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Revised 1977

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Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment

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American National Standard N43.2 Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment

American National Standards Institute
Subcommittee N43-1

Under the sponsorship of the
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Preface

(This preface is not a part of American National Standard N43.2-1977, but is included for information purposes only.)

The problem of radiation hazards connected with the operation of x-ray diffraction and fluorescence analysis equipment has been a continuing one since the advent of such equipment. In 1946 Sectional Committee Z54 of the American Standards Association issued American War Standard Z54.1, "Safety Code for the Industrial Use of X-rays" which included a section on x-ray diffraction units.

In 1967 the American Standards Association was superseded by the USA Standard Institute and Committee N43 was organized under the sponsorship of the National Bureau of Standards to replace Sectional Committee Z54. The scope of the new committee is "standards pertaining to products and equipment, for nonmedical scientific, industrial, and educational uses, involving ionizing radiation sources including radioactive materials, accelerators, and x-ray equipment but excluding nuclear reactors."

The responsibility to develop standards for x-ray diffraction and fluorescence analysis equipment was assigned to Subcommittee N43–1. American National Standard N43.2–1971 "Radiation Safety for X-ray Diffraction and Fluorescence Analysis Equipment" was approved October 6, 1971 and published as NBS Handbook 111. Action to reaffirm the standard with minor revisions was taken in 1976.

Realizing that questions may arise from time to time concerning interpretations of this standard, provisions have been made for an Interpretations Committee in order that uniform handling of questionable cases may be provided. It is recommended that anyone using this standard and desiring an interpretation of a questionable case communicate with the American National Standards Institute.

Suggestions for improvement gained in the use of this standard will be welcome. They should be sent to the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

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American National Standard
Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment

This standard reviews the types of injuries resulting from accidental exposure to ionizing radiation resulting from the operation of x-ray diffraction and fluorescence analysis equipment, establishes equipment design criteria, sets up requirements for approved operating procedures, and recommends the establishment of health surveillance, and personnel monitoring programs. The circumstances under which operation of equipment must be limited to specially designated areas equipped with radiation barriers and warning signs are set forth. Maximum permissible dose limits established by the National Council on Radiation Protection and Measurement are stated. A list of references to selected articles on various aspects of radiation safety is given and notes on the detection and measurement of radiation from x-ray diffraction and fluorescence analysis equipment are included in an appendix.
Key words: Radiation safety; x-ray equipment.

1. Scope

This standard provides guidelines specific to the radiation safety aspects of the design and operation of x-ray diffraction and fluorescence analysis equipment. It does not include electrical safety guidelines or other safety considerations outside the realm of radiation safety.

2. Definitions

The definitions and terms contained in this standard, or in other American National Standards referred to in this document, are not intended to embrace all legitimate meanings of the terms. They are applicable only to the subject treated in this standard.

Controlled Area. A specified area in which exposure of personnel to radiation or radioactive material is controlled and which is under the supervision of a person who has knowledge of the appropriate radiation protection practices, including pertinent regulations, and who has responsibility for applying them (see 5.1.2).

Distribution Factor, Dose (DF). A factor used in computing dose equivalent to account for the nonuniform distribution of internally deposited radionuclides.

Dose, Absorbed. The energy imparted to matter in a volume element by ionizing radiation divided by the mass of irradiated material in that volume element. The special unit of absorbed dose is the rad. One rad equals 100 ergs per gram. (Also commonly called dose.)

Dose Equivalent (H). The product of absorbed dose, quality factor, dose distribution factor, and other modifying factors necessary to express on a common scale, for all ionizing radiations, the irradiation incurred by exposed persons. The special unit of dose equivalent is the rem.

Dose Rate, Absorbed. The absorbed dose per unit time.

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

Exposure Rate. The exposure per unit time.

Fail-safe Design. One in which all failures of indicator or safety components that can reasonably be anticipated cause the equipment to fail in a mode such that personnel are safe from exposure to radiation. For example: (a) if a light indicating "X-RAY ON" fails, the production of x rays shall be prevented, and (b) if a shutter status indicator fails, the shutter shall close.

Installation Enclosure. That portion of an x-ray installation which clearly defines the transition from a noncontrolled to a controlled area, and provides such shielding as may be required to limit the dose rate in the noncontrolled area during normal operation.

Maximum Permissible Dose Equivalent (MPD). The largest dose equivalent received within a specified period which is permitted by a regulatory agency or other authoritative group on the assumption that receipt of such dose equivalent creates no appreciable somatic or genetic injury.

