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EVALUATION OF A SHIPPING CONTAINER FOR NINE
UNIRRADIATED ROVER FUEL ELEMENTS (U)

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Nuclear Division

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3

CONTENTS

SUMMARY	5
INTRODUCTION	7
NINE ELEMENT SHIPPING CONTAINER	9
Description	9
Structural Evaluation	10
Introduction	10
Satisfaction of General Standards for All Packaging	10
Satisfaction of Standards Relating to Normal Transport Environment	11
Satisfaction of Standards Relating to Hypothetical Accident Conditions	11
Criticality Evaluation	13
Introduction	13
Calculational Methods	17
Subcriticality of an Individual Container	19
Subcriticality of Arrays of Containers.	19
Conclusions	21
REFERENCES	23
ACKNOWLEDGEMENTS	25
APPENDIX	27
Extracts from AEC Manual, Chapter 0529 Appendix	27

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5

SUMMARY

A shipping container design for the shipment of small quantities of un-irradiated Rover fuel elements has been evaluated against the fissile material packaging standards given in AEC Manual Chapter 0529.

Based on the results of an engineering analysis, mechanical testing of prototypes, and an associated nuclear criticality safety analysis, the container was found to meet the standards given in Chapter 0529 for a Fissile Class II package, subject to the following loading restrictions:

1. For Class II shipments, each container is to be loaded with no more than 9 elements.
2. The maximum uranium content of an element is not to exceed 346 grams, the uranium loading is not to exceed 1200 mgs/cm³, and the carbon-to-uranium atomic ratio is not to be less than 33 to 1.

A nine-element shipping container loaded so as to satisfy these restrictions is to be assigned 0.5 radiation unit.

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INTRODUCTION

Since 1960, nuclear reactor fuel elements for Rover applications have been fabricated at the Oak Ridge Y-12 Plant. A container¹ for shipments of 44 of these elements has been approved for use in Fissile Class I shipments. Shipments of small numbers of the elements for various experimental purposes are also required, and for these shipments the Class I container is inconveniently large. In the past, containers with a capacity of nine elements have been used in Fissile Class III-type* shipments of small numbers of the unirradiated fuel elements.

Since economic and other benefits derive from making such shipments as Fissile Class II, modifications have been made to the design so that containers fabricated to its specifications could be expected to meet Class II standards. An evaluation program consisting of an engineering analysis, prototype testing, and an associated nuclear criticality safety analysis was undertaken to determine whether these standards are met.

It is the purpose of this report to summarize the results of this evaluation program in sufficient detail that it can serve as the main supporting document for an application to the Atomic Energy Commission for approval of the use of these containers in Fissile Class II shipments.² To provide for ease in cross checking the evaluation with the standards, the standards are referred to by their paragraph numbers and headings as they appear in the AEC Manual.³ In addition, the applicable parts of the Manual have been extracted and are included in the Appendix.

*Definitions of the various fissile classes are given in the AEC Manual.³

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NINE ELEMENT SHIPPING CONTAINER

DESCRIPTION

Figure 1 presents a sketch of the present-design shipping container for 9 unirradiated Rover fuel elements. Some of the features of construction are as follows: The containment vessel, which is not designed to be watertight, consists of a 4-inch Schedule-40 steel pipe, which is 4.5 inches in diameter and has a 0.237-inch-thick wall. One end is permanently closed by a 1/4-inch-thick steel plate welded into place; the other end has a 4-inch Schedule-40 threaded malleable iron pipe cap. This type of containment vessel satisfies the requirements of ICC Specification 2R. The containment vessel is centered in a cylindrical outer container consisting of four 10-gallon capacity, 22 gauge steel drums welded together end-to-end. For support, the vessel is welded to three washer-shaped, 3/16-inch

Figure 1. NINE ELEMENT SHIPPING CONTAINER.

thick steel disks. Two of these disks are in turn welded to the ends of two of the drums while the third is welded to the rims of the two central drums. Each of the four drums has 6 one-inch-diameter holes equally spaced around the circumference to provide free access for water or other liquids should the drum inadvertently become immersed. Two 41-inch lengths of angle iron welded to the drums provide support for transferring the package by fork lift. Two blocks of wood, held in place by steel shipping bands, are provided for access of the fork lift prongs and to prevent the container from slipping off the prongs. This arrangement will be referred to below as the "skid."

