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TRANSPORT OF RADIOACTIVE MATERIAL

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I. THE TRANSPORT OF RADIOACTIVE MATERIAL : HAZARDS AND REGULATIONS

1.1. Beginnings and growth of the transport of radioactive materials

The transport of radioactive substances is not of recent origin. Even before radioactivity was discovered, uranium ore was already being shipped. Uranium was used from the early 19th century in the ceramics industry for the production of enamels and porcelain.

However, shipments of substances emitting ionizing radiation really began to increase after the discovery of artificial radioactivity and nuclear fission ; the discovery of artificial radioactivity led to the use of radioisotopes in scientific research, then in medicine and finally in industry. Since radioisotopes are used in many places at some distance from the production centres, shipments often had to be made under great time pressure owing to the short half-lives of some radionuclides, particularly those used in medical diagnosis.

The discovery of nuclear fission led to the setting-up of experimental "atomic piles" and then to the construction of nuclear power reactors which necessitated the development of a fuel-cycle industry encompassing all the stages in the life of the fuel from uranium ore to the reprocessing of irradiated fuel and the storage of waste and requiring shipments of radioactive materials between the stages of that cycle.

The number of shimpments increased very rapidly from the late 1940s onwards and, by the end of the 1960s, the packages shipped in the world exceeded a million. Nowadays, this number is of the order of 10 millions (3 for the USA, 2 for the European Community). Around 90% of the shipments are of medical radioisotopes, less than 5% comprise nuclear fuel cycle materials, including radioactive waste.

1.2. Transport of radioactive materials and transport of dangerous goods

Although these figures are high, they account for only a very small part, of the order of 2% of all the "dangerous goods" shipped within and between countries.

The term "dangerous goods" covers an extremely wide range of products : explosive materials, flammable substances, toxic substances, corrosive substances, etc. In fact the potential hazards arising from some of these products can exceed those associated with radioactive materials. It is only natural, therefore, that radioactive materials should be covered by the regulations goveming the transport of dangerous goods and form one of the classes (class 7) of goods in that context. Certain principles and general rules relating to the transport of dangerous goods are, moreover, as applicable to radioactive substances as they are to goods in the other classes.

Furthemore, radioactive materials may have other dangerous properties such as chemical toxicity, corrosiveness and explosiveness. Such risks are taken into account by the transport regulations. In practice the transport of such substances must also comply with the provisions in other transport regulations applicable to these properties.

1.3. Hazards associated with radioactive materials

Radioactive materials give rise to quite specific hazards during transport.

- The hazards of external irradiation resulting from the exposure of persons to radiation emitted by an inadequately shielded radioactive substance,

- the contamination hazards arising from the transfer of radioactive substances to the environment, which is likely to occur if dispersible radioactive material escapes from the containment provided by the packaging. This may lead to the internal contamination of members of the public or of the personnel involved in transport operations through inhalation or ingestion,

- the criticality hazard, in the case of fissile materials, that is to say, the risk of initiating an uncontrolled chain reaction following the accidental accumulation of fissile materials exceeding the critical mass,

- the release of the heat caused by radioactivity must aslo be taken into account and the regulations provide both for the effective dissipation of heat to preserve package integrity and the limitation of package temperatures on accessible surfaces in order to prevent persons and goods from suffering damage.

1.4. Potential hazards associated with the transport of radioactive materials

As in the case of all shipments of dangerous materials, it is when the packaging loses its capacity to contain the radioactive material or attenuate adequately the radiation emitted that the hazards previoulsy referred to are likely to arise. This may happen, for example, through an accident or incorrect packaging. However, very slight risks can exit during the transport of radioactive materials even when no accident occurs, and they have to be taken into account in the transport regulations.

In a study of the potential hazards associated with shipments of radioactive materials it is necessary to take into consideration both accident and routine conditions :

Accident conditions

The consequences of destruction of a packaging vary considerably according to the extent of the destruction, the characteristics of the material being transported, the level of radioactivity contained within the package, the type of radiation emitted by the material and the material's capacity to disperse.

