

Guide to the

Design, testing and use of packaging for the safe transport of radioactive materials

UDC 620.267:621.039.746:621.789:656.073.436

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW



Document Sharing Hub

Co-operating organizations

The Nuclear Energy Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives of the following Government department and scientific and industrial organizations:

- Association of Consulting Engineers
- British Electrical and Allied Manufacturers' Association
- British Insurance (Atomic Energy) Committee
- British Mechanical Engineering Confederation Ltd
- Electricity Supply Industry in England and Wales*
- Health and Safety Executive (HM Factory Inspectorate and Nuclear Installations Inspectorate)*
- Institution of Mechanical Engineers
- Institution of Nuclear Engineers*
- Lloyd's Register of Shipping*
- National Radiological Protection Board*
- Scientific Instrument Manufacturers' Association of Great Britain
- United Kingdom Atomic Energy Authority*

The Government department and the scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

- British Railways Board
- Department of the Environment
- Ministry of Defence
- Post Office
- Co-opted experts

This British Standard, having been approved by the Nuclear Energy Industry Standards Committee, was published under the authority of the Executive Board on 30 January 1976

© BSI 01-2000

BS 3895-1 first published May 1965
BS 3895-2 first published January 1968
First revision published in one volume January 1976

The following BSI references relate to the work on this standard:
Committee reference NCE/7
Draft for comment 73/43620 DC

ISBN 0 580 08557 0

Amendments issued since publication

Amd. No.	Date of issue	Comments

Contents

	Page
Co-operating organizations	Inside front cover
Foreword	iii
Section 1. General	
1 Scope	1
2 References	1
3 Definitions	1
Section 2. Design study	
4 General	5
5 Very low concentrations of radioactive materials	5
6 Other concentrations of radioactive materials	6
7 Unlimited concentrations of radioactive materials	6
8 Fissile material	7
Section 3. Design guide	
9 Shielding	7
10 Containment	8
11 Special form	10
12 Heat dissipation	11
13 Pressure build-up	12
14 Mechanical protection	13
15 Thermal protection	15
16 Additional package design requirements for fissile materials	17
17 Vibration	18
18 Security seals	18
19 Lifting and tie-down attachments	18
20 Contamination	19
Section 4. Design approval	
21 Packaging or package designs not requiring competent authority approval	20
22 Package designs requiring competent authority approval	21
23 Criteria of acceptance of package design in respect of packaging tests	22
Section 5. Application for approval and competent authority certification	
24 General	23
25 Application for approval	23
26 Certification	26
Section 6. Manufacture of packaging	
27 General	27
28 Inspection and testing	27
29 Certification	28
Section 7. Use of packaging	
30 General	28
31 Operating, handling and stowage instructions	28
32 Maintenance	28
33 Pre-shipment inspection, examination or tests	29
34 Certification by consignor	31
35 Labelling and marking	32

	Page
Appendix A Regulations for the safe transport of radioactive materials	33
Appendix B A guide to a typical design calculation for mechanical protection	34
Appendix C Specific existing design concepts for Types A and B packagings	35
Appendix D The thermal test — guidance on calculative assessment	37
Appendix E Vibration test	41
Appendix F Design approval for Type A packages. An index to IAEA regulations (1973)	45
Appendix G Design approval for Type A packages. Outline form of approval	46
Appendix H Design and assessment of package containment integrity and test methods used in demonstrating the criteria of acceptance of a prototype and/or the acceptability for shipment	46
Appendix J Consignor's certificate — Example embodying the requirements of the Radioactive Substances (Carriage by Road) (Great Britain) Regulations 1974	57
Appendix K Typical specification for tinplate can	59
Appendix L Typical specification for fibreboard cases and fitments	59
Appendix M Guidance on drum specifications	59
Appendix N Typical specification for protective case with external hollow section crash frame	60
Appendix P Typical specification for a steel reinforced timber case	62
Appendix Q References and bibliography	64
Figure 1 — Nomogram to give the reduction of radiation exposure with distance from a point source	66
Figure 2 — Nomogram to give the shield thickness to reduce an exposure dose rate to a required value	67
Figure 3 — Typical Type A packagings	68
Figure 4 — Typical Type B packagings	69
Figure 5 — Typical protective outer container	70
Figure 6 — Impact calculations: force displacement integrals	70
Figure 7 — Typical reinforced timber protective outer container	71
Figure 8 — Vibration test: spectral density/frequency	74
Figure 9 — Vibration test duration in terms of percentage of rough road	75
Figure 10 — Detail of flask closure joint with provision for leak testing	76
Table 1 — Insulation data	11
Table 2 — Requirements for Type B(U) and B(M) designs	23
Table 3 — Summary of the requirements as to the approval of special form material and package designs	24
Table 4 — Summary of the requirements as to the approval of shipments and prior notification	25
Table 5 — Maximum package radiation levels	30
Table 6 — Maximum permissible levels of non-fixed radioactive contamination	31
Table 7 — Viscosity of fluids at 100 °C and standard pressure	55
Publications referred to	Inside back cover

Foreword

In 1959 the United Nations Economic and Social Council invited the International Atomic Energy Agency (IAEA) to prepare regulations, for recommendation to member states and international organizations concerned, capable of application to the national and international transport of radioactive materials by all modes of transport. The first regulations published in IAEA Safety Series No. 6 (1961) were prepared by two panels, the first dealing with radioisotopes, radioactive ores and materials of low specific activity, and the second with large radioactive sources and fissile materials.

In 1961 IAEA regulations prescribed, in terms of basic principle, requirements for Types A and B packaging and for fissile and large source packages but did not specify design principles and test requirements. Consequently, BSI Subcommittee NCE/4/1, which was set up in 1961 to prescribe methods for the assessment of packaging for the transport of materials other than large radioactive sources and fissile materials, took on the task of devising practical test requirements, and submitted proposals for discussion by the Working Group on Packaging set up by Subcommittee 4 (Radioisotopes) of the International Organization for Standardization Technical Committee 85 (Nuclear Energy) which met in 1962. The United Kingdom Atomic Energy Authority report reference AHSB (S)R19 "The transport of radioactive materials — Interim recommendations for the application of environmental tests to the approval of packaging" took account of this discussion, and was formally submitted by the United Kingdom for consideration by the panel convened in 1963 to revise the regulations recommended by the IAEA for the safe transport of radioactive materials. The actual task of preparing design principles and test requirements was remitted to a packaging panel convened by the IAEA subsequent to the meeting of the main panel. BS 3895-1:1965 was issued so as to be compatible with the prescriptions for test procedures as given in IAEA Safety Series No. 6 (1964), and reproduced these in detail in the text of the standard. At that time few national and international regulations incorporated these texts.

The first revision of the IAEA regulations was completed by the Large Radioactive Source Panel and was published in IAEA Safety Series No. 6 (1967). During the period 1964 to 1967 the British Standards Institution continued to prescribe methods for the assessment of packaging for the transport of large radioactive sources and fissile materials, and issued BS 3895-2:1968 on the same basis as Part 1 giving details of tests in the main text. Part 2 also included a number of appendices giving supplementary and advisory material related to the tests.

It was subsequently decided to prepare this guide superseding Parts 1 and 2 so as to be compatible with the second revision of the IAEA regulations as published in IAEA Safety Series No. 6 (1973) and complementary to the document entitled "Advisory material for the applications of the IAEA Transport Regulations IAEA Safety Series No. 37". Because the IAEA test requirements had become widely accepted by 1972 as compared with 1965 when BS 3895-1 was published, it was decided that the actual text of this revision of BS 3895 should comprise supplementary and advisory material relevant to the tests, restricting reproduction of actual parts of IAEA Safety Series No. 6 (1973) to a minimum. The regulations applicable in the United Kingdom for various forms of transport implement the IAEA recommendations. When using this guide it should be noted that, although the regulations of countries engaged in the nuclear field and regulations for international transport (RID, ADR, IMCO, IATA) make extensive application of the recommendations in IAEA Safety Series No. 6 (1973) for packaging/package design, there are nevertheless minor differences which are not dealt with in this guide.

As and when new concepts, principles and designs are developed, it is intended that this guide will be appropriately revised.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 76, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1 Scope

This guide gives to designers, manufacturers and users of packaging, advice supplementary to, or in amplification of, the recommendations made by the International Atomic Energy Agency for the safe transport of radioactive materials as given in IAEA Safety Series No. 6 (1973) and the advisory material given in IAEA Safety Series No. 37 (1973). This guide should be read and used in conjunction with these recommendations, the appropriate national regulations and any applicable regulations or requirements of the carriers concerned.

(See Appendix A.)

NOTE 1 Throughout the remainder of this guide the IAEA "Regulations for the safe transport of radioactive materials, 1973, revised edition" are referred to as the "IAEA Regulations" or, sometimes, "IAEA". The IAEA "Advisory material for the application of the IAEA transport regulations" is referred to as "IAEA SS.37".

NOTE 2 Materials with a radioactive concentration of 0.002 $\mu\text{Ci/g}$ or less are, for the purposes of IAEA regulations, deemed not to be radioactive material.

NOTE 3 This guide does not deal with the responsibilities of the carriers of packages of radioactive material.

2 References

The titles of the British Standards referred to in this standard are listed on the inside back cover.

References and bibliography are given in Appendix Q.

