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Notes on the Transport of Radioactive Materials

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NOTES ON THE TRANSPORT OF RADIOACTIVE MATERIALS

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A. Principles underlying the IAEA Regulations for the Safe Transport of Radioactive Materials

Introduction

The International Atomic Energy Agency (IAEA), based in Vienna, is a specialised organisation of the United Nations designated with responsibility for providing an international forum for discussion and standardisation of procedures relating to all aspects of radioactive material and nuclear energy.

The Agency publishes the **'Regulations for the Safe Transport of Radioactive Material' (Safety Series No 6)**, an agreed code of practice which has been incorporated into the international codes for the carriage of dangerous goods of the various modes of transport, as well as into most national legislation controlling domestic movements of radioactive material. The most recent edition was published in 1985 and amended in 1986. This edition of the 'Regulations' is likely to be incorporated into all international transport codes on 1st January 1990. Meanwhile, the 1973 Revised Edition (as amended) is being used.

Radioactivity

In order to understand the principles underlying the IAEA Regulations it is necessary to appreciate some of the unique properties of radioactive materials.

Most materials in everyday use are composed of atoms which are physically stable. That is to say the atoms themselves do not change over time. Iron may rust or dead leaves decompose but the original atoms comprising these materials are still present. They are merely recombined with other atoms in different ways, i.e. they have been subjected to chemical processes.

There are certain types of atoms, however, which are not physically stable but spontaneously disintegrate often to form completely different atoms. This disintegration is accompanied by an emission of 'Ionising Radiation', and it is this phenomenon which is known as radioactivity.

Radioactivity is a physical process and it is not affected by chemical processes. Consequently, all chemical compounds of a radioactive element will exhibit identical radiation emissions.

There are 3 main types of radiation, termed **alpha, beta** and **gamma** but some radioactive materials emit other types of radiation such as X-rays and neutrons. Alpha radiation is potentially the most damaging to human tissue, but it is the easiest to shield against - a sheet of paper will suffice - whereas beta radiation is stopped by thin metal or glass. The most penetrating form is gamma radiation and this may require substantial thicknesses of lead or concrete to absorb it effectively.

As they disintegrate, radioactive atoms can emit any combination of the three forms of radiation with a variety of differing energies. However, for a given type of radioactive atom (termed a **'radionuclide'**) the same type(s) and energy of radiation are always emitted. Thus, the amount and quality of radiation emitted by each radionuclide can be accurately predicted and compounds with

very precise levels of radioactivity can be prepared to perform quite specific tasks. In this way the beneficial effects of radioactivity can be fully exploited with no more radioactive material being present than is necessary to do the job. It also means that appropriate safety measures can be specified for each radionuclide and it is on this basis that the IAEA Regulations have evolved.

Measurement of Radioactivity

An important feature of radioactivity is the relative ease with which it can be measured. Indeed, it is significantly easier to do this with relatively inexpensive, portable equipment, than it is, say, to determine the flashpoint of a flammable liquid or the toxicity of a substance by animal experimentation. Measuring devices can be used to monitor and record the level of radiation. Each time a radioactive atom disintegrates a precise amount of radiation is emitted. The number of times this happens per second is termed the **'activity'** of the radionuclide and is measured in units called **Becquerel** (symbol Bq), such that 1 disintegration/second = 1 becquerel. (The activity was formerly measured in units termed **'Curies'** (Ci) which are still in use in certain countries). The Regulations define radioactive materials as being those with an activity of more than 70,000 becquerel per kilogram (70 kBq/kg).

The effect of ionising radiation on tissue depends on the type of radiation, its energy and the amount of radiation absorbed. Properly designed packages can emit very limited amounts of X and/or gamma radiation (but the other types of radiation may have to be considered if the radioactive contents of a package should escape). **'Dose equivalent'** is a term used to determine the relative effect of different types of ionising radiation on tissue and for external sources it is easily measured with suitable instruments. The value is measured in units termed **Sieverts** (symbol Sv). (Again the former units, called **'rem'**, are still being used in certain countries).

