MEDICAL WASTE TREATMENT

ISPRA COURSES: WASTE TREATMENT AND MANAGEMENT, 1993

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ABSTRACT. The aim of this paper is to provide a few practical notions concerning the management, treatment, storage and disposal of the various kinds of waste generated by hospitals. Above all, we wish to look into the procedures that should be adopted to ensure that health-care workers, general public health and the environment are safely protected. If the waste is thoroughly segregated and sorted and the following indications carried out, then these recommendations can help to minimize disposal costs while keeping in line with most current legislation.

1. INTRODUCTION

Hospitals generate large amounts of waste that falls into diverse categories. Most of this waste is of an infectious nature . Other types of waste include toxic chemicals, cytotoxic drugs, flammable and radioactive wastes that can often be considered infectious.
For this reason each hospital should develop an infectious waste management plan that provides for a thorough segregation and treatment of the waste on site. This can facilitate and lower the costs of ultimate disposal.
In this paper, we will look into the main types of hospital waste pointing out methods of on-site segregation and management. Once treated, ultimate disposal is similar to that of conventional
residential waste and as such will be treated in other parts of this course.

1.1. CHIEF AIMS OF HOSPITAL WASTE MANAGEMENT

The main aim on all levels is to minimize risk factors for health care workers, for general public welfare and for the environment.

- *Production:* minimize amounts generated.
- *Collection*: segregation and separation of wastes, designation of deposit areas in the wards, establishment of "safe" routes for transportation of the waste
- *Temporary storage:* sorting, segregation and safe handling of waste in the storage area
- *Treatment and disposal:* choice of the cheapest and most convenient solutions in keeping with state requirements; recycling as much waste as possible.

2. CLASSIFICATION OF MEDICAL WASTES

Wastes are classified according to their source, typology and the risk factors associated with their handling, storage and ultimate disposal.

- Sanitary wastes: contaminated materials, sharp objects, pharmaceuticals, experimental animal carcasses and body parts, human body parts, blood and body fluids, sludges from waste-water plants
- Radioactive wastes
- Chemical wastes: reagents and toxic chemicals, developing solutions from X- ray machines, used machine and cooking oils
- Wastes that can be disposed of together with conventional residential refuse.
- Glassware
- Ferrous and other bulky material
- Masonry rubble and orthopaedic plaster casts
- Other hazardous wastes such as used batteries, fluorescent light tubes and air-conditioning filters.

3. SANITARY WASTES

3.1. INFECTIOUS AND SHARP- EDGED WASTES

These are potentially the most hazardous of all hospital wastes and so deserve deeper consideration .

3.1.1. Definitions

Though normally taken for granted, much confusion surrounds the definition of "infectious" wastes, as we shall see when comparing diverse international regulations.
Italy: All material that has come into contact with contaminated biological and body fluids, or thought to have done so, is considered infectious or potentially infectious. Wastes coming from laboratory activities and chemical-biological research (such as culture dishes and single-use material) are considered infectious if they have come into contact with biological material (not necessarily infected).
E.C. Guidelines: Wastes deriving from medical activities in hospitals and "anatomical substances" are considered to be hazardous. Substances containing living micro-organisms and their toxins, known or thought to cause disease in human beings and other organisms are considered to be "infectious".
U.S.A.: Three categories are defined:

1. Hospital wastes- total waste generated by sanitary structures.
2. Sanitary wastes- that quota of hospital waste deriving from medical activities regarding the diagnosis, treatment and immunization of persons or animals.
3. Controlled sanitary waste- that quota of sanitary waste able to produce infection and transmit disease.

It is clear that these definitions do not coincide entirely. The Italian interpretation, for example, is the strictest and seemingly the most reliable. However, there is no epidemiologic evidence that hospital disposal practices have caused disease in the community . Therefore, identifying wastes for which special precautions are indicated is largely a matter of judgement about the relative risk of disease transmission. Aesthetic and emotional considerations may override the actual risk of disease transmission, particularly for pathology wastes.
In practice, the tendency is to regard between 40 and 50% of hospital waste as hazardous while, from studies carried out, the actual percentage able to transmit disease does not exceed 5% and consists almost exclusively of contaminated sharp-edged instruments (needles, scalpel blades, etc.).

3.1.2. Quantities of waste

In the U.S.A. the amount generated daily is estimated to be between 5 and 7 kgs./patient/day while in Italy, reported amounts are between 3 and 5 kgs./patient/day. See Table n.1

Table n. 1 - *Average contents of hospital wastes*

MEDICATION MATERIALS AND SINGLE-USE ITEMS	32 %
SHARP-EDGED ITEMS: Scalpel blades, hypodermic needles, broken glass, Pasteur pipettes, culture dishes etc.	5 %
PATHOLOGICAL WASTES	8 %
FOOD AND KITCHEN WASTE	15 %
PAPER AND PACKAGING	25 %
GLASSWARE	7 %
OTHERS: Chemicals, Radioactive etc.	8 %

3.1.3. Sources

Most of this waste comes from (See Table n. 2):

- Patient-care areas, operating theatres, wards, day-hospital clinics and dialysis units which discard material used for medication, single-use items contaminated with blood and other body fluids, sharp items, body parts, sacks used for plasma and drains, probes etc.
- Isolation units where everything discarded should be considered contaminated. Besides the above-mentioned, even meal left-overs pose a potential hazard along with any other item that has come into contact with patients.
- Microbiology, Analysis and Pathology laboratories which discard single-use material, culture dishes, body parts, contaminated animal bedding.
- Medical, dental and veterinary surgeries which discard material used for medication, sharps and small body parts, including teeth.

