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AEC RESEARCH AND DEVELOPMENT REPORT

# ESTIMATION OF $^{252}$Cf SHIELDING REQUIREMENTS


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# ESTIMATION OF $^{252}$Cf SHIELDING REQUIREMENTS

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## CONTENTS

## INTRODUCTION

The design of shielding for $^{252}$Cf relates to both the fast neutrons from spontaneous fission of the $^{252}$Cf and the primary gamma rays emitted by the fission products. Interactions of fast neutrons with shielding materials usually produce low-energy neutrons (eventually thermal neutrons) which in turn interact with shielding materials to provide additional (secondary) gamma radiation.

Selection of appropriate shielding materials depends upon the type of radiation to be shielded. For example, low-mass and hydrogenous materials such as water, polyethylene, and paraffin are used for shielding fast neutrons; heavy metals such as lead and iron are used for shielding gamma rays. For $^{252}$Cf, the shielding of thermal neutrons is not a significant problem.

In this report a method to estimate size and weight for shields composed of ordinary concrete (03),* water, paraffin, polyethylene, and "Benelex"** is described. Studies to determine estimates for other shielding materials including lithium are in progress. The effect of $^{10}$B addition on the secondary gamma dose rate is also included. The method described in this report is intended only as a convenient means of estimating shield requirements and is not intended to be a manual for final shield design.

A glossary of nuclear terms and excerpts from DOT regulations on radioactive materials are given for prospective $^{252}$Cf users who have little acquaintance with nuclear terminology or nuclear radiation effects and regulations.

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* Along with a number of minor constituents, ordinary concrete (03) has the following approximate composition (in g/cm$^3$): 0.58 Ca, .02H, .026 Fe, 1.12 oxygen, 0.34 Si and 0.12 carbon. Its shielding capabilities are perhaps the average for shielding concretes.

** "Benelex" is a trademark of the Masonite Corp. and is comprised chiefly of cellulose fibers and lignin. "Benelex -70", for example, contains 6.5% hydrogen, 48.2% carbon, and 45.3% oxygen.

## USE OF SHIELDING ESTIMATES

Calculations presented here can be used to estimate thicknesses for either single component shields or multicomponent shields and weights for single component shields. Generally, multicomponent shields are desirable for minimum size and weight (Figure 1).

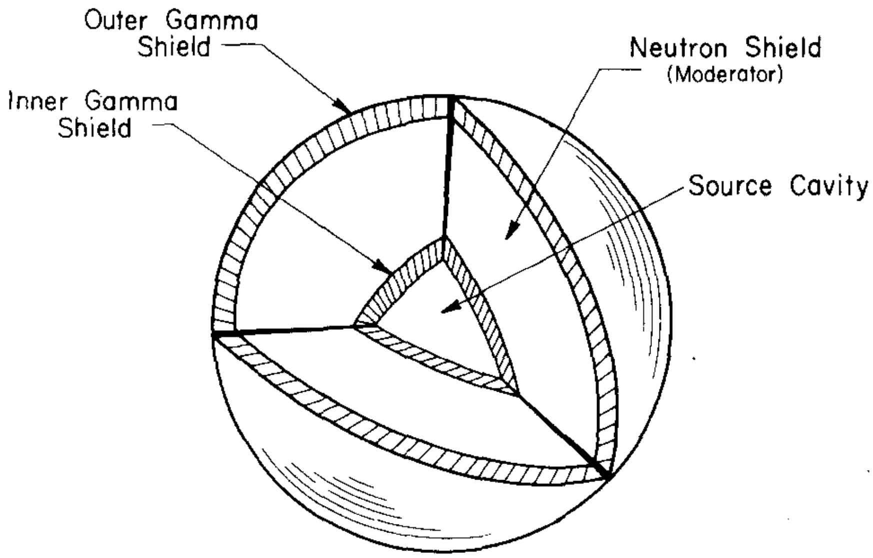


FIG. 1 MULTICOMPONENT CALIFORNIUM SHIELD

In the following examples, a 5-μg $^{252}Cf$ source is surrounded by 20 inches of paraffin. The total dose rate is calculated for a paraffin shield (Example 1), for a paraffin shield with an iron shield (Examples 2-4), and for a paraffin shield with boron and an iron shield (Example 5).

