump pots.
 - (f) Resin degradation in the ion-exchange columns in the plutonium purification cell.
 - (g) Solution put into wrong tank (e.g., No. 1 U product sample tank instead of No. 2 U product sample tank).
- A. 2.
- (a) Flooding conditions
 - (b) Poor mixing; incorrect sample
 - (c) Wrong solution composition, which can cause a loss of product to the HAW stream or poor DF.
 - (d) Loss of product to waste system
 - (e) Low flow of HAF stream
 - (f) Excessive product in plutonium ion-exchange waste catch tank
 - (g) Possible rework of product & resampling
- Q. 3.
- (a) For what purposes is caustic (NaOH or KOH) used at the facility. List the equipment in which it is used.
 - (b) Where is Fe^{++} used in the process and for what purpose is it used?
 - (c) What restrictions are placed on the use of the above chemicals at the facility. Why?
- A. 3.
- (a) Caustic is used in process vent scrubber (V-56) and evaporator off-gas scrubber (V-56) and to regenerate the water demineralizers.
 - (b) Used for valence adjustment in V-33 and for Np rework. It is to be used only for those streams servicing the ion exchangers unless authorized by the safety committee.
 - (c) The caustic could cause precipitation of U & Pu in other portions of the process and result in nuclear safety problems. Ferrous ion is capable of causing undesirable Pu reflux and high loss of Pu from the solvent extraction system.
- Q. 4.
- (a) Assume that 1000 kg of UO_2 has been dissolved in enough nitric acid to product 3000 liters of solution. What is the uranium concentration of the solution in molarity and in grams of U/liter? Show calculations (Molecular WT of U = 238, O = 16).
 - (b) What is the reason for placing limits on the uranium concentration in V-10 and V-20? Where would you find the allowable limits for these vessels given at the facility?
 - (c) If the uranium concentration limits for V-10 and V-20 are defined by the curve shown in Fig. 3.3.2, what would be the uranium concentration that could be used (state whether more than or less than a certain value) if the fuel being processed had an enrichment of 3.5%?

Fig. 3.3.2 Limiting U concentration in V-10 and V-20
(For problem 4, chemistry and chemical engineering)

A. 4. (a) Molecular weight of $\text{UO}_2 = 270$

$$\frac{100,000 \text{ g}}{270} = 3,703.7 \text{ moles of } \text{UO}_2$$

$$\frac{3,703.7}{3,000} = 1.23 \text{ molar solution}$$

$$1.23 \times 238 = 293.8 \text{ g of U/liter}$$

- (b) For criticality control. Technical Specification 1.3.
 (c) The uranium concentration must be less than 1.5 molar.

CHEMICAL PROCESSING SYSTEMS

Q. 1. The schematic diagram below represents certain equipment items in the plant. Label all incoming and outgoing streams in the blocks in these diagrams.

Chemical Processing system
(Figure for problem 1)

- A. 1. (1) HAS (6) HCX (11) IIAS (16) IDS
 (2) HAF (7) HBU (12) IIAF (17) IDF
 (3) HAX (8) HCU (13) IIAS (18) IDX
 (4) HAW (9) IAF (14) IIAW (19) IDW
 (5) HAP (10) HCW (15) IIAP (20) IDP

- Q. 2. Indicate the cycles in which each of the vessels in question No. 1 functions.
- A. 2. (1) 4C-1 Partition cycle
(2) 4C-4 Partition cycle
(3) 4C-7 Second plutonium cycle
(4) 4C-11 Second uranium cycle
- Q. 3. How are the following accomplished in the plant process:
(a) Regeneration silica gel beds 5C-6A and 5C-6B.
(b) Elutriation of plutonium from anion exchange column 5C-1A.
- A. 3. (a) The silica gel is first washed with 0.25 M HNO_3 to rinse out uranium and then treated with 0.4 M oxalic acid solution.
(b) Plutonium is elutriated with 0.6 M HNO_3 .
- Q. 4. List three variables that can cause serious trouble in the ion exchange columns (5C-1A, -1B, and -1C). For each variable give the safe upper limit used at the facility.
- A. 4. (1) Temperature - 80°C
(2) HNO_3 concentration - 8 M
(3) Acid contact time - 24 hr
- Q. 5. Give either a brief description or a simple flow diagram of the major equipment used in the following systems.
- (a) Process steam
(b) Process cooling water
- A. 5. (a) Process steam at 100 psig is generated in process steam generator E-702 using utility steam. The process steam is a closed circuit. After it goes through process vessel it is condensed in by condensate cooler E-702. The condensate from the cooler flows to condense to surge tank V-70 and is pumped back to the process steam generator. Makeup is recycle water to the condensate cooler.
(b) The process cooling water system is a closed loop. Water from storage tank V-70 is pumped through the process equipment. It then passes through heat exchange E-70 where it is cooled by air fans before it returns to the storage tank. Demineralized water is used for makeup.
- Q. 6. List the general sequence for startup of the solvent extraction and solvent recovery system after an extended shutdown for maintenance and/or inventory. (Do not include specific details.)
- A. 6. Makeup aqueous scrub streams
Filling the solvent treatment columns with process solution
Operate in recycle mode
Spinning the solvent treatment system to establish organic quality and temperature
Filling the solvent extraction column with process solution
Filling the HCU concentrator and bringing it to a boil
Establishing process flows.

- Q. 7. Give three systems or pieces of equipment that should be in operation before starting up the LAW evaporation system.
- A. 7. Process off-gas monitoring system
BL-564-1 or 2
Process building ventilation system

POWER AND AUXILIARY SYSTEMS

- Q. 1. According to Technical Specification 6.4, the emergency generator (30T), air compressor (31K), and cooling water pump (32G) must be started and tested how frequently?
- A. 1. Every 3 months.
- Q. 2. The plant fire water system consists of three interconnected systems. Two of these systems are "wet pipe" systems, and one is a "dry pipe" system. (a) Which areas are covered by the two "wet pipe" systems? (b) What area is covered by the dry pipe system?
- A. 2. (a) [1] The yard system consisting of a series of fire hydrants and hose cabinets.
[2] The wet sprinkler systems installed in the office area, cold chemical area, and the utility area.
(b) Warehouses.
- Q. 3. On midnight shift, the radiation alarm (32 RAH) on the cooling water returning to the cooling tower starts to alarm. What action would you take as a Senior Operator assuming your supervision is unavailable? What is the reason for your actions?
- A. 3. (a) Divert cooling water basin in tower to interceptor immediately. Shut down plant.
(b) To prevent activity from recirculating through the utility room equipment.
- Q. 4. An underground storage tank for fuel oil is provided for use in emergencies. List three types of equipment that can be run with this fuel oil in emergencies.
- A. 4. (a) boilers
(b) fire pump
(c) Emergency electrical generator
- Q. 5. (a) List 6 items that are normally on the emergency power system.
(b) Other selected loads may be put on the emergency power system after the pieces of equipment normally on this system are operating. But the addition of such loads will be completed by?
- A. 5. (a) Any six of these items:

<u>Equip. No.</u>	<u>Description</u>	<u>Drive</u>	<u>Emergency Power Source</u>
8E-1	Waste Tank Condenser Fans	Motor	MCC E-1
8E-1A	Waste Tank Condenser Fans	Motor	MCC E-1
6E-6	Steam Superheater	Heater	MCC E
6K-1	Dissolver Off-Gas Blowers	Motor	MCC E-1
6K-1A	Dissolver Off-Gas Blowers	Motor	MCC E-1
6K-2	Vessel Off-Gas Blower	Motor	MCC E-1
6K-2A	Vessel Off-Gas Blower	Motor	MCC E-1
8K-1	Waste Tank Off-Gas Blower	Motor	MCC E-1
8K-1A	Waste Tank Off-Gas Blower	Motor	MCC E-1
31G-1	Fuel Oil Pump	Motor	MCC E
31G-6	Condensate Return Pump	Motor	MCC E
31G-6A	Condensate Return Pump	Motor	MCC E
LT-1	Instrument Power	Transformer	MCC E
LT-E1	Lighting Panel E-1	Transformer	MCC E
LT-E2	Lighting Panel E-2	Transformer	MCC E
LT-E3	Lighting Panel E-3	Transformer	MCC E
LT-E4	Waste Tank Lighting Panel E-4	Transformer	MCC E
32G-2B	Plant Water Pump	Turbine	150# Steam
31G-2	BFW Pump	Turbine	150# Steam
31G-2A	BFW Pump	Turbine	150# Steam
31K-2	Boiler Draft Fan	Turbine	150# Steam
31K-2A	Boiler Draft Fan	Turbine	150# Steam
32G-4B	Cooling Water Circulating Pump	Turbine	150# Steam
31K-1	Plant Air Compressor	Turbine	150# Steam
15K-10A	Process Building Exhaust Fan	Turbine	150# Steam
30P-1	Emergency Generator	Turbine	150# Steam
33G-2	Fire Pump	Engine	Diesel Oil

(b) Authorized personnel, shift supervisor, or higher management.

ADMINISTRATIVE PROCEDURAL RULES

- Q. 1. How often must the liquid level measuring devices which are located in the annular space surrounding a waste tank be checked for operability?
- A. 1. Once per month.
- Q. 2. Certain equipment at the facility is deemed vital to the safe and continuous operation of the plant. List the two kinds of such equipment.
- A. 2. (1) Equipment that can become critically unsafe from a nuclear standpoint.
- (2) Any piece of equipment whose malfunction could reasonably require the shutdown of the plant.

- Q. 3. List 3 rules that apply in handling an emergency condition.
- A. 3. (1) If incident involves wreckage and a person is believed to be alive and trapped, make every effort to rescue him.
 (2) Remove injured persons from the scene with as little direct personal contact as possible.
 (3) Work within the framework of any applicable SOP's covering a specific type of emergency.
 (4) Segregate and detain for further examination those persons who have had possible contact with the radioactive material.
 (5) Do only what is necessary to preserve life and property prior to the arrival of Health and Safety specialists.
- Q. 4. To the maximum practical extent all details of plant operation are controlled by written procedures.
 (a) Name the 3 forms these written procedures take.
 (b) Which one of them is used to modify any of the restrictive procedures established for plant control?
- A. 4. (a) SOP, Run Sheets, and Letters of Authorization
 (b) Letters of Authorization

PHYSICS

- Q. 1. In addition to administrative control, several methods of maintaining the system "critically safe" are used in your plant. These methods include: (a) geometry, (b) concentration, (c) mass, (d) soluble poison, (e) fixed poison, and (f) none. Which method or methods are used for the following operation?
- (1) Dissolvers
 (2) Solvent Extraction partition cycle
 (3) Du Product Tanks 5D, TD
 (4) Moving highly enriched fuel assemblies
 (5) Excessive carryover of Pu in the 5C evaporator condensate into 5D
 (6) Low enriched U storage tank 5D-15
- A. 1. (1) [a] geometry [b] concentration
 (2) [b] concentration
 (3) [a] geometry [e] fixed poison
 (4) [c] mass
 (5) [e] fixed poison
 (6) [b] concentration
- Q. 2. The figure below is a simplified drawing of a process piping change which must be done remotely. A vent line is to be installed between two tanks and is to hang from the crane hook horizontally while it is being moved into position over the tanks. From the information given on the drawing, calculate the weight to be attached to the jumper at point B which will make the jumper balance in a horizontal position.

Figure for problem 2, physics

- A. 2. Total length of jumper = $18 - (2 + 2) = 14$ ft
 length from A to center line of hook = $8 - 2 = 6$ ft
 length from B to center line of hook = 8 ft
 $B(8) - 6(50)$ ($B = 30$ lbs)
- Q. 3. In the plant precautions are taken not to accidentally mix caustic or decontamination reagents with solutions containing uranium or plutonium. How is this related to criticality control?
- A. 3. Extranious chemical could cause the uranium or plutonium to precipitate thus increasing the concentration at certain locations. This increases the possibility of a criticality incident.
- Q. 4. Indicate which of the following isotopes in chemical solutions are safe, unsafe, or of no concern (write S, U, or NC).
 (a) A solution of $\text{Pu}(\text{NO}_3)_4$ containing 200 g/liter of Pu in a 30-gal drum.
 (b) A solution containing 300 g/liter of ^{239}Pu in two 5.1-in.-diam vessel standing side-by-side.
 (c) A solution containing 300 g/liter of ^{232}Th in a 30-gal drum.

- (d) A solution containing uranium enriched to 10% that is to be processed with 38 volume % TBP as the extractant in a 10.25-in.-diam column.
- (e) A solution containing 5 g/liter of ^{235}U in a 55-gal drum. The maximum enrichment of the U is 5 wt % U-235.
- (f) A solution containing 5 g/liter of ^{233}U in a 55-gal drum.
- A. 4. (a) U
(b) U
(c) NC
(d) U
(e) S
(f) S