Table n. 2 - *Hospital waste production* (Source: Cattivelli e Ganapini 1990)

PATIENT-CARE AREAS AND SURGERY	10.8 %
WARDS	33 %
OPERATING THEATRES	4 %
DIAGNOSTIC UNITS	21 %
EMERGENCY UNITS	2 %
SPECIAL DEPARTMENTS: Dialysis, burns, radiotherapy, physiotherapy, mortuary, etc.	4.3 %
INTENSIVE CARE UNITS	4.1 %
CATERING	20.8 %

3.1.4. Assessment of risk factors associated with sanitary waste management.

The actual risk is relatively low and however not greater than that regarding the handling of conventional residential waste. If safety recommendations are followed (see 3.3) hospital wastes are probably safer to handle than urban waste.

As regards live pathogens found in wastes , the most predominant (80-90%) is the genus Bacillus with staphylococci and streptococci varying between 5 and 10%, whereas the most common pathogen is Staphylococcus aureus (from 2-10 colonies per gram of waste). Escheria coli, Pseudomonas Aeruginosa and Candida albicans (from 1 to 8/g) are also common along with varying numbers of other common nosocomial pathogens such as Kleibsella, Proteus, Enterobacter etc..

Studies into the survival rate of the viruses have revealed that much material present in hospital waste is able to carry the viruses, keeping them alive for several days (5-8 days).

However the viral titre tends to decrease rapidly as time passes. The Hepatitis B virus has been detected but its potential to provoke infection has not been established.
We must point out that all the pathogens listed are found in much higher concentrations even in urban refuse. If basic preventive norms are properly observed then infections through the mucosae of the mouth, eyes and nose, respiratory, urinary and gastrointestinal tracts are highly unlikely. The chance of being infected through contact is also negligible, except where sharp-edged waste is concerned.

3.2. OTHER TYPES OF SANITARY WASTE

3.2.1. Pharmaceuticals

These are classified as chemical waste. However, owing to their composition, they can be incinerated along with other sanitary waste. See Table n. 3.
N.B. Wastes containing antineoplastic drugs should be disposed of following precautions reserved for toxic chemical agents.

Table n. 3 - *Main Chemical Wastes*

SUBSTANCE	DISPO-SAL CODES	LOCATION	HAZARDS OF SHORT TERM MANAGEMENT AND TEMPORARY STORAGE
Asbestos	D; A	Removal of roof and insulation	Asbestosis and other pulmonary diseases
Chemical disinfectants: Isopropyl alcohol Ammonia Sodium hypoclorite Iodine Phenolics Quaternary ammonium compounds Glutaraldehyde Formaldeheyde Lysoform Ethylene oxide (residues)	A A A A A B B B B B A	Cleaning, disinfection and sterilization operations	Irritation, necrosis or burns to eye, mucous membrane and skin Coughing, chest tightness, increased heart rate. Pulmonary edema and pneumonitis. Toxic if inhaled and on skin contact Highly inflammable
Antineoplastic drugs	A	Drug preparation and administration	Potential human carcinogenesis and teratogenicity. Local tissue necrosis. Skin and mucous membrane eactions. Nausea, allergic reactions, cough and hair loss.
Pharmaceuticals	B	Drug administration	Local allergic reactions
Freon (containers and residues)	A	Pathology laboratory Central supply dept.	Eye and skin irritation or sensitization
Mercury	D; C	Much hospital equipments Dental amalgams	Severe respiratory irritation, digestive disturbances, renal damage. Dermatitis
Methyl metacrilate	A	Operating rooms	Irritant to eye, skin and mucous membranes. Affects central nervous system
Peroxyacetic Acid	A	Laboratories, central supply, patient care units	Strong eye, skin and mucous membrane irritant. Promotes skin tumours

Solvents: Methyl ethyl ketone Acetone Benzene Chloroform and CCl4 Ether Dioxane Xylene Ethyl alcohol Methyl alcohol	 A A A A A A A B B	Laboratories Also present in: -cleaning agents in housekeeping ; -glues and paints in maintenance;	Nervous system depressants. Headaches, dizziness, weakness, nausea. Irritation of eye and upper respiratory tract. Defatting and dehydration of the skin Highly inflammable
Noxious reagents (eg. benzidine) Fixatives (eg. acroleine) Embedding media Dyes Metal, metal compounds (Pb, Cr, Os, V)	D; A; C A A A D; C	Laboratories	Carcinogens Toxic if inhaled, swallowed or on skin contact
Pesticides	A	Fumigation and pest extermination	Toxic if inhaled, swallowed or on skin contact. Severe respiratory irritation. Edema. Dermatitis. Eye and mucous membrane irritation or necrosis

3.2.2. Body parts

These should be packaged in secure containers. Disinfectant must be added before they are sent to the crematorium.

3.2.3. Body fluid samples

Samples left over from laboratory analysis (urine, faeces, blood etc.) can be discharged into the sanitary sewer, provided they are not contaminated with hazardous or radioactive chemical agents. They do not differ from other excreta of patients and do not increase significantly the infective potential of sewerage. Wherever possible, however, it is advisable to perform disinfection with sodium hypoclorite (post-mortem rooms, pathology laboratories, isolation units).