Noncontrolled Area. Any area to which access is not controlled for purposes of radiation protection (see 5.1.3).

Normal Operation. Operation under conditions suitable for collecting data as recommended by a manufacturer of the x-ray system. Recommended shielding and barriers shall be in place.

Primary Beam. Ionizing radiation from an x-ray tube anode or radioactive isotope which is allowed to pass by a direct path through an aperture in the radiation source housing for use in conducting x-ray measurements.

Primary Radiation. Ionizing radiation coming by a direct path from the x-ray tube anode or an isotope

Radiation Source. An x-ray tube or radioactive isotope.

Radiation Source Housing. That portion of an x-ray system which contains the x-ray tube or radioactive isotope.

Radiation Survey. An evaluation of the radiation hazard potential associated with a specified set of conditions incident to the production, use, release, storage, or presence of radiation sources.

Shall. Where "shall" is used for a provision specified herein, that provision is intended to be a requirement.

Should, is Recommended. "Should" or "is recommended" is used to indicate provisions which are not required but which are here recommended as good practice.

System Barrier. That portion of an x-ray installation which clearly defines the transition from a controlled area to a radiation area and provides such shielding

In cases of accidental exposure, severe burns affecting the upper extremities of the body are the most frequently reported type of injury [1].[1] These are slow to heal and can lead to cancer. Amputation of one or more fingers is sometimes required. [2]. Exposure of the lens of the eye to large doses can result in cataracts and other opacities [3]. Sometimes the damage does not become apparent until years later. Consideration must also be given to other injuries such as genetic damage affecting the future offsprings of irradiated persons.

4. Dose Limits

Standards for maximum permissible doses of ionizing radiation are established by the National Council on Radiation Protection and Measurements (NCRP),[2] and by the International Commission on Radiological Protection (ICRP).[3] The current recommendations of the NCRP [7], which are the basis for the dose rate limits used in this standard, are summarized in table 1. Users of this standard should check with the NCRP at least once a year to obtain the latest recommendaions.

The problem of correctly evaluating doses due to intense small-area beams of low energy x-ray photons is not trivial and results can easily be in error by an order of magnitude. An appendix, Detection and Measurement of Radiation from X-ray Diffraction and Fluorescence Analysis Equipment, has been prepared as an aid in avoiding some of the pitfalls.

5. Installation Requirements

5.1 Area Requirements

The three types of areas recognized in this standard, as well as the dose limits and barriers required, are indicated in figure 1.

5.1.1 *Radiation Area*

5.1.1.1 *Designation of radiation area.* Any area accessible to personnel in which there exists radiation at such levels that the whole body, head and trunk, active blood-forming organs, gonads, or lenses of the eyes could receive in any one hour a dose in excess of 5 mrems, or in any 5 consecutive days a dose in excess of 100 mrems shall be designated a radiation area.

TABLE 1. *Maximum permissible dose equivalent values (MPD)*

Exposure of patients for medical and dental purposes is not included in the maximum permissible dose equivalent.

	Maximum 13-week dose *rem*[a]	Maximum yearly dose *rem*[a]	Maximum accumulated dose *rem*[a]
Controlled areas			
Whole body, gonads, lens of eye, red bone marrow	3	5	[b]5(N–18)
Skin (other than hands and forearms)	—	15	—
Hands	25	75	—
Forearms	10	30	—
Other organs	5	15	—
Noncontrolled areas	—	0.5	—

[a] The numerical value of the dose equivalent in rems may be assumed to be equal to the numerical value of the exposure in roentgens for the purpose of this report.

[b] N = age in years and is greater than 18. When the previous occupational history of an individual is not definitely known, it shall be assumed that he has already received the MPD permitted by the formula 5 (N—18).