3 Definitions

3.1 explanation

for the purposes of this British Standard the definitions given in IAEA regulations are reproduced in this clause and apply unless otherwise indicated. The corresponding IAEA reference is shown in parentheses after the term. Other definitions are given in BS 3455

3.2

A_1 and A_2 (IAEA 109)

A_1 means the maximum activity of special form radioactive material permitted in a Type A package. A_2 means the maximum activity of radioactive material, other than special form radioactive material, permitted in a Type A package. These values are either listed in IAEA Table VII, or may be derived in accordance with the procedure described in IAEA 404 to 411

3.3

allowable number of packages (IAEA 110)

the maximum number of Fissile Class II or III packages which may be grouped together in one place during transport or transit storage

NOTE When the group is made up of packages of different designs, the maximum number of packages has to be such that the following formula is satisfied:

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \dots \text{ does not exceed } 1. \text{ In this formula}$$

$n_1, n_2, n_3, \dots$ are the numbers of packages for which the corresponding allowable numbers are N_1, N_2, N_3 , respectively.

3.4

carrier (IAEA 111)

any organization or private individual undertaking the conveyance of radioactive materials by any means of transport. The term includes both carriers for hire or reward (known as common or contract carriers in some countries) and carriers on own account (known as private carriers in some countries)

3.5

competent authority (IAEA 112)

any national or international authority designated or otherwise recognized as such for any purpose in connection with the IAEA Regulations for the safe transport of radioactive materials

BS NOTE In the United Kingdom the body that should be approached is the Department of the Environment, Dangerous Goods Branch.

3.6

consignment (IAEA 113)

any package or packages, or load, of radioactive materials presented by a consignor for transport

BS NOTE A consignment may consist of several loads; a load may consist of several consignments.

3.7

consignor (IAEA 114)

any person who presents a consignment of radioactive materials for transport, and who is named as consignor in the transport documents. The term "person" includes individuals, organizations, and governments

3.8

containment system (IAEA 115)

the components of the packaging specified by the designer as intended to retain the radioactive material during transport

3.9**design (IAEA 116)**

the description of special form material, package, or packaging which enables such items to be fully identified. The description may include specifications, engineering drawings, reports demonstrating compliance with regulatory requirements, and other relevant documentation

3.10**fissile materials (IAEA 117)**

plutonium-238, plutonium-239, plutonium-241, uranium-233, uranium-235, or any material containing any of the foregoing. Unirradiated natural and depleted uranium do not come under this definition

3.11**freight container (IAEA 118)**

an article of transport equipment designed to facilitate the carriage of goods by one or more modes of transport without intermediate reloading. Small freight containers are those which have either any overall outer dimension less than 1.5 m, or an internal volume of not more than 3.0 m³. All other freight containers are considered to be large freight containers. Each freight container has to meet the following requirements

- a) It shall be of a permanent enclosed character and rigid and strong enough for repeated use.
- b) It shall be fitted with devices facilitating its handling, particularly in transfer from one mode of transport to another.

3.12**full load (IAEA 119)**

any load:

- a) from a single consignor having the sole use of a vehicle or of a large freight container or of an aircraft, or of a hold or compartment of an inland waterway craft, or of a hold, of a compartment, or of a defined deck area of a seagoing vessel; and
- b) in respect of which all initial, intermediate, and final loading and unloading is carried out in accordance with the directions of the consignor or consignee, subject to the requirements of IAEA 146 to 148.

3.13**low level solid radioactive material (LLS) (IAEA 120)**

any of the following

- a) Solids (e.g., consolidated wastes, activated materials) in which:
 - 1) the activity under normal transport conditions is, and remains, distributed throughout a solid or a collection of solid objects, or is, and remains, uniformly distributed in a solid compact binding agent (such as concrete, bitumen, ceramic); and
 - 2) the activity is, and remains, insoluble so that even under loss of packaging, the loss of radioactive material per package resulting from the effects of wind, rain, etc. and from total immersion in water is limited to less than 0.1 A₂ in a period of one week; and
 - 3) the estimated activity averaged throughout the radioactive material does not exceed $2 \times 10^{-3} A_2/g$;
- b) Objects of non-radioactive material contaminated with radioactive material, provided that the radioactive contamination is in a non-readily dispersible form and the level of contamination averaged over 1 m² (or the area of the surface if this is less than 1 m²) does not exceed:
 - 20 µCi/cm² for beta and gamma emitters and the low toxicity alpha emitters indicated in IAEA Table XI.
 - 2 µCi/cm² for other alpha emitters.

3.14**low specific activity material (LSA) (IAEA 121)**

any of the following

- a) Uranium or thorium ores and physical or chemical concentrates of those ores.
- b) Unirradiated natural or depleted uranium or unirradiated natural thorium;
- c) Tritium oxide in aqueous solutions, provided the concentration does not exceed 10 Ci/dm³.
- d) Materials in which the activity, under normal transport conditions, is and remains, uniformly distributed and in which the average estimated specific activity does not exceed $10^{-4} A_2/g$.

e) Materials in which the activity is uniformly distributed and which, if reduced to the minimum volume under conditions likely to be encountered in transport, such as dissolution in water with subsequent recrystallization, precipitation, evaporation, combustion, abrasion, etc., would have an average estimated specific activity of no more than $10^{-4} A_2/g$.

f) Objects of non-radioactive material contaminated with radioactive material, provided the non-fixed surface contamination does not exceed ten times the values given in IAEA Table XI and the contaminated object or the contamination on the object, if reduced to the minimum volume under conditions likely to be encountered in transport, such as dissolution in water with subsequent recrystallization, precipitation, evaporation, combustion, abrasion, etc., would have an average estimated specific activity of no more than $10^{-4} A_2/g$.

g) Objects of non-radioactive material contaminated with radioactive material, provided that the radioactive contamination is in a non-readily dispersible form and the level of contamination averaged over any $1 m^2$ (or the area of the surface if this is less than $1 m^2$), does not exceed:

1 $\mu Ci/cm^2$ for beta and gamma emitters and the low toxicity alpha emitters indicated in IAEA Table XI.

0.1 $\mu Ci/cm^2$ for other alpha emitters.

3.15

maximum normal operating pressure (IAEA 122)

the maximum pressure above atmospheric pressure at mean sea level that would develop in the containment system in a period of one year under the conditions of temperature and solar radiation corresponding to environmental conditions of transport in the absence of venting, external cooling by an ancillary system or operational controls during transport

BS NOTE The period of one year in this definition is reduced to 28 days for packages transported exclusively within the United Kingdom. Any package designed in accordance with the reduced period will be classified as Type B(M), but will not be subject to shipment approval provided that in all other respects the package complies with the requirements for Type B(U) packages.

3.16

multilateral approval (IAEA 123)

approval by both the relevant competent authority of the country of origin and of each country through or into which the consignment is to be transported

NOTE The term "through or into" specifically excludes "over"; i.e., the approval and notification requirements would not apply to a country over which radioactive materials are carried in aircraft, provided that there is no scheduled stop in that country.

3.17

non-fixed radioactive contamination (IAEA 124)

contamination that can be removed from a surface by wiping with a dry smear

BS NOTE A test to determine the level of this contamination is given in IAEA SS 37, 513.

3.18

package (IAEA 125)¹⁾

the packaging, together with its radioactive contents, as presented for transport

3.18.1

Type A package (IAEA 126)

a Type A packaging together with its limited radioactive contents

3.18.2

Type B(U) package (IAEA 127)

a Type B packaging, together with its radioactive contents, which, since it is designed in accordance with specified design and containment criteria (see IAEA 228 to 241), requires unilateral approval only of the package design and of any stowage provisions that may be necessary for heat dissipation

3.18.3

Type B(M) package (IAEA 128)

a Type B packaging, together with its radioactive contents, which, since its design fails to meet one or more of the specific additional design criteria for Type B(U) packages (see IAEA 234 to 241), requires multilateral approval of the package design and, in certain circumstances, of the conditions of shipment

BS NOTE See IAEA 242 to 244.

¹⁾ These definitions are special to the context of the transport of radioactive materials. The general definitions are given in BS 3130.

3.19**packaging (IAEA 129)²⁾**

the assembly of components necessary to ensure compliance with the packaging requirements of the IAEA Regulations. It may, in particular, consist of one or more receptacles, absorbent materials, spacing structures, radiation shielding and devices for cooling, for absorbing mechanical shocks and for thermal insulation. The devices may include the vehicle with tie-down system when these are intended to form an integral part of the packaging

3.19.1**Type A packaging (IAEA 130)**

a packaging that is designed to withstand the normal conditions of transport as demonstrated by the retention of the integrity of containment and shielding, to the extent required by IAEA Regulations, after the tests specified in IAEA 709 to 717, as appropriate

3.19.2**Type B packaging (IAEA 131)**

a packaging that is designed to withstand the damaging effects of a transport accident as demonstrated by the retention of the integrity of containment and shielding, to the extent required by IAEA Regulations, after the tests specified in IAEA 709 to 721, as appropriate

3.20**radiation level (IAEA 132)**

the corresponding radiation dose-equivalent rate expressed in millirem per hour. Radiation levels may be determined by appropriate instruments together with any necessary conversion tables or by calculation. Measured or calculated neutron flux densities may be converted into radiation levels using the data provided in IAEA Table I

3.21**radioactive contents (IAEA 133)**

the radioactive material together with any contaminated solids, liquids and gases within the package

3.22**radioactive material (IAEA 134)**

any material having a specific activity greater than $0.002 \mu\text{Ci/g}$

BS NOTE For mixtures of radionuclides or chains see IAEA 407.