Fuel elements are enclosed in plastic-stoppered one-inch-OD aluminum tubes. These aluminum tubes are wrapped in packing paper and placed inside the containment vessel for shipment.

STRUCTURAL EVALUATION

Introduction

The structural evaluation of the container incorporated an engineering analysis, the results of testing prototype containers and separate containment vessels, and information available based on six years' use of the same type of containment vessel enclosed in a wooden box for Fissile Class III-type shipments. The engineering analysis utilized standard design-analysis techniques. The prototype containers and separate containment vessels were subjected to the hypothetical accident conditions specified in Annex 2 of the AEC Manual (see Appendix). Information on the condition of the containment vessels utilized in shipping over the past six years was obtained from all the sources readily available, including visual inspection of the used vessels.

Satisfaction of General Standards for All Packaging

The requirements of Paragraph II.A., "General Standards for All Packaging" are considered met based on an engineering evaluation of the container construction, on experience with similar containers, and on the proposed use. Specifically:

1. No significant chemical, galvanic, or other reaction will occur because the fuel-element composition is relatively chemically inert toward the materials of construction as are the materials of composition to one another.
2. Positive closure to prevent inadvertent opening is provided by the bolted ring clamp and through use of an ICC Specification 2R inner container as the containment vessel.

3. The skid, which is designed to be used for fork-lift manipulation of the containers, satisfies all requirements for a lifting device on the basis of engineering analysis.
4. Although no part of the container has been designed to serve as a tie-down device, the skid could be so used. On the basis of an engineering analysis, the skid meets the requirements for a tie-down device.

Satisfaction of Standards Relating to Normal Transport Environment

The requirements of Paragraphs II.D., "Evaluation of a Single Package," and II.E., "Standards for Normal Conditions of Transport for a Single Package," in regard to the conditions defined in Annex 1, "Normal Conditions of Transport," have been assessed to be met on the basis of:

1. Engineering analysis.
2. Satisfaction of the generally more severe requirements of Annex 2, "Hypothetical Accident Conditions."

Satisfaction of Standards Relating to Hypothetical Accident Conditions

Three prototype containers were subjected to hypothetical accident conditions as specified in Annex 2. One was subjected to the free drop, puncture and thermal tests in this sequence, one to the free drop and thermal tests and one to only the free drop test. Since the containment vessels are assumed not to be watertight, there was no need to subject the containers to water immersion. The results of this testing are described and illustrated in the sections that follow.

Free Drop - The containers were dropped thirty feet onto a pad especially constructed for use in free-drop tests by the Oak Ridge Gaseous Diffusion Plant. The pad consists of a four-inch-thick steel armor plate welded to steel beams embedded in reinforced concrete.⁴ One container was dropped on the side opposite the wooden blocks in an attitude 15° from the vertical. This attitude was calculated to be the one for which maximum damage would occur on the basis of an engineering analysis and previous tests of drum-type containers. Two others were dropped on end.

Figure 2 is a photograph of the first container after the free drop. The drum did not rupture, nor was there any evidence of any other substantial reduction in the effectiveness of the packaging. Some reduction in the diameter was experienced, but it appears certain that additional array spacing would result due to other deformations experienced. Nevertheless, for criticality assessment of arrays of containers damaged in this fashion, each container was considered to have lost an inch in diameter and an inch in length.

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Figure 2. SHIPPING CONTAINER AFTER A FREE DROP OF THIRTY FEET ON EDGE OF LID. (Photo PH 66 1125).

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Figure 3 is a photograph of one of the other two containers after the free drop. The container did not rupture, nor was there any evidence of any other substantial reduction in effectiveness of the packaging. The length of the container was reduced approximately 5 inches. A criticality assessment of arrays of containers damaged in this fashion was made also.

Puncture - One container was dropped forty inches onto a puncture bar meeting the specifications of Annex 2. The container was dropped on the surface that was evaluated to be the one in which maximum damage would occur on the basis of an engineering analysis and previous tests of drum-type containers.

Figure 4 is a photograph of the container after this test. An indentation of about two and one-half inches occurred without tearing the drum wall. Such damage obviously does not reduce the effective volume or spacing, nor does it permit the entry of a four-inch cube through the surface of the container.