### Single Component Shields

Total dose at the surface of a shield material may be determined by adding the neutron dose rate (Figure 2) and the total gamma dose rate (Figure 3) at a common desired shield thickness and then multiplying this sum by the $^{252}Cf$ source weight.

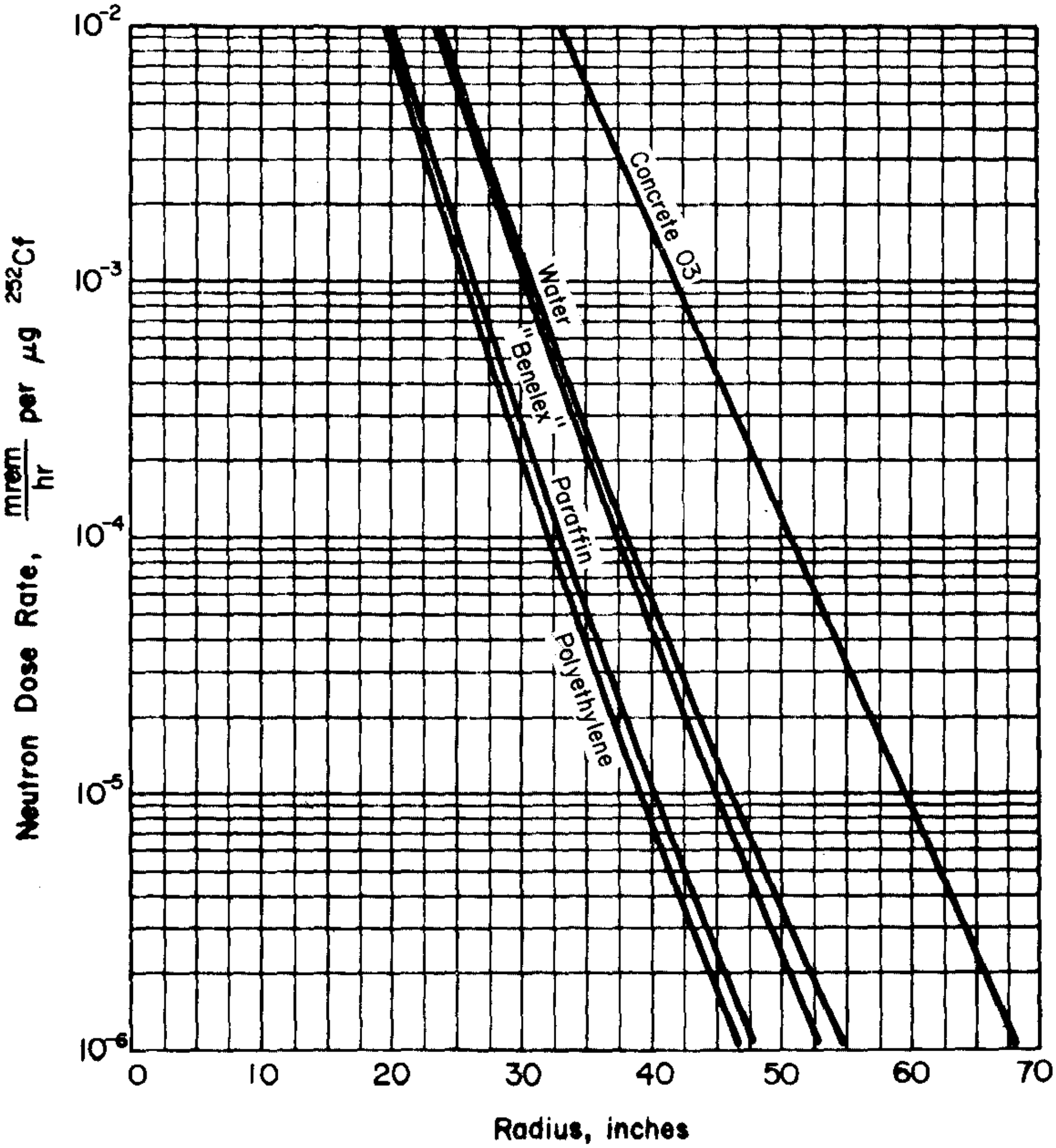


FIG. 2 (Continued)

