BASIC STANDARDS OF RADIATION PROTECTION IN NUCLEAR MEDICINE

by

DR.HALÛK B.SAYMAN

M.D.,İ.Ü. Cerrahpaşa Faculty of Medicine

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ABSTRACT

In this study, the basic standards of radiation protection during routine examinations of Nuclear Medicine or in case of any accident that can happen are explained .

The precautions in safe handling of radioisotopes and methods of use of radioactive sources and as well as their storage and transportation are outlined to lower the exposure of radiation to a minimum.

The specifications of Radiopharmaceuticals used in Nuclear Medicine practice and their standards are overwieved in the next section.

As a case study, a performance test of a scintillation camera approved by AAPM is added to emphasize the importancy of quality control in Nuclear Medicine.

ÖZET

Bu calışmada, rutin Nükleer Tıp incelemeleri veya meydana gelebilecek kazalar sırasında radyasyondan korunmak için temel standartlar açıklanmıştır.

Radyasyon pozunu en aza indirmek amacıyla radyoizotopların emin işlenmesi, radyoaktif kaynakların kullanım metodlarıyla birlikte depolanmaları ve taşınmaları izah edilmiştir.

Sonraki bölümde, Nükleer Tıpta kullanılan radyoformasötiklerin özellikleri ve standartları gözden geçirilmiştir.

AAPM tarafından önerilen, bir sintilasyon kamerasının verim testi de Nükleer Tıpta kalite kontrolünün önemini vurgulamak amacı ile bu çalışmaya eklenmiştir.

TABLE OF CONTENTS

Page

Page

BASIC UNITS OF RADIATION MEASUREMENT

Basic Units of Radioactivity, Radiation Measurement and Radiation Dose:

Roentgen (r)-a unit for expressing exposure from X or gamma radiation in terms of the ionization produced in air, which can be measured by appropriate air ionization chambers and electrical instruments. It is defined as an exposure such that in 0.001293g air, it generates 1 esu (electrostatic unit) of positive charge and 1 esu of negative charge as ion pairs at STP ($0^{o}C$, 760 mm Hg).

Rad -a unit of "absorbed dose" (D) in any medium for any kind of ionizing radiation, that is defined as: 1 rad=100 ergs/gram.

Rem -a unit of "RBE-Dose" or "Dose Equivalent" (DE), used to express the estimated equivalent of any type of radiation that would produce the same biological end point as 1 rad delivered by X or gamma radiation. Thus, DE(in rem)=Dose(in rad)+QFxDF,
where QF (formerly called RBE) accounts for the relative biological effectiveness of the radiation compared to X radiation for protection purposes, and the DF(formerly designated as n) is the distribution factor used to account for differences in the distribution of the rad dose to the organ of concern as a result of uneven uptake of the radionuclide.

Mass attenuation coefficient (μ/ρ) - the fractional number of incident particles (photons) interacting with a given material per unit mass thickness that they pass through, Common units are cm^2/g.

Mass energy-absorption coefficient (μ_{en}/ρ)-the fractional energy removed from incident indirectly ionizing particles (or photons) per units mass thickness. Common units are again cm^2/g.

Curie (Ci) - the most common unit to express the radioactivity (A) of a material; it is the amount of any radionuclide (or combination of radionuclides) in which there are 3.7×10^{10} nuclear transformations or disintegrations per second, or 2.22×10^{12} disintegrations per minute(dpr

International Units:

Becquerel (Bq) - an activity unit which is equivalent to one disintegration in a second. 3.7×10^{10} Becquerel is equal to 1 Curie(Ci).

Gray (Gy) - an absorbed dose unit which is equal to 100 rad.

Sievert - a dose equivalent unit (RBE) which is equal to 100 rem and its unit is joule/kg.

PHYSICAL MEASUREMENT OF DOSE AND BRAGG-GRAY PRINCIPLE

Small-cavity chambers with air-equivalent or tissue equivalent walls have often been used as secondary standard instruments for measuring radiation exporuse or absorbed dose. By use of the modified Bragg-Gray principle, the ionization collected by an electrode within a small cavity in a suitably designed chamber can be related to the energy deposited per gram of wall material; also, the relationship may hold constant for a wide range of energies as long as the Bragg-Gray conditions are fulfilled.

In its simplest form, the Bragg-Gray principle states that the ratio of the energy absorbed per gram of a medium to the energy absorbed per gram of gas in a small cavity in the medium is constant (almost independent of the initial energy of the recoil electrons produced in the medium). Since the energy to produce an ion pair in a gas (W_g) is also apparently independent of energy, we have the Bragg-Gray principle

$$E_m = S_g^m \times W_g \times J_g ,$$

where E_m is the energy absorbed per gram of material, S_g^m represents the relative mass stopping power ratio for electrons in the material and in the air, W_g expresses the average energy required to produce an ion pair in the gas (now usually taken as 34 eV/ion pair), and J_g is the number of ion pairs produced per gram of gas in the cavity. Average mass stopping power ratios are given in Table 1 for electrons of various initial kinetic energies.

The conditions to be met for the Bragg-Gray relation to hold are briefly:

(a) cavity chambers' dimensions must be small compared to the ranges of most secondary ionizing particles;

(b) most ionizing particles should originate in the chamber walls, and very few primary, interactions should occur in the gas;

(c) the fluence of primary and secondary particles should be nearly uniform across the cavity;

(d) the wall of the cavity should be thick enough so that all recoil charged particles traversing the cavity originate within the material, but the wall must not be so thick that it attenuates the primary nonionizing radiation appreciably.

Table 1. Mean Mass Stopping Power Ratios Relative to air (S_m)

$$S_m = \frac{1}{T_o} \int_0^{T_o} S_m \, dT$$

Initial Electron Kinetic Energy (T_o)	Including Density Effect		
	C	Water	Tissue
0.002	1.070	1.238	1.216
0.003	1.064	1.226	1.216
0.004	1.060	1.220	1.199
0.005	1.058	1.215	1.195
0.006	1.055	1.212	1.191
0.007	1.054	1.208	1.188
0.008	1.052	1.206	1.186
0.009	1.051	1.203	1.183
0.01	1.050	1.202	1.182
0.02	1.044	1.191	1.172
0.03	1.041	1.185	1.166
0.04	1.039	1.181	1.163
0.05	1.038	1.179	1.160
0.06	1.037	1.177	1.159
0.07	1.036	1.175	1.157
0.08	1.035	1.174	1.156
0.09	1.034	1.173	1.155
0.1	1.034	1.172	1.154
0.2	1.030	1.166	1.148
0.3	1.027	1.163	1.145
0.4	1.024	1.161	1.143
0.5	1.022	1.159	1.141
0.6	1.020	1.158	1.140
0.7	1.017	1.156	1.138
0.8	1.016	1.154	1.136
0.9	1.014	1.152	1.134
1	1.012	1.150	1.132
2	1.001	1.139	1.121
3	0.985	1.121	1.103
4	0.976	1.110	1.093
5	0.968	1.108	1.084
6	0.961	1.093	1.076
8	0.950	1.080	1.063
10	0.940	1.069	1.052

Cavity chambers may be made with walls having an average atomic number "Z" simulating that of soft tissue, so that they can measure the rad dose more directly. More often, however, r chambers having airequivalent walls are used, with appropriate wall thickness for the X-or gamma-ray energies to be measured. Then the exprosure or "air dose" measured in roentgens (r) can be converted to the appropriate absorbed dose in the tissue expressed in rads, by the equation

$$D_{tissue}\ (rads) = 0.877 \times \frac{(\mu/\rho)_{tissue}}{(\mu/\rho)_{air}} \times R$$

When exposure to X-ray spectra or gamma radiation is measured at or near the surface of the body with an air wall chamber of "equilibrium" thickness, the dose in rads at various depths in the tissue must be corrected for the attenuation by the use of depth dose curves or tables.

ESTIMATION OF HUMAN RISKS OF LOW-LEVEL RADIATION EXPOSURE

Lethal dose (Whole Body). LD_{50}^{30} = 300 to 500 rem when received within a short period of time (say, less than 1 day) and without therapeutic treatment.

Shortening of life span . Estimated at 1 to 4 days per roentgen of exposure early in life, but the exact magnitude is not well established.

Bone cancer. About 4 to 8 cases per million population per 70-year period per rem dose received over a 70-year life span, assuming 10 percent of the natural incidence is result of background radiation; the frequency at low doses by actually be much less than this upper-limit estimate.

Leukemia. An average of about 2 cases per million adults per rem average exposure to the entire population considered per year-at-risk following the exposure, although the incidence-versus-time curve peaks after a latent period that probably varies according to dose level; however, for children irradiated in utero or in preconception gametal stages, recent evidence tends to confirm the earlier data indicating a higher sensitivity by perhaps a factor of 50 to 70.

Cell cancer. Probably no more than 250 cases per million population per 70-year period per rem dose to the population.

Cataracts. More than 1000 rads of gamma or X radiation to the lens of the eye are required, or more than 100 rads from neutrons, to cause an appreciable increase in cataract incidence.

Genetic Effects . A single-generation "doubling dose" to double the natural mutation rate has been estimated to be 40 rems to the entire population. Considering the natural mutation rate, a doubling dose of 40 rems to every member of a population might cause about 1 out of every 200 birth in the next generation to result in a death or failure to reproduce.

Other Radiation Effects . Some additional nonspecific health impairment or loss of vitality might result from cell loss following somatic mutations, although, if the destruction of cells is at a low rate, generation may prevent organ failure or ill health. These additional effects particularly by degenerative cardiovascular and renal diseases, may have a smaller relative increase per rem above natural incidence levels ; but since they are more prevalent, they may somewhat exceed in absolute numbers the excess deaths from radiation-induced cancer. Nevertheless, the total excess mortality

induced by radiation exposure would not be expected to be more than the order of magnitude produced by genetic and carcinogenic effect.

Table 2. Presently Recommended Dose Equivalents to Body Organs of Occupational Workers Exposed to Ionizing Radiation

Body Organ	Max.Dose Eq. in Any 13W. rem/13 Weeks	Annual Per. Dose Equiv. rem/year	Accum Dose Eq.to Age N rem[+]
Red bone marrow	3	5	5(N-18)
Total body	3	5	5(N-18)
Head and trunk	3	5	5(N-18)
Gonads	3	5	5(N-18)
Lens of eyes	3	5	5(N-18)
	4	15	
	8		
Skin	8	30	
	10		
	15		
Thyroid	8	30	
	10		
	15		
Bone	15	30	
Feet, ankles,	20	75	
hands, forearms	25		
	38		
Other single organs	4	15	
	5		
	8		

[+] The 5(N-18) accumulated dose equation may put a ceiling on the 13-week dose, but doses should be kept as far below even this cumulative limit as is feasible.