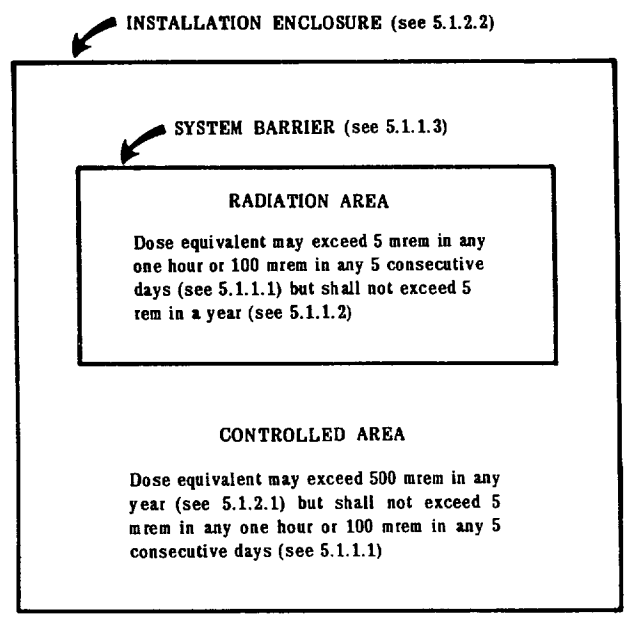

FIGURE 1. *Area designations.*

[1] Figures in brackets indicate the literature references in section 8 on page 8 of this Standard.

[2] 7910 Woodmont Avenue, Suite 1016, Washington, D.C. 20014.

[3] Dr. F. D. Sowby, Scientific Secretary, Clifton Avenue, Sutton, Surrey, England.

5.1.1.2 *Occupancy.* The occupancy of each radiation area shall be limited so that the accumulated dose received by the whole body, gonads, blood-forming organs, or lenses of the eyes dose not exceed 5 rem in a year.

5.1.1.3 *System barrier.* Each radiation area shall be surrounded by a system barrier with sufficient inherent shielding so that the dose equivalent received by individuals in the surrounding controlled area does not exceed 5 mrem in any one hour or 100 mrem in any 5 consecutive days.

5.1.1.4 *Caution sign.* Each radiation area shall be conspicuously posted with a sign or signs bearing the radiation symbol (American National Standard N2.1–1969) and the words,

CAUTION: RADIATION AREA.

5.1.1.5 *Supervision.* Each radiation area should be under the supervision of a radiation protection officer.

5.1.2 *Controlled Area*

5.1.2.1 *Designation of controlled area.* Any area in which the dose equivalent received by individuals may exceed 500 mrem in any year, but does not exceed the levels that would require it to be designated a radiation area (see 5.1.1.1), shall be designated a controlled area.

5.1.2.2 *Installation enclosure.* Each controlled area shall be visibly separated from adjacent noncontrolled areas by an installation enclosure with sufficient inherent shielding so that the dose equivalent received by individuals in the noncontrolled areas does not exceed 500 mrem in any year.

5.1.2.3 *Identifying sign.* Each controlled area shall be identified by an appropriate and easily recognizable sign posted at each entrance.

5.1.2.4 *Supervision.* Each controlled area should be under the supervision of a radiation protection officer.

5.1.3 *Noncontrolled areas*

5.1.3.1 *Dose equivalent limit.* The dose equivalent received by individuals in noncontrolled areas shall not exceed 500 mrem in any year.

5.2 X-Ray System Classification and Requirements

5.2.1 ***Classification.*** X-ray systems for certain specific applications can be designed so that all possible x-ray beam paths are fully enclosed. However, operation requirements such as:

(a) frequent changes of attachments and configuration,
(b) a need for making adjustments with the x-ray beam on, and
(c) motion of specimen and detector over wide angular limits—often make use of a fully enclosed system impractical.

For the purposes of this standard two classes of x-ray systems are recognized. They are designated Enclosed Beam X-ray Systems and Open Beam X-ray Systems.

5.2.1.1 *Enclosed beam x-ray system.* An enclosed beam x-ray system is one in which all possible x-ray paths are fully enclosed according to the requirements of section 5.2.2.3.

5.2.1.2 *Open beam x-ray system.* An x-ray system that does not comply with all of the requirements of section 5.2.2.3 shall be classified as an open beam x-ray system.

5.2.2 *Requirements*

5.2.2.1 *General requirements for all x-ray systems covered by this standard.*

5.2.2.1.1 The dose due to unwanted radiation from components such as high voltage rectifiers shall not exceed 10 mrem in a week in any accessible region 5 cm from the outside surface of the generator cabinet. Assuming that an individual may be in the vicinity of the equipment while it is operating for as long as 40 hours per week, the dose rate should not exceed 0.25 mrem/h.

5.2.2.1.2 The x-ray accessory apparatus shall include a beam trap or other barrier with sufficient shielding so that the dose rate due to the transmitted primary beam does not exceed 0.25 mrem/h under normal operating conditions. The dose rate may be difficult to evaluate in the presence of scattered radiation, and in the case of x-ray tube sources this requirement shall be considered met if the inherent shielding

of the trap or barrier is at least equivalent to the thickness of lead specified in table 2 for the maximum rated anode current and potential. In the case of isotope sources the required barrier thickness should be determined by a qualified expert.