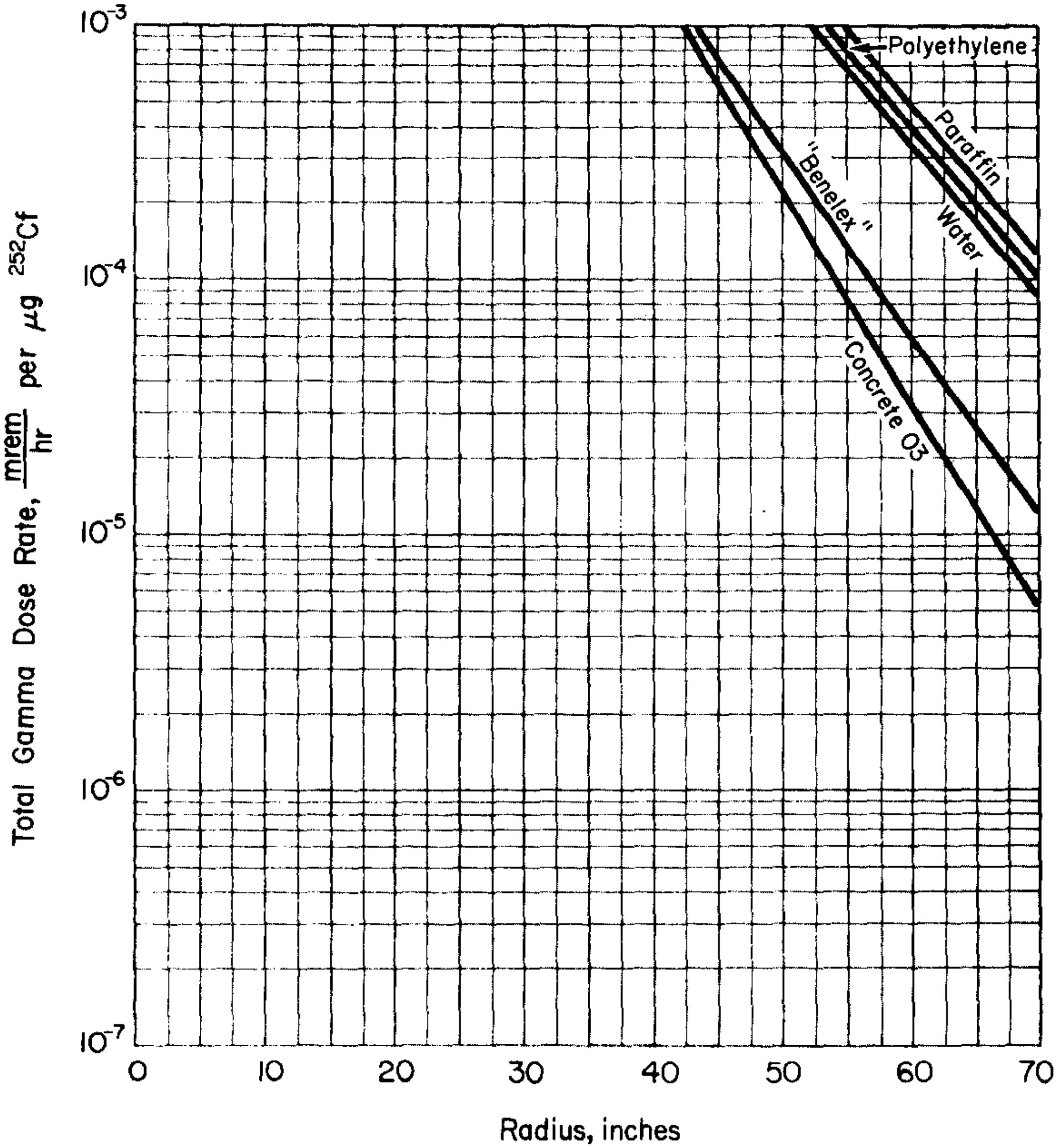


FIG. 3 (Continued)