The IAEA Regulations are based on values measured in becquerels and sieverts (these being the standardised units of the International System - SI) with equivalent values given in curies and rem, rounded down as necesssary.

The Basis of Regulation for Transport

The Regulations contain a **'Table of Radionuclides'** which for each radionuclide lists two values, termed **'A1'** and **'A2'**. These values form the basis used throughout the Regulations for limiting radiation levels and potential hazards.

Type A Packages

The A2 value is the maximum activity that can be safely carried in a 'Type A' package (other than when in 'special form'). That is, a package meeting the criteria for Type A may contain an unspecified quantity of radioactive material provided the level of radiation emitted by that quantity does not exceed the A2 value. Equations are included for the calculation of A2 values for mixtures of radionuclides. Type A packages are designed to withstand the normal level of rough handling that may occur during international transport.

Special Form Material

If the radioactive material is prepared as a specially designed and approved non-dispersable solid (i.e. not as a powder or loose aggregate) or is sealed in an approved robust capsule, then it is classed as **'Special Form'** material. Because these forms are less likely to be dispersed in the event of damage to the package in which they are contained, a greater activity is permitted in a Type A package and for this purpose the A1 value is used.

Type B Packages

Should a quantity of material need to be consigned which has an activity greater than the A2 value, or the A1 value if in Special Form, then a Type B package must be used. These are more sturdy and robust than Type A packages and are designed to withstand severe transport accidents. Their design must be approved either unilaterally by the national competent authority of the country of origin, in which case they are designated **Type B(U)** packages, or multilaterally by the competent authority of each country through which the consignment will travel - **Type B(M)** packages.

Excepted Packages

If the levels of activity of the material in each package do not exceed certain specified limits then the package may be **'Excepted'** from certain of the requirements of the Regulations, in particular labelling. This is permissible because the maximum activity limits are many times smaller than the A1 or A2 values and the external radiation when packaged for transport is so minute that no hazard is likely to arise. Excepted radioactive materials include radioactive materials in limited quantities, instruments, manufactured articles and empty packagings.

Packaging Requirements and Tests

The Regulations lay down stringent requirements to be met by each design of package, with further specific criteria for each package type - Excepted, Type A, Type B(U) and Type B(M). The suitability of a package design is determined by its ability to protect its contents during a series of performance tests.

For example, the 'Water Spray Test' simulates the inadvertent exposure of a package to extreme rainfall conditions - a tropical storm - or to swamping aboard ship. This is followed by the 'Free Drop Test' which determines the (wet) package's ability to withstand being dropped from a height by a crane. Other tests include the 'Stacking Test' and the 'Penetration Test'. A package is considered to meet the requirements of the Regulations if the package's ability to shield and contain its contents is not impaired as a result of the tests. (It should be pointed out, however, that provided the handling and stowage requirements specified in the IAEA Regulations and the other international transport codes are carefully followed, packages containing radioactive materials should never be exposed to these conditions).

The purpose of packaging is two-fold: to **contain** the radioactive material and prevent its dispersal, even in the event of damage to the package, and to **shield** the contents. The second function arises because radiation is able to penetrate solid materials to a certain extent and suitable materials must be

incorporated in the package design to reduce the amount of radiation reaching the external surface. Nevertheless, a residual level of radiation may be detectable and the Regulations contain appropriate measures to ensure that these levels do not exceed safe limits.

Transport Index and Package Category

The maximum level of radiation detectable at a distance of 1 metre from the external surfaces of the package determines its **'Transport Index'** and this together with the maximum radiation level at any point on the surface of the package determines the **'Category'** under which that package should be consigned.

