THE TRANSPORTATION OF
SPECIAL FISSIONABLE SUBSTANCES
(FISSILE RADIOACTIVE MATERIALS)

R.W. BLACKBURN
ATOMIC ENERGY CONTROL BOARD

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1) INTRODUCTION

During this Symposium, you have heard an excellent presentation on what criticality safety is and how it is achieved in nuclear materials processing, fuel fabrication, research facilities, and reactors. I would now like to outline briefly how criticality safety is achieved when special fissionable substances are transported between these various operational areas.

Before I begin, let me identify the terms of reference for this presentation. Firstly, when I refer to transportation regulations, I refer to the more recent regulations — that is the International Atomic Energy Agency (IAEA), "Regulations for the Safe Transport of Radioactive Materials, 1967 Edition" and those national and international regulations which are derived from them. Secondly, this presentation is addressed to criticality safety only, and the lack of reference to radiation safety should not cause us to forget that important aspect. Finally, to be consistent with transport regulations, I shall use the terminology "fissile materials" rather than "special fissionable substances".

2) TRANSPORTATION ENVIRONMENT

Since you have acquired some familiarity with criticality safety, I shall begin by describing the other part of my topic, transportation.

Previous criticality safety discussion has been in terms of fixed facilities where equipment, personnel, and procedures are well defined and may be utilized to promote criticality safety. By contrast, the transport environment is highly variable and fissile shipments may be subject to rigorous normal and severe accident conditions of transport while in the custody of transport personnel who cannot be expected to be knowledgeable in either criticality or radiation safety. This situation occurs while fissile materials may be in close proximity to transport workers and to the general public as passengers, users of transport facilities, and residents of adjacent transport routes.

For criticality safety purposes, the physical transport environment may be identified in terms of normal and accident conditions of transport.

Normal conditions include climatic and mechanical components. The climatic component is defined in terms of temperature and pressure extremes, precipitation, and solar radiation. The mechanical component is defined as a 4 foot drop (as may occur from falling out of a transport vehicle) and compressive and puncture loadings (as may be imposed by overstowed cargo or by the inertial forces of other cargo during a vehicle panic stop).

Accident conditions are defined as consecutive application (to a single package) of 30 ft. flat surface and 4 ft. penetration impacts, followed by fire exposure for ½ hour at 1475°F, followed by water immersion for 3 hrs. These parameters have been chosen to represent a severe transportation accident.

Package performance criteria relative to these conditions of transport and radiation and criticality safety are defined in the regulations.
3) BASIS FOR CRITICALITY SAFETY IN TRANSPORTATION

The objective of criticality safety in transportation is to avoid a criticality accident, whether with a single package or any conceivable array of packages both during normal and accident conditions of transport.

Criticality safety in transportation is based on the basic safety equation and on the fundamental concepts of criticality safety.

The basic safety equation is:

\[ \text{Overall Safety} = \text{Design Safety} + \text{Operational Safety} \]

where

Design Safety = Safety features provided by packaging design and material quantity limitations;

Operational Safety = Operational and administrative controls by shipper, carrier, and regulatory authority.

The fundamental concepts of criticality safety, as have been outlined previously at this Symposium, are:

1) Limit quantity of material per shipment to less than the minimum critical mass and isolate this limited quantity from other fissile materials.

2) Remove neutrons from the system through the incorporation of neutron-absorbing materials in the packaging.

3) Maintain a favourable geometry by shape and/or spacing so that sufficient neutrons escape from the system without initiating further fission reactions.

Considering design and operational safety and the three fundamental concepts of criticality safety, it is obvious that there are many possible combinations which may be used to effect criticality safety. For purposes of orderly presentation, the regulations categorize four basic approaches which are named below and which will be described in greater detail later in this presentation. The four categories are Fissile Exempt, Fissile Class I, Fissile Class II, and Fissile Class III.

Before describing these categories in detail, it is desirable to identify the six contingencies which are significant to a criticality safety evaluation of Fissile Classes I, II, and III packages and shipments.

1) Inleakage of water into a package of undermoderated fissile material.

2) Reduction of effectiveness of neutron absorbing materials by change of their position, change of their physical or chemical form; or in the case of neutron absorbers which are effective only for thermal neutrons, by reduction of efficiency of accompanying moderating materials.
3) Rearrangement of package contents into more reactive arrays by
meltdown on fire exposure;
crushing by impact loadings; or
by escape of contents from package with
resultant loss of geometric constraint
and possible addition of moderator and/or reflector.