3.2.4. Experimental animals

Provided they are not contaminated with noxious chemical agents in high concentrations (in compliance with state requirements) they can be sent for incineration (after disinfection) or for sterilization or to authorised, tertiary waste handlers. Otherwise they must be treated as toxic chemical waste.

3.2.5. Sludge from waste-water treatment plants.

This can be incinerated or buried in sanitary landfills. The only treatment feasible on site is heat-drying which can limit transportation costs. Its use as a fertilizer in agriculture is not normally allowed or advisable.

3.3. HANDLING OF SANITARY WASTE

Before removal from the workplace, ward or laboratory, this waste must be appropriately packaged.

Single-use polyethylene bags should be used as liners. These are judged according to their thickness, durability and tear-resistance. Bags should be puncture-resistant and leak-proof to avoid accidental spillage. They should be placed within a rigid or semi-rigid container

having a capacity of 40-60 litres. These containers may be re-cyclable (in which case stainless steel is recommended) or single-use (of thick cardboard or rigid polyethylene). Plastic materials containing chlorine should be avoided if intended final disposal is effected by means of incineration.
The containers must be clearly identifiable from other types of waste and should be marked as "infectious waste" or with an equivalent marking which complies with state requirements. The universal biological hazard symbol should be clearly defined on the outside together with the date and place of origin (laboratory, operating room etc.).

3.3.1. Handling methods

A sufficient number of containers for infectious wastes must be made available in the workplaces. A small bin (3-5 litres) of rigid polypropylene is also essential for the disposal of sharp equipment (scalpel blades, needles, syringes etc.). Disinfectant should be poured into this container before it is sealed and placed in the main container. The correct dose of disinfectant must be added to the latter, once full, prior to being sealed and sent for disposal. (see above). Bags must not be loaded beyond their weight capacity or volume.
Once closed 48 hours is the maximum storage time limit allowed by Italian regulations.
However, it is advisable to remove the waste frequently (at least every two days) and to avoid using any one container for too long a period. Double bagging should be considered whenever there are high quantities of liquid infectious waste. Should spills or leaks occur, then the 40- litre container must be placed inside a 60- litre one, lined with a polyethylene bag for extra measure. Any spillage must be cleared up promptly using disinfectants.
Infectious wastes should not be compacted prior to treatment as this process could damage the packaging and disperse the contents.

3.3.2. On the ward disinfection

Disinfection of sanitary waste is a precautionary measure aimed at ensuring protection during handling and transportation.
Disinfection can be carried out by means of common disinfectants such as Glutaraldehyde, Lysoform, Orthophenylphenol and Formaldehyde which are added to the containers before they are sealed. Sodium hypoclorite is not advisable when waste is to undergo incineration. Each single product contains indications regarding the optimum dose of disinfectant needed and manufacturers' maximum guidelines for infectious titre and average weight should be adopted. (see 3.4.2.1, .2,.3)
Clearly, where possible, autoclaving is always preferable.

3.3.3. Management of temporary storage area

To avoid any possible contamination some basic measures should be adopted to protect public health and personal hygiene. In particular:

- Personnel involved in the on-site handling of this waste must wear protective clothing (gloves, shoes) during the whole operation of collection, transportation and storage.
- On-site, the different types of waste must be collected separately from designated deposit areas, early in the morning.
- Carts used for transport must be closed and preferably be made of stainless steel which is easy to wash and disinfect after each use. Tilting carts reduce the risk of possible contact.
- The storage area must be fenced off and covered to prevent penetration by rodents, vermin and by the elements. The roof covering must offer protection against rain and bad weather in general.

- Damaged waste containers must be re-packed using suitable materials, such as 100-litre bags having two layers (inner HD polyethylene, outer strong brown paper), which can be easily sealed.
- During this process workers should have the appropriate personal protective equipment. In particular puncture-resistant gloves, water-proof gloves, safety shoes or boots and, if necessary, protective suits with face-shield or splash-proof safety goggles.
- For no reason whatsoever should waste containers be left in the storage area for over 24 hours.
- The temporary storage area must be kept as clean as possible, in line with hygienic requirements. All waste must be packaged to ensure containment and no waste should be seen lying on the ground outside the containers. At the end of each shift, routine cleaning procedures must be performed.
- Traces of spills of liquid waste that might be infectious must be cleaned up promptly using sodium hypoclorite solutions.
- As regards the correct management of the storage area, all workers handling infectious waste should receive infectious waste management training. Refresher courses should also be given periodically. Limited access to the storage area is recommended.

3.4. TREATMENT AND DISPOSAL OF SANITARY WASTES

This waste is destined for either incineration or burial in sanitary landfills. The choice influences the kind of treatment the waste must undergo prior to leaving the hospital.

3.4.1. Incineration

Incineration may be carried out either directly inside the hospital grounds in purposely-built incinerators or in public incinerators. On-site incineration is not usually practised to avoid problems of gas emissions in the hospital area, which are usually the result of bad maintenance and operation.

Incineration is, in itself, a sterilization process, therefore the waste material need only be disinfected on-site to minimize risks during transport. (see 3.3.2 and 3.4.2.5)

Gases are ventilated through the incinerator stacks and the residue of ash is disposed of in landfills.

Public incinerators normally reserve only 10% of their total intake for hospital wastes owing to the high temperatures these produce in the ovens.