GUIDES FOR LIMITING ORGAN AND WHOLE-BODY DOSE

The goal is to avoid all unnecessary radiation exposure, to receive exposure even within the limits discussed above when-and only when-the expected benefits exceed the likely harmful consequences of radiation exposure. Of course, the "harmful consequences" may be estimated by the reader from the Table 2, which presents the basic recommended limits of occupational exposure, to various parts of the body for a period of 13 weeks and for one year, and cumulative limits according to age for certain organs.

The most important thing to remember is that the whole-body dose should remain within the cumulative limit 5 (N-18) rems, where N is the age after the 18^{th} birthday. If this limit is met for workers exposed in a general field of external radiation, and if no appreciable additional extremity exposure or intake of radioactive material is received (which is often the case), then the other annual limits will automatically met. If the exposure is fairly uniformly distributed throughout the year by administrative controls, then the quarterly limits are also easily met.

RECOMMENDATIONS FOR LIMITING EXPOSURES IN EMERGENCIES

Recommendations for limiting the radiation exposure of employees as well as members of the public when unplanned and unexpected situations arise that relase radioactive materials to uncontrolled areas have been

promulgated by various national and international organizations, such as the ICRP (International Commision on Radiological Protection.), NCRP (National Committee on Radiation Protection.), FRC(Federal Regulations Code.). Generally additional references containing data needed for making emergency decisions should be on hand. Below you will find summarized limits for "planned special exposures and emergency exposures", giving the basic dose limits of the various organs of the body in situations where there are good reasons for allowing persons to exceed the limits recommended previously.

(a) a limit of 2 R_{50} committed in any single event to any body organ for a planned special exposure, where R_{50} represents the annual permissible dose equivalent for the respective organ under consideration;

(b) a limit of 5 R_{50} committed in a lifetime to any body organ in planned radiation exposures;

(c) a maximum permissible intake of any radionuclide for planned special exposures corresponding to the intake that would result from breathing at the MPC for 2 years;

(d) a maximum permissible intake from all planned special exposures equivalent to breathing a nuclide at MPC for 5 years;

(e) in addition, planned special exposures are not permitted if a single exposure exceeding $R_{50}/2$ has been received in the previous 12 months or if the worker previously- at any time-received an abnormal exposure exceeding 5 R_{50}.

Also, planned special exposures "are not permitted to organs of reproductive capacity". They are not permitted to gonads, total body, or red bone marrow if the individual's cumulative lifetime limit of 5 (N-18) rem would be exceeded.

SAFE HANDLING OF RADIOISOTOPES

Definitions:

Ionizing Radiation: Electromagnetic or corpuscular radiation capable of producing ions directly or indirectly through matter (for example: alpha rays, beta rays, gamma rays, X rays, neutrons).

Sealed Source: A source of ionizing radiations that is firmly bonded within material or sealed in a cover of sufficient mechanical strength which excludes the possibility of contact with the radioisotope and the dispersion of the radioactive material into the environment under foreseeable conditions of use and wear.

Unsealed Source: Any other source.

External Radiation: Radiation received by the body from radioactive sources external to it.

Internal Radiation: Radiation received by the body from radioactive sources within it.

Dose: A measure of quantity of radiation delivered to a specified absorber.

Radioactive Contamination: The undesired presence of radioactive substances in or on any material.

Radiotoxicity : Toxicity from any kind of internal radiation.

Adequate Protection: Protection against external radiations and against intake of radioactive material such that the radiation dose received by any person from sources external and/or internal to the body does not exceed the maximum permissible levels set for exposure by the competent authority.

Installation: Any accommodation or facility where the radioactive substances are produced, used or stored.

Enclosed Installation: An installation in which the radiation source and all objects exposed are within a permanent enclosure:

(a) to which no person has access, or within which no person (except those undergoing treatment) is permitted to remain during irradiation; and,

(b) which affords under all practical operating conditions adequate protection for all persons outside the enclosure.

Open Installation: An installation which, due to operational requirements does not meet the conditions specified for enclosed installation.

Controlled Area: Area in which exposures may exceed the permissible levels for non-occupationally exposed persons and therefore requires the supervision of a radiological officer.

Responsibility of the Authority in Charge of the Installation:

The authority in charge of the installation is customarily held responsible for the radiological safety of both the workers and the general public. To meet those responsibilities the authority should ensure that the following actions are taken:

(a) Health and safety rules should be prepared for the areas in which radioactive material is to be handled.

(b) All necessary operating instructions should be provided.

(c) Suitable installation and equipment should be provided.

(d) Provisions should be made for necessary medical supervision of the workers and for suitable medical casuality service.

(e) Only persons medically suitable and adequately trained or experienced should be allowed to work with radioactive material.

(f) All workers liable to exposure to ionizing radiation in the course of the their work should be instructed about the health hazards involved in their duties.

(g) Suitable training with reference to health and safety should be provided for all staff.

(h) A person technically qualified to advise on all points of radiation safety should be employed or otherwise provided: "Radiological health and safety officer".

(i) The authority in charge of the installation should consult the radiological health and safety officer on all points of radiation safety.

(j) Appropriate means should be taken to ensure that all persons who may be exposed to radiation hazards know the name of the radiological health and safety officer and how to get in touch with him.

Duties of the Radiological Health and Safety Officer:

The radiological health and safety officer's duties will vary somewhat according to the organizational structure of the group with which he is working and the degrees of the hazard of the class of work undertaken. In general he will assist the authority in charge to carry

out the latter's responsibilities for radiation protection.

In the accomplishment of his duties, he should call for advice or help upon professionally competent persons whenever necessary.

His work will usually include following duties:

Any persons working with radioactive materials should be instructed in the use of all necessary safeguards and procedures and all visitors should be informed of pertinent precautions to be taken. He should recommend that no unnecessary visit is made.

Radioactive material should be prevented from leaving the jurisdiction of the authority in charge under circumstances that may subject other persons to radiation in excess of the limits. He should ensure that the proper arrangements for safe waste disposal are made. Any area inside or outside the installation should be ensured against subjection to radiation levels or concentrations of radioactive material exceeding the maximum permissible levels indicated for such an area. The appropriate authorities (for instance the Fire Dep.) should be notified of the existence of any conditions or situations that, while not normally considered a radiation hazard, may become a hazard under special or unusual circumstances. Measures should be taken to ensure that no modification of equipment or installations which might lead to unforeseen radiation hazards is made without provision of appropriate safeguards.

Measures should be taken to ensure that no radioactive material is dealt with by unauthorized people in the installation.

It should be established that the necessary tasks of monitoring medical supervision, and protection measures are carried out and properly co-ordinated.

Duties of the Worker:

The operating instructions provided should be known. Health or and safety rules should be known and followed. The safety equipment provided should be used properly. The worker should protect both himself and others by acting carefully and working safely.

Any accident or unusual incident on any personal injury however slight should be reported.

Workers exposed to radiation hazards should immediately report any significant ailment and any suspected overexposure to external radiation or any suspected introduction of radioactive material into their systems.

Medical Supervision of Workers:

General Considerations:

Young persons should not be occupationally exposed to radiation. In many countries the minimum age is taken as eighteen years. Special attention should be directed toward protecting women of reproductive age. If x-ray examinations are carried out, care should be given to keep to a minimum the exposure involved.

Medical examinations before employment:

No person should be employed in work involving a possible radiation hazard unless within the period of 2 months preceeding his first employment in that work he has undergone a medical examination.

It is recommended that this medical examination on recruitment include the following:

(a) A complete medical examination, as given in pre-employment examinations , including a personel history covering family.

Medical and occupational background, as well as the usual clinical tests.

(b) Special investigations of those organs and functions which are considered as particularly vulnerable to radiation hazards according to the class of work undertaken, e.g. by hematological examinations, dermatological examinations, ophtalmological examinations, pulmonary examinations, gynecological examinations, and neurological examinations.

Medical examinations during employment:

All persons employed in work involving radiation hazard should undergo medical examinations.

The routine examinations should be carried out every twelve months, or such other periods as the competent authority may require. In the case of suspected over-exposure or internal contamination, the physician should specify any required program of examinations. In the case of workers handling unsealed radioactive isotopes, tests are useful from time to time to determine the total body burden. (more particularly tests of the urine, breath).

Medical Casualty Service:

The form of medical casualty service provided will depend on the availability of medical staff within the establishment.

First aid advice and equipment should be immediately available throughout the working area. The scope of first aid treatment attempted should be based on medical advice.

DETERMINATIONS OF RADIATION EXPOSURE OF PERSONNEL

General Considerations:

The essential aim of radiological protection is to prevent injury from ionizing radiations. Its basis is respect for the recommended maximum permissible doses, but it also calls for systematic observation, to detect any irradiation or irradiation effect. This observation must include both physical and medical control.

Symptoms following irradiation are at present detectable only for relatively high doses. This lack of sensitivity in the clinical examination is aggravated by the lack of specifity of injuries observed, and the often considerable latent time between irradiation and the manifestation of its effects.This in no way reduces the necessity for systematic medical examinations to detect any radiation-induced effects but makes it essential to complement them by rigorous control of the doses received.

Present physical and radiochemical techniques allow the measurement of very low radiation doses and quantities of radioelements. The sensitivity is very helpful, as it permits to detect irradiations considerably lower than those considered permissible. These techniques may be classified as follows:

Personnel Monitoring:

(a) External Radiation Monitoring in which radiation measuring devices are worn by the worker.

(b) Internal Contamination Monitoring in which suitable instruments may be used or the body wastes may be sampled and analyzed, to determine the presence and quantity of radioactive material within the body.

Area Monitoring:

(a) Measurement by the use of radiation measuring instruments and devices.

(b) Calculation based on the amount of radioactive material present, its form and the nature of the processes in which the workers will be exposed.

Determinations by Personnel Monitoring:

Monitoring with personnel Dosimeters: This simple and convenient method should be used for the measurement of external radiation exposure of all workers in the controlled area.

The preferred device is the film dosimeter which permits the measurement of accumulated radiation over a period. This film also may be used and kept as a record of external radiation exposure for each individual.

Similar dosimeters should be used on the hands, wrists or head when these are exposed to radiation.

Pocket ionization chambers, luminescent individual radiation detectors and thimble chambers supplement the above film dosimeters where an immediate and sensitive measurement is needed in connection with a specific task.

In the use of both film dosimeters and ionization chambers for personnel monitoring, serious errors may occur unless standard procedures are adopted.

Monitoring for internal contamination: Whole body or gamma spectrometry radiation detectors may be used to determine the presence and quantity of radioactive material in the body. However, these instruments are expensive and their operation and the interpretation of results is very specialized. A routine program of urine analysis should be drawn up for workers exposed to the possibility of significant internal contamination. The frequency of urine sampling should be evaluated on the basis of an appraisal of the nature and the quantity of the isotopes involved and the operations necessary in the particular process.

