NCRP REPORT No. 61

RADIATION SAFETY TRAINING CRITERIA FOR INDUSTRIAL RADIOGRAPHY

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ouncil on Radiation Protection and Measurements

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Recommendations of the
NATIONAL COUNCIL ON RADIATION
PROTECTION AND MEASUREMENTS

Issued November 1, 1978

National Council on Radiation Protection and Measurements
7910 WOODMONT AVENUE / WASHINGTON, D.C. 20014

Library of Congress Catalog Card Number 78-61401
International Standard Book Number 0-913392-45-6

Preface

This report is intended as a guide for training persons in the safe use of sources of radiation for industrial radiography. Industrial radiography personnel require continuing effective training in radiation safety principles and procedures in order to maintain routine exposures at a low level and to reduce accidental overexposures. Three phases of training are delineated in the report: initial training, on-the-job training, and periodic training. An outline of topics to be considered under each of the training categories, as well as recommendations relevant to the particular category are presented.

The Council has noted the adoption, by the 15th General Conference of Weights and Measures, of special names for some units of the Système International d'Unités (SI) used in the field of ionizing radiation. The gray (symbol Gy) has been adopted as the special name for the SI unit of *absorbed dose, absorbed dose index, kerma,* and *specific energy imparted.* The becquerel (symbol Bq) has been adopted as the special name for the SI unit of *activity* (of a radionuclide). The gray equal one joule per kilogram, and the becquerel is equal to the second to the power of minus one. Since the transition from the special units currently employed—rad and curie—to the new special names is expected to take some time, the Council has determined to continue, for the time being, the use of rad and curie. To convert from one set of units to the other, the following relationships pertain:

$$1 \text{ rad} = 0.01 \text{ J kg}^{-1} = 0.01 \text{ Gy}$$
$$1 \text{ curie } 3.7 \times 10^{10} \text{ s}^{-1} = 3.7 \times 10^{10} \text{ Bq (exactly)}.$$

The present report was prepared by Scientific Committee 42 on Industrial Applications of X Rays and Sealed Sources. Serving on the Committee during the preparation of this report were:

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Members	*NCRP Secretariat*
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The Council wishes to express its appreciation to the members of the Committee for the time and effort devoted to the preparation of this report.

WARREN K. SINCLAIR
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Bethesda, Maryland
May 1, 1978

Contents

1. Scope and Purpose

This report is concerned with the training of industrial radiographers and is devoted principally to those aspects of training that will provide the means to minimize radiation exposure of human beings.

The report is intended as a guide for training persons in the safe use of sources of radiation for industrial radiography. The report should be applied with sound judgment to formulate a training program that is responsive to particular needs. Important considerations that should be reviewed in formulating an appropriate and responsible training program include management practices, the equipment to be used, and applicable regulatory requirements. Provision should be made for continuing training in both a refresher and an updating fashion. Continuing education joined with increasing experience provides the proper foundation for optimizing worker performance with respect to both productivity and safety.

2. Philosophy

2.1 General Statement

Industrial radiography is an indispensable tool for non-destructive testing. Its use, however, entails potential radiation exposure to people. Since such radiation exposure has the potential to be harmful, there is a need to limit radiation doses to people to a level at which the risk is believed to be acceptable to the individual and to society.

Results of studies on the somatic and genetic effects of radiation are reviewed in other NCRP reports (NCRP, 1971). These results have been utilized in developing recommendations for limiting doses to occupationally exposed persons and to members of the general population (NCRP, 1975). Appendix A summarizes these recommendations. These dose limits do not include any dose received by an individual patient as a result of medical practices or from natural background. The NCRP recommendations are centered on the principle that the "lowest practicable" radiation level is the fundamental basis for establishing radiation standards, with due consideration being given to the risks and benefits associated with a given radiation exposure (NCRP, 1971).

To attain the "lowest practicable" radiation doses, radiation workers must be properly trained in the procedures, practices, and use of equipment that will minimize radiation exposures. This Report is directed toward specifying the training necessary for industrial radiographers in order to better accomplish the objective of attaining "lowest practicable" radiation doses.

2.2 The Need for Training Criteria

Radiographers have one of the poorest radiation safety records of any industrial radiation workers. In a study of industrial radiation accidents, Catlin (1969) found that for 152 serious radiation accidents studied, the greatest frequency of accidents by work activity occurred among industrial radiographers. Catlin found that 39 percent of the accidents studied involved industrial radiographers. Of these, 76 percent were due to operator or procedural errors, such as failure to make radiation surveys, and 15 percent were due to equipment failures.