In the case of a non-dispersible solid which emits only alpha radiation, for example, the risk of both contamination and irradiation is very slight. Even in the case of a dispersible solid, the contamination hazard is slight as long as the material is only slightly radiotoxic.

The packaging therefore has to be suited to the material to be shipped and the graded approach of the International Atomic Energy Agency (IAEA) regulations (ref. 1) results in four primary types of package : excepted, Industrial, Type A and Type B which are used according to the quantity and nature of the radioactive contents.

Routine transport

Under routine transport conditions the packaging obviously remains intact throughout the transport operation and no radioactive material escapes. This also applies to other dangerous materials, but two aspects make the case of radioactive materials somewhat different.

(a) for penetrating radiation attenuation follows an exponential curve. This means that, in order to reduce residual radiation to a value which is virtually zero, it would be necessary for the packaging to include a very great thickness of absorbent materials. In practice, the regulations lay down limiting values for the radiation dose rate emitted by the package. These values are such that the resulting doses to workers and the public are low and consistent with the International Commission on Radiological Protection (ICRP) system of dose limitation.

(b) slight radiaoctive contamination of the outer packaging surface is possible in some instances. This is the case, for example, with large transport packages of irradiated fuel (commonly called "fuel flasks"), which are loaded under water in storage ponds in order to protect the operators from the radiation. On leaving the ponds, the flasks are cleaned, but a small amount of residual contamination may remain. The regulations lay down maximum values for such contamination.

1.5. The need for specific regulations

It became evident very early on that there was a need for specific regulations to ensure that radioactive materials would be transported safely and, in particular, that an adequate radiation-protection level would be maintained both for the transport workers and for the public. Rules already existed for the transport of dangerous goods (explosives, highly toxic products, etc) the potential hazard of which was comparable to, or even greater than, that of radioactive substances. The radiation protection principles were likewise well know, but it was necessary to adapt them to transport conditions, just as transport conditions had to be adapted to meet radiation protection requirements.

These requirements were initially developed for the laboratories where radiaoctive substances were handled and the for nuclear reactors and the fuel-cycle plants. In all these fixed installations, the environmental conditions were known and the work was carried out only by specialized personnel who have received suitable training. In the case of the transport of radioactive materials, the materials were and still are shipped by various means of transport and by widely varying routes. The use of radioisotopes in medicine would be seriously compromised if it were necessary to restrict the means of transport to be used or the routes to be followed. Furhermore, even on the routes chosen, accidents may be caused by other vehicles.

The first national regulations for the transport of radioactive materials ("Radioactive Substances Act" put into effect by the British Government) appeared in 1948 and contained the basic elements for regulating transport safety. However, since it was set up in 1957, the IAEA, a specialized agency of the United Nations, has assumed the task of drawing up recommendations at international level to enable national regulations to be harmonized and to facilitate international shipments of radioactive materials.

It should be stressed that it was in connection with the transport of radioactive materials that the first regulations intended to be applied by all countries in the world were prepared, this can be explained by the extent of international transport operations involving radioactive materials.

1.6. Safety regulations and physical protection of nuclear materials

Allowance also has to be made for another hazard of an altogether different nature associated with the shipment of certain radioactive materials, namely, the risk of malicious acts.

The same risk is also present in the shipment of other dangerous materials. However strong a packaging may be, it can always be opened deliberately during transport since it is designed to be opened on arrival. However, in the case of heavy packagings of the type used to transport irradiated fuel, the weight of the components (a lid can weigh several tonnes) acts as its own protection.

This is covered by special regulations at national level and the International Convention on the Physical Protection of Nuclear Materials. The signatory States ot that Convention undertake to apply certain levels of physical protection during international shipments of nuclear materials. They also agree not to undertake imports or exports if these levels of protection are not observed throughout the corresponding international shipments.