4) Loss of spacing between packages which are not neutronically isolated.

5) Immersion in water; burial in snow, or flooding in fire-fighting foam or other source of low-density water - especially for undermoderated packages where the interspersed water contains enough hydrogen to fully moderate the emergent neutrons, but is insufficient to capture them and prevent interaction.

6) Commingling of different fissile package designs which may require different degrees of operational safety.

Let us now proceed with an examination of the fissile categories - Fissile Exempt and Fissile Classes I, II, and III.

4) FISSILE EXEMPT

Fissile exempt shipments include those quantities, concentrations and forms of fissile materials which cannot be made critical under any conditions which could credibly exist in the transport environment. The transportation regulations define fissile materials as Pu-239, Pu-241, U-233, and U-235 and any material containing these radionuclides. This broad definition obviously includes many materials which may be exempted from fissile packaging requirements. These materials are:

4.1) Packages containing not more than 15 grams of any single or combination of fissile radionuclides. Some of you will be familiar with AECB Shipping Containers Order 1/200/63-S-25 which elaborates on this exemption relative to U-235.

4.2) Uranium, natural or depleted, unirradiated or irradiated, in any quantity.

4.3) Homogeneous hydrogenous solutions or mixtures which are stable and overmoderated, and in which the fissile radionuclides are present in limited concentrations and quantities.
4.4) Material in which the only fissile radionuclide is U-235, in which the U-235 concentration does not exceed 1 w/o, and which does not present a lattice arrangement.

Fissile exempt packages are subject to the regulatory requirements for radiation safety.

5) FISSILE CLASS I

Fissile Class I packages are defined as those which are nuclearly safe in any number and in any arrangement under all foreseeable circumstances of transport.

If we consider this definition in the context of the previously-mentioned bases for criticality safety in transportation, we see that the overall safety is provided solely by the design safety of the packaging and that the fundamental criticality control concepts of less than critical mass and removal of neutrons by absorption are utilized.

Criticality safety criteria for Fissile Class I packages and shipments consider the six contingencies and may be generally described as:

5.1) For the individual package, contents shall be limited to 30% of that of a similar system which would be critical.

5.2) For an array of packages following the defined normal conditions of transport, an infinite number of packages shall be subcritical.

5.3) For an array of packages following the defined accident conditions of transport, 250 damaged packages shall be subcritical.

Specific methods of demonstrating compliance with these criteria are specified in the regulations.

A typical example of a Fissile Class I packaging is shown in Figure 1. This packaging utilizes a steel drum outer container, wooden (oak) filler (which serves as mechanical and thermal insulant and moderator for incident neutrons), cadmium sheath which surrounds a stainless steel containment vessel, and finally a polyethylene bottle which contains (in this example) plutonium nitrate. The cost of this particular packaging is approximately $1000.00 per unit.

6) FISSILE CLASS II

Fissile Class II packages are defined as those which are nuclearly safe in limited number and in any arrangement under all foreseeable circumstances of transport.

Relating Fissile Class II to the bases for criticality safety, we find that the overall safety is the sum of design safety (the package must meet certain criteria) and operational safety (to limit the number of packages per shipment). All three fundamental criticality
control concepts may be employed, but the more predominant one is spacing to permit escape of neutrons from the system.

Criticality safety criteria for Fissile Class II packages and shipments are specified in the regulations and may be generally described as:

6.1) For the individual package, contents shall be limited to 80% of that of a similar system which would be critical, and following normal conditions of transport, package volume shall not be reduced by more than 5%.

6.2) For an array of packages following the defined normal conditions of transport, 5 times the allowable number of packages shall be subcritical.

6.3) For an array of packages following the defined accident conditions of transport, 2 times the allowable number of packages shall be subcritical.

The "allowable number" used shall be derived from the more restrictive of the two array criteria.

Having now established an "allowable number" of Fissile Class II packages, we now require a simple operational control to prevent the accumulation of more than this number of packages at any time during transportation.

Radiation safety requires that accumulations of radioactive materials packages be controlled to limit the radiation dose rate adjacent to a stack of packages. This is accomplished by assigning a number to each package (called a transport index) and by specifying that no more than a total of 50 transport index units shall be accumulated in any single transport vehicle or storage location. The transport index is defined as the number expressing the radiation dose rate (in mR/hr) at 1 meter from the external surface of the package. (IAEA Regulations define the centre of the package as the reference datum but North American practice is to use the external surface of the package as the datum.)