In the event of suspected internal contamination, if appropriate, a special series of samples should be collected and analyzed. The biological half-life and the period of body retention should be born in mind in scheduling these samples. Where appropriate urine analysis should be supplemented by fecal analysis, nose swabbing examination of stomach washing and radon breath test.

Determinations by Area Monitoring:

Monitoring by instruments: The use of ionization chambers, pocket ionization chambers and film dosimeters exposed, enable the dose to an individual over any particular time to be inferred.

Measurements of contamination present in the air or drinking water can be used to estimate body uptake. However, considerable errors will occur, especially if the measurements are not representative due to the presence of high specific activity.

Monitoring by calculation: Knowledge of the total radioactive material present, its nature, the processes and the working conditions in a laboratory enable the estimation of possible exposure of personnel. However, considerable experience and technical skill are demanded for such

estimates.

Monitoring of the area: In addition to personnel monitoring to determine the exposure history of individuals, general area monitoring is carried out to determine the need for protective action.

Monitoring of radiation from external sources: All places around radioactive sources emitting penetrating radiation where persons can be exposed to radiation, not neglecting adjoining rooms or places outside the building should be monitored for radiation.

Portable radiation chambers, pocket ionization chambers, GM - counters, scintillation counters may be used.

Monitoring of contamination of surfaces of rooms and equipment: Everything used for work with radioactive materials may be subject to wide-spread contamination.

Contamination by radioactive substances of working surfaces, clothing and equipment can be hazard to health and also may interfere with the work being carried.

It is not yet possible to recommend definite permissible level for surface contamination and contamination of clothing and equipment. However the inexperienced user may adopt any one of a number of proposed levels accepted in certain countries.

It is necessary to carry out a systematic monitoring of contamination of all places and equipment that have been in contact with radioactive materials.

Such monitoring must be performed at least when work has been completed but, if necessary also several times during work.

When alpha or soft beta emitters are used, the walls of beakers, bottles, pipettes and other containers may absorb most of the radiation so that monitoring from outside of these containers might be insufficient.

Experimental animals, their excreta and premises; such as cages where they are kept should be monitored.

Monitoring of contamination of the air: In cases where radio - active aerosols, gases or powders are handled or produced a reliable system of monitoring of the air after filtering, before releasing it into the open, should be carried.

For monitoring aerosols the airborne substance are either deposited by electrostatic precipitation, impactors, or by filtration.

Some radioactive gases can only be monitored after collection by radiochemical or other means.

Monitoring of contamination of water: A reliable assessment of the contamination of waters to be released to public drains or sewers is necessary. Sampling may prove necessary, in which case the radioactive substances dissolved may require concentrating before activity measurement can be carried out.

Monitoring of skin and clothing: This should always be carried out when working with unsealed sources. No person should leave the working place (room) without checking for contamination.

Monitoring for contamination of the skin and clothing may be performed by a thin window-GM-counter. When alpha contamination may occur independently of beta and gamma radiation an alpha-selective monitor should also be provided.

METHODS OF USE OF SEALED SOURCES

Sources should always be handled in such a way that proper location is possible at all times. Inventories should be kept.

If any person has reasons for believing that a source has been lost or mislaid he should notify the "radiological health and safety officer" immediately.

If the loss is confirmed, the competent authority should be notified without delay.

Sources should be handled in such a way that the radiation dose to personnel is reduced to a minimum by such methods as shielding, distance and limited working time.

Areas subject to high radiation levels should be clearly marked and of necessary, roped off.

Beams of radiation arising from a partially shielded source should be clearly marked and of necessary, roped off.

Sources should not be touched by hands, instead tools should be used. Works with radioactive materials should be planned to permit as short an exposure as possible.

Shielding: Adequate shielding should be provided.

For beta rays the protection of eyes, face and body can be accomplished, by transparent plates of moderate thickness.

For gamma rays the protection of head and body may be affected by screens of adequate shielding effect for the source in question.

In addition shielding for direct radiation, shielding may be necessary to give adequate protection against the back-scattering from the floor and ceiling.

Bricks used for shielding sources should overlap to prevent penetration of the radiation at the joints.

Shielding should, as far as possible, be near the source.

As there are many possibilities for error in shielding calculation, the adequacy of shielding should always be tested by direct measurement.

Choice of Radioactive Material and Suitable Processes:

When a choice between several isotopes of varying toxicities is possible, one of relatively low toxicity should be used.

Materials of low specific activity should be used if possible.

The working methods should be studied and procedures adopted to avoid as much as possible the dispersal of radioactive material, in particular through the formation of aerosols, gases, vapours or dusts.

Wet operations should be used in preference to dry ones.

The quantity of radioactive substances necessary for a specific purpose should always be chosen as small as possible.

Choice and Design of Work Places:

General considerations:

Special consideration should be given to the choice of fire-proof construction for the buildings. As a rule the choice of location of premises should be such that there is small risk of landslide or flood.

The radioisotope working areas should be marked.

Floors, walls, working surfaces: These should be such as to be easily kept clean.

The walls and the ceilings should be covered with a washable, hard, non-porous paint; the floor with such materials as linoleum rubber tiles or vinyl. The junction of floors and walls should be rounded off in order to facilitate cleaning. Corner, cracks, and rough surfaces should be avoided. The working surfaces should be covered with non-absorbent material and disposable covers are a great comfort in practice. They must be able to weigh the necessary shieldings against gamma radiations.

Sinks: Sinks should be provided in connection directly to main pipe. Connections to open channels should be avoided. Taps should be designed for operation by foot, knee or elbow, rather than by hand.

Furniture: It should be reduced to a minimum and easily washable. Dust collecting items such as drawers, shelves and hanging lamps should be as few as possible.

Lighting: The working premises should be adequately lighted.

Ventilation:Provision for adequate ventilation should be included in the original design of the premises.

Considerations should be given to any need to treat or filter incoming air.

Routes of entry and exit for the ventilating air should be indicated. Siting of inlet and exhausted vents should be such as to prevent any recirculation of exausted air. The need to filter air exhausted will depend on surrounding neighborhood.

Protective Clothing:

Protective clothing apporpriate to the radioactive contamination risks should be worn by every person in the controlled area, even if only very small quantities of radioactive materials are manipulated. The different color or any means of identification may be used. It should not, in any case, be worn outside the controlled area.

The working clothes and town clothes should be kept in separate cubicles or changing rooms. When changing from one to the other one should be careful to avoid cross contamination risks.

Rubber gloves should be worn when working with unsealed radioactive substances. They are provided to protect against contamination of the skin and are of no value for protection from penetrating radiation.

Care should be taken not to needlessly contaminate objects by handling them with protective gloves, in particular light swithches, taps, door knobs and other surfaces. The gloves should be either taken off or a piece of non-contaminated residue, should be interposed.

Contaminated gloves should be washed before taking them off. A method of putting or and removing rubber gloves without contaminating

the inside of the gloves should be used.

Personal Protective Measures:

No unsealed radioactive sources should be manipulated with bare hands. No solution should be pipetted by mouth in any isotope lab. It is recommended that special precautions be taken to avoid punctures or cuts, especially when manipulating the more dangerous radioisotopes.

Anyone who has an open skin wound below the wrist (protected by a bandage or not) should not work with radioactive isotopes without medical approval.

The use of containers, glassware, and other equipment with cutting edges should be avoided.

Glass blowing by mouth should be avoided in places where unsealed radioactive substances are utilized.

Only self-adhesive labels should be used in controlled areas. Labels requiring to be wetted should be avoided.

The following should not be introduced or used in working places containing unsealed sources.

(a) Food or beverages. (Where necessary; drinking fountains)

(b) Smoking items or snuff tobacco.

(c) Handbags, lipsticks and other cosmetics, or items used to apply them.

(d) Handkerchiefs, other than those mentioned below.

(e) Utensils for eating or drinking.

Disposable paper towels and paper handkerchiefs of the equivalent should be provided for workers, special containers should be placed in the working places, in which these towels and handkerchiefs should be discarded after use.

These should be treated as radioactive residue.

Hands should be washed throughly before leaving the controlled area.

Showers should be taken when recommended by the radiological health and safety officer. Monitoring of hands, shoes and street clothing, if worn at work, may also be necessary before leaving the controlled areas.

Control of the Air Contamination:

All operations likely to produce radioactive contamination of the air through the production of aerosols (heating radioactive solutions) smoke or vapors, should be done in an air tight enclosure kept below atmospheric pressure (glove box) or in a fumehood.

STORAGE OF SOURCES

Place of storage:

When not in use, radioactive sources should be kept in a place of storage assigned for this purpose only.

The place of storage should be adequately shielded.

Only authorized personnel should be allowed to introduce or remove sources from the place of storage which should be secure against tampering.

The place of storage should be in a room provided with a suitable means of exit that can be operated from the inside.

The place of storage should be chosen so as to minimize risk from fire.

The places where sources are stored should be inspected regularly and checked for possible contamination.

Conditions of Storage:

All radioactive sources should be clearly labelled, giving information on the activity and nature. It may be found desirable to include the name of the person who is responsible for the source.

The containers for beta-- emitting isotopes should have adequate thickness to reduce the primary radiation to a safe level. Considerable Bremsstrahlung may arise from high intensity sources and additional shielding should be provided if necessary.

Radioactive gas releasing sources containing rooms should be efficiently ventilated by mechanical means.

Storage operations:

Records should be kept of all stored radioactive sources.

They should give clear information on type of the source, activity and time of removal and return as well as the name of the person responsible for the source during the usage.

Periodic inventories should be performed.

Bottles and containers should be chosen to open easily.

Bottles containing radioactive liquids should be placed in vessels large enough to hold the entire contents of the bottles in case of breakage.

TRANSPORTATION OF RADIOACTIVE MATERIAL

The amount of radioactive material moved should be limited to that required.

Transportation should be done in adequately shielded and closed containers. The containers should be constructed to prevent accidental

release of the source material in case of upset.

If radioactive material in liquid or gaseous form or in powder, or other dispersible solid form is in a shatterable container it should be transported in an outer non-shatterable and large enough container to hold the entire contents of the inner one. With liquid sources the container should be provided with absorbing material able to retain all the liquid in case of breakage.

Suitable means should be provided for the transport of the source to and from the transport container.

The transport container should be clearly marked with warning signs.

Containers in transit should bear a transportation tag showing necessary information for safety such as: (a) nature of contents, (b) physical condition, (c) activity in Curies, (d) dose rate of radiation at contact of outer surface of the container, (e) dose rate at a specific distance, (f) kind of packing.

In case of unshielded sources the transportation tag should, in addition, certify that the outsides of the container and carrier are free from contamination.

Any loss of radioactive materials during transport should at once be reported to "radiological health and safety officer".

Suitably trained workers should be in charge of all transportation of hazardous quantities of radioactive material inside an establishment.