II. REGULATIONS, THE BASIC PRINCIPLES

2.1. Basic principles of radiological protection

The IAEA Regulations for the Safe Transport of Radiaoctive Material are traceable to, and based upon, the recommendations of the ICRP. These recommendations set out a system of dose limitation based upon three basic principles of radiation protection. These principles are :

- Justification, no activity giving rise to exposure to ionizing radiation should be undertaken unless it produces a positive net benefit,
- optimisation : exposure to radiation must be kept as low as reasonably achievable (ALARA),
- individual dose limits, the exposure of workers and the general must not exceed prescribed limits.

The IAEA regulations require the relevant competent authorities to arrange for periodic assessments of the exposures arising from the transport of radioactive material to be made in order to ensure that the above system of dose limitation is being complied with.

It is agreed that the transport of radioactive material is justified. Transport is an important component of national and international programmes for the use of radioactive materials in medicine, agriculture, industry, research and the generation of nuclear power, justification of transport is a corollary of the justification of the use of radioactive material.

Work on the optimization of protection in the transport of radioactive material is continuing in the IAEA and its member states but it seams doubtful, in view of the low collective doses involved (see appendix), that the implementation of alternatives to the IAEA provisions will be really necessary. Nevertheless, Radiation Protection Programmes, including optimization, will be required in the next edition of the IAEA regulations forcasted late 1996 and to be implemented around 2000. The specific provisions of the IAEA regulations deal primarily with requirements related to the design and testing of packages and experience has shown that compliance with the IAEA regulations ensures a high degree of safety and low radiation doses.

The framework for the incorporation of the, then current, recommendations of the ICRP (ICRP 26, ref. 2) into the 1985 edition of the IAEA transport regulations was laid down by an IAEA advisory group in 1979. Following the publication of ICRP 60 (ref. 3), an IAEA technical committee established a programme of work to incorporate this system of radiological protection into the next edition of the transport regulations.

2.2. Basic principles of the IAEA regulations

The regulations contain the techical and administrative provisions necessary to guarantee an acceptable level of safety without over-complicating the performance of transport operations or burdening those involved with an excessive amount of administrative detail. The regulations aim to protect people, property and the environment by containing the radioactive material, controlling radiation levels, safely dissipating heat and preventing accidental criticality during transport.

This protection is achieved in practice by a combination of measures which ensure that the packaging is appropriate to the quantity and nature of the radioactive contents and by certain simple handling, storage and stowage precautions. Safety by virtue of design is preferable to safety dependent on operational controls because the former relies to a much lesser degree on human intervention and is therefore less influenced by human errors. As far as practicable therefore, the aim is to achieve the requisite safety standard through the design of the package, thus reducing operational controls to a minimum.

The regulations, therefore, do not impose generally the use of special vehicles or specific routes but ensure that safeguards appropriate to the nature and quantity of the radioactive material are "built in" to the design of the package. Full allowance is made in doing this for the possibility that severe accidents may occur in transport.

Radiation and release limits from packages under both normal and accident conditions of transport are prescribed and design performance standards, independent of the means of transport by which the package may be carried, are specified. A graded approach to package design and testing requirements is adopted and these requirements become more stringent as the hazard posed by the radioactive contents increases. This results in four types of packages being defined : Excepted, Industrial, Type A and Type B.

The various limits for the control of releases of radioactivity are based upon the activity contents limits for Type A packages. For each radionuclide, two activity limits are determined, designated A1 for non-dispersible material and A2 for dispersible material. These limits are also used for other purposes in the regulations such as specifying Type B package release limits, and specifying the contents of Industrial and Excepted packages. The limiting values for each radionuclide are calculated from consideration of the possible exposure pathways according to various accident scenarios. As an example, the exposure of a person staying 30 minutes at one meter from a dammaged package is limited to 50 mSv. The activity contents limits for Type A packages, A1 and A2, are then radionuclide dependent. For the cobalt 60 A1=A2=0.4TBq, for plutonium 239 A1=2TBq and A2=0.0002TBq.