TABLE 2. *Thickness of lead required for a primary beam barrier located 5 cm from the focal spot*

Anode current (mA)	Thickness of lead (mm)		
	50 kVp	70 kVp	100 kVp
20	1.5	5.6	7.7
40	1.6	5.8	7.9
80	1.6	5.9	—
160	1.7	—	—

5.2.2.1.3 A warning light or device of fail-safe design labeled with the words "X-RAYS ON," or other words having similar meaning shall be located near any switch which energizes an x-ray tube.

5.2.2.1.4 A fail-safe light or indicator in a conspicuous location near the radiation source housing shall be used to indicate when the x-ray tube is on or the port of the radioactive source is open.

5.2.2.1.5 A label bearing the conventional radiation symbol and the words, **CAUTION: THIS EQUIPMENT PRODUCES X RAYS WHEN ENERGIZED—TO BE OPERATED ONLY BY QUALIFIED PERSONNEL,** or other words having similar meaning shall be attached near any switch which energizes an x-ray tube.

5.2.2.1.6 Systems that contain an x-ray tube shall be equipped with an interlock that shuts off the tube if it is removed from the radiation source housing or if the housing is disassembled.

5.2.2.1.7 A label bearing the conventional radiation symbol and the words, **CAUTION: THIS EQUIPMENT CONTAINS RADIOACTIVE MATERIAL—TO BE OPERATED ONLY BY QUALIFIED PERSONNEL,** or other words having similar meaning shall be attached to the control panel of each x-ray system that contains a radioactive source.

5.2.2.1.8 A label bearing the conventional radiation symbol and a statement of (a) the type of radioactive material, (b) the activity in curies or millicuries, and (c) the date of measurement of the activity shall be attached to the radiation source housing of each x-ray system that contains a radioactive source.

5.2.2.1.9 Normal operation procedures and alignment procedures shall be documented by the manufacturer of the x-ray system, or by the person in charge of use of the system if the radiation source housing and x-ray accessory apparatus are not compatible components supplied by the same manufacturer.

5.2.2.1.10 Normal operation procedures shall be such that a qualified operator following instructions will not receive in any one hour a dose equivalent in excess of 37.5 mrem to the hands and forearms or 2.5 mrem to the whole body, gonads, blood-forming organs or lens of the eye.

5.2.2.1.11 Alignment procedures should be such that a qualified worker aware of the radiation hazards will not receive in any one hour a dose equivalent in excess of 37.5 mrem to the hands and forearms or 2.5 mrem to the whole body, gonads, blood-forming organs, or lens of the eye while following these instructions. If either of these dose rates is likely to be exceeded, a definite warning shall be included in the alignment instructions.

5.2.2.2 *Requirements for open beam x-ray system in addition to general requirements in 5.2.2.1.*

5.2.2.2.1 All shutters shall be provided with a "shutter open" indication of fail-safe design.

5.2.2.2.2 Radiation levels external to the x-ray tube housing with all shutters closed shall not exceed 2.5 mrem/h as measured at 5 cm from the surface of the housing within which an x-ray tube is operating at full rated power at maximum rated accelerating potential.

5.2.2.2.3 Each port of the radiation source housing shall be provided with a beam shutter interlocked with the x-ray accessory apparatus coupling, or collimator, in such a way that the port will be open only when the collimator or coupling is in place. Shutters at unused ports shall be secured to prevent casual opening.

5.2.2.2.4 A guard or interlock which prevents entry of any part of the body into the primary beam path should be utilized.

5.2.2.2.5 Radiation exposure levels in the vicinity of controls and adjustments of the x-ray accessory apparatus used during normal operation shall not exceed 37.5 mrem/h to the hands or 2.5 mrem/h to

the whole body, gonads, blood-forming organs, or lens of the eye.

5.2.2.2.6 A system barrier shall be provided to meet the requirements of 5.1.1.3.

5.2.2.3 *Requirements for enclosed beam x-ray system in addition to general requirements in 5.2.2.1.*

5.2.2.3.1 The radiation source, sample, detector and analyzing crystal (if used) shall be enclosed in a chamber or coupled chambers that cannot be entered by any part of the body during normal operation.

5.2.2.3.2 The inherent shielding of the chamber walls shall be sufficient to limit the dose rate in all regions 5 cm from its outer surface to 0.25 mrem/h during normal operation.