In a more detailed study of radiography overexposures, Scott and Gallaher (Scott and Gallaher, 1972) evaluated accidents and high dose incidents for the period June 1963 through December 1971. They found operator errors and management errors to be primary contributors to most accidental high exposures. In the case of operator errors, the most frequent error (40 percent) was failure to perform a radiation survey. Another major operator error (19 percent frequency) was inadequate radiation surveys. Management errors identified were inadequate records, use of unqualified personnel, failure to calibrate instruments regularly, and inadequate training programs. Although the majority of overexposures to industrial radiographers involve whole-body overexposures, a number of serious injuries have been associated with a relatively small number of cases of high exposure of the hands (McGuire and Brooks, 1976; Saenger, 1977). Scott and Gallaher (1972) do not identify inadequate training itself as being a major direct cause of radiation accidents. They do point out, however, that the failure to survey, which is a major cause of overexposure, is due in part to an inadequate awareness of the consequences or effects of radiation. They point out the need for training programs that emphasize the biological effects of radiation, personal safety, and the safety of others. It is clear that improved training could lead to improvement in many of the categories that Scott and Gallaher identify as contributing to overexposures.

In a more recent analysis of radiation overexposures[1] reported to the Nuclear Regulatory Commission from 1971 to 1976 (McGuire and Brooks, 1976), 113 of 325 overexposures, or 35 percent, involved industrial radiography. Of 50 overexposures requiring prompt notification, 29 of these, or 58 percent, involved industrial radiography. Of 12 overexposures requiring immediate notification 11, or 92 percent, were industrial radiography incidents. Of the 52 causes given for industrial radiography overexposures, at least 34, or 65 percent, were due to operator error. The root cause was deduced to be poor training.

A study of 698 reported incidents in Texas from 1970 to 1976 showed that 51 of 236, or 22 percent, of the overexposures under 3 rem and 80

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[1] A reportable overexposure is any exposure in excess of the pertinent regulatory limit; overexposures may be categorized according to reporting requirements, which are based on the degree of exposure, e.g.:

1. Timely (30-day) notification — any overexposure
2. Prompt (24-hour) notification — a whole-body dose of 5 rem or more
3. Immediate notification — a whole-body dose of 25 rem or more

of 179, or 45 percent, of the overexposures over 3 rem involved industrial radiography (Bailey *et al.*, 1976). The authors of this study concluded that most of the incidents in industrial radiography resulted from improper use of survey instruments, failure to survey, or disregard for procedures.

Factors contributing to the opportunity for unsafe operations in industrial radiography include:

1. Presence of high energy penetrating radiations;
2. High emissivity, x-ray output, or source activity;
3. Personnel presence outside of confined areas;
4. Malfunction of radiographic equipment;
5. Field operations in remote areas resulting in limited supervision;
6. Imperfect understanding or concern by management regarding radiation safety;
7. Limited formal education and inadequate training of industrial radiographers.

The first three of the factors cited above are mandatory in the performance of many tests that are required by industry. High energy is required for the radiation to be transmitted through the specimen being inspected because specimens are normally constructed of thick and dense materials such as steel. High emissivity is required to attain economically acceptable exposure times. Some radiography sources must be portable to permit use in field locations, since the items to be radiographed are frequently located in distant facilities (e.g., ships, cross-country pipelines, aircraft, off-shore oil production platforms, nuclear power plants) and cannot be readily moved into shielded areas.

The last three factors cited are related to human actions. Study of radiation accidents in industrial radiography indicates that the great majority of overexposures or radiation injuries are directly traceable to operator failure rather than to equipment problems. Thus, the most effective way of reducing accidents would seem to be to train employees to adhere to established and well-documented procedures, to exercise common sense and sound judgment, and to use the protective equipment and devices provided in the manner specified.

2.2.1 *Industrial Organization*

(a) The organization of industrial radiation safety programs should parallel that of the general work safety programs. Requirements for such a program are discussed elsewhere (AIF, 1969; HRN, 1969; NBS, 1970). Briefly summarized, the overall responsibility for safety in its broadest sense rests with highest management. However, responsibility for safety permeates every level of both line and staff organizations; and the ultimate responsibility for safety, in its narrowest sense, rests with each individual worker.

The manager of an organization has the responsibility to protect both employees and the general public from unnecessary exposures to radiation sources being used and, therefore, *should*[2] have available a person knowledgeable in the basic principles of protection against radiation and radioactive materials. The manager *shall* assure that adequate training in radiation safety is provided for employees at the beginning of employment and at regular intervals thereafter, as necessary for the individual's own protection and the protection of others. Such training may also be needed for ancillary personnel, such as laborers who assist the radiographer, shipping and receiving clerks, material handlers, and janitorial staff.

(b) Each organization using radiography sources *shall* appoint a qualified individual as the Radiation Protection Supervisor (RPS). The RPS *shall* be responsible to management for establishing and maintaining the radiation safety policies designated by management. The RPS *should* be involved in all phases of the training program for radiographers to ensure appropriateness and effectiveness. Additional responsibilities of the Radiation Protection Supervisor (RPS) are specified elsewhere (NCRP, 1968).