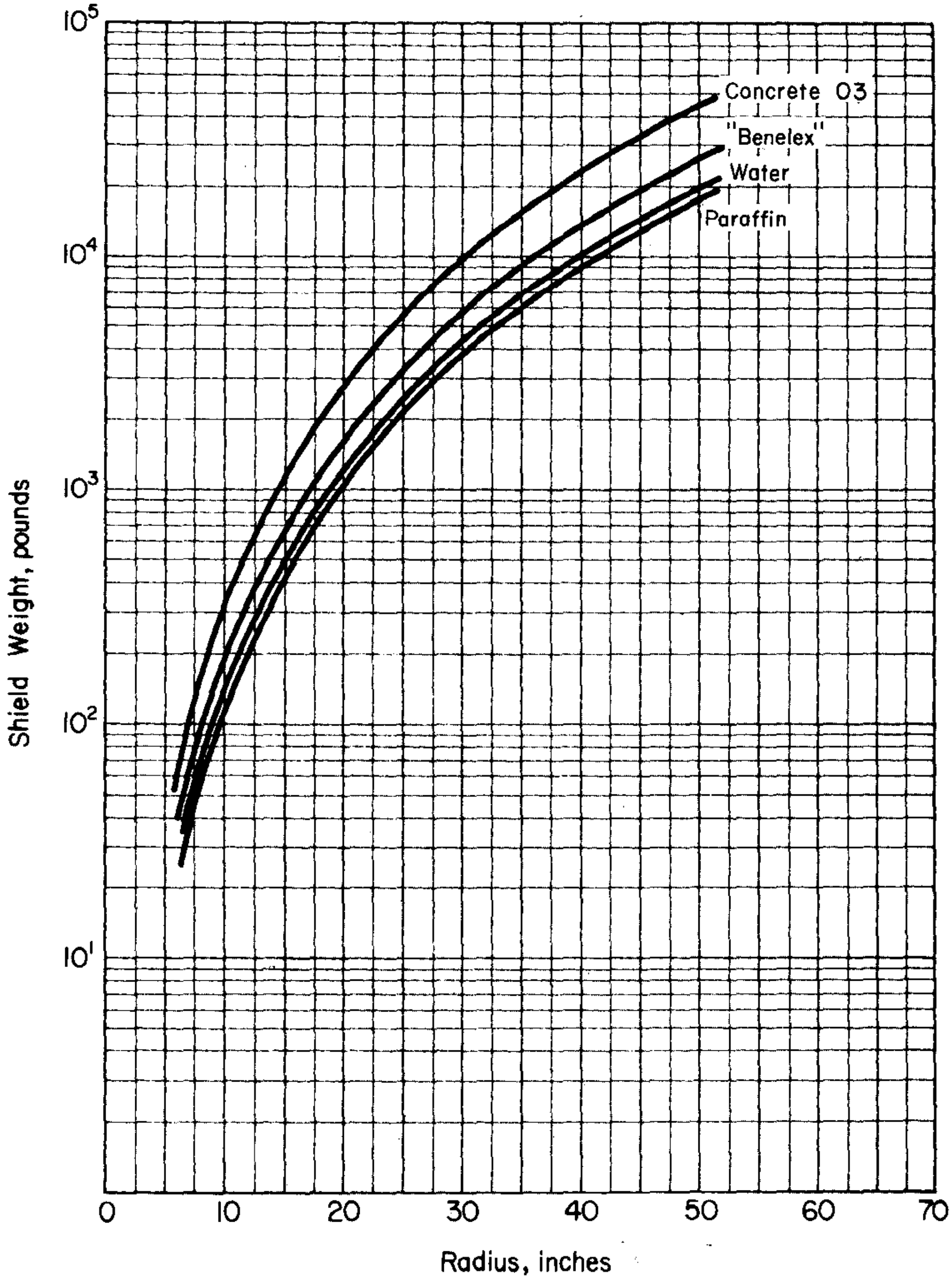


FIG. 4 SPHERICAL SHIELD WEIGHT

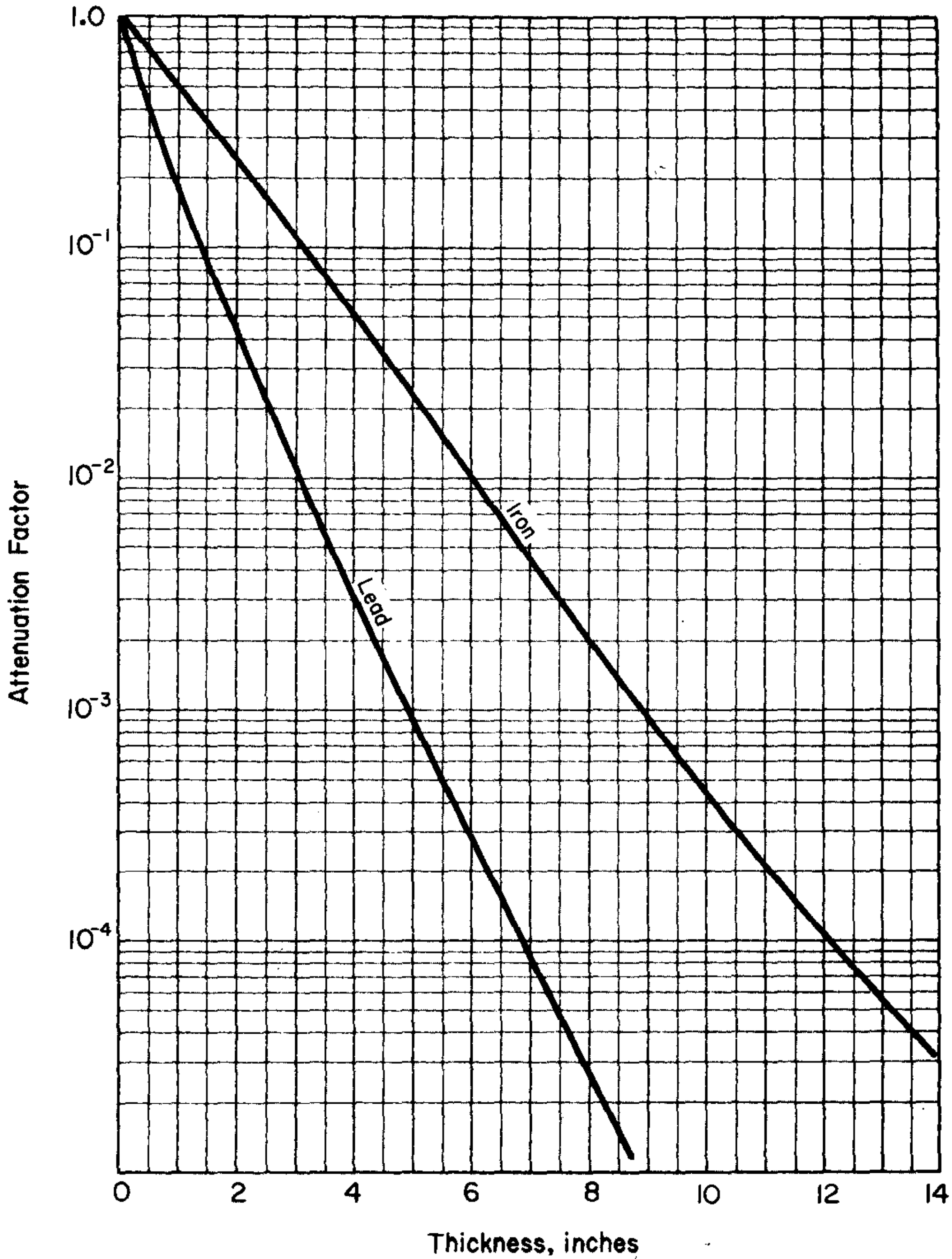