2.3. *Package types*

(a) Excepted packages

Excepted packages contain quantities of radioactive material which are sufficiently small to allow their exception from many of the specific design and use requirements applicable to other package types. For solid materials the package limits are 10^{-3} A1 or 10^{-3} A2. Their radioactive content is so limited that even if their contents were to be released during transport the potential hazard would be very small. Therefore they are not designed to withstand an accident or even an incident. Such packages, however, must meet general design requirements to assure the safe handling and strowage of the package, and to exclude adverse effects of shock, vibration, collection and/or retention of water and degradation of the packaging materials. Hundreds of thousands of Excepted packages are transported each year. Typical contents of Excepted packages include radioisotopes for research or medical diagnosis, and radioluminescent clocks or compasses.

(b) Industrial packages

Industrial packages are used to transport materials of high bulk but low radioactivity, such as mineral ores, and certain non-radioactive objects having low levels of surface contamination. Some of these materials could otherwise be carried in bulk. They provide only a low internal radiation hazard either because the radioactivity is low or because it is not easily dispersed. There are three grades of Industrial package (IP-1, IP-2 and IP-3), graded in relation to the hazard posed by their contents. Tests are specified in the regulations to ensure that they are sufficiently strong to withstand an incident but not necessary a severe accident.

(c) Type A packages

Many Type A packages carrying a variety of radioisotopes for medical and industrial use are transported. They are intended to provide a safe, economical means for transporting relatively small quantities of radioactivity (less than A1 or A2) and although the limits of radioactivity specified are less restrictive than for Excepted packages they are still sufficiently low that they would create little risk from external radiation or contamination even in the event of a release. They are expected to retain their integrity under the kind of abuse considered normal during transport, being dropped during loading or unloading, having other cargo stacked on top of them, being punctured, and being exposed to rain. They must satisfy tests to demonstrate these qualities but are not designed to withstand a severe accident.

The majority of Type A packages are used for the transport of small quantities of radiopharmaceuticals. Typical packaging for these consists of a sealed glass phial "penicillin bottle" container holding the material, a lead pot to provide shielding, absorbent material, an intermediate metal canister, polystyrene packing material, and an outer cardboard box. Although the regulations do not formally provide for Type A packages to survive serious transport accidents, experience indicates that in practice many of this type are capable of doing so.

(d) Type B packages

Type B packages are used to carry the largest amounts of radioactivity. It is required that these packages be able to withstand the effects of severe accidents and must demonstrate their ability to satisfy a range of demanding tests for resistance to impact, penetration, fire engulfment and water immersion.

Each design of Type B package must be approved by the Competent Authority of the country in which the package was designed and under some circumstances by the Competent Authority of each country through or into which it is shipped. Type B packages are used for carrying radioisotopes, irradiated nuclear fuel and similar highly radioactive materials.

Type B package designs, although all are certified as being in accordance with the regulations, vary widely. Some portable radioagraphic containers weigh only 15kg whilst irradiated nuclear fuel flasks may weigh 100 tonnes. The numbers of movements involved also vary widely, radiography sources being transported much more frequently than irradiated fuel flasks.

(e) Packages containing fissile material

Under certain conditions some radioactive material can initiate a self-sustaining neutron chain reaction producing much heat and radiation. This state is called "criticality" and the materials are called "fissile materials". The consequences of such a criticality accident would be serious and the regulations impose extra requirements on packages containing fissile material.

This is done for excepted packages by severely limiting the quantity and form of the contents having regard to their fissile properties as well as their radioactive ones.

For the other three package types the regulations provide that all fissile packages must be shown to be safe under any conditions likely to be encoutered during transport. To this end the packages are subject to the stringent tests for Type B packages and assessed on criticality related criteria. The number of packages allowed to accumulate in one location is limited. A safety factor ensures that even if the permitted number of packages is exceeded a criticality accident would not occur.

Every design of package to carry fissile material must be approved by the Competent Authority of the country in which the package is designed, and by the Competent Authority of each country through or into which it is shipped.