(c) Radiographers *shall* be responsible at the job site for the safe utilization of radiography sources and *shall* be adequately trained to accomplish this assignment. Radiographers *should* be supervised to the extent necessary to ensure adequate performance. In addition, the radiographer *shall* adhere to radiation protection requirements to the satisfaction of the RPS.

(d) When a major contractor subcontracts for radiographic work, the contract between the firms *should* clearly delineate responsibilities for radiation safety. For example, the radiographer *should* have responsibility and authority for designating exclusion areas, to be honored by all other contractor personnel at the job site.

2.2.2 *Instructors of Radiography Personnel*

Individuals selected to provide instructions in radiation safety to radiography personnel *should* be competent in a pertinent area of

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[2] Recommendations throughout this report are expressed in terms of *shall* and *should*. *Shall* indicates a recommendation that is necessary to meet the currently accepted standards of radiation protection. *Should* indicates an advisory recommendation that is to be applied when practicable.

science or engineering, e.g., health physics. Instructors *shall* have experience in the operation, handling, or use of radiation sources commensurate with the type and complexity of work anticipated to be performed by the students. The instructors *shall* know the characteristics of the radiation sources and know the types of hazards involved with these sources, including the handling of malfunctions of high level sources. They *shall* be familiar with the maximum permissible doses (NCRP, 1971) and the dose limits. They *shall* be knowledgeable in the methods for minimizing personnel exposures. They *shall* know the necessary techniques for personnel monitoring, radiation surveying, and how to interpret the results. They *shall* know the rules of the regulatory agencies concerned with the radiographers' activities.

3. Personnel

3.1 Introduction

The discussion of Section 2.2 leads to the conclusion that radiography personnel require effective training in radiation safety principles and procedures. Furthermore, such training must be on a *continuing* basis using periodic retraining programs. In this way radiographers can refresh and renew their understanding of radiation safety, and reaffirm the necessity for observing the applicable precautions and for following established procedures. Another reason retraining programs are needed is the fact that the rules and regulations pertaining to radiation safety tend to constantly change, becoming more detailed and generally more complex as more knowledge is gained on radiation effects. A more pragmatic reason for retraining programs is to introduce advances in equipment, techniques, and procedures.

3.2 Selection of Radiography Personnel

Selection and training of radiographers require a commitment on the part of management not only to the training of radiographers, but also to the selection of managers and supervisors who will be responsive to the need for such training. Within organizations that use radiography, managers *should* have sufficient knowledge of radiation hazards to enable them to understand the necessity of radiation safety training programs. Managers *shall* require that the supervisors and radiographers diligently and specifically implement training policies and procedures that have management approval. Individuals who have been selected as supervisors of radiographers *shall* have thorough knowledge of all company policies and procedures pertinent to their responsibilities in radiation safety. An individual who is to serve as a Radiation Protection Supervisor (RPS) must have a thorough knowledge of: (1) management policies; (2) company administrative and operating procedures; and (3) safety procedures that are related to protection against radiation exposures.

Radiographers *should* have a minimum educational background of a high school diploma or its equivalent. Because of the need to make simple mathematical calculations, radiographers *should* have mathematical ability equivalent to competence in basic high school algebra. Management *should* recognize that a person who fails to develop safe working habits or who has a past record of substandard performance on any assignment. Such a person *should not* be trained as a radiographer. A radiographer's physical condition *should* be compatible with job requirements, such as, strength to handle moderately heavy equipment or climb ladders. In some cases a radiographer may need the stamina to work long hours under adverse environmental conditions, including extreme heat, cold, dust, mud, rain, rough terrain, etc.

3.3 Personnel Training

While training is a continuing process, it is convenient to recognize three distinct phases of training: initial, on-the-job, and periodic. Each is described below. This division into these phases should not imply that there should be any relaxation of the requirement to adopt improved methods for controlling radiation exposure as they are developed. As field conditions change, the radiographer, supervisor, and RPS *shall* make the necessary adjustments to equipment, operating procedures, and safety procedures to accomplish the assigned tasks and to continue the protection from unnecessary radiation exposures.