3.3.2.2 Operator Classification — Typical Examination Questions with Answers.

RADIOLOGICAL SAFETY

- Q. 1. (a) Where are limited quantities of radioactive material discharged to the environment from the facility?
 (b) List two types of radioactive materials that are discharged.
 (c) What instrument is used to measure the amount of radioactive material discharged?
- A. 1. (a) To the plant stack
 (b) KR-85, I-131, particulate alpha and gamma, tritium.
 (c) Stack monitor (also process vent monitor, sand filter inlet monitor).
- Q. 2. What type of instrument is installed at the facility to detect a criticality incident? Give the location of one of these instruments.
- A. 2. (a) Neutron detectors.
 (b) UF₆-Pu load out area, lab area, fuel storage basin.
- Q. 3. (a) List two precautions that are observed to prevent a criticality incident during plutonium loadout.
 (b) How is the release of radioactive material to the operating area avoided during plutonium loadout?
- A. 3. (a) No more than one Pu bottle in loadout hood at one time. Bottles will be removed from hood and placed in a bird cage. Full bottles will never be manually handled in or out of the loadout hood.
 (b) Loadout is done inside a hood. Any spillage or leakage in the hood is immediately cleaned up to maintain the hood in a clean condition. The person performing the loadout will wear gloves. A hoist will be used to move product bottles.
- Q. 4. Give the two preferred methods for criticality control at the facility. What method is used in the leacher reservoir (V-10)? Which method is used for the Pu concentrator (V-30)?
- A. 4. Favorable geometry and concentration control.
 Leacher reservoir — concentration control, Pu concentration-geometry.
- Q. 5. When monitoring yourself for alpha contamination approximately how close to the surface being monitored should the survey probe be held? Why?
- A. 5. Less than 1 inch. The mean range of alpha particle (from U and Pu) in air is about 1 inch.
- Q. 6. (a) Name three ways radioactive material can enter the human body.
 (b) Give one protective device or precaution that is used to prevent the intake of radioactive material by each of the ways given above.

- A. 6. Ingestion, inhalation, absorption or through breaks in the skin. Protection against ingestion, no eating, chewing, or smoking in contamination areas. Gas masks or supplied air equipment is used to prevent inhalation, gloves and protective clothing are used to prevent contact of radioactive material with the skin.
- Q. 7. What is a contamination zone? How does this differ from a Radiation Area?
- A. 7. A contamination zone is an area where there is a possibility that radioactive material is loose in the area. A radiation area is an area where penetrating radiation may be present but no loose radioactive material.
- Q. 8. Does a full-face canister mask offer complete protection against radioactive airborne particles at any concentration?
- A. 8. No. A full-face canister mask is good up to $4(10^{-11})$ $\mu\text{Ci/ml}$ alpha and $2(10^{-8})$ $\mu\text{Ci/ml}$ beta.
- Q. 9. Who at the facility is responsible for tagging or posting any equipment or condition that represents a safety hazard and/or unsafe working conditions?
- A. 9. Any employee.
- Q. 10. What are the radiation limits in Contamination Zones 3 and 4?
- A. 10. Zone 3: >2.5 , <100 mrem/hr
Zone 4: >100 mrem/hr
- Q. 11. What monitor should be available during plutonium loadout?
The PPH continuous air monitor and the PAC monitor.
- Q. 12. (a) List three different types of radiation emitted by radioactive elements.
(b) Which type is the most penetrating?
(c) What units are used to express the amount of ionizing radiation present?
- A. 12. (a) alpha, beta, gamma
(b) gamma
(c) mr/hr

STANDARD AND EMERGENCY PROCEDURES

- Q. 1. If plant evacuation is necessary, you as Control Room Operator will do (a) What? (b) How is this done?
- A. 1. (a) Actuate the intermittent-sounding evacuation horns.
(b) By closing the manual switch on the intercom box in the Control Room.
- Q. 2. What system lines are blanked off or locked out before each high-enriched uranium campaign?

- A. 2. (1) Those used only during low-enriched uranium campaigns.
(2) Those on decontamination systems.
(3) Those that can introduce precipitants into vessels containing solutions of fissionable isotopes.
- Q. 3. During high-enriched uranium loadout, what information do you give to the chemical process operator?
- A. 3. Liquid level and density in 5D-13.
- Q. 4. List the six steps you are to take in preparing to evacuate the control room assuming the plant is operating.
- A. 4. (a) Shut off HAF feed to 4C-1 column.
(b) Shut off steam and turn on cooling water to dissovlers.
(c) Shut off steam to high level evaporator (7FIC-3).
(d) Shut off steam to low level evaporator (7FIC-4).
(e) Shut off steam to remote evaporator (7C-4) by reducing 7FIC-2 to zero.
(f) Shut off steam to Pu evaporator (5C-2) by reducing 5FIC-4 to zero.
- Q. 5. After performing the above operations (question 4) as rapidly as possible, you are to evacuate by (a) what route to the outside and proceed to (b) what in case a general evacuation has been announced. If general evacuation has not been announced, proceed to the nearest area where (c) what instrument is not sounding and wait for instruction from (d) whom.
- A. 5. (a) South stairwell
(b) Staging area
(c) Radiation instrument
(d) Shift supervisor.
- Q. 6. Identify the radiation areas within the plant operating areas by giving their names and distinguishing characteristics.
- A. 6. Zone 1 - areas having a radiation reading of ≤ 0.02 mrem/hr
Zone 2 - areas having a radiation reading of ≥ 0.02 and ≤ 2.5 mrem/hr.
Zone 3 - areas having a radiation reading of > 2.5 and ≤ 100 mrem/hr.
Zone 4 - areas having a radiation reading of > 100 mrem/hr.
- Q. 7. What is a General Emergency? Give two examples of incidents that would constitute a General Emergency.
- A. 7. A General Emergency is an emergency that results in releasing quantities of contamination to the off-site environment significantly in excess of allowable releases for the facility. Two examples: (1) release of excessive amount of radioactive iodine.
(2) critical incident followed by the release of contaminants to the environs.
- Q. 8. Who administers the specific plan during all emergencies?
- A. 8. The senior operator.

- Q. 9. What are the three types of emergencies established in the facility emergency procedures?
- A. 9. (a) area (b) site (c) general
- Q. 10. Give two requirements regarding the status of the stack that must be met before dissolution of fuel can be started in vessels 3C or 3C-2.
- A. 10. The stack monitor and sampler must be on operation and the wind speed must be over a specified velocity.
- Q. 11. Give the three special precautions that must be observed in operating the plutonium ion exchanger beds.
- A. 11. (1) Temperature not to exceed 80°C
(2) Resin not contact HNO_3 stronger than 8 M
(3) Resin contact time with plutonium nitrate solution not to exceed 24 hr.
- Q. 12. What information and approval must be obtained before low level wastes can be transferred to the underground waste storage (WT)?
- A. 12. (a) Proper neutralization of the waste must be assured
(b) S/S approval must be obtained.
- Q. 13. Who is required to verify the analysis and excess caustic calculations before high level waste is transferred to underground storage?
- A. 13. Shift supervisor.
- Q. 14. In the Lock and Tag Procedure, (a) what information is placed on the tag attached to a lock? and, (b) by whom is the tag to be removed?
- A. 14. (a) The reason why it is used.
(b) A person whom the one attaching it designates.
- Q. 15. (a) What means is used to unplug B-type sample lines?
(b) What solution is used to unplug Pu samplers?
- A. 15. (a) Process water at pressures not over 150 psig
(b) Dilute HNO_3 (0.6 M)
- Q. 16. What are the limitations on the number of product bottles that can be placed inside the plutonium glove box at any one time? Why?
- A. 16. (a) Only one bottle at a time
(b) To make it critically safe
- Q. 17. For what purpose should the boric acid solution in the dissolver be used?
Where are the valves that release this solution?
- A. 17. To quench a criticality incident in the dissolver
At the control panel.