Thermal - Following the free-fall and puncture tests, two containers were inserted in an exposed-coil, electrical-resistance-heated, thermostatically controlled furnace. Just prior to insertion, the furnace temperature was raised to 1525°F. It dropped to 1300°F immediately after insertion but attained the desired level of 1475°F after 15 minutes. One-half hour after the temperature reached 1475°F the containers were removed from the furnace.

Figure 5 shows the prototype containers upon completion of the thermal testing. No loss of containment or change of dimensions which could affect array spacing occurred to the containers as a result of this test. (Note: The wooden blocks were removed prior to insertion in the furnace to prevent ignition.)

CRITICALITY EVALUATION

Introduction

The nuclear criticality safety of a loaded container and of arrays of loaded containers in conservative approximations to shipping configurations were investigated using the results of reactor theory calculations. The standards for safety used in this investigation are those given in the AEC Manual^{2,3} applying to Fissile Class II packages. In order to provide some margin for changes in Rover fuel element design, the analysis was done for a hypothetical fuel-element loading of 346 grams U/element which corresponds to a uranium density of 1200 mgs U/cm³ in the fuel element matrix material and a carbon-to-uranium atomic ratio of 33 to 1. This loading is greater than the fuel-element loadings presently contemplated for shipment in these containers.

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Figure 3. SHIPPING CONTAINER AFTER A FREE DROP OF THIRTY FEET FLUSH ON END. (Photo PH 67 421)

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Figure 4. SHIPPING CONTAINER SHOWING IMPACT AREA OF PUNCTURE BAR.
(Photo PH 66 1120)

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Figure 5. POST-THERMAL-TEST APPEARANCE OF SHIPPING CONTAINERS. (Photo 120272)

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Calculational Methods

The calculations were performed using the S_n transport theory code ANISN⁵ in the S_4 approximation, and the Monte Carlo transport theory code KENO.^{6,7} Hansen-Roach sixteen energy-group neutron cross sections⁸ were used for all the materials. The calculational codes and the cross sections are considered well-established for this use on the basis of their success in calculating a large variety of experimental critical assemblies, including, for the KENO code, hydrogen-moderated and reflected arrays of fissile units. An infinite cylinder mock-up of a water-flooded loaded containment vessel was devised for use with the ANISN code. Finite cylinder mock-ups of a loaded container were devised for use with the KENO code. These mock-ups are shown in Figures 6 and 7. The fuel elements were homogenized with their individual aluminum tubes to form the fuel regions of the mock-ups. The material compositions and densities for the various materials indicated in the drawings are given in Table 1. It is to be noted that the fuel

Table 1

MATERIAL DESCRIPTION FOR CALCULATIONSFuel Elements

Matrix Volume	288 cm ³ /element
Material Density (max)	3.07 gms/cm ³
Uranium Density (max)	1200 mgs/cm ³
Graphite Density (constant)	1.87 gms/cm ³
Uranium Enrichment	93.15 wt %

Aluminum Tubes

Dimensions	1-inch OD, 0.035-inch wall
Density (aluminum)	2.7 gms/cm ³

Steel

Density (carbon steel)	7.82 gms/cm ³
------------------------	--------------------------

Foam Rubber

Foam rubber packing taken as water at half normal density

region length is 55 inches, whereas, due to packing techniques, fuel elements longer than 54.75 inches cannot be shipped in this container. The bottoms of the drums and the three-sixteenths-inch-thick steel plate between the two central drums of a container were not mocked up, and the inside length of the containment vessel has been reduced about one-

Figure 6. SECTION OF AN INFINITE CYLINDER CALCULATIONAL MOCKUP OF A LOADED CONTAINMENT VESSEL.

Figure 7. SECTION OF THE MIDPLANE OF A FINITE CYLINDER CALCULATIONAL MOCKUP OF A LOADED CONTAINER.

quarter inch. Also, the pipe cap was replaced by a steel plate the same as on the opposite end. It is evident from the calculational results discussed below that the effect of not mocking up some of the steel present in the container is to increase the reactivity of the mock-up over that of the actual container. Finally, the mock-up has 20 gauge steel drum walls rather than the 22 gauge actually to be used. The difference of 0.006 inch in wall thickness obviously has a negligible effect on the results of the calculations.