FIG. 5 ATTENUATION OF PROMPT FISSION GAMMA RAYS FROM A POINT ISOTROPIC SOURCE OF $^{252}Cf$

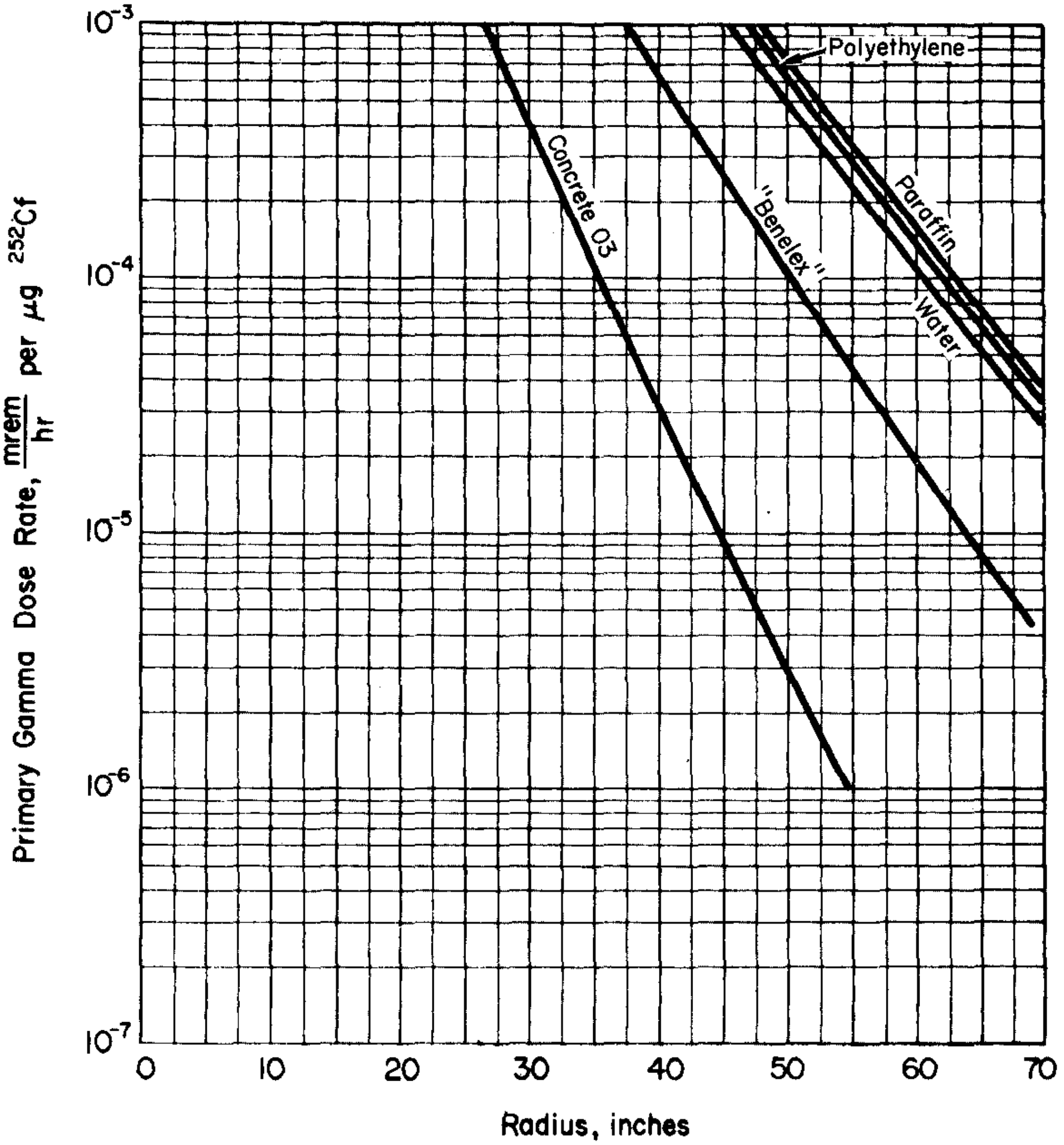


FIG. 6 (Continued)

constitute less than 1% of the total neutron dose rate.