- Q. 18. Three basic plans are called for in the facility emergency shut-down and evacuation procedure for the Control Room. Name these plans.
- A. 18. Plan I, Plan II, Plan III
- Q. 19. What is done with waste material from high-enriched uranium loadout? Why?
- A. 19. It is reprocessed to reclaim high-enriched uranium.
- Q. 20. Prior to plutonium load out, what plant lines are blanked shut?
- A. 20. Decontamination system and water addition lines.
- Q. 21. What information is given to the Control Room Operator during enriched uranium load out? What request is made of the Control Room Operator during this load out?
- A. 21. (a) intent to transfer high-enriched uranium product solution to measuring pot.
(b) request control room operation to turn on air sparge to tank 5D-13.
- Q. 22. (a) During a complete electrical power failure what 3 pieces of equipment start automatically using emergency power.
(b) After a power failure what other systems must be switched to the emergency generator within 15 minutes? How is this done?
- A. 22. (a) Emergency exhaust blower BL-897-3, air compressor C-871, process vent blower BL-564.
(b) The 24-V DC system and the UPS system. They are manually switched at the north instrument gallery, MCC EE-13.
- Q. 23. List the conditions that will cause a crash shutdown of the plant.
- A. 23. Low instrument air pressure, low UPS system voltage, low voltage on 24-V system, loss of power on either incoming lines, push button on main panel.
- Q. 24. (a) List one precaution that is observed at the facility to prevent the formation of red oil.
(b) Give a precaution that is observed at the facility to avoid solvent fires.
(c) List two precautions that are observed to prevent an undesirable ion exchange resin reaction.
- A. 24. (a) Red oil is an explosive material produced when TBP and concentrated uranyl nitrate are heated together above 135°C. The temperatures in the HCV and HAW concentrators are limited to less than 135°C. Precautions are used to keep solvent out of the HCV concentrator such as using decanter V-203, and feed enters top at fractionating tower where organic would be vaporized. HA column interface control system will shut off HAW if before organic can go to HAW concentrator.
(b) Keeping temperature below the flash point. Elimination of ignition sources, eliminate solvent leakage, and provide level detection instrumentation for leakage in cell sumps.

- (c) Temperatures in ion exchange units are limited to less than 80°C. Nitric acid strength is limited to less than 8.0 molar, resin will not be left loaded with Pu for more than 24 hours, the ion exchange units will not be allowed to become highly pressurized.
- Q. 25. (a) What special privileges does the holder of a Safety Certification A have at the facility regarding entry into operating areas?
- (b) What special privileges does a holder of a Safety Certification B have at the facility regarding entry into operating areas?
- A. 25. (a) Class A — unescorted access to any location in the facility, subject to supervisory approval.
- (b) Class B — unescorted access to areas of the facility which are not exposure control areas, HF areas, or the fluorine generation building.
- Q. 26. List 3 rules that should be followed to avoid personal contamination while working in an exposure control area.
- A. 26. Assume all surfaces are contaminated, do not remove protective clothing in area unless approved by supervisor, perform all work with at least one other person present to monitor and to keep a record of exposure time.
- Q. 27. What procedure should be followed for leaving an exposure control area during the following types of emergencies.
- (a) In case of an injury
- (b) In case of a building evacuation
- (c) In case of a criticality incident
- A. 27. (a) Follow normal surveys and procedures only to the extent that it will not delay urgent first aid.
- (b) Remove gloves, footwear, and outer coveralls. Make an effort not to contaminate equipment or personnel outside of contamination area.
- (c) Run from the area immediately.
- Q. 28. (a) For what types of work is a Radiation Work Permit required? What type of information is given on the RWP?
- (b) For what type of work is a Special Work Permit required? For how long a period of time is the SWP valid?
- A. 28. (a) Routine or repetitive work in an exposure control area. It will specify all precautions necessary for assuring the radiation safety for that job.
- (b) For specific work in an exposure control area. It is valid only during the shift in which it was issued.
- Q. 29. If a tool or other object is located in a contamination area what procedure must be followed to obtain an unconditional release to move the object from the contamination area?
- A. 29. It should be first surveyed in the exposure control area (can be by a person holding an "A" certification). If it appears to be clean it can be moved out of the area and the final survey made by Plant Safety.

INSTRUMENTATION AND CONTROLS

- Q. 1. For a remotely operated air-to-close valve, at what pressure (psig) does the valve start closing and at what pressure is it completely closed?
- A. 1. Starts closing at 3 psig and is completely closed at 15 psig.
- Q. 2. If the full-scale range of a level instrument is 50 inches of water, what would be the depth of liquid above the lower probe if instrument read 25% of full scale. The density of the liquid is 2.0. Show all calculations.
- A. 2. $\frac{0.25 \times 50}{2} = 6.25 \text{ in.}$
- Q. 3. Draw a schematic of the sump jet and liquid removal instrumentation system.
- A. 3.

Instrumentation and controls
(For problem 3)

- Q. 4. From the schematic in Fig. 3.3.3, which is typical of your plant's transmitter rack piping, tell how you would determine whether:
- (a) The zero point of the instrument is correct.
 - (b) The high pressure liquid level probe is partially plugged.
 - (c) The low pressure liquid level probe is completely plugged.
- A. 4. (a) Open valve A with Rotameters B and C set at their normal rates and if the recorder returns to zero the zero point is correct.
- (b) With valve A closed increase the flow of air through Rotameter C slightly above the normal rate. If the line is restricted this will cause an increase on the level recorder.
 - (c) With valve A closed there will be no flow through Rotameter B.
- Q. 5. What are two types of instruments that are used to measure liquid levels at the facility?
- A. 5. Ultrasonic sensors, air bubblers, float-type instruments, conductivity probes.