Subcriticality of an Individual Container

The standards of Paragraphs II.C.1. and II.E.2. of the Manual pertain to the subcriticality of individual packages under specified conditions. Although it is assumed that water can leak into the containment vessel and the structure of the container is such that water is not excluded from immediately surrounding the containment vessel, the standards of Paragraph II.C.1. are for more effective moderation and reflection than the standards of Paragraph II.E.2. Thus, satisfaction of the standards of Paragraph II.C.1. will ensure satisfaction of the standards of Paragraph II.E.2. To determine the optimum moderation in the containment vessel, ANISN calculations were made of the k_{eff} of the mock-up of Figure 6 for fuel matrix loadings of 600 and 1200 mg U/cm³ under several conditions of moderation. In each case, the k_{eff} was the greatest for the maximum amount of water possible in the containment vessel. The maximum k_{eff} was 0.58 and occurred for the 1200 mg U/cm³ loading. Thus, the standards are adequately satisfied.

It is to be noted that some conservatism is present in the calculations due to the homogenization of the fuel elements, aluminum tubes, and water inside the container.

Subcriticality of Arrays of Containers

It became apparent on preliminary analysis that arrays of the containers under hypothetical accident conditions would be so much more reactive than arrays under normal conditions of transport that the number of radiation units to be assigned to a container would be determined by the maximum-sized subcritical array under accident conditions. Therefore, the analysis of arrays under these conditions was made first.

As stated in the discussion of structural evaluation, two damaged conditions were considered, one in which the container length and diameter were each reduced one inch, and one in which the length was reduced five inches and the diameter left unchanged. The former corresponds to a volume reduction of 15% and the latter to a volume reduction of 7.6%. The magnitude of the latter is considered the more realistic.

To determine the optimum array moderation, a series of KENO calculations was made in which the array moderation was mocked up by water layers about the individual containment vessels. Water was assumed to have leaked into the containment vessels to the maximum extent (see the discussion of individual container criticality). A 10 x 10 x 2 high reflected array of 200 containers was used for this study. The containers were on a square pitch, stacked two high, and adjacent containers were touching. The skids were not mocked up in this or any of the subsequent array calculations. The array was surrounded by a six-inch-thick water reflector. It should be noted that the height to which containers were stacked in this array and in the other arrays calculated was chosen so as to make the ratio of the array height to the square root of its base as near unity as possible. (There is experimental evidence that arrays with such ratios near unity are more reactive than those with ratios far from unity.⁹)

The results of the calculations are plotted in Figure 8. The uncertainties indicated are the 95% confidence level bounds on the statistics of the calculation only. That is, the effects of uncertainties in the cross sections, etc., are not included. The curve has been merely sketched in to help indicate the trend of the results. It is apparent from the results that the array is more reactive when there is no array moderation. This result is not unreasonable since there is a relatively thick layer of iron between the fissile material and any array moderating material and this layer will absorb thermal neutrons. Also, the array is well-reflected so that, the array neutron leakage is low.

Figure 8. EFFECT OF ARRAY WATER MODERATION ON THE CRITICALITY OF AN ARRAY OF CONTAINERS 10 X 10 X 2 ARRAY OF INTERNALLY MODERATED CONTAINERS 6-INCH WATER REFLECTOR ABOUT ARRAY.

The most reactive arrangement of containers would be on a triangular pitch with adjacent containers touching, since such an array has the greatest density of fissile material of any pattern in which the containers are not deformed. At present, however, the KENO code cannot be used to analyze triangularly pitched arrays directly, and so the following approximate treatment was made. The density of containment vessels in an array of damaged containers on the above-described triangular pitch was calculated. Then, the array spacing of a square-pitched array of containers with the same density of containment vessels was found. Such an array requires a reduction of 7% in the outside diameter of the damaged container mock-up. The k_{eff} 's of $9 \times 9 \times 2$ high arrays of 162 containers were calculated with the containment vessels internally flooded with water and the arrays reflected by 6 inches of water. For the array in which the container diameter and height were both reduced the result was 0.95 ± 0.01 and for the one in which the container length only was reduced the result was 0.92 ± 0.02 . As in Figure 8, the uncertainties indicate the 95% confidence interval bounds. Present experience with the KENO code dictates that the higher result can be considered at most 1 or 2% subcritical; therefore, no larger arrays were analyzed.