LABORATORY RECORDS

A detailed record must be kept of each shipment received and of its disposition. The record should show doses administered, decay loss, and waste disposal. A bound logbook with numbered pages is suitable for this purpose. Some manufacturers provide a duplicate label with their radiopharmaceuticals. This duplicate label can be pasted at the top of a fresh page in the log and a corresponding entry made in the table of contents at the front of the book. Each dose used is given a line entry on the page beneath the label. A typical entry would include the following:

(a) Date

(b) Original activity per unit volume or per capsule

(c) The factor for physical decay to the present day

(d) The present activity per unit volume or per capsule, that is the original activity multiplied by the decay factor

(e) The activity to be dispensed

(f) The volume required, that is, the activity to be dispensed divided by the activity per unit volume

(g) The name of the patient or other designation of the use if no patient is involved

(h) The initials of the person dispensing the materials

It is convenient to have a separate section or separate logbook for each isotope with a long half-life, particularly ^{14}C and ^{3}H, to facilitate determination of the amount on hand.

Permanent records of radiation exposure to personnel are also required. The necessary records for each employee can be maintained by regular filing of film badge reports.

CARE OF RADIOISOTOPE PATIENTS

Administration of Radioactive Drugs:

There is no rule for the administration of radioisotopes which does not apply equally well to the administration of other drugs. No drug should be administered unless prescribed by a licensed physician. Administration of radioisotopes requires, in addition, that the physician be licensed specifically for the radioactive compound used, for the amount to be used, and for the purpose intented.

Before any drug is administered the identity of the patient should be carefully confirmed. One must take care not to suggest a name to a patient; the hard of hearing and the overly obliging often agree to any name suggested. If the patient is not personally known to the physician or to the laboratory staff, identification should be required. A wrist identification band or an identification slip from ward personnel who know the patient is helpful. For radioisotope therapy, insist that the patient be known personally by the physician in charge of the treatment or that the patient's physician accompany him. The normal referral procedure usually provides ample opportunity for the treating physician to become acquainted with the patient.

As a precaution against real or imagined fetal damage, no therapeutic dose of radioisotope should be administered to a woman of child-bearing age if there is any possibility that she may be pregnant.

Unless there is particular urgency, it is even wise to schedule diagnostic radioisotope tests during the first 10 days to 2 weeks of the menstrual cycle.

Nursing Care for Radioisotope Patients:

The recommended maximum permissible dose for nurses is the same as that for other radiation workers. The exposure of the ward nurse caring for patients who have received diagnostic doses of radiation can be regarded as very small. Iodine 131 probably constitutes the greatest hazard. Brucer (1951) has estimated that nurse sitting at the bedside of a patient who received 100 mCi of ^{131}I would receive 200 mR/day. Sear (1964) reports a dose rate of 1 mrem/h mCi for the first day and only half that amount on the second. The dose for thyroid scanning is about 50 μCi, and for liver and lung scanning between 100 and 200 μCi. The nurse would normally spend only a small fraction of the nurse 40 hours sitting at the side of a patient's bed. At the foot of the bed, the dose rate for ^{131}I in the patient's thyroid is only about one tenth that at the side of the bed.

The suggestions outlined in the remainder of this section are adequate for nursing patients who have received diagnostic or small therapeutic doses of radioisotopes. These precautions are recommended for the protection of other patients and for the protection of nurses who have frequent contact with radioisotope patients. These precautions are not adequate, however in the care of patients who have received large doses of radioactive drugs for the treatment of carcinoma.

Laundry, except when grossly contaminated, can be disposed of in the usual manner. Contaminated linen may be found after the following: vomiting shortly after an oral dose of any radioisotope; urinary

incontinence after large diagnostic or therapeutic doses of iodide ^{131}I or doses of Hippuran ^{131}I or chlormerodrin ^{197}Hg for renal function studies; fecal incontinence following rose bengal ^{131}I for liver scanning. Where there is a question of contamination, the radiation safety officer should be contacted. Contaminated linen should be placed in a seperate bag for monitoring and disposition by the radiation safety officer. Normally, radioactive linen will be stored by him until physical decay permits its return to the hospital laundry.

Bedpans, urinals, basins, food trays, and similar items are likely to be contaminated by patients who have received the larger diagnostic doses or smaller therapeutic doses of radioisotopes. In most cases, urinals and bedpans may be emptied as usual. After therapeutic doses, the container may be decontaminated or washed in the usual manner and returned to the patient for his continued use. Within a few days the amount of radioactivity excreted decreases markedly, and the container can be washed and returned to general use. If any doubt exists, request that the radiation safety officer monitor the equipment. Food trays and basins present less of a problem and are seldom significantly contaminated.

When therapeutic amounts of radioisotopes are administered, specific instructions must be issued to the nursing staff. These should be attached to the patient's chart, posted in the nursing station, and discussed with the nursing staff at intervals. The following instructions for ^{131}I therapy, quoted from the AEC Licensing Guide(USAEC) provide an example. These comparatively stringent precautions are required in the care of patients treated with large doses of ^{131}I. Simpler instructions are adequate for small therapeutic or diagnostic doses.

NURSING INSTRUCTIONS FOR PATIENTS RECEIVING THERAPEUTIC DOSES OF IODINE ^{131}

Patient _____

This patient was administered ___ mc of _____ on _____ at _____ am
isotope date pm

by _____
name of physician

(a) If the patient's clothes or bed linens are contaminated by fluid originating in the patient, notify the above physician.

(b) Wear rubber gloves while handling contaminated objects. Place gloves in "Contaminated" container after use.

(c) Nurses or other attendants shall not remain in the immediate proximity of the patient for more than a total_____hours during _____ period.

(d) Visitors must remain outside of tape on floor and patient must remain in bed while visitors are in the room during _____.
period

(e) Unless otherwise notified, all excreta may be disposed of in the normal manner.

(f) The patient may be released from the hospital after _____ days. The above named physician will make this calculation.

(g) In the event of death immediately notify Dr. _____ (Tel: _____) or Dr. _____ (Tel: _____) and do not remove the body from the room. Dr. _____ will issue appropriate instructions for handling cadaver.

(h) When the patient is discharged, room will be surveyed for contamination before remaking room.

ACCIDENTS

Identification of Accidents:

Any unplanned happening which could affect radiation safety is considered an accident. The most essential and often the most difficult problem in coping with accidents is the recognition that an accident has occured.

Precautionary Measures:

All work should be carried out according to some prearranged plan. Appropriate accident instructions should be prepared and the staff should thoroughly understand them.

The staff should be familiar with the position and method of use of the protection and first-aid equipment for emergencies. Equipment should be checked regularly to ensure that it is in good working order.

No person should undertake dangerous work without someone standing by who can assist in case of trouble.

Actions Common to All Accidents:

The control of measures for dealing with any accident should be the responsibility of one individual.

All accidents should be fully reported and also should be investigated and appropriate measures should be taken to prevent repetition of the accident.

Accidents Involving Radioactive Contamination:

Radioactive materials may be accidentally released by a spill, by a failure of equipment or by rupture of a sealed source. The actions which may be appropriate to prevent wide-spread contamination and exposure of personnel in such a case and the order in which such actions should be taken will depend upon the circumtances involved.

Persons in the vicinity of the spill or release who are liable to contamination as a result of the accident should be given appropriate information immediately.

Protection of personnel and the containtment of the radioactive material in the room in which the accident occurs should be given primary consideration.

Persons directly contaminated by a wet spill should immediately remove clothing affected and throughly wash the hands and other contaminated areas of the body.

If an inhalation hazard exists, all persons not involved in carrying out planned safety procedures should vacate the contaminated area immediately.

The "radiological health and safety officer" in the area should be given all available information and the nature and extent of the release.

If considerable contamination of the air is suspected, inhalation of radioactive material should be minimized by holding the breath.

After all persons are out of the room, it may be desirable to prevent further escape of radioactive material from the room by sealing the doors and closure with adhesive tape.

Except in case of injury or other urgent need, persons who have vacated in contaminated area should not leave immediately until they have been monitored to limit further spread of radioactivity.

The extent of the area of contamination should be determined and the area roped off with warning signs.

Safe and efficient decontamination procedures should be arranged.

DECONTAMINATION

Decontamination of Personnel

The "radiological health and safety officer" should set up instructions and facilities (materials and equipment) for normal decontamination and first aid procedures in conformity with the paragraph on "medical casualty service". The staff should be fully acquainted with these procedures

Measures To Be Taken In Case Of Internal Contamination: Radioactive contamination of personnel can be internal through ingestion, inhalation, wounds or skin penetration. If anyone suspects internal contamination in case of an accident during work, it should be immediately reported to the "radiological health and safety officer".

Internal contamination is essentially a medical problem, parallel in some ways to the absorption of chemical toxins. Special corrective procedures should therefore combine with normal medical practice under medical advice and supervision.

Aims of the corrective procedures are: (a) try to eliminate as much of the internally introduced contaminant still remaining in the mouth, gastro-intestinal or respiratiory tract, as quickly as possible and try

to prevent or reduce its uptake into the bloodstream and tissues; (b) try to prevent fixation of the contaminant in the body or try increase its excretion from the body.

For the first of these aims it is sometimes necessary that the contaminated person or another non-medical person takes immediate action (in the first seconds or minutes) for instance, to promote the mechanical elimination of the contaminant by vomiting or expectoration.

In case of contaminated small open wounds, cuts, punctures, or other injuries, the wound should be immediately washed and bleeding encouraged if necessary, and referred to the medical officer.

For the second of the aims indicated above any further procedure of internal decontamination; e.g., more complicated chemical or physico-chemical methods, is a matter of medical treatment. It should be undertaken as soon as possible but only under medical supervision.

Measures To Be Taken In Case Of External Contamination

Of Personnel: External contamination on the person can be a hazard in three ways:

(a) It may cause injury from local exposure of the skin.
(b) It may penetrate the intact skin (especially in the presence of certain organic solvents).
(c) It may eventually be transferred into the body by ingestion or inhalation.

The danger of loose activity being eventually carried into the body is by far the most critical hazard, so that decontamination procedures are primarily concerned with loose contamination.

As a rule, except for decontamination of hands, or except in cases of emergency as agreed upon by the "radiological health and safety officer" all mild decontaminating procedures described in the two paragraphs below should be carried out under supervision of the "radiological health and safety officer." Attempts to remove contamination which resists mild procedures should only be made under medical supervision.

The immediate washing of contaminated areas with water and scap is the method of choice for removing loose contamination, subject to certain elementary precautions: (a) tepit water, not too hot, should be used; (b) soap should not be abrasive or highly alkaline; (c) washing can be helped by scrubbing with a soft brush only and in such a way as not to abrade the skin; (d) the skin should be washed for a few minutes at a time, then dried and monitored.

Washing could be repeated if necessary (as indicated by monitoring) providing there is no indication of the skin getting damaged.

If this procedure fails, only mild detergent approved by the "radiological health and safety officer" might be used, although repeated applications of detergents to the same area of the skin, hands for instance might injure the skin and make it penetrable.