5.2.2.3.3 The sample chamber closure shall be interlocked with the x-ray tube high voltage supply or a shutter in the primary beam so that no x-ray beam can enter the sample chamber while it is open unless the interlock has been consciously and deliberately defeated.

5.2.2.3.4 The interlock required by section 5.2.2.3.3 shall be of fail-safe design.

5.2.2.3.5 If there is more than one port in the radiation source housing or more than one radiation source, all requirements under 5.2.2.3 must be satisfied for each port in every source housing associated with the system.

6. Operating Procedure Requirements

6.1 Federal, State, and Local Regulations

Installations may be subject to federal, state or local regulations which may involve registration, licensing, and compliance with specific rules. For example, disposal of a radioactive source must be in accordance with specific regulatory requirements and not by discarding as normal waste. The radiation protection supervisor and person in charge of the installation shall be familiar with applicable regulations.

6.2 Radiation Protection Surveys and Inspection

A radiation survey and inspection of protective devices according to the requirements of *General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV*, American National Standard N543–1974. Nat. Bur. Stand. (U.S.) Handb. 114 (May 1974) [5] shall be made before a new installation is placed in routine operation, and whenever changes are made that could adversely affect radiation protection. In addition, a periodic survey at least once every six months is recommended.

6.3 Testing of Radioactive Sources

All radioactive sources shall be tested for surface contamination prior to initial use and subsequently tested for leakage at least once every six months. If there is reason to suspect that a source may have been damaged, it shall be tested for leakage before further use.

6.4 Normal Operation

Only those procedures specified by the manufacturer of the x-ray system should be used unless an alternate procedure has been specified and approved by the radiation protection officer or other person in charge of the x-ray installation.

6.5 Repair and Alignment

Most severe injuries occur during non-routine operations such as repair and alignment [9]. It is recommended that the radiation protection officer, or other person in charge of an x-ray installation be advised when these operations are to be undertaken.

6.5.1 No operation involving removal of covers, shielding materials or tube housings; or modifications to shutters, collimators or beam stops shall be performed without ascertaining that the tube is off and will remain off until safe conditions have been restored. The main switch, rather than safety interlocks, shall be used for routine shutdown in preparation for repairs.

6.5.2 No x-ray tube shall be operated without a suitable housing to restrict the radiation to a well defined beam.

6.5.3 Alignment procedures recommended by the manufacturer of the x-ray system shall be used when available.

6.5.4 Special alignment procedures should not be used unless approved by the radiation protection officer or person in charge of the x-ray installation.

6.5.5 If an alignment procedure may result in increasing the dose rate in any area so that the usual designation of that area no longer applies, the person in charge shall erect temporary barriers and warning signs as required and shall keep the area under surveillance until normal operation has been restored.

6.5.6 Repairs should be carried out on an uncluttered surface so that pieces left out during assembly will be conspicuous.

6.5.7 After reassembly the x-ray system shall be checked by the radiation protection officer or other person in charge.

Particular attention should be given to the alignment of shielding, shutters and collimators. Lead parts should be inspected for damage or distortion which could result in radiation leakage and should be mounted in such a way that they will not cold-flow because of their own weight.

6.6 Use of Nonstandard Accessories

Any device for use with an x-ray tube shall be regarded as a nonstandard accessory unless it is a compatible component manufactured specifically to fit the radiation source housing used. Nonstandard accessories shall not be aligned or operated until procedures have been approved (sections 5.2.2.1.9 through 5.2.2.1.11) and a radiation survey carried out.

It is recommended that no new accessory be aligned or operated until procedures have been reviewed and a radiation survey carried out.

7. Personnel Requirements

It should be stressed that recommendations with respect to the installation and operation of the equipment are not in themselves sufficient to guarantee adequate protection. Such protection depends largely on the expert knowledge of the staff and on their cooperation in carrying out the instructions prepared by their supervisor in the interests of radiation protection. A 16-mm film that is recommended for indoctrination of new users of diffraction and spectroscopic equipment is now available.[4]

[4] "The Double Edged Sword" is a 22 minute color film produced by Durrin Films, Inc. under a contract with the National Bureau of Standards for the Bureau of Radiological Health. The film may be purchased from National Audiovisual Center (GSA) Washington, D.C. 20409, or borrowed from Association Sterling Films, 600 Grand Avenue, Ridgefield, NJ 07657. A videotape version (¾" cassette or ½" EIAJ) is also available on free loan from Training Resources Center (HFX-70) FDA, BRH, 5600 Fishers Lane, Rockville, MD 20852.