Fig. 3.3.3. Instruments and controls
(For use with problem 4)

- Q. 6. (a) Assume that a vessel is equipped with a bubbler type level instrument having a range of 0-100 inches of water and a density recorder having a range of 1.0 to 1.5 g/cm³. If the level recorder reads 80% of full scale and the density recorder shows the density of the solution to be 1.2 g/cm³ what is the depth of liquid above the bubbler tube?
- (b) If the vessel described above holds 10 liters of solution per inch of depth what is the volume of solution in the vessel for the conditions indicated above?
- A. 6. (a) $(100 \times 0.8)/1.2 = 66.7$ inches liquid depth
 (b) $66.7 \times 10 = 667$ liters volume
- Q. 7. (a) What are two types of instruments that are used to measure flow rates of liquids at the facility?
- (b) Give one other method that is used to determine the flow rate of a liquid stream that does not depend on the use of a flow instrument.
- A. 7. (a) Orifice, rotometer, electromagnetic flowmeter.
 (b) Calibration tanks.
- Q. 8. Identify the following instrument symbols.
(a) PDI	(c) IFRC	(e) SIC
(b) TIC	(d) WR	(f) DI
- A. 8. (a) PDI Pressure differential indicator
 (b) TIC Temperature indicating controller
 (c) IFRC Interface level recording controller
 (d) WR Weight recorder
 (e) SIC Speed indicating controller
 (f) DI Density indicator
- Q. 9. Explain the method used to pump HAF to Extraction Column V-202. How is the flow measured? How is the flow rate controlled?
- A. 9. A double air lift pump is used to pump HAF. A level indicator and controller in metering pot V-202F controls the air flow to the second air lift pump which controls the feed rate.
- Q. 10. What does the interface controller at the top of strip column V-203 control to maintain the interface at the desired level?
- A. 10. The interface controller controls the air flow to an air lift that pumps the HCU stream from V-203 to HCU Decanter V-203DC.
- Q. 11. Answer the following questions regarding the GE/MAC controller shown in Fig. 3.3.4. In the control circuit shown the GE/MAC is being used to control the flow of water through a pipe. Disregard the instrument settings shown in the drawings.
- (a) If the manual/automatic transfer switch is in the AUTO position what would the position of the deviation indicator tell you about the water flow rate? At what position would you expect the deviation indicator to be in normally?
- (b) With the manual/automatic transfer switch in the AUTO position what information would the output meter give you?

- (c) If you are controlling the water flow manually and want to switch to automatic control at the same flow rate how can this be accomplished with a minimum of disruption to the flow?
- (d) What is the purpose of the two 0-100 positions on the manual/automatic transfer switch?
- A. 11. (a) The deviation indicator indicates the difference between the set point value and the actual flow rate of water. Normally, the controller should keep the deviation low so that the deviation indicator would be near the set point at mid-scale.
- (b) The output meter is an indication of how wide open the control valve is.
- (c) To switch smoothly from manual to auto set the set point adjust (thumb wheel) to the approximate setting that will give the desired flow, then switch the manual/transfer switch to bal., adjust the thumb wheel to give zero deviation, and then switch to AUTO.
- (d) In the 0-100 position beside the AUTO position the controller operates automatically but the deviation indicator gives the approximate value of the process variable (water flow rate). The 0-100 position beside the MAN position gives the same information for manual operation.
- Q. 12. (a) What method is used to control the flow rate of an air lift pump?
- (b) How is the volume of liquid transferred by a jet usually controlled?
- A. 12. (a) The flow rate of air to the air lift. Other factors that influence the pumping rate or pump size and submergence.
- (b) By turning the motive fluid (steam or air) on or off.

CHEMISTRY

- Q. 1. Identify the names of the chemicals described by the following formula.
- (a) $\text{Fe}(\text{NH}_2\text{SO}_3)_2$
- (b) $\text{UO}_2(\text{NO}_3)_2$
- (c) NaNO_2
- (d) $\text{H}_2\text{C}_2\text{O}_4$
- (e) $\text{Pu}(\text{NO}_3)_4$
- (f) H_3BO_3
- (g) $\text{Ca}(\text{OH})_2$
- (h) I_2
- (i) NaOH
- (j) Na_2CO_3
- A. 1. Ferrous sulphamate, uranyl nitrate, sodium nitrate, oxalic acid, plutonium nitrate, boric acid, calcium hydroxide, iodine, sodium hydroxide, sodium carbonate.

GE/MAC BASIC CONTROLLER

Fig. 3.3.4. Instrument control circuit
(For problem 11)

- Q. 2. Assume you have prepared 100 liters of HNO_3 . The analysis indicates the concentration is 3.2 molar. The desired concentration is 3.0 ± 0.1 molar. How much water should be added to correct the concentration? Show all calculations?
- A. 2. $\frac{100 \times 3.2}{3.0} - 100 = 6.7$ liters
- Q. 3. (a) What chemical is used to change the valence of Pu(III) to Pu(IV) in the Process?
(b) What is the purpose of changing the valence of plutonium to IV in the feed conditioner tank (XC2)?
- A. 3. (a) Sodium nitrite (NaNO_2)
(b) The Pu is changed to IV valence so it can be reextracted into the organic phase.
- Q. 4. What protective clothing and equipment is required when sampling or unloading concentrated HNO_3 or caustic from a carrier?
- A. 4. Rubber gloves, acid suit, hat and goggles.
- Q. 5. What uranium compound is produced when UO_2 reacts with HNO_3 in the dissolver?
- A. 5. Uranyl nitrate - $\text{UO}_2(\text{NO}_3)_2$
- Q. 6. (a) What are the IAX, IDX, and HAX streams called?
(b) What are the HAS, IAS, and IIAS streams called?
- A. 6. (a) Organic
(b) Scrub
- Q. 7. What two main functions are performed by the partition cycle done in vessels 4C-1, 2, 3, and 4?
- A. 7. (a) The bulk of the fission products are removed and
(b) The uranium and plutonium are split into two separate streams.
- Q. 8. Why is hydroxylamine nitrate added to the stream containing U, Pu, and Np before it enters the HCU concentrator (V-26)?
- A. 8. Hydroxylamine nitrate is added to help adjust the valences of U, Pu, and Np so that the Pu will load on the Pu Ion Exchanger (V-30) and U and Np will pass through.
- Q. 9. (a) In what equipment is most of the fission products separated from the U, Pu, and Np products?
(b) In general terms explain how this separation is accomplished.
- A. 9. (a) In extraction column V-20.
(b) U, Pu, and Np are selectively extracted from the aqueous feed (HAF) into the organic phase while most of the fission products remain in the aqueous phase. This is done in a pulse column to promote contact between the aqueous and organic phases.