By Paragraph II.I., a minimum of 0.5 radiation unit can thus be assigned to each container if at least 400 undamaged containers are subcritical in any arrangement if closely reflected by water. Using the triangular-to-square pitch approximation technique described above, the k_{eff} of a $12 \times 12 \times 3$ reflected array of 432 containers was calculated to be 0.42 ± 0.03 . The array was reflected by six inches of water. Therefore, the assignment of 0.5 radiation unit to each container is justified.

It is to be noted that considerable conservatism was built into the calculations of arrays of undamaged containers beyond that mentioned previously in that the container skid was not included in the calculational mock-up. Thus, the density of packages in the arrays calculated was far greater than could actually occur in a shipping array of more than a few containers. Some conservatism is present in the calculations of arrays of damaged containers for the same reason, even though some or all of the wooden parts of the skids would likely burn off in a fire.

CONCLUSIONS

Based on the structural and criticality safety evaluations detailed in this report, it is concluded that the shipping container meets all the standards for use of the container in Class II shipments of Rover fuel elements subject to certain restrictions on the number of elements to be shipped in a single container and on the fuel-element composition. These restrictions are primarily due to the limited extent of the

criticality safety evaluation which, however, was of an adequate extent for the proposed use of the shipping containers. The restrictions are:

1. For Class II shipments, each container is to be loaded with no more than nine fuel elements.
2. Fuel elements to be shipped in these containers under Class II conditions are to be of the uranium carbide-graphite type with a maximum uranium loading of 1200 mgs/cm³ of fuel matrix, corresponding to a maximum of 346 grams of uranium per element, and a minimum carbon-to-uranium atomic ratio of 33 to 1.

A container loaded for shipment so as to satisfy these restrictions is to be assigned 0.5 radiation unit.

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25

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APPENDIX

EXTRACTS FROM AEC MANUAL CHAPTER 0529 APPENDIX

The specific standards against which the fuel element shipping container has been evaluated are as follows from AEC Appendix 0529:

II. PACKAGE STANDARDS

A. General standards for all packaging

1. Packaging shall be of such materials and construction that there will be no significant chemical, galvanic, or other reaction among the packaging components, or between the packaging components and the package contents, and:
2. Packaging shall be equipped with a positive closure which will prevent inadvertent opening, and:
3. Lifting devices
 - (a) If there is a system of lifting devices which is a structural part of the package, the system shall be capable of supporting three times the weight of the loaded package without generating stress in any material of the packaging in excess of its yield strength.
 - (b) Each lifting device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the containment or shielding properties of the package, and:
4. Tie-down devices
 - (a) If there is a system of tie-down devices which is a structural part of the package, the system shall be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of ten times the weight of the package with its contents, and a horizontal component in the transverse direction of five times the weight of the package with its contents.

- (b) If there is a structural part of the package which could be employed to tie the package down and which does not comply with subparagraph a. of this paragraph, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

C. Criticality standards for fissile material packages

- 1. A package used for the transport of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that water leaks into the containment vessel, and:
 - (a) Water moderation of the contents occurs to the most reactive credible extent consistent with the chemical and physical form of the contents; and:
 - (b) The containment vessel is fully reflected on all sides by water.

D. Evaluation of a single package

- 1. The effect of the transport environment on the safety of any single package of radioactive material shall be evaluated as follows:
 - (a) The ability of a package to withstand conditions likely to occur in normal transport shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the normal conditions of transport as specified in II.E., and:
 - (b) The effect on a package of conditions likely to occur in an accident shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the hypothetical accident conditions as specified in II.F.

E. Standards for normal conditions of transport for a single package

- 1. A package used for the shipment of fissile material or a large quantity of radioactive material, as defined in I.A.6., shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in Annex 1 of this part:
 - (a) There will be no release of radioactive material from the containment vessel, and:

- (b) The effectiveness of the packaging will not be substantially reduced.
2. A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in Annex 1 of this part; considered individually:
- (a) The package will be subcritical, and:
 - (b) The geometric form of the package contents would not be substantially altered, and:
 - (d) There will be no substantial reduction in the effectiveness of the packaging, including:
 - (1) Reduction by more than five percent in the total effective volume of the packaging on which nuclear safety is assessed;
 - (2) Reduction by more than five percent in the effective spacing on which nuclear safety is assessed, between the center of the containment vessel and the outer surface of the packaging; or
 - (3) Occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a four-inch cube.
- F. Standards for hypothetical accident conditions for a single package
2. A package used for the shipment of fissile material shall be designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in Annex 2 of this part as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed in Annex 2, the package would be subcritical. In determining whether this standard is satisfied, it shall be assumed that:
- (a) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents, and:
 - (b) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents, and:

- (c) There is reflection by water on all sides and as close as is consistent with the damaged condition of the package.