7.1 Responsibility

7.1.1 The owner or the person in charge of a controlled area shall be responsible for the evaluation of needs and the formation of policy with respect to radiation protection. He shall be responsible for the working conditions and for the instruction of all persons working in the area regarding radiation hazards and methods of control. He shall also be responsible for carrying out all specified instructions and maintaining prescribed operating conditions. He should insure that adequate medical examinations and radiation monitoring of personnel are carried out.

7.1.2 Each worker shall, upon the instruction of a qualified expert or responsible supervisor, follow the recommendations and instructions which have been drawn up in the interest of radiation protection.

7.1.3 Each worker shall use the protective devices provided.

7.1.4 Each worker shall bring to the attention of those in charge any defect or deficiency in radiation protection devices and procedures.

7.2 Health Surveillance

7.2.1 All new personnel in radiation work should have a preplacement medical examination. Notes should be made of the family history, of the previous occupational history and of previous x-ray diagnostic examinations or radiation therapy. The preplacement examination should include a complete blood count, with determination of erythrocyte and leukocyte levels and a differential white cell count. It should be recognized that the examination is directed toward determining the "normal" condition of the worker at the time of employment, and toward noting any abnormalities that might later be confused with radiation damage.

7.2.2 In cases where there has been previous occupational exposure, the total accumulated dose should be recorded and any appropriate additional medical examinations performed. These should include ophthalmological examination, with particular reference to changes in the lens, and examination of skin and nails.

7.2.3 Adequate periodical medical examination should be carried out, particular attention being paid

to the eyes and to the skin of the hands and the face. Due to the nature of the radiation hazards, reliance should not be placed on blood counts and personnel monitoring alone which might give rise to a false sense of security.

7.2.4 Doses received as a result of occupational exposures should be systematically checked with appropriate instruments (see appendix) to ensure that the maximum permissible doses are not exceeded.

7.2.5 If any worker is likely to accumulate in any one calendar quarter more than 25 percent of the maximum permissible dose per calendar quarter (table 1), then an individual cumulative dose record shall be kept.

7.3 Personnel Monitoring

7.3.1 The deficiencies of personnel monitoring devices are well known. However, according to a recent report [10] on seventeen cases of accidental exposure, the film badge gave the first indication that an accident had occurred in five of the cases. The use of suitable personnel monitoring devices is recommended.

7.3.2 If the cumulative doses recorded exceed those recommended in table 1, the person or persons exposed, the owner or the person in charge of the controlled area and any cognizant regulatory agency shall be notified and a written report shall be sent to the director of the laboratory.

8. References

The following list includes publications 1–10 referred to in this standard and 11–13 referred to in the appendix. Publications 14–25 (not cited) are suggested as sources of information on specific topics indicated by the titles.

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[20] *Radiological Protection in the Use of X-ray Crystallographic and Spectrometric Equipment.* Department of Employment and Productivity, Advisory and Information Unit, Baynards House, 1 Chepstow Place, London, W.2., 1969, 11 pp.

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9. Revision of American National Standards Referred to in This Document

When the following standards referred to in this document are superseded by a revision approved by the American National Standards Institute, the revision shall apply:

General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV, American National Standard N543-1974. Nat. Bur. Stand. (U.S.) Handb. 114, 60 pages (Feb. 1975).

Radiation Symbol, American National Standards Institute N2.1–1969.

Appendix

Detection and Measurement of Radiation from X-Ray Diffraction and Fluorescence Analysis Equipment

(This Appendix is not a part of American National Standard N43.2–1977, but is included for information purposes only.)

A1. Nature of the Radiation

Typical acceleration potentials are 25 to 50 kVp for diffraction tubes and 25 to 100 kVp for those used in fluorescent analysis ([8], p. 1096). The upper limit for the energy of x-ray photons is, therefore, 50 or 100 keV. There is no theoretical lower limit to the energy of the photons in the white radiation continuum, but the intensity below about 5 keV is low and the x-rays are readily attenuated. The continuum can be assumed to extend from 5 to 100 keV with an intensity maximum in the range 20 to 30 keV, depending on the accelerating potential.

Superimposed on this continuum are the lines of the characteristic spectrum of the anode. These constitute less than half of the output in the case of tubes used for diffraction. The energies involved are generally in the range 5.4 to 17.5 keV.