- Q. 10. Why are the valences in the XPW stream adjusted after leaving the Pu ion exchanger (V-30).
- A. 10. So that the Np and any remaining Pu will load on the Np ion exchanger V-33.
- Q. 11. Give either the name or number of the vessel or equipment in which the following operations occur.
- (a) UNH is converted to UO_3 .
 - (b) Low level acid is produced.
 - (c) High level acid is produced.
 - (d) U, Pu, and Np is stripped from an organic phase into an aqueous phase.
 - (e) Organic solvent is washed with dilute HNO_3 for cleanup.
- A. 11. (a) UNH calciner V-40
 (b) UNH concentrator V-41
 (c) HAW concentrator V-53
 (d) Strip column V-20
 (e) SB column V 23
- Q. 12. In preparing 180 liters of 0.75 molar NaNO_2 solution how much sodium nitrite powder is required? Show calculations. (Atomic weights Na = 23, N = 14, O = 16)
- A. 12. $\text{Mw of NaNO}_2 = 23 + 14 + 2(16) = 69$
 $(69 \times 0.75)180 = 9,315$ grams of NaNO_2 required

PHYSICS

- Q. 1. Give three means of preventing criticality in the Plant.
- A. 1. Any 3 of the following:
- (a) concentration, (b) geometry, (c) neutron poisons, and
 - (d) mass limit.
- Q. 2. Which of the following isotopes are fissionable and thus could cause a criticality incident if improperly handled?
- (a) ^{233}U , (b) ^{238}U , (c) ^{235}U , (d) ^{232}Th , (e) ^{239}Pu
- A. 2. ^{233}U , ^{235}U , ^{239}Pu .
- Q. 3. What is meant by the term "enriched" as applied to uranium? Define what low enriched uranium is at the facility.
- A. 3. Enriching uranium means increasing the ^{235}U content. Low enriched uranium at the facility has a ^{235}U content of less than 5%.
- Q. 4. Which of the following vessels are suitable for containing aqueous solutions of plutonium nitrate of the concentrations used at the plant. Why? What restrictions, if any, would be required?
- (a) A 30-gallon stainless steel drum, (b) A 55-gallon carbon steel drum, (c) A 4-1/2-in.-diam polyethylene bottle.
- A. 4. (c) 4-1/2-in.-diam bottle. A 4-1/4-in.-diam cylinder geometry is always safe for Pu solution at any concentration. Such bottles must be kept separated by the use of bird cages or similar means.

- Q. 5. (a) What is the purpose of fixed neutron poisons in the Plant?
 (b) Why are fixed neutron poisons used in the disengaging section of several solvent extraction columns?
- A. 5. (a) Fixed neutron poisons are used for criticality control.
 (b) Because the disengaging sections are not geometrically safe.

EXTRACTION EQUIPMENT AND CHARACTERISTICS

- Q. 1. During the establishment of interfaces in organic continuous columns, each interface controller is set initially at (a) what set point (b) then what equipment is set at run plant conditions before the organic flow is started?
- A. 1. (a) 50% of chart (b) the pulser.
- Q. 2. The extraction columns are operated with which phase (a) continuous; the other columns are operated with which phase (b) continuous. (c) Why are the extraction columns operated in this manner?
- A. 2. (a) organic (b) aqueous
 (c) The extraction columns are operated organic continuous because the solvent is lighter than water. This makes it possible to push the solvent with pulsers upward through the column against a downward flow of the aqueous phase containing the metallic ions to be extracted in order to obtain good extraction through good contact between the phases.
- Q. 3. Match the following solvent extraction columns with the function of each unit. Place the letter listed below appropriately on separate paper for each of the columns given.
(1) 4C-8	A. Partitioning Cycle Extraction Column
(2) 4C-12A	B. Partitioning Cycle Partition Column
(3) 4C-7	C. 2nd Uranium Cycle Strip Column
(4) 4C-9	D. Partitioning Cycle Plutonium Scrub Column
(5) 4C-4	E. Partitioning Cycle Strip Column
(6) 4C-10	F. None of these
(7) 4C-3	G. Plutonium Cycle Extraction Column
(8) 4C-11	H. 1st Uranium Cycle Strip Column
(9) 4C-2	I. 2nd Cycle Extraction Column
(10) 4C-12	J. Diluent Wash Column
(11) 4C-1	K. Plutonium Cycle Strip Column
- A. 3. K, J, G, F, E, H, D, I, B, C, A
- Q. 4. State the locations of the following pulse columns in the plant:
 (a) 4C-1, (b) 4C-7, (c) 4C-10, and (d) 4C-12
- A. 4. (a) XC1, (b) XC2, (c) XC2, and (d) XC3.

PURIFICATION SYSTEM

- Q. 1. (a) State the upper temperature limit in the solvent washers.
 (b) Why are the pumps in the solvent treatment system not to be operated without a supply of liquid in the lines?
- A. 1. (a) 140°F
 (b) Because they are lubricated by the liquid being pumped.
- Q. 2. List the chemicals used in the silica gel column regeneration and tell the purpose of each.
- A. 2. 0.25 M HNO₃ to remove uranium
 0.4 M oxalic acid to remove zirconium and niobium
- Q. 3. What is the direction of flow during the washing cycle of the plutonium ion exchange operation? Why?
- A. 3. Upflow; reason: to facilitate the removal of gases in the columns.
- Q. 4. (a) Related to the operation of other plant equipment, when are the solvent treatment systems put into operation?
 (b) What two tanks of solution must be available before the startup of the solvent treatment system?
- A. 4. (a) Before the startup of the solvent extraction columns.
 (b) 0.2 M Na₂CO₃ in 14D-26B and 0.4 M HNO₃ in 14D-4.
- Q. 5. (a) Plutonium is loaded onto the ion exchange beds at what temperature? (b) Later plutonium is eluted from these beds into what vessel?
- A. 5. (a) 60°C; (b) 5D-4
- Q. 6. What chemicals are used in solvent purification at the facility. Give a reason for using each chemical.
- A. 6. Na₂CO₃ — to avoid precipitating uranium; removes traces of metal salts and DBP.
 HNO₃ — to neutralize any residual carbonate; a cleaner separation of phases can be made in acid than in alkaline solution.

EVAPORATORS AND WASTE SYSTEM

- Q. 1. In a given maloperation, neutron poison was not added to 7D-S when required, what indications of this would you look for?
- A. 1. The level inventory on 7D-8, and 14D-32; also administrative check and data sheet.
- Q. 2. Give the following features for the new interceptor system at the facility: (a) material of construction and (b) provision for sampling at the same time waste is being discharged from the system.
- A. 2. (a) Stainless steel lining, and (b) will allow sampling of one while the second section may be discharged.

- Q. 3. Seven evaporators located in the plant are listed below. Give the use for each and state which are batch, continuous or both.

Equipment Item

	7C-5	5C-5	
	7C-4	5C-4	
	7C-2	5C-2	
	7C-1		
A. 3.	7C-5	General Purpose	Batch
	7C-4	Rework	Both
	7C-2	Lo level waste	Batch
	7C-1	Hi level waste	Both
	5C-5	Hi enriched U product	Continuous
	5C-4	Lo enriched U product	Continuous
	5C-2	Pu product	Batch

- Q. 4. (a) What safety device is incorporated on the steam coil of the low level waste evaporator (7C-2)?
 (b) How does it work?
- A. 4. (a) An automatic air pressurization safety system.
 (b) The system opens if the pressure in the steam coil drops below 5 psig.
- Q. 5. List the major pieces of equipment in the typical evaporator system at the facility.
- A. 5. Evaporator; reboiler, condenser

DISSOLUTION EQUIPMENT AND CHARACTERISTICS

- Q. 1. Give these means used to prevent a critical incident in the dissolvers.
- A. 1. Any three of these:
- (1) Mass control by limiting the quantity of fuel dissolved.
 - (2) Concentration control by limiting the quantity and strength of acid used for dissolution.
 - (3) Density control by using a sparger in the bottom to keep solids from settling out.
 - (4) Fixed poison control — poison in concrete.
- Q. 2. Name the items that are recorded during a dissolution. Why are they recorded?
- A. 2.
(1) specific gravity	Reason:	To control the acid and fissile material concentrations.
(2) liquid level	Reason:	To prevent critical incident from too low a solution level.
(3) pot temperature	Reason:	To control the rate of reaction.
(4) pressure	Reason:	To prevent dissolving at a positive pressure.
(5) off-gas temperature	Reason:	To protect filters from too high a gas temperature; to prevent condensation on filters.