Use of organic solvents or of acid or alkaline solutions should be avoided.

Special attention should be paid to proper decontamination of creases, folds, hair and of such parts of the hands as finger nails , inter-finger space and the outer edges of the hands.

Care should be taken to avoid as much as possible the spreading

of the contamination to uncontaminated parts of the body and to avoid internal contamination. If there is a risk of such a spread, an attempt should first be made to remove the contamination locally with absorbent material, and, if necessary, with a proper masking of the adjacent non-contaminated areas of the skin. A non-contaminated open wound should be protected. After each decontamination operation, the treated place should be dried with a fresh non-contaminated towel or swab, and monitored. All towels and swabs, used in the decontamination process should be treated as contaminated material.

While decontaminating the face, special care should be taken not to contaminate the eyes or lips.

Decontamination of the eyes should be undertaken immediately. Not only the radioactive isotope is to be considered, but also the chemical nature of the contaminant and eventual complications due to foreign bodies and mechanical or chemical irritants. Additional irritation of the eyes by decontamination procedures should be avoided. Immediate irrigation of the eyes with a copious amount of water or with appropriate medically approved solutions is recommended. These solutions and a suitable vessel for eye washing should be provided for first-aid. After this first procedure every case of contamination of the eyes should be submitted to medical control and further treatment.

Attempts to remove contamination which resists washing should only be made under medical supervision.

Decontamination of Equipment

Decontamination of Glassware and Tools: The decision to decontaminate material must take into account the continuing value of the material compared to the cost of decontamination.

Where the half-life of the contaminating element is short, it may be desirable to store tools and glassware for decay of activity rather than to attempt decontamination.

Decontamination of equipment should generally be done as soon as possible after its use. In many cases this will prevent the contamination from getting fixed being ultimately more difficult to deal with. It will often be found that surfaces that have been kept moist are easier to clean.

The cleaning of contaminated glassware and tolls should be done with great care by informed persons in a well ventilated hood set aside in the lobaratory for that purpose, or in special decontamination areas.

If it is necessary to dismantle any equipment prior to decontamination procedures, careful monitoring should be carried out during the operation.

Glassware can be cleaned by any of the normal chemical agents, of which chromicacid solution is probably the most useful. Other cleaning agents are concentrated nitric acid, ammonium citrate, penta sodium triphosphate and ammonium bifluoride.

Metal tolls and similar equipment should be washed with a detergent combined with brisk brushing to dislodge trapped contamination. Contamination resisting this treatment may be washed is stronger agents including dilute nitric acid or a 10% solution of sodium citrate or ammonium biflour Other cleaning can be chosen based on the material of construction of the equipment and the likely chemical nature of the contaminant. Stainless steel could be treated with sulphuric or, as a last resord, hydrochloric acid.

If the decontamination causes any corrosion of the metal, future decontamination will be more difficult to remove and a coat of glossy paint on the decontaminated surface is desireble. Contamination preventation by the use of strippable coatings or plastic covers is useful. A coat of paint may provide adequate protection from soft emitters which prove resistant to decontamination.

The uptake of radioactive substances by glassware may be reduced by a preliminary treatment with the corresponding inactive chemical.

In some cases immersion in solutions of the non-radioactive isotope of the contaminant may be tried, although this is a slow procedure.

The solutions used for cleaning should not be returned to the stock bottles between uses.

Laboratory equipment should be surveyed for residual contamination following decontamination procedures. If the residual contamination indicates that the level of activity remains greater than that specified as permissible, equipment should not be reused and should be regarded as radioactive waste.

Decontamination Of Working Areas, Benches, And Other Surfaces: As soon as possible after contamination of working areas, benches, and other surfaces has occured or has been detected, decontamination should be carried out by suitably equipped and informed persons.

All surface should be cleaned by wet methods if possible, as the use of dry methods may create a dust hazard. For porous materials of construction which prove unsuitable for cleaning by wet methods, vacuum cleaning with proper filtration of the rejected air might be attempted; in any case special precautions in using dry techniques are necessary.

Cleaning tools should be assigned to the area in which the operations are being performed and not removed or used elsewhere without careful decontamination.

Paintwork can be cleaned with soap (or detergent) and water or, in extreme cases, removed with a paint remover. Polished linoleum can be cleaned with soap and water , followed, if necessary, by the removal of the wax polish by means of a solvent.

If the contamination is by alpha or soft beta emitters, the radiation may possibily be controlled by painting over. The use of two coats with the undercoat in a contrasting color is useful to indicate any wearing away of the protective coat. This method of contamination control should be used with caution with respect to future possible uses of the installation.

If after attempted decontamination adequate protection cannot be assured, the contaminated rooms or premises should be abandoned and contaminated removable objects disposed of in accordance with the requirements of the competent authority. Acess to these abandoned areas should be forbidden to unauthorized persons and such areas should be identified by an appropriate and recognizable warning sign.

Decontamination of Clothing , Hospital Linen or Similar Items:

In any handling of contaminated clothing appropriate precautions should be taken to prevent or control contamination of the worker and of the surrounding areas by the formation of aerosols. The sorting of contaminated garments will often need to be carried out in a fume hood. Care must be taken to prevent airborne contamination from clothing placed in storage.

Contaminated clothing and linen should not be released to public laundries without the approval of the "radiological health and safety officer".

With short-life radioactive contamination, storage is recommended until the activity has fallen to safe levels.

It will usually be desirable to wash the contaminated clothing in specially provided laundering facilities; the area where decontamination goes on should be monitored. Personnel in charge of these facilities should be provided with protective coats and suitable gloves.

Contaminated garments should be segregated into batches of differing degrees of activity to avoid cross-contamination.

Routine washing of moderately contaminated clothing may be carried out according to schedules recommended for commercial laundry practice. However, it may be advantageous to substitute a standart detergent (chosen on the basis of economy) for the soap because of the tendency of latter to form deposits which may fix the activity in the fabric.

Clothing with resistant contamination or high levels of activity is dealt with by longer periods of washing and especially by repeated rinsings.

Rubber gloves and other rubber goods and plastics usually decontaminate readily. Such items should first be washed with an ordinary laundry formula. If this does not prove effective, rubber items can be washed in dilute nitric acid or agents chosen in the light of the nature of the contamination. This should be followed by a wash using scoring powder and a thorough rinse in running tap water.

If the clothing, linen or similar items cannot be decontaminated to a safe level, it should be regarded as radioactive waste.

RADIOACTIVE WASTE CONTROL AND DISPOSAL

Waste Collection

In all working places where radioactive wastes may originate, suitable receptacles should be available.

Solid waste should be deposited in refuse bins with foot-operated lids. The bins should be lined with removable paper bags to facilitate removal of the waste without contamination.

Liquid waste should, if no other facilities for liquid waste disposal exist, be collected in bottles kept in pails or trays designed to retain all their contents in the event of a breakage.

All receptacles for radioactive wastes should be clearly identified. In general, it will be desirable to classify radioactive wastes according to methods of disposal or of storage, and to provide seperate containers for the various classifications used. Depending upon the needs of the installation, one or more of the following bases for classification of wastes may be desirable:

(a) Gamma radiation levels (high, low)

(b) Total activity (high, intermediate, low)

(c) Half-life (long-short)

(d) Combustible, non-combustible

For convenient and positive identification, it may be desirable to use both color coding and wording.

Shielded containers should be used when necessary.

It is generally desirable to maintain an approximate record of quantities of radioactive wastes released to drainage systems, to sewers, or for burial. This may be particularly important in the case of long-lived radioisotopes. For this purpose it is desirable or necessary to maintain a record of estimated quantities of radioactivity deposited in various receptacles, particularly those receiving high levels of activity or long-lived isotopes. Depending upon the system of control used by the installation, it may be desirable to provide for the receptacle to be marked or tagged with a statement of its contents.

Radioactive wastes should be removed from working places by designated personnel under the supervision of the "radiological health and safety officer."

Waste Storage:

All wastes which cannot be immediately disposed of in conformity with requirements of the competent autrority have to be placed in suitable storage.

Storage may be temporary or indefinite. Temporary storage is used to allow for decrease of activity, to permit regulation of the rate of release, to permit monitoring of materials of unknown degree of hazard or to await the availability of suitable transport. Indefinite storage in special places has to be provided for the more hazardous wastes for which no ultimate disposal method is available to the particular user.

Storage condition should meet the safety requirements for storage of sources.

The storage site should not be accessible to unauthorized personnel(Control of animals should not be overlocked).

The method of storage should prevent accidental release to the surroundings.

Appropriate records should be kept of storage.

Disposal Of Wastes To The Environment:

General Considerations: Disposal of radioactive wastes to the environment should be made in accordance with the conditions established by the "radiological health and safety officer" and by the competent authority.

The ways in which radioactive materials may affect the environment should be carefully examined for any proposed waste disposal method.

The capacity of any route of disposal to safely accepted wastes depends on evaluation of a number of factors, many of which depend on the particular local situation. By assuming unfavorable conditions with respect to all factors it is possible to set a permissible level for waste disposal which will be safe under all circumstances. This usually allows a very considerable safety factor. The real capacity of a particular route of waste disposal can only be found by a lengthy study by experts.

The small user should first try to work within the restrictive limits which are accepted as being safe and which will usually provide a workable solution to the encountered problem of waste disposal. Such a restrictive safe limit is provided by keeping the level of activity at the point of release into the environment below the permissible levels for non-occupationally exposed

persons recommended by the International Commission on Radiological Protection for activity in drinking water or in air. This rule should be superseded if the competent authority provides any alternative requirements or if local studies by experts provide reasonable justification for other levels.

Disposal To Drains And Sewers: The release of wastes into drains does not usually need to be considered as a direct release into the environment. Hence, a restrictive safe limit will usually be provided if the concentrations of radioactive waste material based on the total available flow of water in the system, averaged over a moderate period (daily or monthly), would not exceed the maximum permissible levels for drinking water recommended by the International Commission on Radiological Protection for individuals occupationally exposed. This would provide a large safety factor since water from drains and sewers is not generally to be considered as drinking water. However, in situations where the contamination affects the public water supply, the final concentrations in the water supply should be to the levels set for non-occupationally exposed persons. Some present studies suggest that if the contamination affects water used for irrigation the final concentrations in the irrigating water should be a factor of at least ten below the levels set for occupational exposure and the possible build up of activity in the irrigated lands and corps should be carefully surveyed.

Finally, prior to release of wastes to public drains, sewers and rivers, the competent authorities should be informed and consulted to ascertain that no other radioactive release is carried out in such a way that the cumulated release may result in a hazardous situation.

Radioactive wastes disposed to drains should be readily soluble

or dispersible in water. Account should be taken of the possible changes of pH due to dilution, or other physico-chemical factors which may lead to precipitation or vaporization of diluted materials.

In general, the excreta of persons being treated by radioisotopes do not call for any special consideration. (This, however, does not apply to the unused residues of medical isotope shipments).