The process of incineration is especially useful in that:

a) it reaches a good level of sterilization and thus widens safety margins

b) waste volume is considerably reduced-90-95%

c) heat produced can be used leading to considerable savings on heating costs

Disadvantages of this method are:

a) emissions of HCl (caused chiefly by PVC combustion), dioxin, furan and metals (Pb, Hg, Cd).

b) fusion of thermoplastic resins which do not burn and may clog the oven grids.

c) having to limit the percentage of high energy, heat-producing wastes that can be mixed with residential refuse, in order to reduce the risk of over-heating which could damage the refractory oven walls.

d) disappointing results and incomplete sterilization, chiefly due to operator mistakes or bad design.

e) In fact, over-loading, intermittent loading and inadequate combustion temperatures do not completely destroy some types of contaminated wastes such as needles, blades and experimental animal carcasses. In this way infectious material may be emitted from the stacks. Improper incineration of waste with high moisture and low energy content, such as pathology waste, can also lead to emission problems.

Obviously, all these difficulties can be overcome if incinerators are properly designed, maintained and operated. We shall not go deeper into the subject as it has already been broadly examined in other, specific lessons.

3.4.2. Disposal in sanitary landfills.

The viability of sanitary landfills is chiefly linked to potential hazards posed by microbic titres, that is to say the time needed to inactivate them and the possibility of a dispersion of the micro-organisms.

From studies carried out, it has been reported that suitably inoculated Polioviruses and Salmonella are inactivated in less than 10 days, due mainly to temperatures reached spontaneously by the heaped waste. (approx. 60 C.). However, possible contamination of the water bed through percolation into the ground cannot be excluded. Although this may occur, as it does above all in urban waste landfills, it is natural that the widespread use of such methods for infectious wastes could give rise to public concern. To get round this problem, wastes are sterilized prior to leaving the hospital.

Obviously, disposal in sanitary landfills saves on costs and is far cheaper than incineration. Discounting general public fears which, as stated, are largely groundless, the main disadvantage of the landfills is that it adds to the already high amounts of residential waste.

3.4.2.1. Steam Sterlisation (Autoclaving)

The most common method is autoclaving. From a technical aspect, the sterilization of waste differs from that of other materials used in hospitals, chiefly in the amounts to be treated daily.

Steam sterilisation involves the use of saturated steam within a pressure vessel, at temperatures high enough to kill infectious agents. Sterilisation is accomplished by steam penetration, and is most effective with low-density material.

Treatment at 134 C (2.1 atm) for at least 75 mins. is normally enough.

Furthermore it is essential to re-sterilize both vapour fumes emitted by the autoclave (temperature at 400 C.) and condensation before unloading. (temperature 138 C. for 5 mins.).

Precautions that should be taken using steam sterilisation:

- Plastic bags (being heat-labile they may crumble or melt) should be placed in a rigid container, to prevent spillage and drain clogging.
- Care should be taken to separate infectious wastes from other hazardous waste. Waste that contains antineoplastic drugs, radioactive or toxic chemicals that would be volatilized by steam, should not be steam-sterilized.
- Autoclaves should be routinely inspected and serviced, and the process should be monitored to ensure that the equipment is functioning properly.
- Techniques to minimize personal exposure should be adopted, including:
  - Use of protective equipment
  - Prevention of aerosol formation
  - Prevention of waste spillage during autoclave loading and unloading
  - Management of spills

3.4.2.2. Microwave sterilisation

Sterilization may not be effective if the steam does not penetrate deeply into the waste load or into some of its particular components (eg. bags, syringes and other objects in polyethylene or polypropylene). The problem could be solved if the waste were to be ground prior to the sterilization process but, as we have said, this is not allowed unless the grinding takes place inside the autoclave. As regards this method, efficient systems exist in commerce using microwaves to heat the mass of waste, after it has been ground and moistened. There are many kinds and in some cases the process is automatic and uninterrupted. The whole system is air and water-tight.

Typical processing cycle:

- loading- waste is fed into the hopper which is then hermetically closed
- grinding- waste is first ground then forced along passage by means of a feeder screw
- the waste is then vapour heated in two steps, first to 58 C. to activate the spores and moulds, then to 116 C.
- treatment with microwaves which pass through the entire waste load (which has been moistened by the steam) raising the temperature evenly to 141 C. The temperature may be increased by adding ethylene glycol to the vapour.
- unloading and repacking.

At end of the cycle the whole system is automatically washed down and sterilized.

3.4.2.3. Chemical disinfection

Chemical disinfection is the preferred treatment for liquid wastes, but it can be used in treating solid infectious waste. The following factors should be considered:

- Type of microorganism
- Degree of contamination
- Weight of waste
- Amount of proteinaceous material
- Type of disinfectant
- Contact time
- Mixing requirements
- pH and temperature

Ultimate disposal of chemically-treated waste (ideally incineration) should be in accordance with legislative requirements.

Other sterilisation techniques such as Thermal Inactivation, Gas Sterilisation, and Sterilisation by Irradiation are also available and used in particular situations.

4. CHEMICAL WASTES

Generally speaking, waste from analysis laboratories, disinfection operations and central supply, containing highly toxic agents and solvents, labelled Xt , Xn, T , T+, or F, are to be considered noxious or toxic.