2.4. Package labelling

Other than excepted packages, which are not labelled externally, packages are classified into three categories. These categories are defined in terms of the radiation levels which may be encountered at the surface of the package, and in terms of a quantity known as the Transport Index which is based on radiation and criticality criteria and used to control the accumulation of packages. In order to simplify recognition and facilitate control, there is a different label for each category. Each label includes the trefoil, an easily identified and understood symbol, but they differ in termes of colour (white or yellow) and in the presence or absence or red stripes.

Excepted packages and Category I (not more than 0,005 mSv/h at any point on external surface) - White label packages have low external radiation levels, and they can be handled and transported without special precautions.

Category II (0,005 to 0,5 mSv/h) - Yellow label and Category III (more than 0,5 mSv/h) - Yellow label packages (with 2 and 3 red stripes, respectively) indicate higher radiation levels. The number of such packages permitted to accumulate in a single location is limited, persons should not remain in the vicinity of these packages unnecessarily.

2.5. Revision and updating of the regulations

It is an integral part of the philosophy underlying the IAEA Regulations that they should be subject to continuing review and, where necessary, revision.

The Regulations were initially developed in 1961 and have been periodically revised to account for changes in technology and operating practices. Revised editions were issued in 1965, 1968, 1973 (amended in 1979), and in 1985 (amended in 1990).

In the reviews carried out since the first edition, attempts have made to strike a balance between the need to take account of technical advances and operational experience, and the desirability of providing a stable framework of regulatory requirements.

During the process which led to the 1985 Edition of the Regulations it became apparent that changes needed to be made in the revision process. Issues related to transport needed to be addressed on a continuous basis. The new process, adopted after the issue of the 1985 Edition of the IAEA regulations, called for a cycle of approximately ten years leading up to the next comprehensively revised edition. Review panels would meet every two years, producing from their first and second meetings supplements to the existing regulations, a new revised edition of the regulations would be publised after ten years.

During this revision process neither the classification of packages, nor the packaging strength tests have changed to any great degree. One of the aims of the review process is to ensure that packages approved under an earlier version of the regulations should be able to be used under subsequent ones until the end of their useful lives.

By this dynamic process, adherence to the IAEA Regulations continues to ensure that shipments of radioactive materials enjoy an extremely high level of safety without imposing undue administrative constraints.

The Regulations will continue to evolve in the future in order to respond to changing circumstances or perceptions and against this background the IAEA is currently addressing two particular issues : the transport of UF6 and the transport of radioactive materials by air. Two guides for the former, the latest of which is IAEA-TECDOC-608 "Interim guidance on the safe transport of uranium hexafluoride", and a IAEA-TECDOC-702, "The Air Transport of Radioactive Material in large quantities or with high activity" in which a new type of package (Type C) is proposed.

2.6. Monitoring of effectiveness of the regulations

In order to determine the effectiveness of the regulations in protecting persons, property and the environment against the hazards associated with the transport of radioactive material it is necessary to be able to estimate, over a period of time, both the radiation exposures arising during transport, and the consequences or potential consequences of accidents which have occurred.

The IAEA Regulations explicitly require the Competent Authorities to arrange for periodic assessments to be carried out to evaluate the radiation doses to workers and to members of the public due to the transport of radioactive material in order to ensure that the above system of dose limitation is being complied with. The advisory material (ref. 4) associated with the regulations states that such information should be collected and reviewed at intervals of about 5 years, more frequently if circumustances such as rapidly changing patterns of transport warrant.

The expenditure of ressources on such assessments needs to be commensurate with the scale and magnitude of the transport of radioactive material in the particular Member State. Those most involved may undertake a systematic programme of dose surveys to cover the full range of operations by all modes, those with less transport in radioactive materials may address only those operations likely to give rise to the highest exposures or which are of particular concern. Still other countries may not yet have the ressources, whether money or expertise, to discharge this particular obligation in a systematic way.

A lead has been given by IAEA to encourage these assessments. A database on radiation exposures in transport called EXTRAM has been set up by IAEA. Data on the main sources of worker exposure and an estimate of the collective dose to members of the public are collected at five yearly intervals with data being initially collected for 1990.