The transport index also provides a simple and convenient method of controlling the allowable number of Fissile Class II packages. By modifying the definition of transport index so that for Fissile Class II packages, the transport index is the greater of the number expressing the radiation dose rate in mR/hr at one meter from the package external surface or the allowable number of packages divided by 50, we have a control to prevent accumulation of more than an allowable number of Fissile Class II packages even though these packages may be of a different design and may have originated from different shippers.

Fissile Class II packaging, because of its convenience and low cost is proving to be the most popular type of fissile packaging. A typical example of Fissile Class II packaging is shown in Figure 2. This packaging uses a steel drum as the outer container, a doubly-capped piece of pipe as the inner container, four steel rod spacers to maintain the concentricity of inner and outer containers, and packed vermiculite to provide thermal insulation and impact shock absorption. The cost of a container of this type is approximately fifty dollars per unit.
7) **FISSILE CLASS III**

Fissile Class III packages and shipments are those which have not been demonstrated to fulfill all the criteria for Fissile Exempt and Fissile Classes I and II and which are safe by reason of special arrangements by the shipper and carrier. The IAEA Regulations define "special arrangements" shipments as those which "may only be transported with the prior approval of the competent authorities of all countries affected by the movement. In such case the competent authority or authorities shall impose conditions adequate to ensure that the transport of the consignment shall be no less safe than if all the relevant provisions of these regulations had been complied with." Usually, greater emphasis is placed on the "operational safety" component of the basic safety equation than on the "design safety" component.

No approval criteria are defined for Fissile Class III shipments other than each shipment must be specifically approved by the regulatory authority and each application for approval must consider the six transportation contingencies described earlier. The commingling contingency is usually controlled by providing an exclusive-use transport vehicle or by escorting the shipment.

Fissile Class III is used for shipments which do not meet the other fissile criteria and for "one-off" shipments where economics favour the use of exclusive-use or escorted transport rather than the provision of an expensive packaging.

8) **OTHER REGULATORY REQUIREMENTS**

Fissile materials are subject to all other relevant regulatory requirements relating to radiation safety.

All Fissile Class I, II, and III packagings and Fissile Class III shipments require regulatory authority approval. In addition, all Fissile Class III shipments require prior notification to the regulatory authority.

All Fissile Class I, II, and III packagings require labelling and indication of transport index. The label does not identify the package contents as fissile material; however, the shipping documents require this identification.

Current regulations contain a specification fissile packaging—the Specification 6L with which some of you are familiar. (Figure 2 illustrates a Specification 6L packaging). A specification packaging is one whose permissible contents and significant design features are defined in the regulations. Any shipper may fabricate and use these packagings in the specified manner without further approval from the transport regulatory authorities. Specification packagings provide significant benefits for shippers and regulatory authorities and it is our hope to cooperate with the nuclear industry to develop and approve additional specification packagings on a North American and international basis.

9) **CONCLUSION**

This presentation has been a very brief summary of criticality safety in the transport of fissile materials. Anyone who has a detailed interest is invited to follow up on any aspect of this topic during the discussion period which follows or at any other time.
A FISSILE CLASS I PACKAGING FOR PLUTONIUM NITRATE

Capacity: 3 liters

MAXIMUM PLUTONIUM LOADING: 700 gm

COST: APPROX. $1000. PER UNIT
THREADED CAP, TOP AND BOTTOM

¼" DIA. STEEL ROD SPACERS (4-90° APART)

FILLED WITH VERMICULITE

6" DIA. SCHEDULE 40 STEEL PIPE 30" LONG (ICC-2R)

55 GALLON DRUM (ICC-6J)

**FIGURE 2**

A FISSION CLASS II PACKAGING (SPECIFICATION 6L)

ALLOWABLE NUMBER = 40 PACKAGES (TRANSPORT INDEX = 1)*

PERMISSIBLE LOADING = Up to 14 Kg U-235 per package
(H/U5 ≤ 3, metal, oxide, alloys etc.)

COST: APPROX. $50. PER UNIT

* Current regulation limit total transport index (current terminology is "radiation units") to 40 units. IAEA Regulations permit 50 units.