The category of each package - 'I-White', 'II-Yellow' or 'III-Yellow' - is declared by affixing the appropriate label on opposite sides. The name of the radionuclide must be shown on the label together with the maximum activity of the package contents. For consignments in Categories II and III the Transport Index must also be shown. This is the basic information required respectively to identify the contents, to assess the hazard posed by the contents and to determine the residual radiation level of the package. Using this information, particularly the Transport Index, the appropriate stowage and segregation requirements can be observed both in storage and during transit, as prescribed in the IAEA Regulations and the applicable transport code.

Exclusive Use

Should a package possess a Transport Index greater than ten it must be transported in a conveyance which is used exclusively for the carriage of goods between the consignor and the consignee(s). The conveyance is then said to be under 'exclusive use' - a condition which ensures that only the properly informed parties to the consignment are involved in the loading and unloading of goods from the conveyance and that the appropriate safety precautions are observed for these higher levels of surface radiation. 'Exclusive Use' also allows greater accumulations of TI to be carried.

Documentation

Apart from the labelling of packages and the placarding of conveyances, the presence of radioactive materials in a consignment must also be clearly indicated on the accompanying documentation. All hazardous cargoes must be described on a 'Dangerous Goods Declaration' in which the consignor certifies that the goods are described, packaged, labelled and marked in accordance with the appropriate regulations. The IAEA Regulations specify the wording of the declaration to be used for radioactive materials and also the precise information to be shown on the document.

Subsidiary Hazards

In addition to possessing the property of radioactivity, radioactive materials retain the chemical properties of their non-radioactive conterparts. For example, a toxic substance can be made radioactive but will still possess its original properties, including that of being poisonous. The radioactive characteristics are additional. Therefore it is necessary to take account of any other hazardous properties that the radioactive material may possess when preparing a consignment for transport. Whatever the other hazards may be, the

radioactive designation always takes precedence (other than in the case of 'excepted' radioactive materials).

Transport Regulations

The basic rules governing the transport of radioactive material have been drawn up by the International Atomic Energy Agency (IAEA). These have been published, together with explanatory and advisory material, as follows:

IAEA Safety Series No 6, Regulations for the Safe Transport of Radioactive Material;

IAEA Safety Series No 7, Explanatory material for the Application of the IAEA Transport Regulations;

IAEA Safety Series No 37, Advisory Material for the Application of the IAEA Transport Regulations.

These regulations, adapted and rearranged where necessary, are reproduced in the regulations for each mode of transport:

Transport by air - the International Civil Aviation Organisation (ICAO), Technical Instructions for the Safe Transport of Dangerous Goods by Air (also shown in the IATA Dangerous Goods Regulations).

Transport by sea - the International Maritime Organisation (IMO), International Maritime Dangerous Goods Code.

Transport by rail (within most of Europe) - International Regulations Concerning the Carriage of Dangerous Goods by Rail (RID).

Transport by road (within most of Europe) - European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR).

In addition to the modal requirements for international transport, it is always necessary to follow the national regulations of every country involved. For example, in the United States of America reference must be made to:

Code of Federal Regulations, Title 49 (49 CFR).

B. Reference information

Radioactive Material Some substances are so feebly radioactive that no hazard can arise. For the transport regulations, radioactive material is defined as any material with a specific radioactivity more than 74 kBq/kg.

Fissile Materials Containers of fissile materials will have a Transport Index and will require labels according to the category (I, II or III) just as for other types of radioactive material. However, the transport of fissile materials is highly specialised and strictly controlled by government regulations. Fissile materials will be rarely encountered and the requirements for them are not covered by the video nor in these notes.

Half Life Radioactive material decays at a rate determined by nature. The half life is the time it takes for the activity to be reduced by half. For example, if half the radioactivity decays in 3 days - then, of the amount remaining, half will decay in a further 3 days. The half life of various substances varies from a few seconds to many thousands of years.

Special Form This term refers to radioactive material where there is an extremely low risk of contamination occurring. This may be due to its being in massive, solid form or to its being encapsulated in a robust sealed container which can only be opened by destroying it. For such materials a larger level of activity is permitted in a Type A package.