3.23**special form radioactive material (IAEA 135)**

either an indispersible solid radioactive material or a sealed capsule containing radioactive material. The sealed capsule has to be so constructed that it can be opened only by destroying the capsule
special form radioactive material has to meet the following requirements:

- a) it shall have at least one dimension not less than 5 mm;
- b) it shall comply with the relevant test requirements specified in IAEA 726 to 737.

The special form concept in general permits the inclusion of a greater activity in a Type A package

3.24**specific activity (IAEA 136)**

the activity of the radionuclide per unit mass of that nuclide. The specific activity of a material in which the radionuclides are essentially uniformly distributed is the activity per unit mass of the material

3.25 transport index**3.25.1****transport index for a package (IAEA 137)**

either:

- a) the number expressing the maximum radiation level in millirem per hour at 1 m from the external surface of the package; or
- b) for Fissile Class II or Class III packages, the larger of the following numbers:
 - 1) the number expressing the maximum radiation level under a);
 - 2) the number obtained by dividing 50 by the allowable number of such packages.

3.25.2**transport index of a freight container (IAEA 138)**

the sum of the transport indices of all packages within the freight container, except that for freight containers carrying Fissile Class III packages, shall be 50 unless the sum of the transport indices of the packages necessitates a higher figure, or for freight containers not carrying Fissile Class II or Class III packages and in the case of full loads only, the number expressing the maximum radiation level in millirem per hour at 1 m from the external surface of the freight container multiplied by the value in IAEA Table II appropriate to the maximum cross-sectional area of the freight container

²⁾ These definitions are special to the content of the transport of radioactive materials. Also in this guide, *industrial packaging* means packaging which meets the requirements of IAEA 201 to 208 and 210; *strong industrial packaging* means packaging which meets the requirements of IAEA 201 to 210. The general definitions are given in BS 3130.

3.25.3

transport index for low specific activity material or low level solid radioactive material transported as a full load or transported by land or sea in a compact stack, or stored in a compact stack (IAEA 139)

this is the number expressing the maximum radiation level at any point 1 m from the external surface of the load multiplied by the value in IAEA Table II appropriate to the cross-sectional area of the load. For uranium and thorium ores and concentrates, in the absence of actual measurements or calculations, the maximum radiation level at any point 1 m from the external surface of the load may be taken as:

- 40 mrem/h for ores and physical concentrates of uranium and thorium
- 30 mrem/h for chemical concentrates of thorium
- 2 mrem/h for chemical concentrates of uranium other than uranium hexafluoride.

3.25.4

the number expressing the transport index (IAEA 140) is rounded up to the first decimal place

3.26

uncompressed gas (IAEA 141)

gas at a pressure not exceeding ambient atmospheric pressure at the time the containment system is closed

3.27

unilateral approval (IAEA 142)

approval by the competent authority of the country of origin only

3.28

unirradiated uranium (IAEA 143)

uranium containing not more than 10^{-6} g of plutonium per gram of uranium-235 and a fission product activity of not more than 0.25 mCi of fission products per gram of uranium-235

3.29

uranium — natural, depleted, enriched (IAEA 144)

natural uranium means chemically separated uranium with the naturally occurring distribution of uranium isotopes (approximately 99.28 % uranium-238, 0.72 % uranium-235). Depleted uranium means uranium containing less than 0.72 % of uranium-235, with the remainder being uranium-238. Enriched uranium means uranium containing more than 0.72 % uranium-235, with the remainder being uranium-238. In all cases, a very small amount of uranium-234 is present

3.30

vehicle (IAEA 145)

a road vehicle (including an articulated vehicle, i.e. a tractor and semi-trailer combination) or railroad car or railway wagon. A trailer is considered as a separate vehicle

BS NOTE Railroad car means a railway covered van; railway wagon means a railway open wagon.

Section 2. Design study**4 General**

A packaging/package design study should be made to ascertain the requisite packaging standard before detailed design work is commenced. The criteria for determining the necessary standard are concerned, in the main, with the quantity of radioactivity to be carried, its toxicity, its physical and chemical form and whether or not it is fissile. The IAEA Regulations list the radionuclides and specify the quantities which may be carried in Type A packaging depending on whether the material is in special form (A_1 quantities) or non-special form (A_2 quantities). When the contents exceed the limits for Type A packaging, it is necessary to design to Type B standards.

Where a packaging is intended to be used for a variety of different contents, consideration should be given to all intended assemblies of component parts and the maximum quantities to be carried, particularly since permitted leak rates are related to the specific radionuclide in the package. Consequently, a known leak rate might be acceptable in terms of activity for one radionuclide but not acceptable for another.

Clauses 5 to 8 serve as a guide to the standard of packaging required and give the relevant IAEA references. Designers should refer to Table 3 and Table 4 in order to establish what approvals are necessary.

5 Very low concentrations of radioactive materials (see IAEA 134)

Materials in which the radioactive concentration is 0.002 microcuries per gram ($\mu\text{Ci/g}$) or less are not considered to be radioactive in the transport sense and are therefore exempted from the requirements of the IAEA Regulations. For this reason there are no regulatory requirements for the carriage of a number of slightly radioactive nuclides, both natural and artificial.

6 Other concentrations of radioactive materials

6.1 LSA(Ref. IAEA 314 to 316). Materials with a specific activity greater than 0.002 $\mu\text{Ci/g}$, but which fall within the definition of low specific activity material, may be carried as follows subject to specified limits and labelling provisions:

- a) in bulk as a full load, or
- b) in industrial packagings transported individually (see clause 21);
- c) in packages transported as a full load.

6.2 LLS (Ref. IAEA 317 and 318). Low level solid radioactive material has to be transported as a full load in strong industrial packagings which meet the requirements of IAEA 201 to 210 which includes the performance tests of Volume 4 of the UN Transport of Dangerous Goods 1970 edition ST/ECA/81/Rev 2, E/CN2/CONF./10 Rev 2.

7 Unlimited concentrations of radioactive materials

7.1 General

7.1.1 Exempt items (Ref. IAEA 301 to 313). Small quantities of radioactive materials and instruments and articles such as clocks, electronic tubes etc., containing radioactive materials are exempt from much of the regulatory requirements if the level of radioactive content conforms to limits prescribed in IAEA Regulations. Similar exemptions apply to empty packages provided that they have been decontaminated internally to specified levels and any radioactive labels covered over or removed.

7.1.2 Other materials (Ref. IAEA 109, 401 to 411). Radioactive materials not covered in clause 5, 6.1, 6.2 and 7.1.1 have to be assessed on the basic activity limits A_1 and A_2 of the contained radionuclides and where their radioactive content is less than A_1 or A_2 , as appropriate, Type A packaging is a required minimum standard.

7.2 Type A (Ref. IAEA 201 to 227). The basic concept of a Type A packaging is that under normal conditions of transport, including likely rough handling during loading or unloading, the contents of the package shall not be released nor surface dose rates increased to the hazard of the public.

Specific tests are laid down for the testing of packagings and acceptance criteria established. It should be noted that Type A packages designed as Fissile Class packages are required to be assessed against the tests laid down for Type B packages, and although not required to pass the tests successfully the test results are taken as the basis of the nuclear safety assessment.

Type A design requirements are specified in section 3, 21.3 and 23.2.

7.3 Type B

7.3.1 Packaging intended to carry contents in excess of the limits for Type A packages have to meet additional design requirements such that, even in a severe accident, there is no significant hazard to persons. (Ref. IAEA 228 to 244.)

Approvals in accordance with Table 3 and Table 4 have to be obtained from the competent authority before such packages may be used for transport.

7.3.2 Specific regulatory provisions to prevent breach of containment as a result of build up of internal pressure in the package consequent to heat and/or evolution from the radioactive contents are applicable to packages whose contents exceed the activity limits of Type A packages.

7.3.3 The basic philosophy underlying the design of a Type B package is that, given compliance with stowage provisions for dissipation of heat as specified in the package design approval certificate, no operational controls are required during transport to ensure integrity of containment and shielding features. Furthermore, the design is required to be such that if, after being left unattended for a period of 1 year for international transport, or 28 days for transport within the UK only, the package becomes involved in a severe accident involving impact followed by fire, the containment and shielding features are maintained within the limits specified in the IAEA Regulations. Careful consideration of the design implications of the specific design criteria for Type B(U) packages in relation to the intended package contents is therefore necessary at this stage, together with an estimate of the “maximum normal operating pressure” as defined in 3.15 (Ref. IAEA 228 to 241).

7.3.4 A Type B(M) package design has to meet all the basic design requirements for Type B(U) and, as far as practicable, the specific criteria for Type B(U) packages. Consequently, the application for approval to the competent authorities of the countries concerned has to specify which of these specific criteria are not satisfied by the design, and, for each such criterion, state the operating control(s) to be imposed on the shipments in compensation. (Ref. IAEA 242 to 244.)

7.3.5 Should a design fail to meet either of the standards set for Type B(U) or Type B(M) packages, shipments are only possible under special arrangements. A package to be shipped under special arrangements is required to meet the regulatory requirements as far as possible. The design has to be assessed against these requirements and compensatory measures are imposed in respect of any deficiencies (see **26.5.3**). (Ref. IAEA 819 to 821.)