3.3.1 *Initial Training*

Initial training is that training given to all prospective radiographers *before* they are assigned responsibilities as radiographers. The topics that *should* be included in initial training are:

I. FUNDAMENTALS OF RADIATION AND RADIATION PROTECTION
  A. Structure of Matter
    1. Elements, molecules, compounds
    2. The atom
      a. Structure of the atom
      b. Isotopes and nuclides
  B. Radioactivity and Radiation
    1. Natural (background) radiation and man-made radiation

2. Nuclear reactions
   a. Nuclear fission
      (1) Chain reactions
      (2) Fission products
   b. Activation of nuclides
3. Radioactive decay
   a. Types of decay
   b. Activity—the curie
   c. Fundamental decay law
4. Radiation producing devices
   a. X-ray production
   b. Neutron generators

C. Nature and Consequences of Radiation Exposure
1. Biological effects of radiation
   a. Types of effects
      (1) Somatic
      (2) Genetic
   b. Radiosensitivity
2. Dose-effect relationships
   a. Classification of doses
   b. Effects of acute irradiation dose
   c. Chronic doses and late effects
3. Radiation quantities and units
   a. Exposure—roentgen
   b. Absorbed dose—rad
   c. Dose equivalent—rem
   d. Quality factor
4. Nature of radiation health problem
   a. External radiation
   b. Internal radiation contamination
5. Physical examinations
   a. Preoperational base-line data
   b. Exposure evaluations

D. Radiation Hazard in Proper Perspective
1. Philosophy of radiation benefits and risks
2. Personnel exposures
   a. Background
   b. Man-made sources
      (1) Occupational exposure
      (2) Medical exposure
3. Radiation risk to radiographers
4. Maximum permissible doses for occupational workers
   a. Quarterly and annual dose limits
   b. Lifetime dose limits

E. Control of Hazards from External Radiation Sources
1. Time as a factor in radiation protection
2. Distance as a factor in radiation protection

        3. Radiation attenuation and shielding
            a. Attenuation of alpha and beta particles and neutrons
            b. Attenuation of electromagnetic radiation attenuation
                (1) Linear attenuation coefficient
                (2) Half-value layers, tenth-value layers
                (3) Reduction factors
    F. Control of Hazards from Internal Radiation Sources
        1. Control of contamination
            a. Modes of entry into the body: Ingestion, Inhalation, Absorption
            b. Leak-testing of sources
        2. Maximum permissible concentrations
    G. Measurement of Radiation
        1. Basic concepts of radiation dosimetry
            a. Dose
            b. Dose rate
        2. Personal monitoring devices
            a. Pocket dosimeters
            b. Badges: Film and TLD
        3. Survey meters
            a. Types
                (1) Ion chamber
                (2) Geiger counter
                (3) Solid state detectors
            b. Basic characteristics and limitations
        4. Instrument calibration
        5. Radiography source standardization calculation
            a. Frequency of calibration
            b. Error analysis

II. FUNDAMENTALS OF RADIOGRAPHY
    A. Introduction to Radiography
        1. The radiography process
        2. Radiography applications
        3. The radiograph
    B. Elements of Radiography
        1. Characteristics of radiation sources
            a. X-ray sources
                (1) Effects of voltage, current, and filtration on x-ray intensity
            b. Gamma-ray sources
            c. Neutron sources
        2. Geometric principles
        3. The specimen
        4. Radiography film
            a. Film characteristic
            b. Chemical processing
    C. Radiography Techniques
        1. Exposure calculations
        2. Exposure arrangements

- D. Interpretation of Radiographs
  - 1. Concepts of interpretation
  - 2. Metal discontinuities
  - 3. Codes and specifications

III. LICENSING AND REGULATION OF RADIOGRAPHY

- A. Requirements of Pertinent Federal and State Regulatory Agencies
  - 1. Nuclear Regulatory Commission
  - 2. Agreement states
  - 3. Other bodies (e.g., port authorities, cities, counties, etc.)
- B. X-Ray Machine Registration
- C. Radiography License for Using Radionuclide Sources
  - 1. Requirements for a specific license to use by-product materials for radiography
    - a. Conditions and control
    - b. General considerations for protection against radiation
    - c. Precautionary procedures and records required
    - d. Qualifications and training of radiography personnel
    - e. Organizational structure
    - f. Operating procedures
    - g. Internal inspection system
    - h. Record systems
- D. Transportation of Radiography Sources
  - 1. Federal and state regulations
  - 2. International Atomic Energy Agency recommendations

IV. RADIATION EMERGENCY PROCEDURES

- A. Types of Emergencies
  - 1. Personnel overexposure
  - 2. Equipment malfunctions
  - 3. Lost sources
  - 4. Exposures of non-radiography personnel
- B. Emergency Plans and Responses
- C. Reports and Follow-Up
- D. Case Histories

V. SUGGESTED LABORATORY EXERCISES

- 1. Time and distance factors in radiation protection (inverse square law; time, distance, dose, and dose-rate relationships)
- 2. Radiography source calibration
  - a. X ray
  - b. Radionuclide
- 3. Survey meter calibration
- 4. Radiation attenuation
- 5. Radiation scattering
- 6. Radiography exposure techniques
  - a. X ray
  - b. Radionuclide
- 7. Leak testing sealed sources