Labels Packages containing "excepted" radioactive materials do not require a "radioactive" label. All other packages of radioactive materials must have the correct diamond shaped label corresponding to their category (i.e. I, II or III) on two opposite sides. Some packages intended for transport by air may need a "cargo aircraft only" label (this requirement must also be shown on the shipping documents). Packages containing liquid radioactive materials do not usually require a "this way up" label.

Markings Packages containing "excepted" radioactive material do not require any special external markings. All other packages containing radioactive materials must be marked as follows:

a) The proper shipping name of the contents and the corresponding UN identification number.

b) The name and address of either the shipper or the consignee.

c) The gross mass, if this exceeds 50 kg.

d) The type of package, i.e. "Type A", "Type B(U)" or "Type B(M)".

Transport Documents

The documentation must contain a signed declaration from the consignor or shipper to say that the consignment has been properly described and is correctly packaged, marked and labelled. For air transport this declaration must appear on the "Dangerous Goods Transport Document".

The transport document must also contain the following information:

a) The words "Radioactive Material" (unless these words are included in the proper shipping name).

b) The proper shipping name and identification number from the UN list.

c) The name or symbol of the radionuclide(s).

d) The activity in each package.

e) A description of the physical and chemical form of the material, or whether it is in special form.

f) The identification mark for each competent authority certificate applicable to the shipment.

g) The category of the package (i.e. I, II or III).

h) For categories II and III, the Transport Index.

i) Details of any special instructions for stowage, handling, routing, etc.

Excepted Packages

If the total activity and the surface radiation level are both within specified very low limits, and certain other conditions are met, packages may be termed 'excepted'. (Note that such packages were previously called 'exempted'). Excepted packages are not excepted from all the requirements. Categorization, labelling and marking are not required; but a correct description must appear on the transport documents, although a 'shipper's declaration' is not necessary. The requirements for Type A and Type B packages do not apply, but certain minimum packaging requirements must be met.

It should be remembered that the contents of such packages are still radioactive. If a package is damaged, appropriate precautions need to be taken.

In some cases, there may be local requirements to label excepted packages and/or to document them in the same way as other packages of radioactive materials. Such requirements will need to be followed even though they are not in conformity with the regulations of the International Atomic Energy Agency.

Exposure to Radiation

If all the applicable rules are followed, transport workers will not be exposed to harmful quantities of radiation. However, it is prudent never to be unnecessarily exposed to radiation. The main methods by which workers can

reduce radiation exposure are (1) keeping the time of exposure as short as possible, (2) keeping the distance from the radiation source as large as possible.

TIME — Keep contact with packages short.
Do not loiter in the immediate vicinity of packages.
When moving packages, handle without delay.
Do not carry on long conversations near packages.
Do not use packages as a table for completing paperwork.

DISTANCE — Try to avoid leaving packages near to desks, offices or other occupied areas.
Store packages at the furthest reasonable distance from working areas.
When moving packages use a cart or truck, if possible.

Transport Index

The Transport Index is the maximum radiation dose rate at a distance of 1 metre from the package surface, measured in μSv/h and divided by 10.

Categories of Packages

Category I - White : any package with a surface radiation level not exceeding 5 μSv/h; such low levels indicate an insignificant radiation hazard but if the package is damaged there could be a contamination hazard.

Category II - Yellow : any package with a surface radiation level between 5 μSv/h and 500 μSv/h or any package with a transport index of 1 or less.

Category III - Yellow: any package with a surface radiation level between 500 μSv/h and 2 mSv/h or any package with a transport index of more than 1, with a maximum of 10.

It must be emphasised that the package category depends on both the transport index and the surface radiation level.

Dosemeters A dosemeter can be used to measure radiation dose levels. However, special training is needed to use such instruments correctly and the instruments require frequent calibration and checking. If used by untrained personnel misleading results may be obtained.

The evaluation of possible radiation hazards involves more than just meter readings, particularly in relation to damaged packages or where contamination is involved. Any such situation must be dealt with by experts.