8 Fissile material

8.1 General. Unless exempted by virtue of low fissile content or concentration, packages containing fissile material have to be in accordance with either Fissile Class I, II or III. These classes differ in the extent to which reliance is placed for criticality safety upon the inherent properties of the package or upon controls imposed during shipment.

8.2 Approval. All Fissile Class I, II and III package designs require multilateral approval, except for designs in accordance with particular conditions defined in IAEA Regulations which result in a relaxation of the approval procedures (c.f. **8.4** and Table 3).

In addition, multilateral approval is required for shipment of all Fissile Class III packages. Notification to the competent authorities of each country through or into which the consignment is to be transported, is required in respect of all shipments of Fissile Class III packages which require multilateral design approval.

8.3 Choice of Class. The choice of which Fissile Class to use as the basis of criticality safety in a given case needs to be governed only by convenience and economics, since an equal standard of safety is intended to be intrinsic to all three classes. However, where the widespread international use of a given design is contemplated, Fissile Class I or II are preferable since they generally avoid the necessity for multilateral shipment approval and notification (see Table 4).

8.4 Assessment. IAEA 611 to 614 and 620 to 624 define certain quantities and geometric shapes of fissile materials which are nuclearly safe for transport. In other cases the design of Fissile Class I, II or III packages has to be subjected to assessment by a criticality specialist who has to take into account data on the test performance of the packages, such as deformation of the package components on impact and the extent of possible water ingress etc.

8.5 Class I. Fissile Class I packages are nuclearly safe in any number and in any arrangement entirely by virtue of the inherent properties of the packaging and the permitted contents.

Such packages have to be assessed as performing satisfactorily under tests specified in IAEA Regulations. They will usually be of robust design. See IAEA Section VI.

8.6 Class II. Fissile Class II packages are nuclearly safe in any arrangement provided that no more than the allowable number of such packages are permitted to be grouped together in transport.

Since the allowable number depends upon the properties of the packaging and contents under the conditions and tests specified in IAEA Regulations, the criticality safety of Fissile Class II packages relies partly upon design and partly upon an operational control. See IAEA Section VI.

8.7 Class III. Fissile Class III packages are nuclearly safe by reason of special precautions, or special administrative or operational controls imposed on the shipment. See IAEA Section VI.

Section 3. Design guide

9 Shielding

9.1 Sources of radiation

9.1.1 General. Shielding requirements are dependent upon the nature of the source of radiation and in this context consideration is given to alpha, beta, gamma and neutron radiations; these are discussed individually in **9.1.2** to **9.1.5**.

9.1.2 Pure alpha emitters. Any container which satisfies the containment requirements of **10.2** is adequate for absorbing alpha particles from sources of any size.

9.1.3 Pure beta emitters. Beta particles (electrons) are of poor penetrating ability and are therefore easily absorbed in thin shields. A useful working rule is that the required thickness of shielding material T (cm) is given by the relationship of half the maximum energy E of radiation (MeV), divided by the density R (g/cm³), i.e.

$$T = \frac{0.5 E}{R}$$

Very energetic beta particles, however, when abruptly stopped in materials of high atomic number (lead for instance) will produce secondary radiations known as bremsstrahlung; accordingly, when high energy beta emitters (above 5 MeV) are transported and it is necessary for other reasons to employ shields of high atomic number, composite shields are preferable; the inner shield being of low atomic number (e.g. aluminium, plastics, glass).

In general terms, the high integrity of the container which is necessary for other reasons (mechanical strength, fire resistance, containment, etc.) will ensure that sufficient overall beta shielding thickness is inherent in the design.

9.1.4 Gamma emitters. Gamma quanta are physically similar to X-rays but generally of considerably higher energies; they are therefore very highly penetrating and, where space is at a premium (normal in transport situations), require shielding materials of high atomic number (e.g. iron, lead, tungsten or depleted uranium).

Data for the calculation of shielding barriers against gamma radiation for a wide range of materials and geometry are given in BS 4094-1. If the shield design is adequate for the gamma emitters of the isotopes concerned, it will be more than adequate for the much less penetrating beta emitters.

9.1.5 Neutron emitters. Neutrons are uncharged particles, and in transportable sources could have energies from a fraction of an electron volt up to several mega electron volts. High energy neutrons are very penetrating and, in order to obtain sufficient attenuation, shielding has to be used to moderate the neutrons to less than a few electron volts when they can be “absorbed” by the shield. The terms “fast neutrons” and “thermal neutrons” are frequently used to describe neutrons with energies at which moderation and absorption predominate respectively.

The best moderating materials are those with a high hydrogen content, e.g. water and polyethylene, and among the best absorbers are natural boron which absorbs all energies, and cadmium which absorbs energies within the thermal range. Steel which is often present as a structural material is also a good absorber. An optimum neutron shield is therefore usually a hydrogenous layer followed by an absorbing layer.

An important effect which has to be considered in the shield design is the emission of gamma quanta during the process of thermal neutron capture. The gamma radiation is derived from the neutron flux in each shield layer. Appropriate shielding is then provided.

The calculation of neutron penetration and flux is, for all but the simplest geometrical arrangement of a single shield material, not practicable by simple methods; computer codes to evaluate multi-energy group penetration are in use. Specialist advice should be obtained.

9.2 Shielding media. Reference has been made already to shielding materials in 9.1 but the final design of the shielded container will inevitably have to satisfy several, sometimes conflicting, criteria which are considered later.

Accordingly, the container design will be a compromise incorporating different materials (metals, plastics, rubber and wood etc.) in order to meet the design requirements.

In view of transport requirements and the general incentive for close storage of freight the tendency will be to keep containers as small as possible consistent with meeting acceptable dose rates and this automatically imposes a limit on the choice of materials.

9.3 Shielding by distance. It can be shown that radiation level is inversely proportional to the square of the distance from the source.

This inverse square law may be expressed:

$$\frac{D_1}{d_1^2} = \frac{D_2}{d_2^2} \text{ or } \frac{D_1}{D_2} = \left[\frac{d_2}{d_1} \right]^2$$

where

D_1 is the radiation level at distance d_1 from the source;

D_2 is the dose rate at distance d_2 from the source.

This law applies strictly only for a point source of radiation but is sufficiently accurate for distance to source size ratios of 10 : 1 or greater. Figure 1 is a nomogram for the application of this principle; Figure 2 is a nomogram for the estimation of half and tenth value shielding thicknesses applicable to required attenuations.

Mathematical treatment of radiation levels around large or long sources is to be found in BS 4094-1.

10 Containment

10.1 General

10.1.1 Type A and Type B packaging have to incorporate a containment system intended to retain the radioactive material in the transport environment within the limits prescribed in the IAEA Regulations. The designer has complete freedom in this respect provided that, at the time of application for approval, he declares what constitutes his containment system and is able to demonstrate compliance of that system with the regulatory performance criteria. For example, a designer may specify that his containment system comprises a glass bottle, containing the radioactive contents, within a lead pot inside a tinsplate can. All the various component parts are thus able to contribute to containment to the extent that they are demonstrated to retain their integrity under the prescribed regulatory test conditions.

10.1.2 The containment system has to be closed by a positive fastening device(s) which cannot be opened unintentionally or by pressure arising within the package.

10.1.3 Where the containment system forms a separate unit of the packaging, the containment system has to be closed by a positive fastening device which is independent of any other part of the packaging.

10.1.4 The containment system has to be designed to retain its radioactive contents under the reduction of ambient pressure to 24.5 kPa³⁾.

10.1.5 The designer has to ensure physical and chemical compatibility of the contents with the materials of construction of the containment system. He has also to take into account, where applicable, the chemical or radiolytic decomposition of vulnerable materials, particularly liquids, and consequent gas generation.

10.1.6 Any valves, other than pressure relief valves, through which the radioactive contents could otherwise escape have to be protected against unauthorised operation and additionally be sealed to retain any leakage from the valve itself.

10.1.7 A radiation shield, which encloses a component of the packaging specified as part of the containment system, has to be designed to prevent the unintentional release of that component from the shield. Where the shield and the component within it form a separate unit, the shield has to be closed by a positive fastening device which is independent of any other part of the packaging.

10.1.8 In general, packaging for radioactive material is most vulnerable under normal and accident conditions of transport in the vicinity of closures. Designers should endeavour to provide the maximum protection to these features by ensuring that they are situated within the general profile of the structure and are thus afforded protection by less vulnerable components. This is particularly important where the containment system is essentially the outer vessel.

10.1.9 The design of packaging has to take into account the variations in temperature to which the packaging may be subjected during transport and storage. In this respect – 40 °C and + 70 °C are considered as satisfactory limits in the selection of materials. Tests to determine low temperature properties of materials should be carried out in order to establish the propensity of the materials to brittle fracture. The Charpy impact and/or Pellini drop tests are suitable for this purpose but other tests may be carried out provided they give comparable information. It is generally known that with very thick components, as might be the case where mild steel constitutes both shielding and containment, the ductile mode of failure under impact conditions could be completely suppressed. This is because general yielding becomes more difficult as the restraint imposed by greater thicknesses increases, and brittle behaviour predominates up to a relatively high temperature. In view of this, material testing has to be supplemented by control of design and fabrication techniques with adequate standards of workmanship and inspection.

For other useful literature see Appendix Q [18].