4.1. CLASSIFICATION OF CHEMICAL WASTES

This waste must be classified at the time of collection and separated to avoid mixing chemicals that are incompatible. They must be placed in easy to seal, appropriate polyethylene or metal containers (according to their physical-chemical nature). They should be separated from other waste and classed according to type:

1. Noxious chemical substances in water solutions
2. Non halogenated mixtures of laboratory solvents and organic compounds
3. Halogenated mixtures of solvents and organic compounds
4. Mixtures of solid metals, non metals, oxides, anhydrides, hydroxides and salts
5. Volatile heavy metals
6. Expired laboratory reagents.

This classification is aimed to minimize disposal costs (eg. incineration of chemical non-chlorinated waste costs $ 200-500/ tonne. That of chlorinated waste costs up to $1200/ tonne).

The sealed containers must be clearly labelled indicating the source of origin, typology, amount of contents and date. See Table n. 3 - *Main chemical wastes*

4.2. OTHER CHEMICAL WASTES

4.2.1. Waste developers from X-ray processing.
Separate storage tanks should be installed for used developer and fixing solutions. The size of the tanks must correspond to average amounts produced and be able to hold the liquid for at least 15 to 20 days.
If output is fairly low storage containers can be installed near the X-ray processors thus avoiding the need to carry out installation work.
The tanks or containers should have level indicators in order to avoid over-filling. A suitably-sized, water-tight containment tank is, anyway, advisable to avoid any leakage of the waste liquids.

4.2.2. Mineral, vegetable and animal oils.
The former consist of machine oils used in the maintenance sector and the latter of vegetable oils and animal fats used in the kitchens. They must be collected separately and sent to tertiary, licensed re-cycling sites or co-operatives.

4.3. COLLECTION

Personnel in charge of collection must transfer these containers to their designated zone in the storage area and place them in predisposed, water-tight containers. If this waste is made up of organic solvents or other flammable material it MUST NOT be kept in the hospital basement area but in a safe place until collection.

4.4. STORAGE OF CHEMICAL WASTE

This must be performed in compliance with safety precautions in designated, water-tight containment tanks and separated from other types of wastes. The volume of these tanks should be at least a third of the total volume of the containers to be held.
The most common hazards of improper storage include:

- Mercury trapped in porous sinks that continues to vaporise
- Improper storage of perchloric acid that might result in an explosion
- Azides that combine with the metals (Cu, Pb) or Ammonium in plumbing systems and may form explosive combinations when dry
- Organic solvents that continue to vaporise
- Unsafe storage of flammable substances.

Stations should be installed to receive, handle and dispense volatile or corrosive chemicals. Appropriate protective equipment, eye washes and emergency showers should be provided. Workers should be trained in emergency procedures and routine safety practices.

4.5. DISPOSAL

4.5.1. Disposal codes
A - Burning in an incinerator licensed for chemical waste , equipped with after-burner, fly-ash control system and gas scrubber
B - Incineration with other hospital waste
C - Burial in landfills licensed for harmful chemical wastes
D - Chemical treatments, neutralisation or inactivation
We do not aim to go deeply into this aspect today as other specific course lessons are provided on the subject. Suffice it to say that ultimate disposal, whether this be incineration, chemical treatment or toxic waste landfill, must be entrusted to reputable, licensed waste handlers to ensure that disposal is performed following good safety practices and according to international and state requirements.

5. RADIOACTIVE WASTES

5.1. INTRODUCTION

This paragraph is intended to provide information about radioactive wastes that can be produced in hospitals, protection against ionising radiation and some practical indications related to those wastes. The goal is to provide easily understood information on radioactive waste management *on site*, remembering that when radionuclides are completely decayed, they must be treated as conventional wastes, depending on their toxicity, hazard (see previous paragraphs); other information about radioactive waste treatment is dealt with in other sections of this course.
The reference limits for radiation exposure used here are recommended by the International Commission on Radiological Protection, ICRP. This Council is internationally acknowledged and its guidelines are commonly accepted, even if not completely adopted by all countries. Recently, on the basis of radiobiological and epidemiological studies (UNSCEAR88), the Commission (ICRP90) has suggested a reduction of the limits, diminishing the old ones by a factor greater than 2.
Naturally, it is necessary to manage these nuclides in such way that, while their activity is decaying to negligible levels, there will not be excessive exposure of persons to radiation (NCRP89); all pertinent activities should be carried out under the supervision of a qualified expert (Gi78). An understanding of the safety procedures relating to radioactive materials, some knowledge of the phenomenon of radioactivity and the characteristics of some isotopes is essential (Sh90).

5.1.1. The phenomenon of radioactivity

Atoms with unstable nuclei *spontaneously* transform (decay) and release energy. Following this process they undergo to a stable state. The energy released may be in the form of electromagnetic waves, X or γ rays, or high-speed and charged particles, β^-, β^+ or α; some nuclides emit just one of these types, others emit two or three. γ and X rays have a wide range of energies and penetrating abilities, while β radiations can pass through thin-walled containers; high energy β-particles can penetrate a few millimetres into shielding materials; α radiations are easily absorbed and will not penetrate the walls of common containers, but they are rarely used in medicine. All these types of radiation must be considered, it being necessary to shield containers or areas where radioactive wastes are stored.