- Q. 3. Draw a schematic showing the treatment of the dissolver off-gases.
A. 3.

Dissolution equipment and characteristics
(Fig. for Problem 3)

- Q. 4. (a) What medium is used to heat the dissolvers? (b) Why is it used? (c) What means is used on the heating medium line to control the dissolution rate?
- A. 4. (a) steam
(b) steam is a convenient means of heating and its temperature is easy to control by controlling its pressure.
(c) pressure control on the steam inlet.
- Q. 5. Assume that you are making a dissolution in one of the dissolvers. Give the abnormal conditions that will automatically shut off the heat to the dissolver and actuate the cooling water.
- A. 5. High dissolver steam pressure; low liquid level in the dissolver.

EQUIPMENT DESIGN AND CHARACTERISTICS

- Q. 1. Give two major functions that the UNH concentrator (V-40) accomplishes in the process. Briefly describe how each of these functions is accomplished.
- A. 1. Used to concentrate the UNH stream by boiling in the reboiler and to recover LL acid by contacting nitrogen oxides with water in the fractionation section.
- Q. 2. (a) What equipment is provided for the removal of iodine, acid fumes, and particulate matter from the vessel vent system?
 (b) What method is used to prevent gaseous iodine from the leacher (ME-124) from entering the cell area?
 (c) List two pieces of equipment that are vented to the condenser vent header.
 (d) Through what vessel is all of the solvent extraction equipment vented?
- A. 2. (a) Process Vent Scrubber (V-56), Silver Reactor (V-56), off-gas filter (V-57).
 (b) The leacher is kept at a negative pressure with respect to the cell and water seals are used.
 (c) UNH concentrator (V-40), Pu concentrator (V-30), Np concentrator (V-33), HCU concentrator (V-26), LL waste concentrator (V-50), flow pot (V-53), feed tanks to waste calciner V-53 and V-53.
 (d) Organic storage tank V-23.
- Q. 3. What is the purpose of the remote head used on some of the Lapp pumps? What adjustment may be required to make the remote header operate properly?
- A. 3. The remote head is used to prevent the radioactive fluids being pumped from entering the pump room area. The quantity of fluid between the remote head and main head must be adjusted occasionally, and also vented or bled on occasions.
- Q. 4. Figure 2 is a sketch of extraction column V-20 and strip column V-20 with 6 of the process streams numbered (some streams are not shown). Answer the following questions about the system.
- (a) Where does stream 1 go after leaving V-20?
 (b) Which streams are aqueous?
 (c) Which of the streams contain most of the fission products?
 (d) Which streams contain the Pu, U, and Np?
 (e) What is the purpose of the air pulsers?
- A. 4. (a) to off-gas scrubber V-53. Also may be recycled to HA feed tank V-20.
 (b) 1, 3, 5
 (c) 1
 (d) 4, 5
 (e) To increase the contact between the aqueous and organic phases.

- Q. 5. What is the purpose of HCU decanter V-20 DC?
- A. 5. Separates traces of organic from the feed to the HCU concentrator to prevent organic from entering the concentrator.
- Q. 6. The Pu ion exchanger (V-30) is controlled by a switch which has 6 positions. These are: off, operate, operate with rinse, Pu strip, add resin, and remove resin. There are also two timers and a START button associated with the Pu ion exchanger. Answer the following questions about the Pu ion exchanger.
- (a) Before the Pu IX controller is used how should the control switches for the individual valves in the system be set?
 - (b) Briefly describe what is occurring in the extraction, scrub, and elution sections when the switch is in the "operate" position. What is the function of the two timers?
 - (c) What is the purpose of the START button?
 - (d) How do you know where to add resin or remove resin from the Pu ion exchanger?
- A. 6.
- (a) The interlock switch should be on and all the individual switches for the Pu IX system should be in the AUTO position.
 - (b) In the extraction section Pu is loaded onto the resins. In the scrub section the resin containing the Pu is washed with concentrated HNO_3 to remove impurities. In the elution section Pu is removed from the resin with dilute HNO_3 . In this position the ion exchanger operates automatically and the two timers control the time for the push and load cycles.
 - (c) While the Pu IX unit is in operation and in the load cycle the START button stops all pumps and sets valves for push cycle thus shortening the load cycle.
 - (d) Resin should be added when 2 of the level indicator lights go off. Management determines when the resin should be drained.
- Q. 7.
- (a) After leaving the Pu ion exchanger (V-30) how is the plutonium stream prepared for load out?
 - (b) Describe briefly how plutonium product is loaded into product bottles.
- A. 7.
- (a) The plutonium nitrate solution is concentrated in Pu concentrator V-30, then sampled and cooled in V-30.
 - (b) 10 liters Pu solution is loaded into V-30. A transfer nozzle is placed in the Pu product bottle. Then two valves are actuated to drain the Pu solution into the product bottle by gravity.
- Q. 8. Record the designation number of each of the following pieces of equipment.
- (a) Dissolvers
 - (b) Vessel off-gas scrubber
 - (c) Feed adjustment and accountability tank
 - (d) Recovered acid storage tank
 - (e) Low enriched uranium product storage tank

- A. 8. (a) 3C-1, 3C-2
(b) 6C-3
(c) 3D-1
(d) 7D-5
(e) 5D-15A&B
- Q. 9. What treatment is given the off-gas from the dissolvers to remove acid fumes and iodine.
- A. 9. The dissolver off-gas is scrubbed with caustic in scrubber 6C-6.
- Q. 10. What precautions should be observed while starting and operating centrifugal pumps to prevent damage to the bearings and seals?
- A. 10. These pumps should not be run dry.
- Q. 11. Where is the interface located in columns where the aqueous phase is continuous?
- A. 11. In the upper disengaging section
- Q. 12. What are the two methods that are available for feeding HAF solution to column 4C-1?
- A. 12. Air lifts and feed pots.
- Q. 13. Figure 1 is a sketch of pulse column (4C) and some of its auxiliary equipment. Label all boxes with the proper names or functions of these parts.
- A. 13. (a) pulser
(b) organic inlet - HAX
(c) liquid level probes
(d) aqueous waste - HAW
(e) aqueous feed
(f) poison plates
(g) organic outlet
(h) vent
- Q. 14. Give the meaning of each part of the following code on a sample bottle.
3D-1-U/10ABCD/11-23
- A. 14. 3D-1 U / 10 ABCD / 11-23
 vessel unadjusted feed tenth batch four duplicate date
 samples are to
 be pulled
- Q. 15. In heat exchangers such as acid recovery system should the pressure in the coils be maintained at a higher or lower pressure than the process pressure? Why?
- A. 15. Higher pressure so that any leakage will be into the process rather than into the cooling water.
- Q. 16. Name the means of removing radioactive contamination from the ventilation air streams at the facility.
- A. 16. Gas washers, scrubbers, filters, and silver reactors.