In order to measure the dose from both the continuum and the characteristic spectrum a survey meter should have energy absorption characteristics similar to air throughout the energy range 5 to 100 keV.

A2. Sources of Radiation

Hazardous radiation may come from the following sources ([9], p. 6–2):

1. The primary beam.
2. Leakage or scatter of the primary beam through cracks in ill fitting or defective equipment.
3. Penetration of the primary beam through the tube housing, shutters or diffraction apparatus.
4. Secondary emission from the sample or other material exposed to the primary beam.
5. Diffracted rays.
6. Radiation generated by rectifiers in the high-voltage power supply.

The primary beam is most hazardous because of the extremely high exposure rates. Exposure rates of 4×10^5 R/min at the port have been reported for ordinary diffraction tubes [1].

The leakage or scatter of the primary beam through apertures in ill fitting or defective equipment can produce very high intensity beams of possibly small and irregular cross section.

Diffracted beams also tend to be small and irregular in shape. They may be directed at almost any angle with respect to the main beam, and occasionally involve exposure rates of the order of 80 R/h for short periods.

The hazard resulting from penetration of the useful beam through shutters or the x-ray tube housing is slight in well designed equipment. Adequate shielding is easily attained at the energies commonly used for diffraction and fluorescence analysis.

Radiation from the high voltage power supply may result from gassy rectifiers. The effective potential is twice the potential applied to the x-ray tube, and the radiation is very penetrating. This condition can arise at any time and the only effective countermeasure is

to shield the assembly that contains the rectifiers and check at least twice a year for radiation leakage.

In addition to the six sources of radiation listed above, large quantities of primary radiation may be accidentally released as the result of removal of parts of the system or the improper installation of accessories. Immediate detection of the condition is the only effective way to reduce the exposure of personnel. In installations where disassembly of shielding components and changes of accessories occur frequently, consideration should be given to the use of an area monitor having audible and visible indicators that are actuated when a preselected radiation level has been exceeded.

A3. Choosing a Radiation Survey Meter

One of the major problems in carrying out a radiation survey program is to obtain a detector with good energy independence at very low photon energies ([10], p. 105–127).

The type of instrument generally recommended for accurate measurements of exposure rates at low x-ray energies is an ionization chamber with a thin (1.0 mg/cm^2) plastic window. Calibration corrections may be required at low x-ray photon energies ($<$ 6.5 keV), but these energies are an important part of the spectrum only when an iron or chromium anode is used.

In general, for the accuracy required in radiation protection surveys, no corrections are required so long as the whole sensitive area of the detector is in a uniform radiation field. In this connection, the relatively large size of the ionization chamber (3½ inch diameter for a typical survey instrument) must be listed as a disadvantage of this type of instrument because of the resulting low sensitivity when used in searching for beams of small cross section.

Instruments which count individual x-ray photons (Geiger counters, scintillation detectors, Si(Li) detectors) offer high sensitivity in a small cross section, and are generally superior to ionization chambers for detecting beams of small cross section. The response is generally very energy dependent and the readings must be interpreted with care. Readings obtained with a Geiger counter in the soft x-ray range are particularly unreliable. However, the primary need is to find and mechanically eliminate small beams by adding shields or correcting unsatisfactory assembly methods. The use of the simpler counters for this purpose is quite acceptable.

A4. Evaluating the Exposure Rate Due to Small Beams

A4.1 *Instrumental methods.* An instrument which is calibrated for radiation that exposes the entire active area uniformly will give an erroneously low reading when exposed to a beam having a smaller area ([10], p. 155–162), and the scale reading must be multiplied by a factor.

$$f = \frac{\text{Area of detector}}{\text{Area of beam}}$$

Beams as small as 0.01 cm^2 are commonly encountered around single crystal diffraction apparatus and correction factors of 6000 or more may be required for a 3½-inch diameter ionization chamber. In such cases it becomes difficult to detect beams in which the dose rate may be hundreds of times greater than permissible.

To resolve this difficulty in connection with the detection and measurement of x-radiation from color television receivers[5] the NCRP has allowed for the fact that the smaller the beam the less is the likelihood that the same area of an individual will be repeatedly or continuously exposed. The standard for home television receivers permits the dose rate to be averaged over an area of 10 square centimeters. The same practice is acceptable for surveys around x-ray generator cabinets and system barriers, but in the vicinity of x-ray tube housings, beam ports, collimators, and specimen chambers where small, intense beams are likely to be encountered, it is recommended that the area over which the dose rate is averaged be limited to 1 cm^2.