5.1.2. Half-life

Spontaneous decay is governed by an exponential law, where fifty percent of all atoms of a given radionuclide will transform during its characteristic time period, called *half-life.* This quantity is specific for each radionuclide and cannot be changed in any way, because no physical or chemical method able to disrupt the radioactivity exists. After 1, 2, 3, 5 or 10 half-lives, the remaining atoms will be 50%, 25%, 13%, 3% and 0,1% of the original activity, respectively. The half-life of radionuclides vary in nature from a fraction of a second to billions of years. Those that are used for medical purposes, either diagnosis or therapy, have a half-life ranging from a few minutes to many years; generally short lived radionuclides are used.

5.1.3. Some Physical Data

In Table 4, are listed the radionuclides currently used as unsealed sources in research, diagnostic or therapeutic procedures in hospitals. It also contains some physical data, significative for protection: half-lives, radiation emitted, type of application (D=Diagnostic, R=Research, T=Technology, Th=Therapeutic), gamma ray constant, annual limits on intake for professional workers and the limits of concentration in water and in air for the general public.

5.2. RADIOACTIVE WASTE PRODUCTION

For the purpose of this paper we need only deal with unsealed sources, since sealed ones, generally used for brachytherapy (placed directly in tissue), teletherapy (for external irradiation of patient) or other purposes (bone densitometers, blood irradiators, gas chromatography), are stored until their complete decay, in authorised facilities other than the hospitals (see other section of this course).
Unsealed sources of radionuclides may be found in several locations within the hospital. They are used in clinical laboratories for analysing blood samples, in research laboratories for in vitro, in vivo or animal studies, and in nuclear medicine departments for both diagnosis and therapy (NCRP82).

5.2.1. Diagnosis and Research Laboratories

Agents specially targeted to an organ or organ system are labelled with radionuclides (radiopharmaceuticals) and administered in tracer amounts to the patient (2÷200 MBq), such as ^{18}F, ^{57}Co, ^{67}Ga, ^{133}Xe and ^{195}Au. In some tests, such as radioimmunoassay (RIA), small amounts of radioactive materials (0.2÷20 MBq), ^{125}I or ^{14}C or ^{3}H (liquid scintillation counting, hundreds of Bq), are added to fluids or specimens extracted from the patient. These activities produce radioactive wastes mixed with biological matrices or patient secretions (generally urine); after their complete decay they can be regarded as *infectious waste* or, sometimes, as hazardous waste containing solvents.
Many medical institutions have one or more clinical research laboratories using radioactive tracers, and producing wastes in the same amount and with the same matrices used in diagnosis.

5.2.2. Therapy

Unsealed sources of radionuclides for therapeutic uses may be found in the departments of nuclear medicine, endocrinology or radiation therapy. Relatively large activities (≥50 MBq) of these radionuclides (such as ^{131}I and ^{32}P) are used for treatment of various pathological conditions. During such procedures, the patient may be a significative source of radiation exposure and his biological liquids must be regarded, as such, as hazardous wastes. In the case of spent generator, e.g. ^{99}Mo-^{99m}Tc, it must be returned to the manufacturer.

5.3. ON SITE STORAGE FOR DECAY

Most radioactive material used in medical applications is short-lived and will decay to levels which permit them to be disposed of within a short period of time (day, month or year), depending on the half-life of the nuclides involved.

5.3.1. On Site Storage For Decay

Adequate space (properly shielded, ideally ventilated and taking fire risks into consideration) is generally made available for storage of radioactive waste on site. Storage is also a solution to the handling of contaminated bedding, clothing and equipment. Usually after a sufficient storage period, 10 half-lives, and following checks with appropriate instrumentation, these materials can be classified as non-radioactive and released from restriction after the removal or destruction of all radioactive warning signs or labels. Longer decay periods are necessary if significant levels of radioactivity are detected after this time.

5.3.2. Some Practical Aspects For Radioactive Storage

Here are briefly detailed some practical aspects related to radioactive waste storage; further details can be found in specialised issues (NCRP64, ICRP77, BRH81, Sh90).
The storage area must be secure from unauthorised removal or access. Sources must be labelled and area signs posted; facilities should be designed to provide any shielding necessary to limit external irradiation. The radionuclides must be stored in suitable (metallic) containers that are adequately shielded: radiation at 30 cm from the surface must be less than 50 μSv/h. It may be necessary to store some radioactive materials under refrigeration; flammable solvents constituting an explosion hazard, must be stored in explosion-proof refrigerators. For solid waste, covered metal canisters should be used to contain non-flammable solid wastes; plastic bags should be used as liners. Materials contaminated with radioiodine should be enclosed in two bags before storing. Records must be kept of the disposal of all radioactive wastes as evidence that regulations have been observed.

5.3.3. Long Lived Radionuclide Storage

When the radioactive material has a half-life that makes it impractical to store on site for decay (e.g. ^{14}C, ^{22}Na, ^{57}Co) or if the facility has inadequate storage space, transfer to a licensed commercial radioactive waste disposal site is required. For this reason it is necessary to distinguish between short-lived and long-lived radionuclides: in this way the user can save on much costly investment.

5.4. RADIOACTIVE WASTE TREATMENT

General principles of on-site treatment methods of radioactive wastes, are based on the fact that it is impossible to disrupt or change the radioactivity of a signed material; the only feasible treatment that can be made on site consists of:

- trying to limit the volume as far as possible
- fixing the radionuclides on another support,
- diluting the activity thus obtaining accepted concentrations for disposal (if the total annual activity released is lower than permitted limits).