Wastes should be flushed down by a copious stream of water.

The dilution of carrier-free material by the inactive element in the same chemical form is sometimes helpful.

Maintenance work on active drains within an establishment should only be carried out with the knowledge and under the supervision of the "radiological health and safety officer." Special care should be given to the possibility that small sources have been dropped into sinks and retained in traps of catchment basins.

The release of waste to sewers should be done in such a manner as not to require protective measures during maintenance work of the sewers outside the establishment, unless other agreement has been reached with the authority in charge of these sewers. The authority in charge of the sewer system outside the establishment should be informed of the release of radioactive wastes in this system; mutual discussion of the technical aspects of the waste disposal problem is desirable to provide protection without unnecessary anxiety.

Disposal To The Atmosphere: Release of radioactive waste in the form of aerosols or gases into the atmosphere should conform with the requirements of the competent authority.

Subject to the preceeding paragraph concentrations of radioactive gases or aerosols at the point of release into the environment should not exceed the accepted maximum permissible levels for non-occupationally exposed persons as set forth in the appropriate current national or international standards which have been established for maximum permissible levels for exposure to external radiations and for radioactive contamination of air and water.

If higher levels are required and protection is based on an elevated release point from a stack, such levels can only be set after examination of local conditions by an expert.

Even if activity below permissible levels is achieved at the release point for an aerosol, a hazard of nuisance may still arise from fall-out of coarse particles. Therefore, the need for filtration should be assessed.

Used filters should be handled as solid wastes.

Burial Of Wastes: Burial of wastes in soil sometimes provides a measure of protection not found if the wastes are released directly into the environment. The possibilities of safe burial of waste should always be appraised by an expert.

Burial under a suitable depth of soil (about one meter) provides economical protection from the external radiation of the accumulated deposit:

A burial site should be under the control of the user with adequate means of excluding the public.

A record should be kept of disposals into the ground.

Incineration of Wastes: If solid wastes are incinerated to reduce the bulk to manageable proportions, certain precautions should be taken.

The incineration of active wastes should only be carried out in equipment embodying those features of filtration and scrubbing as may be necessary for the levels of activity to be disposed off.

Residual ashes should be prevented from becoming a dust hazard, for example by damping them with water, and should be properly dealt with as ordinary active waste.

GENERAL SPECIFICATIONS OF RADIOPHARMACEUTICALS

Definition of Radiopharmaceutical Product:

Radiopharmaceuticals are radioactive preparations, which are administered to man for therapeutic or diagnostic purposes and are not contained in sealed sources and which therefore undergo metabolic changes in the organism.

Classification Based on the Relevant Nuclear Chemistry Operations:

Five groups of preparations can be distinguished.

(a) Radioactive preparation obtained by irradiation of a target followed by solution of this target. ^{24}Na, ^{42}K, belong to this category.

(b) Radioactive preparations obtained by chemical separation of a radionuclide from an irradiated target. ^{131}I, ^{32}P, ^{51}Cr, ^{64}Cu.

(c) Radioactive preparations obtained by labelling synthesized organic molecules or an organic molecule of biological (animal or plant) origin with a radionuclide. This category includes a large number of ^{131}I-labelled molecules used in medicine:

Cholografin, Hippuran, Hypaque, Renografin, RoseBengal, Thyroxine, Urokon, human serum albumin, insulin, etc. Some of these molecules have also been labelled with ^{125}I.

(d) Radioactive collodial preparations are produced by precipitation of metals, metalloids or salts, such as colloid ^{198}Au, Yttrium-90 or chrome phosphate (^{32}P) in the form of particles of diameter less than 100 nm in a stable suspension.

(e) Isotope generators producing short-lived radioactive emitters when required. These preparations are the most complicated since they involve the irradiation of a target, the separation of the parent radioactive element, its adsorption on a carrier. (non-exchange resin, inert adsorbent powder, etc.) and elution of the daughter radionuclide which is alone of interest from the point of view of the user. The preparations available at the present time include ^{68}Ga generator from ^{68}Ga, $^{99}Tc^{m}$ from ^{99}Mo, ^{137}Ba from ^{137}Cs, ^{113}In from tin-113.

Classifications as a Function of the Pharmaceutical Form:

Classification by pharmaceutical form depends on the method by which the labelled radionuclide or molecule is introduced into the human organism. Two principal methods of administration are used, oral and parenteral and these govern which of the four pharmaceutical forms is preferred.

(a) Solutions for oral administration:

They are supplied in solution in penicilline-type bottles from which the required volume can be removed in one or more operations. This involves radioactive contamination of glassware, pipettes and of the lips and oral cavity of the patient. Removal

of the solution in more then one operation can give rise to errors in volume measurement and to bacterical and or chemical contamination. The aim should always be to use single dose bottles thus avoiding this disadvantages. The products are prepared in the form of aqueous, dilute alcoholic or oily solutions.

(b)Gelatin capsules

The capsule form has the advantage of avoiding the dosage errors since each capsule contains a specific amount of the radionuclide in question. The disadvantage of this form is the possible development of faults in the capsules; for example failure of the capsule to dissolve or incomplete solution in the digestive tract.

(c)Solutions for injection

As in the case of solutions for oral administration, these are supplied in pencilline-type ampoules or bottles containing one or more doses. They are sterile, generally isotonic and apyrogenic. They have to be removed under aseptic conditions in a sterile syringe prior to injection.

(d)Solutions in single-dose syringes

It has the advantage of reducing to a minimum handling by medical personnel with the consequent risk of occupational irradiation and prevents the occurance of bacterical contaminations provided that all aseptic precautions are taken at the production stage.

(e)Lyophilized product

These are preparations which can be dissolved extemporaneously with an appropriate solvent and administered either orally or parenterally.

Purity Criteria for Radiopharmaceutical Products:

Criteria of nuclear purity and chemical purity will be defined separately.

Criteria of nuclear purity include the following elements:

(a)Radionuclidic purity ; or radioactive purity or radioisotopic purity is the ratio, expressed as a percentage, of the activity of the radionuclide in question to the total activity of the source. Ex: Presence of ^{199}Au besides ^{198}Au.

(b)Radiochemical purity is the ratio, expressed as a percentage, of the radioactivity of the radionuclide in question, present in the given chemical form, to the total radioactivity of this radionuclide present in the source. For example presence of sodium iodate in a solution of sodium iodide is an impurity.

Criteria of chemical purity include the following elements:

(a)Chemical purity is the ratio, expressed as a percentage, of the mass of material present in the given chemical form to the total mass of material contained in the source.

(b) The isotopic carrier is made up of stable isotopes of radionuclide in question added to the radioactive preparation and present in the same chemical form as the radionuclide.

The combination of the concepts of nuclear purity and chemical purity gives rise to the following definitions:

(a)The specific radioactivity is the ratio of the radioactivity of the radionuclide in question to the total mass of the element or of the chemical form in question.

(b)The radioactive concentration of solutions is the ratio of the radioactivity of the radionuclide in question to the

volume of solution in which it dissolved.

Methods of purity control:

(a)Identification of the radionuclides

(b)Measurement of the radioactivity

(c)Verification of the radionuclide purity

(d)Verification of the radioactivity concentration

(e)Verification of the chemical purity

The methods of radionuclide identification include, for the ease of beta emitters, plotting a curve for absorption in matter and a decay curve, and also using a gamma spectrometer to verify the absence of gamma emitters.

In the case of gamma emitters, plotting the gamma emission spectrum can generally be used for detecting the presence of other gamma emitters but not that of beta emitters.

Verification of radiochemical purity is by the electrophoresis and chromatography methods.

The chemical purity can be estimated with sufficient accuracy and speed by determining the metal and metalloid content by means of radiation emission spectrometry.

Radiopharmaceutical Specifications:

(a)Radioactivity concentration

(b)Radionuclide purity

(c)Chemical purity

(d)Spesific radioactivity

(e)Radiochemical purity

(f)Sterility

(g)Pyrogenicity

(h)Isotonicity

(i)Biological affinity

"CGR GAMMA CAMERA PERFORMANCE TEST:"

This test is principally based on AAPM Report No:6. Tc-99m spectrum is selected at 140 keV and a single channel with variable window settings is used in acquisition.

All images are recorded on Polaroid and multi-image cameras as well as computer discs.

The recommended circular lead mask to cover edge packing could not be obtained.

1. Maximum count rate of the camera:

Collimator is removed and approximately 500 µCi of Tc-99m source is used. Maximum count obtained is 92.818 cps.

2. Uniformity testing:

a) Intrinsic Uniformity:

i) On-peak Uniformity:

Approximately 100 µCi of Tc-99m in a point source configuration is obtained. It is placed 2.50 m.away from the central axis of the detector with a diameter of 390 mm.

3.000.000 counts are collected with a count rate of approximately 5900 cps at 20% window setting. (Fig.1)

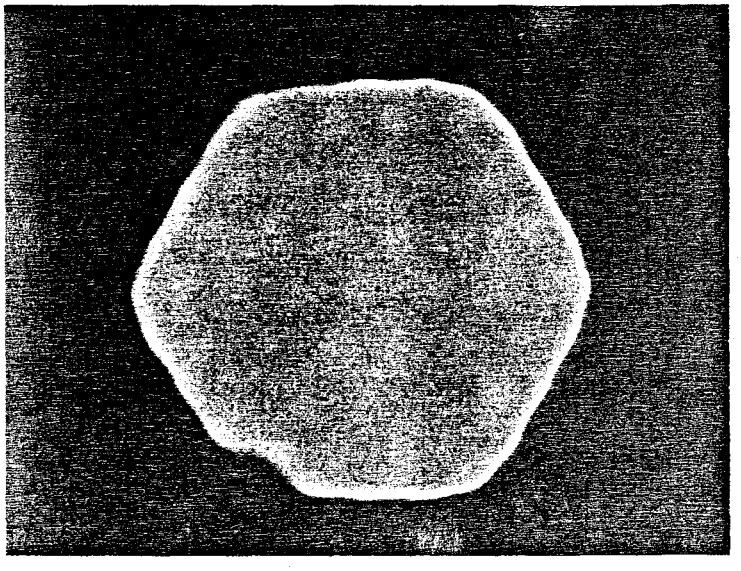

Figure 1. Field flood image at 20% window.

Again field flood image is obtained at 30% window setting, collecting 3.000.000 counts. (Fig.2).