On this basis it may be assumed that the largest correction factor that will need to be applied will be numerically equal to the sensitive area of the detector in square centimeters. In general,

[5] X-ray Protection Standards for Home Television Receivers, Interim Statement of the National Council on Radiation Protection and Measurements (NCRP), Approved, February 23, 1968. Available from NCRP, 7910 Woodmont Avenue, Suite 1016, Washington, D.C. 20014.

$$\dot{X} = \dot{X}_{scale} \qquad \text{for } A_{beam} > A_{detector}$$

$$\dot{X} = \frac{A_{detector}}{A_{beam}} \dot{X}_{scale} \text{ for } 1\ \text{cm}^2 < A_{beam} < A_{detector}$$

$$\dot{X} = \frac{A_{detector}}{1\ \text{cm}^2} \dot{X}_{scale} \text{ for } A_{beam} < 1\ \text{cm}^2$$

where $\dot{X}$ is the exposure rate and A is the area.

A4.2 *Film methods.* X-ray film in a low absorption opaque envelope is a useful adjunct to the survey meter in searching for radiation leaks. This method often gives recognizable shadows of features of the x-ray equipment that effectively locate the leak. An estimate of the cross section of the beam can be obtained for use in correcting readings of a survey meter, or the film method itself can be made to give a quantitative estimate of the dose if calibration data are available ([10], pp. 185–212). An additional advantage of the film is its suitability for integrating over a long period in order to detect very weak beams and to give an indication of the dose averaged over a period of time that includes all the steps of a given procedure. The latter sometimes leads to the detection of a possibly hazardous transient situation.

Of special interest to those checking equipment in the field where darkroom facilities may not be available, is a cassette for use with high speed film packets (ASA 3000). An air cushion forces the film into contact with a fluorescent screen during exposure. Exposure times are generally shorter than with conventional films, and development facilities are built in, so that the photograph can be viewed after only 15 seconds.

A4.3 *Fluorescent screen method.* Fluorescent screens are occasionally useful, but their low sensitivity generally limits their effectiveness to cases involving a direct beam from the x-ray tube anode. This being the case, the screen should be mounted on a long handle to minimize any risk of exposing the hands. It should be viewed through a lead-glass shield. The sensitivity can be improved by darkening the room completely and allowing 20 minutes or longer for the eyes to become dark adapted.

A5. Calibration

The accuracy of any radiation detector is only as good as its calibration. All radiation survey meters should be checked periodically against a reference instrument[6] having a calibration traceable to the NBS primary standard chamber. This calibration check should be carried out for all of the qualities of interest.

A6. The Use of a Check Source

As a means of detecting abrupt changes in calibration resulting from component deterioration or hidden damage, a check source should be provided. Iron–55, which decays by electron capture directly to the stable isotope manganese–55 is suggested for this application. It emits the 5.9 keV x-ray characteristic of manganese–55. This radiation represents the extreme low energy range of the spectrum encountered in survey work and provides an excellent test of an instrument's capabilities in this most difficult range. A 50 μCi source is sufficient to provide exposures in the range 10–100 mR/h, and its half life (2.7 years) is long enough to insure a reasonably long useful life. The source should be mounted in a jig that will insure fixed geometry. If possible, the exposure rate should be established when the survey instrument has been recently calibrated. Thereafter it is only necessary to correct for the activity and, possibly, variations in air absorption due to changes in barometric pressure and relative humidity. The simplicity of the spectrum facilitates making such corrections.

Another function of the check source is in determining the stability of survey instruments, although a source of higher energy photons might be preferred for this application to avoid any possible influence of variations in air absorption.

[6] Secondary standard or substandard.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This standard reviews the types of injuries resulting from accidental exposure to ionizing radiation resulting from the operation of x-ray diffraction and fluorescence analysis equipment, establishes equipment design criteria, sets up requirements for approved operating procedures, and recommends the establishment of health surveillance, and personnel monitoring programs. The circumstances under which operation of equipment must be limited to specially designated areas equipped with radiation barriers and warning signs are set forth. Maximum permissible dose limits established by the National Council on Radiation Protection and Measurement are stated. A list of references to selected articles on various aspects of radiation safety is given and notes on the detection and measurement of radiation from x-ray diffraction and fluorescence analysis equipment are included in an appendix.

17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)
Radiation safety; x-ray equipment

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