Units

Activity -

Values of activity should be given in the standardised (SI) unit, the becqueral (Bq), or multiples of the becquerel. Values using the

old unit, the curie (Ci), can also be given - but should appear after the SI value. In all cases the units used must be clearly shown.

1 Bq = 1 disintegration per second = 2.7×10^{-11} curie.

or 1 TBq = 27 Ci and 1 mCi = 37 MBq

Radiation dose -

Values of radiation dose should be given in the standardised (SI) unit, the sievert (Sv) or submultiples of the sievert. Values using the old unit, the rem, can also be given - but should appear after the SI values. In all cases the units used must be clearly shown.

1 Sv = 100 rem

or 1 rem = 0.01 Sv = 10 mSv

Prefixes -

Submultiples			Multiples		
10^{-3}	milli	m	10^{3}	kilo	k
10^{-6}	micro	μ	10^{6}	mega	M
10^{-9}	nano	n	10^{9}	giga	G
10^{-12}	pico	p	10^{12}	tera	T

C. Radioactivity in transit - a questionnaire

1. What is the purpose of the regulations?
A To ensure the safety of the public and of those who have to handle radioactive materials.

2. Why must delays be avoided?
A Delays may render the product useless and could, in some cases, put patients at risk.

3. What are the natural sources of radiation?
A Rocks, soil, water, vegetation, sun, food and our own bodies.

4. What are some sources of man-made radiation?
A X-rays, luminous watches, nuclear power plants, medical and industrial products.

5. What is the meaning of "half life"?
A The time taken for half the radioactive atoms in a substance to decay.

6. Why is this important in health care products?
A If the decay proceeds too far, the product is useless.

7. Can radiation be seen or felt?
A No.

8. Can radiation be detected with instruments and its intensity measured?
A Yes.

9. What are the three main types of radiation?
A "alpha", "beta" and "gamma".

10. What type of radiation can there be from an intact and properly designed package?
A There will be no "alpha" and no "beta", but there may be a small amount of "gamma" radiation.

11. What are the two kinds of hazard to the human body from radioactive materials?
A External radiation from sources outside the body and internal radiation from material which has entered the body.

12. How long will the hazard continue from a) external radiation b) internal radiation?
A a) The hazard from external radiation will continue until the source is removed.
b) The hazard from internal radiation will persist until the material is passed out of the body or it decays.

13. What are the four basic principles used to minimize radiation hazards?

A 1 - Shielding, (which reduces the intensity of the radiation);
2 - Distance, (the further away you are the less the intensity of the radiation);
3 - Time (keep exposure time to a minimum);
4 - Containment (in approved and undamaged packaging).

14. a) What is the physical law which relates the level of radiation to a change in distance from the source?

A The inverse square law, ie, the radiation level varies in inverse proportion to the square of the distance from the source.

b) If you double your distance from a source, how much is the radiation level reduced?

A To a quarter.

c) If distance from a source is increased by four, how much is the radiation level reduced?

A To one sixteenth.

15. What are "special form" capsules and materials?

A These are indispersable solids or robust containment capsules.

16. What is the purpose of the radioactive package label?

A To clearly identify the contents as radioactive, to classify the package, to show the principal radionuclide and the activity of the contents.

17. What are the three basic types of packages?

A Excepted, Type A, Type B.

18. What name was previously used in place of "excepted"?

A "Exempt"; this name is still in use where the latest IAEA regulations have not yet been adopted.

19. Do excepted packages require any external label?

A No.

20. Why is this?

A Because the level of radiation and the amount of radioactivity are so low that they present no significant hazard.

21. What sort of label is required for a Type A Category I package and what does this signify?

A. A White label; the radiation level is low enough for few restrictions to be needed for handling or stowage.

22. What sort of label is required for higher categories?

A Yellow II or Yellow III

23. Which category represents the highest level of hazard?

A Yellow III.