10.1.10 Where it is not possible to demonstrate a satisfactory material performance in the temperature range given in **10.1.9** a suitable range may be agreed with the competent authorities concerned with a particular shipment. Such a package would fail to meet a specific Type B (U) requirement and would thus become Type B (M). Where packages are to be transported exclusively within the United Kingdom the temperature limits of – 10 °C and + 70 °C may be assumed.

10.2 Containment integrity

10.2.1 Type A packaging has to be so designed that under the conditions of the tests specified in the IAEA Regulations there is no release of the radioactive contents. In the case of Type B packages the loss of the radioactive contents is restricted to prescribed amounts under specified conditions and such features as seals and gaskets have to be designed to ensure the retention of the contents within these limits. The suitability of such features at elevated temperatures, which result from the generation of heat by the contents or under thermal test conditions, have to be established.

³⁾ This is equivalent to 0.25 kgf/cm².

10.2.2 The IAEA Regulations specify the requirements for containment systems under normal and accident conditions of transport. In order to qualify as Type B (U) a package has to meet all of these requirements. Where a package fails to meet one or more of the specific additional requirements for Type B (U) packages (see IAEA 234 to 242) it may, subject to certain conditions, be classified as Type B (M). Since certain of these requirements apply under the conditions of the thermal test with the package initially at its maximum normal operating pressure, the effect of pressure and temperature should be considered at an early stage in design.

10.2.3 With respect to the permitted release of radioactive material from Type B (M) packages, designs are divided into those intended to vent continuously and those not so intended. The conditions under which these releases are permitted and the amounts of such releases are specified in the IAEA Regulations.

10.2.4 Where direct demonstration of activity leaktightness is not practicable, the permissible physical leak rate may be calculated by making a pessimistic assessment of the release of gaseous (or soluble) radioactive isotopes from the source into the surrounding medium and from the resulting calculations of radioactive concentration working back to a leak rate from the containment system.

The calculations in appendix H.2 show how this may be carried out. It should however be recognized that a prescribed standard of containment in engineering terms will result in varying releases of radioactivity dependent upon the specific activity of the escaping radionuclide.

10.2.5 In considering leakage testing at the design stage, the directional bias of a potential leak in operation should be taken into account and compared with the test methods available. For example, if vacuum test methods are proposed, it may be possible to use either the evacuated hood method wholly or partially, or design with this in mind by provisions of double "O" ring seals or double welds with test connections for evacuating the space between them.

10.2.6 The gas tightness specification should meet the requirements of BS 3636 and be such that it will establish the leakage under the same directional bias as that to which the packaging or relevant part of the packaging will be exposed under operational conditions.

10.2.7 The designer should choose materials and means of sealing the containment system capable of withstanding the extremes of environmental conditions to be expected in service for the duration of the operational life of the packaging or until its turn-round or schedule maintenance.

11 Special form

11.1 Activity limit. Previously, materials which are virtually non-dispersible had an arbitrary limitation on the activity which could be contained in a Type A package. This single arbitrary limit was applicable to all radionuclides. The introduction of individual radionuclide A_1 values (see 3.2 and clause 4), based upon external radiation only except in the case of pure alpha emitters, has led to an increased activity limit in the majority of cases for special form radioactive materials transported in Type A packages.

11.2 Design requirements. Some materials are non-dispersible in their natural form, others may be made so by enclosing them in a capsule. Whether they are naturally in special form or made so by encapsulation, the regulations require the material to withstand a number of stringent design requirements.

11.3 Approval. In the past, the onus for deciding whether or not a material was naturally in special form remained with the consignor. This has led to problems of interpretation internationally; for instance, some consignors have considered massive cobalt metal as natural special form, whereas evidence is available to show that irradiated cobalt, other than short irradiated material, is often covered with a flaking oxide layer. To avoid misinterpretations in the future, the IAEA Regulations call for unilateral competent authority approval of all special form materials, unless specifically exempted under IAEA Section III.

11.4 Encapsulated sources. The designer of encapsulated sources is concerned that the source will remain leaktight during its use, will not be affected by corrosive atmospheres, and will withstand being trapped in shutter mechanisms of exposure containers without creating a radioactive hazard. BS 5288 provides a list of performance tests suitable for sealed sources but not necessarily applicable to special form in transport. However, gamma sources for such uses as in radiography, teletherapy and oil-well logging will in fact generally meet special form requirements. Many other sources, particularly those with thin foil windows, will probably not qualify as special form.

11.5 Dynamic bend test. The performance tests for special form materials are devised to show ability to withstand a number of accident conditions, one of which is being trodden on after a fire in which a Type A packaging, originally containing the source, has been virtually destroyed. For this reason long slender sources, which would be particularly vulnerable under such a condition, are required to undergo an additional dynamic bend test.

11.6 Assessment. After a prototype of special form material has been subjected to performance tests, it has to survive a leaching assessment. It may not always be necessary to use radioactive material in the prototype. A helium leak test in lieu of radioactive leaching, providing the specified maximum leak rate is less than 10^{-8} cm³/s at standard conditions may be sufficient demonstration.

Should radioactive material be used, it is essential that due care is taken in choosing the activities and specific activity in relation to the sensitivity of detection, so that scaling up to the maximum activity content of the special form can be justified, e.g. simply specifying that the activity released is less than 0.05 μ Ci when only 100 μ Ci has been used in a prototype for which approval is requested for 100 Ci is meaningless.

12 Heat dissipation

12.1 For Type B packages the designer should show by calculation or reference to experimental tests that the heat generated by the source will be dissipated safely for all normal and accident conditions as represented by the tests given in IAEA Regulations.

Particular note should be made of the effect of elevated temperatures upon the reaction between the source and its cladding and any heat transfer medium upon non-metal seals and other components, upon the surface temperature of the package, upon the vapour pressure of heat transfer media, and upon biological shielding materials.

12.2 The surface temperature of a Type B package has not to exceed 50 °C except where the package is transported as a full load. Under full load conditions Type B(U) packages are restricted to an accessible surface temperature of 82 °C. A higher temperature may be allowed for Type B(M) packages with competent authority approval.

In considering the effects referred to above, an ambient temperature of 38 °C has to be assumed for international transport, and 26 °C where transport is restricted to the UK. Similar arrangements may be agreed with other countries. In all cases where an ambient temperature less than 38 °C is assumed the package will be classified as Type B(M); however, where a temperature of 26 °C is assumed, such a package will not be subject to shipment approval, solely on this account, for movements within the United Kingdom.

12.3 IAEA 232 states that the insolation to be considered is that given in column (2) of Table 1. Where transport is restricted to the UK the values given in column (3) of Table 1 may be assumed; however such a package will be classified as Type B(M) but will not be subject to shipment approval solely on this account.

Table 1 — Insolation data (see 12.3 and 13.2)

Form and location of surface	Insolation for 12 hours per day	
	(2) World wide	(3) UK only
	J/cm ² (g cal/cm ²)	J/cm ² (g cal/cm ²)
Flat surfaces transported horizontally:		
base	none	none
other surfaces	3 350 (800)	1 675 (400)
Flat surfaces not transported horizontally:		
each surface	837 (200) ^a	413.5 (100) ^a
Curved surfaces	1 675 (400) ^a	837.5 (200) ^a

^a Alternatively, a sine function may be used, adopting an absorption coefficient and neglecting the effects of possible reflection from neighbouring objects.

With regard to solar heating the requirements of IAEA may be summarized as follows:

Regulatory aspect	Package Type	Is solar heat to be considered?
Surface temperature of package [IAEA 231 b) and 240]	Type B(U) and Type B(M)	No
Normal conditions of transport [IAEA 231 a) and 242]	Type B(U) and Type B(M)	Yes
Tests for packaging (IAEA 702)	Type B(U) and Type B(M)	Yes, to be taken into account in the subsequent evaluation of the test results
Specific additional Type B(U) requirements a) Stress limitation (IAEA 237) b) Thermal test (IAEA 238) c) Pressure limitation (IAEA 239)	Type B(U)	Yes

In the case of Type B(M) packages, solar radiation has to be taken into account in assessing compliance with a), b) and c) above, where the relevant prescriptions of IAEA 237 to 339 are claimed to be met (IAEA 242).

12.4 The heating effects of radioactive sources in watts is given by:

$$\frac{S \times E}{6.24} \times 10^{-12}$$

where

S is the source strength in disintegrations per second

E is the total decay energy in MeV.

It may be considered conservative to assume that all heat generation takes place within the radioactive material and that steady state conditions have been reached prior to dispatch of the package.

A long radioactive source may have non-uniform heat generation along its length.

Calculation of the heat dissipation within and from a package should form part of the application for approval and show clearly any essential controls which are intended to form part of the shipment requirements of a Type B(M) package (see IAEA SS. 37, 526 to 535).

Where heat dissipation is effected by means of vents in the outer parts of a package, consideration should be given to the effects of the tests in the IAEA Regulations, assuming the least advantageous attitude during the test. See stowage provisions in **31.2**.

13 Pressure build up

13.1 General. The design of the packaging must take into account the necessity of ensuring that the integrity of the containment system is maintained to the prescribed standard taking into account any build-up of internal pressure. Particular consideration should be given to the points in **13.2** to **13.5** for their possible effect upon pressure within packaging designed to Type B standard.