Appendix to Chapter 4

LIST OF COURSES FOR THE TECHNICAL IMPROVEMENT PROGRAM

<u>Course No.</u>	<u>Course Name</u>	<u>Source</u>
1	Field Sketching	duPont ^a
2	Positive Displacement Pumps	Ditto
3	Equipment and Material Handling — Chain Hoists	Ditto
4	Fundamentals of Calibration	Ditto
5	Level Measurement — Part 3 (Differential Pressure)	Ditto
5A	Level Measurement — Part 2 (Buoyancy Displacers)	Ditto
5B	Level Measurement — Part 4 (Electrical Devices)	Ditto
6	Valves and Their Functions	Ditto
7	Reading and Preparing Simple Line and Bar Graphs	Ditto
8	Measurements	Ditto
9	Equipment and Material Handling — Knots	Ditto
10	Level Measurement — Part 1 (Gage Glasses and Floats)	Ditto
11	Equipment and Material Handling — Crane and Hoist Signals	Ditto
12	Plant Mathematics — Numerical Prefix and Powers of Ten	Ditto
13	Plant Mathematics — Part 5 (Simple Algebra)	Ditto
14	Plant Mathematics — Part 6 (Ratio and Proportion)	Ditto
15	Reading Engineering Drawings	Ditto
16	Temperature Measurement — Thermocouple Theory	Ditto
17	Equipment and Material Handling — Wire Rope Slings	Ditto
18	Equipment and Material Handling — Wire Rope Fittings	Ditto
19	Equipment and Material Handling — Identification and Care of Wire Rope	Ditto
20	Temperature Measurement — Part 1 (Basic Physics and Terms)	Ditto

^aIndustrial Training Library of Programmed Instruction courses. These courses are available from: E. I. duPont de Nemours & Co. (Inc.), Industrial Training Service, Room 7450, Nemours Building, Wilmington, Delaware 19898.

<u>Course No.</u>	<u>Course Name</u>	<u>Source</u>
21	Introduction to the Periodic Chart of the Atoms	The Welch Scientific Co., 7300 N. Linder Avenue, Skokie, Ill. 60076
22	Liquids and Solutions	Jay A. Young, Prof. of Chemistry, King's College, Wilkes-Barre, Pa.
23	Gases: Kinetic and Molecular Theory of Gases	Renée Ford, Center for Programmed Instruction, Inc., Published by Holt, Rinehart, and Winston, 383 Madison Avenue, New York 17, New York
24	Gases: Gas Laws	Ditto
25	Two series on General Science:	
25A	Work and Machines	<i>General Science Series: Work & Machines</i> — Halmuth H. Schaefer and Arthur P. Jeffries, Published by: Teaching Materials Corp., 575 Lexington Avenue, New York 22, New York
25B	Sound	
25BB	Light	
25C	Electricity	
25CC	Communications	
25D	Biology	
25E	Chemistry	
25-1	Matter in Motion (Motion)	<i>General Science Programmed Learning Laboratory</i> , James Macrae, Francis A. Earl, Rodrigo Panares, Published by: Accelerated Instruction Methods Corp., 179 North Michigan Ave., Chicago 17, Ill.
25-2	Matter in Motion (Force)	
25-3	Matter in Motion (Energy & Work)	
25-4	Matter in Motion (Simple Machines)	
25-5	Structure of the Universe (Earth)	
26	Fundamentals for Chemical Plant Operators, Part II (Chemistry)	duPont ^a
27	Fundamentals for Chemical Plant Operators, Part I (Physics)	Ditto

<u>Course No.</u>	<u>Course Name</u>	<u>Source</u>
28	Fundamentals for Chemical Plant Operators, Part III (Equipment)	duPont ^a
29	Fundamentals for Chemical Plant Operators, Part IV (Instrumentation)	Ditto
30	Reactor Operator Study Handbook — Vol. II (Radiation Safety and Control)	ORNL Course: ORNL-TM-2034, Volume II
31-1A	Part 1: Introductory Calculus — TEMAC Programmed Learning Materials (by Daniel Bobrow)	Encyclopaedia Britannica Press, 425 N. Mich. Ave., Chicago, Ill.
31-1B-1	Part 2A: Introductory Calculus — TEMAC Programmed Learning Materials (by Daniel Bobrow)	Ditto
31-1B-2	Ditto	Ditto
31-2	Quick Calculus (A Short Manual of Self-Instruction by Daniel Kleppner and Norman Ramsey)	John Wiley & Sons, Inc., New York, N.Y.
32-1	Applied Calculus, Vol. 1 (Pergamon Programmed Text by D. J. Bell)	Pergamon Press, New York
32-2	Techniques of Differentiation and Integration — A Program for Self-Instruction (by Herman Meyer and Robert V. Mendenhall)	McGraw-Hill Book Co., New York
33	The Simple Slide Rule	duPont ^a
34	Radiation Monitoring — A Programmed Instruction Book (by James E. Wade and G. E. Cunningham, General Electric Co., Richland, Wash.)	USAEC, Div. of Tech. Information, Oak Ridge, Tennessee 37830
35	Study Guide for Sienko and Plane: Chemistry, Third Edition (by John B. Russell)	McGraw-Hill Book Co., New York
36	New Employees Safety Training	duPont ^a
37 (I-IV)	Safety Training Observation Program	Ditto
37 (V-VIII)	Safety Training Observation Program (Concluded)	Ditto
38	Fortran IV Programming — A Guide to Fortran IV Programming (by Daniel D. McCracken), 1965	John Wiley & Sons, Inc., New York, N.Y.
39	Reactor Operator Study Handbook — Vol. IV (Heat Theory and Fluid Flow)	ORNL Course: ORNL-TM-2034 (Vol. IV)

<u>Course No.</u>	<u>Course Name</u>	<u>Source</u>
40	Reactor Op. Study Hdb. — Vol. III (Reactor Physics)	ORNL Course: ORNL- TM-2034 (Vol. III)
41	Reactor Op. Study Hbk. — Vol. V (Instrumentation and Controls)	ORNL Course: ORNL- TM-2034 (Vol. V)
42	Reactor Op. Study HBK. — Vol. I (Elementary Mathematics)	ORNL Course: ORNL- TM-2034 (Vol. I)

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