The IAEA also set up a database in 1989 called EVTRAM on accidents and incidents occurring in the transport of shipments of radioactive material. The database is updated annually and it is intended that is should be extended retrospectively to cover events occurring after 1 January 1984. On behalf of the European Commission (DG XVII), studies on accidents occurring in the transport of radioactive material have been performed. One such study is an analysis and review of accidents and incidents in Member States during the period 1975-1986, and a second study concerns the lessons learnt from such events (ref. 5, 6).

Analysis of accidents and incidents occurring in transport shows that few accidents ever result in significant radiological consequences although some incidents involving radioagraphy sources have given rise to cases of serious overexposure.

The excellence of these results can be put down to the existence of stringent, uniform regulations that have been rigorously enforced for several decades, and the adequacy and implementation of which are regularly being reviewed and updated by groups of experts. Although an excellent safety record alone is not a reason for complacency, it is without doubt an indication that the integrity of the packages can be maintained under a variety of accident conditions.

APPENDIX

RADIATION DOSES TO WORKERS AND THE GENERAL PUBLIC RESULTING FROM THE TRANSPORT OF RADIOACTIVE MATERIALS

a) France

The estimation of doses received by workers and members of the general public has been undertaken in France on a triennial basis since 1981 (ref. 7). The studies undertaken look at all modes of transport and cover the carriage of radiopharmaceuticals, irradiated nuclear fuel, wastes and other sources. They indicate that doses received by workers are generally low and have changed little during the ten year study period. Exposure data for workers for 1990 is given in table 1 below.

- Table 1 -

Materials	Annual Doses		
	Mean mSv	Max mSv	Collective ManSv
Radiopharmaceuticals	10	23	0.25
Irradiated Fuel	0.65	4.7	0.007
Wastes	1	5.05	0.03
Others	0.24	1.5	0.004
Total collective dose			0.30

Individual doses to members of the public are negligible and it is estimated that the collective dose to the public would not exceed one half of the above figure.

The largest exposures come from the transport of radiopharmaceuticals where a very large number of small packages are manually handled. Smaller exposures arise from the remote handling of a few large fuel flasks.

b) The United Kingdom

Individual and collective doses for workers and members of the public have been estimated in the UK for the different transport modes (ref. 8). These are summarised in Tables 2 and 3.

- Table 2 (Worker Exposure) -

Mode	Max. Individ. (mSv)/yr	Collective (ManSv/yr)
Road/Rail	16.0	0.4
Air	0.4	0.1
Sea	0.4	-

- Table 3 (Exposure of Members of the public) -

Mode	Max. Individ. (mSv)/yr	Collective (ManSv/yr)
Road/Rail	0.006	0.04
Air	0.1	0.5
Sea	0.05	-

The highest occupational doses arise in road transport from the movement of a particular radioisotope, the technetium generators, for hospital use. Doses to members of the public are low, the highest doses arising from the transport of medical radionuclides. The figures should be compared with the annual doses from natural background radiation of about 2mSv/yr on land and 0.7mSv/yr at sea.

The above exposures for road/rail transport relate to the year 1989, those for sea transport were not made in a single year but different areas of the transport pattern were addressed over the period 1985 to 1989. For air transport exposure information was obtained in 1987 and reviewed in 1991.

c) Germany

In Germany a prospective study of the radiation exposures likely to arise from the transport radioactive waste to the Konrad waste disposal site by various routes has been made (ref. 9).

On the basis of the volume of waste to be transported and its characteristics and that of the transport containers, estimates of annual radiation exposures were made for various groups of people for two different transport scenarios. The results appear in Table 4.

- Table 4 -

	Transport : 20% by road 80% by rail	Transport : 100% by rail
Collective dose (ManSv)	Approx. 0.3	Approx. 0.2
General Public (Critical Group) (mSv)	0.1	0.2

The main exposure of workers would arise from the rail component of these two scenarios, it is estimated that this would not exceed 0.7mSv per year.

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