13.2 Temperature. Due consideration should be given to the following.

a) The range of ambient temperature to be considered under normal conditions of transport is – 40 °C to + 38 °C. For transport exclusively within the United Kingdom the range is – 10 °C to + 26 °C. It should be noted that the freezing of liquids can result in pressurization or bursting forces.

b) The effect of increases in temperature due to self heating by absorption of radiation from the contents and solar radiation. The values for insolation to be assumed are given in Table 1.

c) The effect of increases in temperature as a result of subjecting the package to an environment of 800 °C as specified in IAEA 720.

13.3 Radiolysis and corrosion effects. Gases may be produced within the package by the radiolytic decomposition of liquid contents or of the heat transfer medium or by chemical reaction of solid contents with a liquid heat transfer medium (e.g. fuel element cladding such as magnox reacts with water). Account should be taken of the variation of the rate of gas production with temperature.

13.4 Pressure. The containment system has to be adequate to retain its radioactive content under a reduction of ambient pressure to 25.4 kPa (0.25 kg/cm²). The IAEA Regulations prescribe specific additional criteria for Type B (U) packages. Certain of these relate to performance standards a condition of which is that the package shall be considered to be at the maximum normal operating pressure at the outset. In showing compliance with such criteria it is necessary to recognize that for international transport, by definition, the maximum normal operating pressure is that pertaining when the package has been left unvented and unattended for a period of one year. For transport exclusively within the United Kingdom the period is 28 days.

13.5 Pressure relief devices. A Type B (U) packaging has not to include a device for pressure relief from the containment system which would allow the release of the radioactive contents under the relevant test conditions specified in IAEA.

14 Mechanical protection

NOTE Useful references are given in Appendix Q.

14.1 General

14.1.1 Mechanical protection of radioactive source transport packages is necessary to retain:

- a) the integrity of the radiation shielding to keep the dose rate within the specified limits;
- b) the integrity of the containment system to the extent that any leakage of the radioactive contents is within the limits specified in IAEA Regulations (see clause 23);
- c) any characteristics assumed for the purpose of criticality assessment where the contents are fissile (see 23.4).

To achieve these results the package has to provide protection against impact sustained in a collision, or fall, or from a falling object, the damaging effects of which have been simulated by a series of tests. It has therefore to be so constructed that it will satisfy the test acceptance criteria given in clause 23 or be demonstrated by other means to the satisfaction of the competent authority that it can be exempted from the test by virtue of the adequacy of the design to withstand such tests.

Mechanical protection has generally to be a compromise between strength and flexibility. It has to be strong enough to prevent disintegration, penetration or severe fracture and the consequent loss of thermal protection and/or exposure of the inner container to substantial mechanical damage, impairment of radiation shielding or loss of containment, but flexible enough to lozenge or preferentially collapse to give the maximum retardation distance. In this way, deceleration forces are kept as low as possible by reducing the peak forces and averaging them as much as possible over the whole deceleration period whilst the kinetic energy of the system is being dissipated in work done in deformation of the surfaces of the impacting bodies and in strain within the various components making up the package.

Some failures of mechanical protection may also serve the function of thermal protection, space shielding, containment or liquid radioactive source absorption.

In considering mechanical protection, particular attention has to be given to the most vulnerable attitudes of a package where maximum damage and/or serious consequences of failure are more likely to occur.

14.1.2 The majority of the earlier types of radioactive transport packagings had biological radiation shields of lead and, with the introduction of the first transport regulations in 1961, it became necessary, for economy and for practical reasons, to find a means of satisfying the regulations whilst retaining existing packaging. Experience arising in development and testing of packages has shown that the provision of thermal shields, space shielding or additional containment can also supplement mechanical protection and this has, in the main, been the course of development to present design standards for both adaptation of unapproved packages to approved standards and for purpose designed packages. This approach for the latter category brings economic benefits arising from the versatility of outer packaging incorporating features such as mechanical protection, thermal protection, containment or space shielding, in being able to accommodate a variety of interchangeable inner packagings thereby avoiding duplication of these features.

A further important design consideration is whether the package is intended to be returnable or non-returnable. It is sometimes advantageous to design a light, low cost shielded container as non-returnable, the mechanical protection being relatively simple. This is a question of the economics, the initial cost of the packaging being related to the transport cost of the empty package on the return journey. In relation to the regulatory requirements, non-returnable packagings, whether of Type A or Type B, have not to be of a lower standard than returnable packagings. Typical examples of non-returnable packagings are given in Figure 3 and Figure 4.

Mechanical protection may be afforded by:

- a) energy absorbing materials of construction;
- b) energy absorbing construction;
- c) external deformable structures, e.g. fins, shock absorbers;
- d) internal deformable structures, e.g. clamping systems.

14.1.3 Energy absorbing materials. Examples of energy absorbing materials in common use for mechanical protection are:

- a) resin bonded granulated cork;
- b) expanded polystyrene (self extinguishing type);
- c) multi-wall corrugated fibre board;
- d) compressed wood fibre;
- e) timber;
- f) engineers' felt;
- g) rubberized hair.

14.1.4 Energy absorbing construction. An example of energy absorbing construction for mechanical protection is the use in a timber case design of bolts and screws, without gluing, in such a way that the various planks can slide past, or pivot across each other or lozenge without breaking up (see Appendix P and Figure 7).

14.1.5 External deformable structures. Examples of external deformable structures are:

- a) cooling fins;
- b) hollow frames;
- c) removable "egg box" structures embodying fins tied at their outer edges.

14.1.6 Internal deformable structures. Design should be such that energy is absorbed by parts which do not contribute to the integrity of the containment or shielding.

14.1.7 Calculative assessment. A guide to the use of calculations in the demonstration of mechanical integrity is given in Appendix B. For further information on experimental work see Appendix Q [12] and [2].

14.2 Type A packaging

14.2.1 A Type A package has to be so constructed that it will satisfy the test acceptance criteria given in **23.2**. If the packaging is to contain fissile material requiring criticality assessment, attention is called to the additional requirements of **23.4**.

Possible design philosophies for the mechanical protection of Type A packaging are as follows.

- a) Provision of a containment system inherently so robust that it needs no extra mechanical protection.
- b) Provision of an outer jacket in which the shielded container is centrally disposed by the use of packing material, blocking and/or clamps. In some cases the packing or cushioning material may itself form the outer jacket. The outer jacket may perform a secondary function such as space shielding or further containment. The cushioning material may also, in some cases, function as liquid absorbent.
- c) Provision of external members to give mechanical protection by preferential collapse, thus increasing the stopping distance and hence reducing deceleration forces.

14.2.2 Many variations of the design approach in **14.2.1 b)** are possible and many such designs have been tested and accepted for approval. A diagrammatic representation of some is shown in Figure 3.

The particular types are listed in **C.1**.

14.3 Type B packaging

14.3.1 A Type B package has to be constructed so that it will satisfy the test criteria given in **23.3**.

Possible design philosophies for the mechanical protection of Type B packaging are (see Figure 4).

- a) Provision of a containment system inherently so robust that it needs no extra mechanical protection.
- b) Provision of an outer jacket in which the shielded container is centrally disposed, by the use of packing material, blocking and/or clamps. In some cases the packing or cushioning material may itself form the outer jacket. The outer jacket usually performs secondary functions of thermal protection and space shielding. This system may be subdivided into those packages with removable and those with non-removable inner shielded containers.

c) Provision of external members such as fins and hollow frames, to give mechanical protection by preferential collapse, thus increasing the stopping distance and hence reducing deceleration forces.

14.3.2 Design of Type B packaging is mainly dependent on the type of shielding selected. Bare lead, lead-in-steel, depleted uranium or tungsten alloy are often used for gamma and X-ray attenuation. In the case of neutron emitters, hydrogenous or boron-loaded shielding may also be required. For Fissile Class 1 packaging a combination of hydrogenous material enclosing sheet cadmium may be used to absorb incoming neutrons. Combinations of the gamma and neutron shielding may be required with consequent complication of the design. Where the shielding is affected by heat (melting of lead or decomposition of hydrogenous material), thermal protection is required.

Particular types of design concepts are considered in C.2.

15 Thermal protection

15.1 Thermal protection incorporated in Type B packaging is necessary so that in severe accident conditions it will:

- a) retain the integrity of the radiation shielding to keep the radiation level within the specified limits, and
- b) retain the integrity of the containment system to prevent leakage of the radioactive contents within the specified limits.

The packaging has therefore to be so constructed that it will satisfy the test acceptance criteria given in 23.3. Guidance on calculative assessment is given in Appendix D.

15.2 Principles. Thermal protection may be provided by one or more of the following.

- a) Provision of a thermal protective envelope to impede heat transfer to the inner packaging.
- b) Utilization of the thermal capacity of the package to restrict its temperature rise during the regulatory test period.
- c) Utilization of heat resistance inherent in the materials of construction (including their ablative properties).

In considering the principles to be adopted attention should be given to other, sometimes complementary, requirements. The thermal protection may also serve one or more of the multiple functions of mechanical protection, space shielding, weather-proofing and, provided that the material affording such protection is inside the containment system, radioactive liquid absorption. In addition, consideration has to be given to the temperature resistance and thermal properties of the radioactive content, its containment and its safe limiting temperature and also the safe limiting temperature of the radiation shield. Furthermore, packages containing radioactive sources of high thermal power may not be able to tolerate complete enclosure for thermal protection owing to the conflicting requirements of unrestricted heat loss from the package and restricted heat gain in a fire. Hence the need for ventilation referred to in C.2.5 and Appendix N.