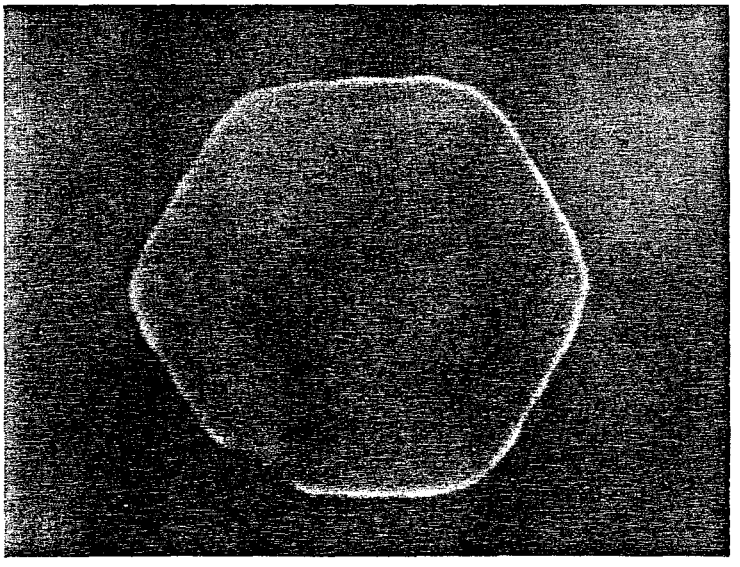

Figure 2. Field flood image 30% window.

Finally another field flood image is obtained at 15% window setting, collecting 3.000.000 counts. (Fig.3).

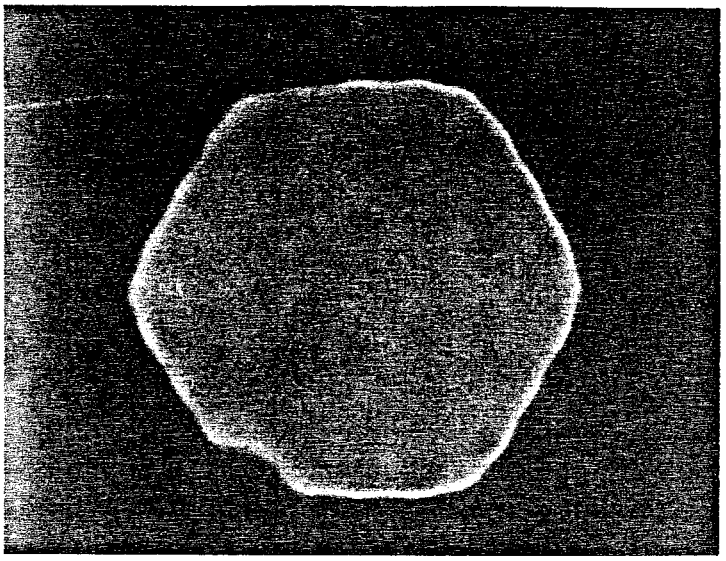

Figure 3. Field flood image at 15% window.

ii) Off-peak uniformity:

A 20% window is positioned above the photopeak until the count rate falls 90% of the optimum cps, and 3.000.000 counts are collected. (Fig.4). Afterwards the window is positioned below the photopeak again until the count rate falls 90% of the optimum cps, and 3.000.000 counts are collected. (Fig.5).

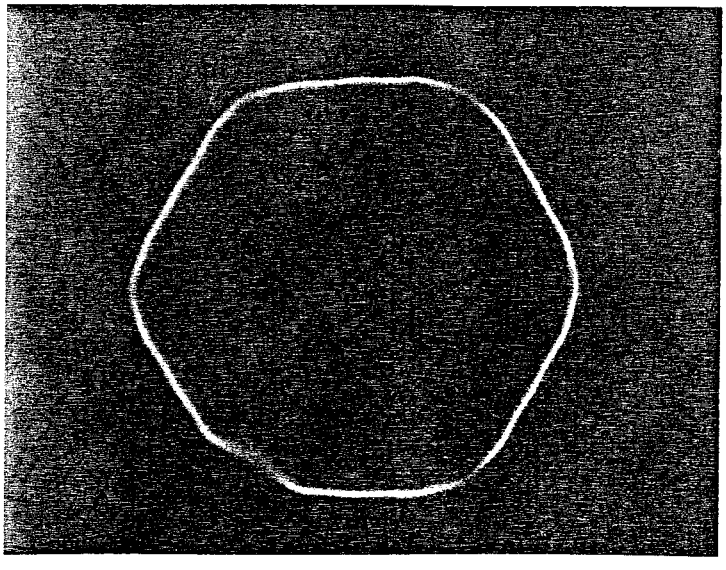

Figure 4. Window positioned above the photopeak.

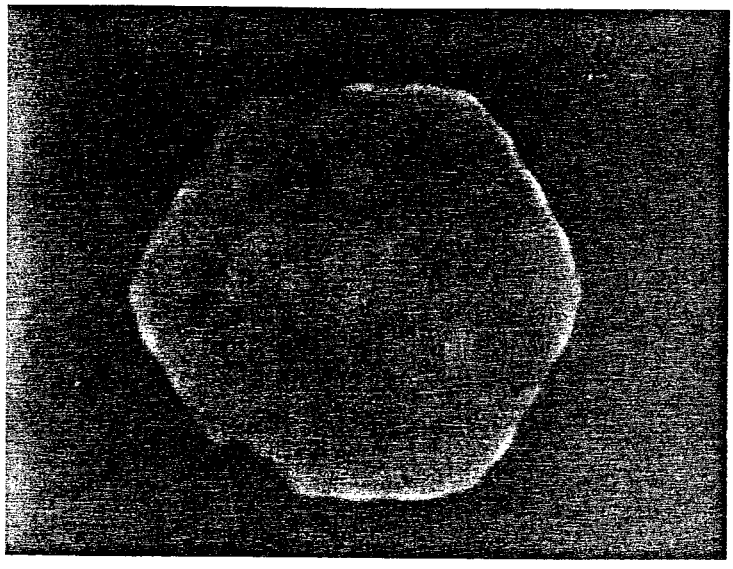

Figure 5. Window positioned above the photopeak.

All images are inspected for possible non-uniformities, and results are reported to the technical service.

3. Spatial resolution and distortion:

a) Intrinsic resolution:

Approximately 100 μCi of Tc 99m in a point source configuration is placed 2.00 m. away from the central axis of the detector, 20% symmetrical window is selected about the photopeak.

A four quadrant transmission pattern is placed on the detector surface and 3.500.000 counts at a rate of 7200 cps are collected. (Fig.6).

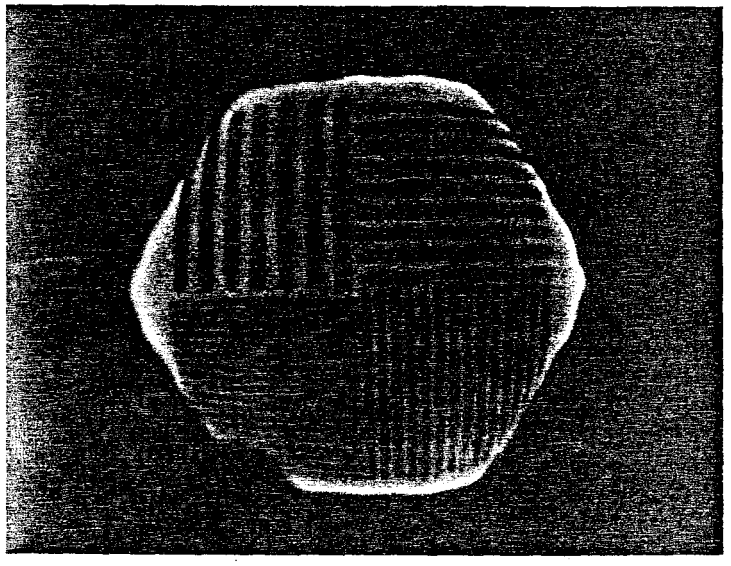

Figure 6. Field flood image with the transmission pattern

The same image is obtained by turning the transmission pattern by 180°. (Fig.7).

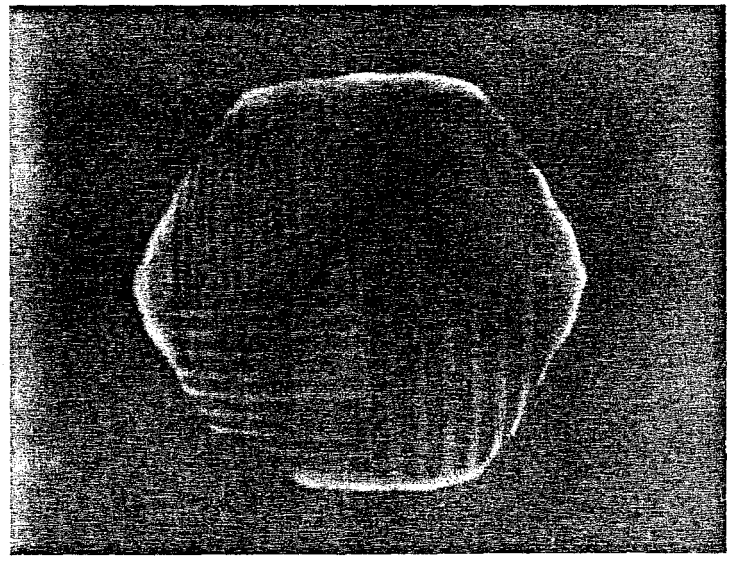

Fig.7. Field flood image, transmission pattern turned by 180°

4. Relative Point Source Sensitivity Over the Field of View:

A Tc-99m source is collimated in a lead container 6mm thick with a single whole 3mm in diameter.

20% window is centered about the 140 keV photopeak. The camera

head without the collimator is directed horizontally above the collimated source standing on a table. The source strength is adjusted so that no more than 10k cps are detected.

The source is placed 75%, 50%, 25% of distance from the center of field of view succeedingly on the +X axis, -X axis, +Y axis and -Y axis respectively. At all points cps values are recorded. (Table 3).

Sensitivity variation is calculated by the formula:

$$\text{Sensitivity Variation:} \mp 100 \left(\frac{\max - \min}{\max + \min}\right)$$

	75%	50%	25%
+X	6141	6173	6225
-X	6214	6062	6132
+Y	5984	6041	6223
-Y	6085	6097	5910

Table 3.

$$\text{Sensitivity Variation:} \mp \left(\frac{6225-5910}{6225+5910}\right)$$

$$: \mp 2.596$$

CONCLUSION

Evaluation of all images of uniformity test implies that the peak calibration and the window setting of the gamma camera under test are out of tune. This results in the appearance of the PM tubes' shadows on the images.

The transmission pattern used in the study of the intrinsic resolution has a bar distance of 5 mm at least. For such a camera as used in our study this is not a meaningful space but actually it is inspected that the resolution is good in all quadrants of the crystal. Also no spatial distortion is observed of the bar images on both directions

The sensitivity variation of ∓ 2.5 is also between normal limits.