G. Evaluation of an array of packages of fissile material

1. The effect of the transport environment on the nuclear criticality safety of an array of packages of fissile material shall be evaluated by subjecting a sample package or a scale model, by test or other assessment, to the hypothetical accident conditions specified in II.H., II.I., or II.J. for the proposed fissile class, and by assuming that each package in the array is damaged to the same extent as the sample package or scale model. In the case of a Fissile Class III shipment, the manager or other designated official may, taking into account controls to be exercised by the shipper, permit the shipment to be evaluated as a whole rather than as individual packages, and either with or without the transporting vehicle, for the purpose of one or more tests.
2. In determining whether the standards of II.H.2., II.I.1.b., and II.J.2. are satisfied, it shall be assumed that:
 - (a) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package, the chemical and physical form of the contents, and controls exercised over the number of packages to be transported together, and:
 - (b) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.

I. Specific standards for a Fissile Class II package

1. A Fissile Class II package shall be so designed and constructed and its contents so limited, and the number of such packages which may be transported together so limited, that:
 - (a) Five times that number of such undamaged packages would be subcritical in any arrangement if closely reflected by water; and:
 - (b) Twice that number of such packages would be subcritical in any arrangement if each package were subjected to the hypothetical accident conditions specified in Annex 2 of this appendix as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Annex 2, with close reflection by water on all sides of the array and with optimum interspersed hydrogenous moderation unless

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31

there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in II.G.

2. The minimum number of radiation units for each Fissile Class II package is calculated by dividing the number 40 by the number of such Fissile Class II packages which may be transported together as determined under the limitations of Paragraph 1. of this section. The calculated number shall be rounded up to the first decimal place.

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ANNEX 1

NORMAL CONDITIONS OF TRANSPORT

1. Heat - Direct sunlight at an ambient temperature of 130°F in still air.
2. Cold - An ambient temperature of -40°F in still air and shade.
3. Pressure - Atmospheric pressure of 0.5 times standard atmospheric pressure.
4. Vibration - Vibration normally incident to transport.
5. Water Spray - A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet during a period of thirty minutes.
6. Free Drop - Within 2 1/2 hours after conclusion of the water spray, a free drop through the distance specified below onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

Free Fall Distance

<u>Package Weight</u>	<u>Distance</u>
Less than 10,000 pounds	4 ft
10,000 to 20,000	3 ft
20,000 to 30,000	2 ft
More than 30,000 pounds	1 ft

7. Corner Drop - A free drop onto each corner of the package in succession or in the case of a cylindrical package, onto each quarter of each rim, from a height of one foot. This test does not apply to packages which are not constructed primarily of wood or fiberboard, or to packages exceeding 10,000 pounds in weight.

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8. Penetration - Impact of the flat circular end of a vertical steel cylinder one and one-quarter inches in diameter and weighing 13 pounds, dropped from a height of four feet normally onto the exposed surface of the package which is expected to be most vulnerable to puncture.
9. Compression - For packages not exceeding 10,000 pounds in weight, a compressive load equal to either five times the weight of the package or two pounds per square inch multiplied by the maximum horizontal cross section of the package, whichever is greater. The load shall be applied during a period of 24 hours, uniformly against the top and bottom of the package in the position in which the package would normally be transported.

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ANNEX 2

HYPOTHETICAL ACCIDENT CONDITIONS

1. Free Drop - A free drop through a distance of thirty feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.
2. Puncture - A free drop through a distance of forty inches striking, in a position maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be six inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such a length as to cause maximum damage to the package, but not less than eight inches long. The long axis of the bar shall be normal to the package surface.
3. Thermal - Exposure for thirty minutes within a source of radiant heat having a temperature of 1475°F and an emissivity coefficient of 0.9, or equivalent. For calculational purposes, it shall be assumed that the package has an absorption coefficient of 0.8. The package shall not be cooled artificially until after the thirty-minute test period has expired and the temperature at the center of the package has begun to fall.

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