Other important considerations in choosing the principles to be adopted for thermal protection are the size and mass of the package, the proposed mode of transport, whether the package will be returnable or non-returnable and whether the same thermal shield is to be utilized for carrying a variety of inner shielded containers to form a number of different packaging combinations.

15.3 Application of the principles

15.3.1 Thermal protective envelope

15.3.1.1 This principle utilizes an envelope of fire resistant material to enclose the inner shielded container. It may be subdivided into three variations as follows.

- a) Unventilated thermal protective envelope with removable inner shielded container, (see concepts A to E of Figure 4).
- b) Ventilated thermal protective envelope with removable inner shielded container, (see concepts D and E of Figure 4).
- c) Unventilated thermal protective envelope as part of an integral packaging, (see concept F of Figure 4). The outer casing has to be provided with fusible plugs of, for example, lead or plastics to relieve internal pressure during a fire.

The main advantage of a separate ventilated or unventilated thermal protective envelope to house a removable inner container is that the latter may be varied. In addition it performs the complementary functions of contributing to mechanical protection and space shielding. In light packaging it can be made relatively simple and cheap, and may be non-returnable. An example of a heavy ventilated package is shown in Figure 5.

15.3.1.2 The materials described in a) to e) below are suitable for use in thermal protective envelopes. Such material is effective only if the heat cannot find a more conductive path to the inner container.

a) Resin-bonded granulated cork is satisfactory at a thickness of 50 mm and also affords some energy absorption; 125 mm is required for packaging in which paraffin wax is used as a neutron moderator. Large containers of about 6 t require a steel shell of 3 mm minimum thickness to protect the core. The insulating structure has to be suitably supported against the container it is enclosing.

b) Cane-fibre is a little heavier than cork. The minimum satisfactory thickness is 75 mm.

c) Hardwoods as used for neutron moderation can also provide fire resistance but are heavier and more expensive than cork. It has been found that during a thermal test at 800 °C for a period of 30 min the depth of charring, for the purposes of criticality assessment, is as follows.

Timber	Bare	Steel-clad
Teak	19 mm	11 mm
Green heart	13 mm	8 mm
Iroko	34 mm	24 mm

Tests indicate that the internal temperature of the package during a fire will reach a higher value if the timber is steel-clad than if it is bare.

d) Wet plaster of paris sometimes with other additives, e.g. polyethylene, may be used for composite packagings. It is poured wet into the chamber formed between the inner container and the outer case.

e) Exfoliated vermiculite in loose-fill form is not generally recommended, since it compacts in the course of time and is dusty. However, it may be used as a simple solution for packaging that has to be assembled at short notice for a single shipment.

The effectiveness of these materials depends on combinations of:

- low thermal conductivity
- latent heat of contained moisture or other volatiles
- heat of chemical combination
- formation of a moving gas blanket which carries off heat
- formation of an insulating layer of char which restricts access of air.

Examples of the thermal envelope type of construction are given in Figure 4, concepts A, B, C, D, E and F. Concepts A to E inclusive have removable inner packaging and concept F has integral packaging. Concepts D and E can be developed as ventilated designs for use with sources of high thermal power.

15.3.2 Utilization of thermal capacity. This principle depends on the thermal capacity of the package being able to restrict its temperature to a level significantly below that specified for the thermal test within the test time, so that by judicious choice of materials their maximum safe temperatures are not exceeded.

The principle is applicable to large heavy packages. It also may be applied to lighter packages by combining it with the principle described in **15.3.1**. This is achieved by enclosing the primary radiation shield within a secondary radiation shield of steel. The latter will itself withstand the thermal test temperature and at the same time increase the thermal capacity and so provide a thermal shield for the primary radiation shield. Tests have shown that in certain cases 50 mm thick steel plate is sufficient to prevent lead shielding from reaching its melting point. Packaging embodying this principle is shown in concept H of Figure 4.

15.3.3 Utilization of inherent heat resistance of materials. This principle depends on the properties inherent in the design and materials of construction being resistant to the maximum temperatures reached in the test. For example, if the radioactive source and/or its containment and the radiation shielding are able to retain their integrity at temperatures in excess of the thermal test temperature then the test acceptance criterion in **23.3** is satisfied.

An example of such a package is a strontium titanate source within a high melting point containment vessel, enclosed within a tungsten alloy radiation shield. The materials have to be stable, temperature resistant and relatively inert at the test temperatures and so designed that the thermal aspect of the test acceptance criteria will be satisfied. However, it is emphasized that the other non-thermal test criteria still have to be satisfied.

A diagram illustrating this principle is given in concept G of Figure 4.

16 Additional package design requirements for fissile materials

16.1 Criticality. Radioactive materials which are also fissile materials have to be packed and shipped in such a manner that criticality cannot be reached under any foreseeable circumstances of transport. Contingencies which have to be taken into account in the assessment of the criticality of each package design include:

- a) inleakage of water to the package followed by preferential drainage from different parts of it and, in certain cases, e.g. where a liquid heat transfer medium is present, the effects of outleakage of a liquid;
- b) loss of efficiency of built-in neutron moderators or absorbers. Factors considered here could be loss of such shielding due to fire or mechanical damage, alteration of the relative positions of shield and deterioration under long term operating conditions;
- c) rearrangement of the contents either within the packaging or due to escape from it;
- d) reduction of spacing within or between packages;
- e) immersion in water or snow; the latter may be considered, if convenient, as water of reduced density;
- f) effect of temperature including resultant chemical or physical changes to the contents.

16.2 Validity of criticality data. In using criticality data, obtained either by calculation or experiment, for the criticality clearance of transport packages, adequate allowance should be made for any possible inaccuracy in the data or uncertainty concerning their validity.

16.3 Criticality factors. If any of the factors affecting the criticality of a given material, such as the nature and masses of fissile nuclides present, or the enrichment, concentration, density or moderation, are not known within reliable limits, the optimum foreseeable values have to be assumed in the criticality assessment. In particular, irradiated nuclear fuel should be assessed for criticality purposes as having the degree of irradiation corresponding with the optimum reactivity of the fuel, unless it can be guaranteed that the degree of irradiation is confined within a range having a lesser reactivity in which case the optimum values for the latter case may be assumed. The word “optimum” is used here in the sense of “most favourable to the establishment of criticality”.

16.4 Package design. Package designs for fissile materials, other than those below certain contents limits per package and/or of certain compositions which are specified in IAEA Regulations as qualifying for exemption, have to comply with Fissile Class I, Fissile Class II, or Fissile Class III requirements. In principle, Fissile Class I packages are intended to be inherently sufficiently unreactive to other fissile packages as to require no operational controls during transport for criticality safety purposes. Fissile Class II packages are subject to restriction of numbers in transport by limiting the total number of transport indices for groups of packages loaded or stored together. The package design criteria together with fissile contents limits are such as to provide an adequate safety margin against criticality in any foreseeable circumstances based on this one control. Fissile Class III packages may rely partly or wholly on operational controls to provide criticality safety. The basic designs meeting the criteria for the fissile classes are discussed in **16.5**, **16.6** and **16.7**.

16.5 Fissile Class I designs. Packages have to be designed to be satisfactory when assessed against the test criteria for the relevant class of package as set out in **23.4** and the safety criteria set out in IAEA 605. Means of arriving at Fissile Class I package designs are given in IAEA Regulations in the form of a “scheme of calculation” and a “physical model” accompanied by tables of permissible contents. Both of these systems were based upon earlier, more restrictive concepts of Fissile Class I and therefore embody substantial conservatism in relation to the present criteria. In the case of the “scheme of calculation”, an acceptable and more relaxed alternative to the use of the published neutron energy spectrum for obtaining the surface multiplication of an undamaged package would be to use the equilibrium energy spectrum occurring at the outer surface of such a package in an infinite array of like packages.

16.6 Fissile Class II designs. Packages have to be designed to be satisfactory when assessed against the test criteria for the relevant class of package as set out in **23.4** and the nuclear safety criteria set out in IAEA 615. In general, the evaluation of an allowable number for a Fissile Class II package design will take account of spacing or neutron absorption afforded by the packaging in the assessment of interaction between packages. It is possible however to arrive at Fissile Class II permissible contents and corresponding allowable numbers taking no account at all of the packaging but considering the material of the contents alone in the most reactive mixture with water. A specification of Fissile Class II packages, so based, is given in IAEA Regulations.

16.7 Fissile Class III designs. Although there are no completely general criteria relating to the design of Fissile Class III packages examples of designs have been given in IAEA Regulations which are based upon the derivation of an allowable number of packages analogous to the allowable number for Fissile Class II. The allowable number for these Fissile Class III examples is such that twice this allowable number of undamaged packages or the allowable number of damaged packages itself (see 23.4) has to be subcritical. Consignments of these packages may include up to the allowable number subject to specified restrictions on loading, transport and storage. Because the basic design criteria are analogous to those of Fissile Class II, a published specification enables approved Fissile Class II package designs to be transported under these Fissile Class III terms with an allowable number per consignment double that calculated for Fissile Class II purposes. Another specification affords Fissile Class III terms for a design analogous to the Fissile Class II design discussed in 16.6 but with quantities per package effectively increased by a factor of 2.5.

17 Vibration

IAEA 215 required that a package shall be capable of withstanding the effects of any vibration or vibration resonance which may arise during normal transport without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole; in particular, nuts, bolts and other securing devices shall be designed to prevent them from becoming loose or being released unintentionally even after repeated use.