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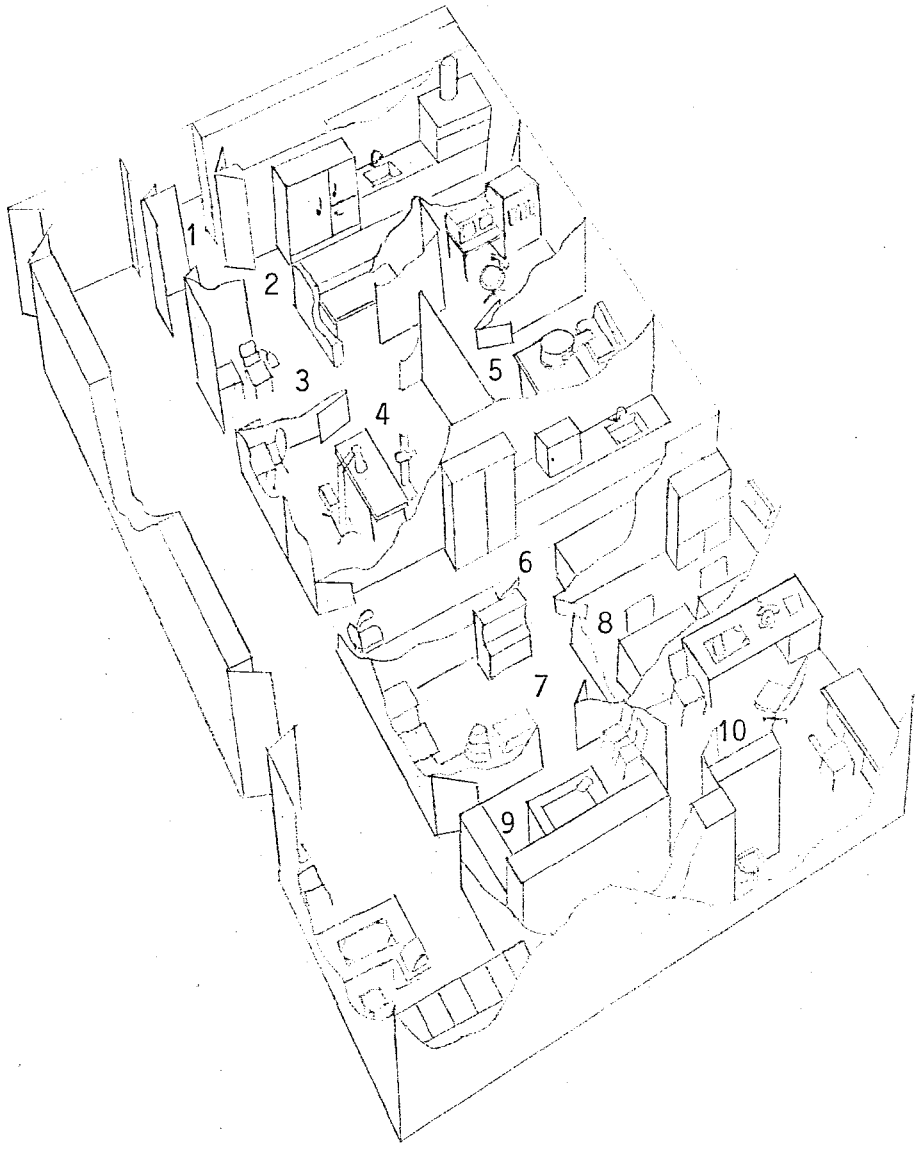

A SMALL NUCLEAR MEDICINE LABORATORY

1.Isotope receiving,storage,and waste.2.Dose dispensing.3.Patient bleeding, dressing,examination.4.Rectilinear camera room.5.Gamma camera room.6.Sample preparation for RIA.7.Counting.8.Technicians' office.9.Secretary office. 10.Physician's office.Toilet facilities and locker are also required although they are not shown in the diagram above.

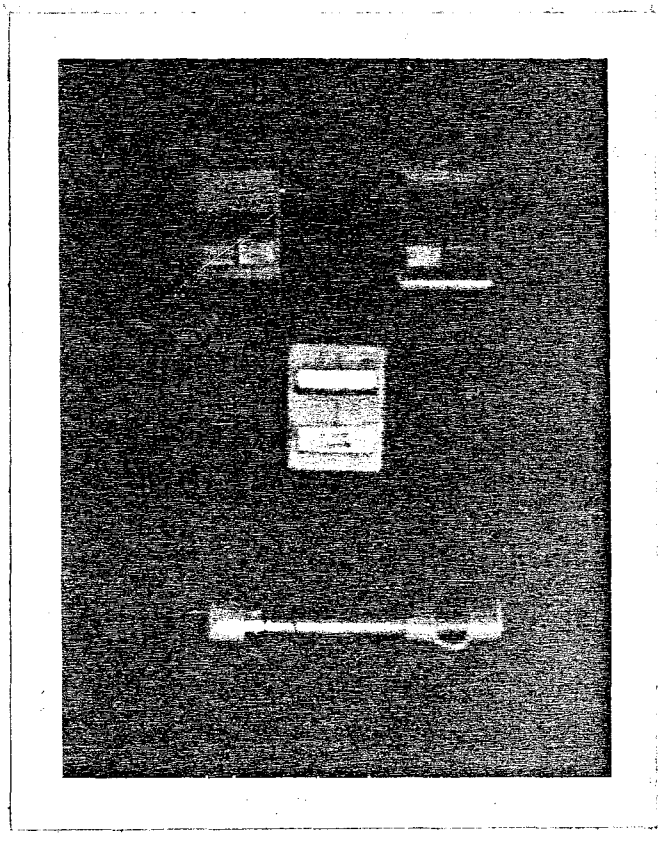

Figure 8.At the top the inside view of a typical film batch.In the middle,after the batch assembled.Below a pocket dosimeter.

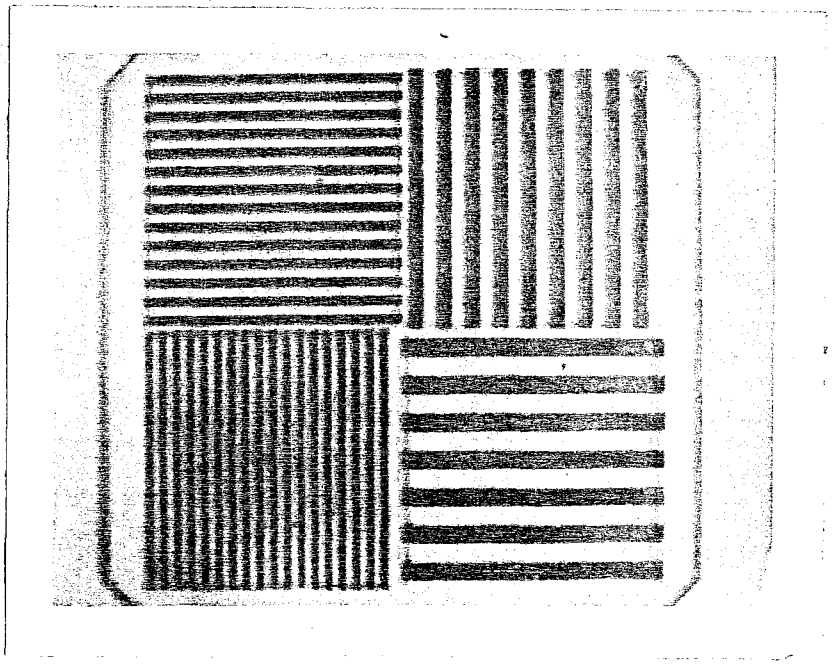

Figure 9.The transmission pattern used in the gamma camera performance test.

ANNEX

A Nuclear Medicine Department in Turkey is selected as a model for determinations of the availability and usefulness of the basic standards in radiation protection previously mentioned in this study.

Dosage and Administration: The ^{99m}Tc generator ,widely used in this clinic is eluted by technicians daily and all the radiopharmaceuticals to be used are aseptically prepared by the physicians.Date ,activity in Curies ,elution time and volume are all indicated on the tag of the container.Also laboratory records are kept for each radionuclide that is used.

Purity control is done from time to time and the dosage is calculated by means of mathematical calculations or according to activity yielding tables.

Plastic injectors are used in administration of the radiopharmaceuticals individually for each patient.

In case of Radioactive Iodine therapy ,again the dosage is calculated mathematically and non-disposable glasses are used.These glasses are left to decay under the running water but no chemical decontamination procedure is applied. Sinks used are specially constructed.

Table 3

	Radiation doses and administered radionuclides used in the clinic under consideration
Whole-Body scanning	20 mCi Tc-99m
Thyroid scanning	0.8 mCi Tc-99m
Liver/Spleen Scanning	3 mCi Tc-99m
Brain scanning	10-15 mCi Tc-99m
Renal scintigraphy	Dynamic:15 mCi;Static:3-4 mCi Tc-99m;200 uCi I-131
Isotopic angiography	20 mCi Tc-99m or Tl-201
Venography	5 mCi

In table 3 ,the radiation doses used in scanning the various organs are shown which are all between internationally accepted limits.

Handling of the Radioisotopes: The clinic may be classified as a controlled area ,but there is no supervision of a particular "radiological health and safety officer" ,but general protective measures are taken or controlled by the user of the radioactive sources ,individually.

In the accomplishment of their work ,the technicians are directed by the responsible physicians.

After a complete medical examination ,all persons employed in work ,involving radiation hazard are undergone periodic health examinations carried out every six months.These examinations are consisted of red and white blood cell counts with leukocyte formula and hemoglobin concentration.

Determination of Radiation Protection: Radiation is checked out by dose monitors in the areas where any radiation hazard exists.

All the personnel use the film batches in addition with the pocket dosimeters which are periodically evaluated by the competent authority Çekmece Nükleer Araştırma ve Eğitim Merkezi (ÇNAEM).

No air contamination monitoring is carried out routinely,except once for a research by ÇNAEM.

Lighting and ventilation facilities are adequate.

Two GM-type radiation monitors are used in detecting the overall radiation exposure of the patient waiting room and adjoining aisle in the clinic.

In the waiting room three detectors are placed at various points and checked at 09:30 a.m.,12:00 a.m., and 15:30 p.m. during successive three days.These time intervals are chosen in respect to the rush hours of the clinic

As it is shown in table 4 no appreciable radiation exposure could be detected at the end of the third day.

Table 4

		First Day		Second Day		Third Day	
Hours		0-3	3-6	6-24	24-27	27-35	35-38
Exposure mR	Patient Room	0.0	0.0	0.0	0.0	0.0	0.0
	Aisle	0.0	0.0	0.0	0.0	0.0	0.0

Waste Storage and Disposal:Waste baskets of adequate wall thickness for shielding the radiation inside of it is used all over the clinic.

Wastes which are left to decay are stored in safe rooms behind the bricks of enough thickness and afterwards they are disposed in firmly closed plastic bags,off.

Sinks are connected directly to main pipe by lead shieldings. All the taps can be operated by hands.

Conclusion:Although the protectionary measures applied are not ideal according to the standards,they are at acceptable levels due to the local conditions

It would be wise to use all the recommended standards as much as possible in order to work safely and keep the environment free of radio-active wastes.