In the hospital setting, care should be exercised also to ensure that radioactive and infectious wastes are segregated and kept away from ordinary trash. If waste is both radioactive and infectious, it should be sterilised before disposal as radioactive waste (see previous chapter: 3 - Sanitary wastes). Radioactive waste should be inspected for unwanted materials such as tissue or infectious material prior to (on or off site) storage for decay.
Again, during on-site storage there must no risk of a chemical reaction that might cause an explosion or the release of chemically toxic or radioactive gases. This is usually accomplished by the following precautions:

a. liquids must be neutralised (pH 6 to 8) prior to placement in the waste container;
b. containers of volatile compounds must be sealed to prevent airborne activity;
c. highly reactive materials (such as metallic sodium or potassium) must be reacted to completion before storage.

5.4.1. Volume Reduction or separation

With facilities for disposal continually diminishing, and disposal costs continually rising, it is important that users work to reduce the volume of radioactive waste generated. Compacting on site leads to large reductions in volumes of solid waste that is disposed of by transfer to a commercial burial site, with a great reduction of costs.
Users can also reduce waste designated for disposal as radioactive by carefully monitoring all waste generated and designating as radioactive only those wastes giving positive readings.

Some institutions have realised very large savings in the disposal of scintillation vials by acquiring vial crushers, separating the contents from the crushed vials, rinsing the fragments and disposing of them as non-radioactive while the vial contents are disposed of as bulk liquids.

5.4.2. Incineration

A bulk-reducing method is incineration, but this usually requires state permission. It is the method of choice for putrefiable materials, especially animal carcasses. Carcasses containing ^{14}C and ^{3}H leave very little radioactive ash, that must however be disposed of as radioactive waste. Incineration is an attractive option also when the waste material is a fuel itself, such as for example scintillation fluids prepared for liquid scintillation counting, that consist mainly of toluene or xylene, solvents with a high heat content. Naturally, incineration must be performed in compliance with regulations concerning this activity (see other sections of this course).
It must be noted that radioactive animal carcasses can also be disposed of by: burial under approved conditions, maceration and subsequent disposal as liquid waste to the sewers, preservation and storage for decay of radioactivity or transfer to a special disposal organisation.

5.5. RADIOACTIVE WASTE ON DISPOSAL

Radioactivity can be released into the environment in such a way that natural processes transfer it back to man only in such amounts so that, in combination with other sources of radiation, the resulting radiation doses are consistent with recommended limits. Consequently, radioactive waste disposal is permitted only when the waste satisfies three requirements:

1. the concentration of radioactivity released into gas or in water must not exceed limits specific for each radionuclide; the maximum concentration may be evaluated for the boundary of the restricted area and averaged over a year,
2. total annual activity disposed of is lower than fixed limits (e.g. for liquid waste it is $3.7 \cdot 10^{10}$ Bq, for USA).
3. once decayed and before disposal, the radioactive waste must be treated as conventional waste, i.e. classified depending on the contents of the waste, chemical or toxic contaminants; consequently, the deregulated radioactive wastes are still subject to state regulations governing other toxic or hazardous properties of the materials.

5.5.1. Liquid waste

Liquid waste from medical and research establishments consists of suspensions and solutions of radioactive substances. Biological waste such as excreta or macerated material is also regarded as liquid waste.
Generally the sewerage system is convenient and recommended for the on-site disposal of the low-level soluble (non toxic and not chemical) wastes remaining after counting experiments, or excreta or blood samples; sewerage cannot be used for the disposal of high-level concentrated solutions, such as master solutions used in radionuclide synthesis.
Complications arise when the material to be disposed of is also toxic or is a chemical hazard, such as flammable solvents, that are not miscible with water and should not be flushed down the drain.

5.5.2. Solid Waste

Solid wastes usually consist of used generators and contaminated syringes, glassware, laboratory clothing, linen, cleaning materials, bench covers and insoluble radioactive material, e.g. precipitates from radiopharmaceuticals.

Burial is sometimes preferred; but it requires authorisation. Users have to demonstrate that local land burial is preferable to other disposal alternatives. They have to submit information and justification (where applicable) on the type and activity of material to be buried, the packing, burial location, nature of burial site, control of the site, record keeping and radiation safety procedures. For all these reasons, burial is not yet carried out on site, but only by state boards, that collect the radioactive wastes of all users.

5.5.3. Airborne Waste

When gaseous wastes are routinely discharged into the environment, some assessment of the local conditions is compulsory to determine permissible amounts of disposal. Decisions can be made regarding the height of any stacks or the need to equip ventilation systems with filters.

6. OTHER KINDS OF HOSPITAL WASTE

6.1. WASTES THAT CAN BE DISPOSED OF WITH CONVENTIONAL URBAN WASTE.

6.1.1. General Description

This waste must not be contaminated with any biological fluids. It must come from wards that DO NOT treat patients with infectious diseases. Typical contents are:

- Waste coming from hospital kitchens and food preparation
- Left-over food from staff canteens and patient wards (patients not affected by infectious diseases)
- Paper material from administration offices
- Developed X-rays
- Packing material.

All of these can be grouped with residential refuse in terms of disposal and, as such, can be disposed of or re-cycled under the same regulations. If necessary they may be sterilized or disinfected as a precautionary measure. If facilities are available for waste separation then paper, plastic and silver from X-rays can be recuperated and the remaining waste buried in landfills or incinerated.