As a guide to designers a vibration test is given in Appendix E. Another vibration test is given in IAEA SS. 37, Annex 2 to Section VII.

18 Security seals

The IAEA Regulations require that the outside of every package shall incorporate a feature such as a seal which is not readily breakable and which, while intact, will be evidence that the package has not been opened.

The type and mass of the package will, in the main, dictate the type of security seal to be used, but designers should ensure that the method chosen is such that it will not be impaired during normal handling of the package in transport.

The methods of sealing are many but the following are typical of those used in practice in respect of packages for radioactive materials.

- a) The packaging may be such as to be effectively destroyed on opening, e.g. the outer container may be a carton sealed with gummed or self-adhesive tape which cannot be re-used to seal the package.
- b) Crimped metals seals used on the closures of drums, lead and steel pots and small boxes. The seals are crimped onto the ends of a suitable lace or locking wire and are embossed with an identifying pattern. The method used to secure the closure itself should be independent of the security seal.
- c) Padlocks used on the larger type of timber box and also for the massive type of steel or lead/steel flask. A feature, such as a drilled pillar, is incorporated into the box or flask design so that when the padlock is fitted through the drilled hole it is not possible to gain entry into the package.

19 Lifting and tie-down attachments

19.1 General. The packaging has to be so designed that the package can be easily handled and secured in or on the conveyance during transport.

19.2 Lifting aids. For packages from 10 kg to 50 kg, handles, for manual lifting only, should be fitted. Those above 50 kg have to be equipped with lifting attachments to permit safe handling by mechanical means.

19.3 Lifting and design. The design of lifting attachments for the package have to be in accordance with established safety practice and have to embody safety factors in respect of "snatch" lifting or other shock loading.

19.4 Lifting safeguard. Any other feature on the outer surface of the packaging which could be used to lift the package has to be either completely covered or removed during transport or has to be designed to support the entire mass of the package.

19.5 Avoidance of damage. The design of the packaging has to be such that the normal use of lifting devices will not produce stress in any material of the packaging such as to reduce the effectiveness of containment, shielding, nuclear safety control or heat dissipation.

19.6 Tie-down aids. Tie-down attachments have to be designed so that they are capable of withstanding the stresses due to acceleration or retardation that occur during normal transport conditions without the ability of the package to meet the requirements of IAEA Regulations being impaired.

19.7 Acceleration and deceleration. The acceleration or retardation that should be assumed in the design of restraints such as anchor and attachment points and tie-down members will depend upon the means of transport used to convey the package, but the following should be taken as minimum values ($10 \text{ m/s}^2 \approx 1g$):

Road	20 m/s ²	Longitudinal	} These accelerations should be assumed to occur simultaneously.
	20 m/s ²	Lateral	
	10 m/s ²	Vertical	
Rail ^a	60 m/s ²	Longitudinal	
	20 m/s ²	Lateral	
	10 m/s ²	Vertical	
Sea	20 m/s ²	Longitudinal	
	20 m/s ²	Lateral	
	10 m/s ²	Vertical	
Air	30 m/s ²	Longitudinal	
	15 m/s ²	Lateral	
	30 m/s ²	Vertical	

^a The actual figures however will depend upon the type of rail vehicle used and also the type of service, i.e. wagon load, block train etc., so at the packaging design stage it is advisable to consult the British Railways Board on the actual figures to be adopted.

Unless specifically designed to preclude other orientations, or called for in the shipment controls on Type B(M) packages, or subject to a special arrangement for non-regulation packages, it cannot be assumed that packages will be stowed in any particular orientation.

19.8 Tie-down safeguard. Any feature on the package not specifically designed as a tie-down attachment, but which could be used for this purpose, should be securely covered or locked so as to prevent its use as a tie-down device, or alternatively be capable of withstanding the specified stresses.

19.9 Severe accident precautions. Under severe accident conditions, the stresses that occur may be significantly greater than those that occur under normal transport conditions so tie-down attachments should be designed in such a way that, should they be stressed to their breaking point, the containment, shielding, nuclear safety and heat dissipation of the package will not be impaired.

19.10 Instructions for handling, assembling and dismantling packages. Attention should be given at the design stage to the methods of closing and of opening packages and the mechanical handling aids, if any, considered necessary. Operating instructions should be prepared and the design should call for these instructions to be clearly marked or referenced upon an appropriate part of the package assembly.

20 Contamination

20.1 General. Decontamination should be considered at the design stage in relation to the surface itself and the contamination expected. If practical, probable contaminants should be identified and their properties established, bearing in mind the intended usage of the packaging. Specific cleaning recommendations may then be feasible.

20.2 Surface design. Surfaces, internal and external, should be smooth, free from protrusions, crevices, overlaps, and bubble holes. Angles should be rounded. Closure joints, lettering plaques and other external features should be so designed as to avoid retention of dust or moisture and to facilitate cleaning. Anchorage and lifting points and the associated equipment should be so designed as to avoid chafing of the surfaces of the packaging. Stainless steel surfaces with a surface roughness of $1.6 \mu\text{m}$ or less (see BS 2634) are suitable for normal decontamination requirements, but even this material is not fully resistant to decontamination and may need grinding and polishing from time to time. It may be necessary to use expensive materials to resist corrosive attack so that thought should be given to minimizing the area exposed to attack.

The longer the surface remains contaminated the more destructive the decontamination is likely to be.

20.3 Surface treatment. The ideal surface treatment would be permanent, smooth, impermeable, chemically inert, fire resistant, radiation resistant, mechanically hard and strong, easily cleaned and cheap. Contamination would easily be removed from it. Since the ideal does not exist, selection has to be made from proprietary surface treatments. As far as practicable the surface finish should resist attack by the decontaminant. The design should provide sufficient thickness of material to allow for its gradual removal during contamination.

20.4 Assessment of surface treatments.

Reference should be made to BS 4247. BS 4247-1 gives a method of test for ease of decontamination. BS 4247-2 gives a guide to the selection of materials and on interpretation of the test results.

The health and safety department of British Nuclear Fuels Ltd., Windscale, the Paint Research Station at Teddington and the Manchester University Radiological Protection Service are a few of the independent authorities who can test in accordance with BS 4247.

The test described in BS 4247 is intended to be applicable to as many surface finishes as possible to enable the user to examine and choose materials where only light activity is present. Fission product contamination from irradiated fuel ponds is in a category for which a different standard test may be required and discussions on this are in progress.

BS 4247 relates specifically to ease of decontamination. It does not follow that a product which is satisfactory in this respect will be satisfactory in all others.

20.5 Strippable coatings. Where contamination is heavy it may be more economical to provide temporary surfaces on the top of a permanent decontaminable surface. It is easier to remove this than to attempt to decontaminate permanent surfaces. Where there is no provision for the disposal of liquid effluent or where, because of inaccessibility or danger of cross-contamination, the use of detergents is ruled out, a mechanically strippable coating may be used. To meet this requirement a film based on pre-vulcanized rubber latex combined with a complexing detergent has been developed. To decontaminate, a second coating may be applied on top of the contamination and the double layer removed as one. As an alternative, strippable paint or strip lacquer can be used. Resistance to wear is dependent on the thickness of coating applied. Strippable coatings are sometimes difficult and therefore costly to remove; this should be taken into account in making a choice.

20.6 Application of surface treatments. Surface treatments may be rendered useless unless the manufacturer's instructions are followed implicitly.

Raw metal surfaces are usually rough, and are liable to corrosion which will hold contamination and possibly encourage the formation of chemical complexes difficult to remove. All metal surfaces should be prepared to give clean surfaces free from rust and, if necessary, by the use of mechanical blasting, to give the required key. Where this is not possible an etching primer should first be applied. Surface preparation of steel is dealt with in CP 2008.

Surface preparation and priming has to be part of the manufacturer's whole coating procedure.

Mechanical blasting and priming at the container manufacturer's works has economical advantages both in corrosion prevention and in prolonging the life of the coatings but the primer has to be that recommended by the coating supplier.

Consideration should also be given to having the whole coating system applied at the container manufacturer's works.

The coating manufacturer should be consulted regarding the correct application of his material; it is essential that the process is supervised at all stages.

Certain surface finishes, because of their flammability, may give rise to explosive conditions during application unless adequate ventilation is provided. Some of the finished surfaces obtained may also support the rapid spread of flame. Fire prevention advice should be sought.

Section 4. Design approval

21 Packaging or package designs not requiring competent authority approval

21.1 Packaging for items exempt under IAEA Section III and for low specific activity material not in bulk. These have to be packed in such a manner that under normal conditions of transport there can be no leakage of radioactive material. Packaging has to meet the general design requirements of IAEA 201 to 208, but is not required to satisfy any specified performance tests. Useful information on packaging is given in BS 1133.

21.2 Packaging for low level solid materials. These materials require strong industrial type packaging which has to satisfy performance tests for packaging of dangerous goods specified in Volume 4 of the United Nations "Transport of dangerous goods" 1970 edition. Again, information on packaging is given in BS 1133.

21.3 Type A packages

21.3.1 Firms or organizations proposing to use Type A packages should appoint a person responsible for:

- a) internally approving Type A packaging and signing certificates of approval;
- b) maintaining approval records, including the technical supporting documents on which approval is based and master copies of the certificates.