6.1.2. Glassware

It can be collected in separate bins and re-cycled, since 70% of the total amount is made up of top quality phleboclysis glass. Care must be taken to remove pharmaceutical residues, tubing and any needles. If the glassware is contaminated then common sense requires it to be disinfected in the workplace before disposal. The re-cycled material is normally reused in the glass or cement industry.

6.1.3. Ferrous or bulky material

This may be sent for recycling after disinfection (if necessary).

6.1.4. Masonry rubble and orthopaedic plaster-casts

The former may be reused or buried in landfills. Plaster casts can undergo the same treatment provided they do not come from isolation patients. Otherwise they must be treated as potentially infectious.

6.1.5. Garden waste

This can be used in the preparation of compost.

6.2. OTHER HAZARDOUS WASTES

Besides those mentioned so far, hospitals generate other hazardous wastes. These include used batteries, fluorescent light tubes, used car batteries and air-conditioning filters, all of which are also present in residential waste. This waste must also be discarded and collected in separate bins and sent to reputable, licensed waste handlers to ensure that their ultimate disposal is performed according to regulations.

I. APPENDIX A: REGULATIONS

Legislation regarding the subject of waste disposal is, indeed, very complex and one which deserves a separate lesson in order to be treated fully. We wish only to stress a few points.
I.A. ITALIAN AND EUROPEAN LEGISLATION: Italian requirements are derived mainly from E.C. guidelines, according to which, hospital wastes are considered as "special" and/or toxic, noxious and, as such, are subject to restrictions in both transportation and temporary storage. In particular, in a ministerial decree of 25/5/89, hospital wastes were classified and disposal systems were recommended for the diverse types of hospital waste.
I.B.U.S. LEGISLATION: E.P.A. has not issued any specific requirements regarding the transportation or disposal of hospital waste due to lack of reliable scientific data. Therefore, individual state requirements are adopted. Some states adhere to guidelines contained in the M.W.T.A., but this has given rise to considerable controversy.
However, the indications provided by this paper, if properly carried out, can help to overcome the basic and technical aspects of most current legislation, whereas from a bureaucratic point of view (forms, registration, declarations etc.) obviously state or national requirements must be complied with.

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TABLE: *Characteristics of some unsealed radioactive sources used in medicine*

Radionuclide (symbol)	Half-life	Nuclear Radiation Emitted	Applications	Gamma Ray Constant♠ [μSv·m²·h⁻¹·MBq⁻¹]
Hydrogen 3 (^{3}H)	12.3 years	β-	D, R, T	-
Carbon 14 (^{14}C)	5730 years	β-	D, R, T	-
Fluorine 18 (^{18}F)	110 min	β+	D, R	0.1851
Sodium 22 (^{22}N)	2.6 years	β+; γ	D	0.3590
Phosphorus 32 (^{32}P)	14 days	β-	D, R, Th	-
Sulphur 35 (^{35}S)	87 days	β-	D	-
Chromium 51 (^{51}Cr)	28 days	γ	D	0.00632
Cobalt 57 (^{57}Co)	271.8 days	γ	D	0.04087
Iron 59 (^{59}Fe)	45 days	β-; γ	D	0.1787
Copper 64 (^{64}Cu)	12.7 hours	β+; β-; γ	D	0.03514
Gallium 67 (^{67}Ga)	78 hours	γ	D	0.03004
Molybdenum 99 (^{99}Mo)	66 hours	β-; γ	D, R	0.03046
Technetium 99m (^{99m}Tc)	6 hours	γ	D	0.03317
Indium 111 (^{111}In)	2.8 days	γ	D	0.1356
Iodine 125 (^{125}I)	60 days	X; γ	D, R	0.07432
Iodine 131 (^{131}I)	8 days	β-; γ	D, Th	0.07640
Xenon 133 (^{133}Xe)	5.2 days	β-; γ	D	0.02783
Gold 198 (^{198}Au)	2.7 days	β-; γ	D, Th	0.07881
Thallium 201 (^{201}Tl)	3 days	X; γ	D, R, T	0.02372

TABLE – continue

Radionuclide	ALI♥ [MBq·year⁻¹]	Water ♣ Concentration [MBq·m⁻³]	Air ♣ Concentration [Bq·m⁻³]
Hydrogen 3	1000	0.370	37
Carbon 14	40	0.011	1.1
Fluorine 18	400	-	-
Sodium 22	7	0.0022	0.333
Phosphorus 32	8	0.003	0.185
Sulphur 35	70÷100♦	0.037	1.11
Chromium 51	400÷500♦	0.185	11.1
Cobalt 57	60÷90♦	0.022	0.33
Iron 59	10	0.0037	0.185
Copper 64	200	-	-
Gallium 67	80	0.037	3.7
Molybdenum 99	10÷30♦	-	-
Technetium 99m	1000	-	-
Indium 111	-	0.022	3.33
Iodine 125	1	0.00074	0.111
Iodine 131	0.8	0.00037	0.074
Xenon 133	-	noble gas	185
Gold 198	10	-	-
Thallium 201	300	0.074	11.1

Notes: ♠ source: ORNL/RSIC-45/R1, ed. Unger L.M., Trubey D.K.; ♦ Depending of the chemical composition of radionuclide ; ♥ source: ICRP Publication n.61; ♣ Source: U.S. Nuclear Regulatory Commission, 1988