Figure 7 shows the effect of boron on the relative capture gamma dose in a water shield. Relative capture gamma dose also decreases with boron addition in other hydrogen-containing shields. Calculations show shield size and weight can be markedly reduced by adding boron, especially for large $^{252}Cf$ sources. The total dose rate in Examples 3 and 5 decreases 35% with boron-10 addition.

Example 5

Source: 5 μg $^{252}Cf$

Shield: 1/2 inch of iron, 20 inches of paraffin with 2 mg/cc boron-10 added

Dose rate per μg $^{252}Cf$ in mrem/hr

| | | |
|---|---|---|
| Neutron | .010 | (from Figure 2) |
| Primary gamma (.12 x .75) | .090 | (from Figures 5 and 6) |
| Secondary (.08 x .19) | .015 | (from Figures 3, 6 and 7) |
| TOTAL | .115 | |

Total dose rate: 5 x .115 = 0.58

## ACKNOWLEDGMENTS

The author wishes to thank D. H. Stoddard for many helpful discussions and for contributing the material presented in Figure 5, and also to thank W. R. Cornman for assistance in organizing and presenting the estimation method.

# APPENDIX B
# NUCLEAR TERMS

Excerpts from

*Nuclear Terms, a Brief Glossary*[6]

**absorber** Any material that absorbs or diminishes the intensity of ionizing *RADIATION*. Neutron absorbers, like boron, hafnium, and cadmium, are used in control rods for reactors. Concrete and steel absorb gamma rays and neutrons in reactor shields. A thin sheet of paper or metal will absorb or attenuate alpha particles and all except the most energetic beta particles.

**alpha particle** [Symbol $\alpha$ (alpha)] A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, hence is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of *radiation* (alpha, beta, gamma) emitted by radioactive material, being stopped by a sheet of paper. It is not dangerous to plants, animals or man unless the alpha-emitting substance has entered the body.

**background radiation** The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements, both outside and inside the bodies of men and animals. It is also called *natural radiation.* The term may also mean radiation that is unrelated to a specific experiment.

**barn** [Symbol b] A unit area used in expressing the cross sections of atoms, nuclei, electrons, and other particles. One barn is equal to $10^{-24}$ square centimeter.

**beta particle** [Symbol $\beta$ (beta)] An *elementary particle* emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to $1/_{1837}$ that of a proton. A negatively charged beta particle is identical to an *electron.* A positively charged beta particle is called a *positron.* Beta radiation may cause skin burns, and beta-emitters are harmful if they enter the body. Beta particles are easily stopped by a thin sheet of metal, however.

**biological shield** A mass of absorbing material placed around a reactor or radioactive source, to reduce the radiation to a level that is safe for human beings.

**cross section** [Symbol $\sigma$ (sigma)] A measure of the probability that a *NUCLEAR REACTION* will occur. Usually measured in *barns*, it is the apparent (or effective) area presented by a *target* nucleus (or particle) to an oncoming particle or other nuclear radiation, such as a photon of gamma radiation.

**inelastic scattering** (See *scattering.*)

**intermediate (epithermal) neutron** A neutron having energy greater than that of a thermal neutron but less than that of a fast neutron. The range is generally considered to be between about 0.5 and 100,000 electron volts.

**ionization** The process of adding one or more *electrons* to, or removing one or more electrons from, atoms or molecules, thereby creating *ions*. High temperatures, electrical discharges, or nuclear radiations can cause ionization.

**ionization chamber** An instrument that detects and measures ionizing radiation by measuring the electrical current that flows when radiation ionizes gas in a chamber, making the gas a conductor of the electricity.

**ionizing radiation** Any radiation displacing electrons from atoms or molecules, thereby producing *ions*. Examples: alpha, beta, gamma radiation, short-wave ultraviolet light. Ionizing radiation may produce severe skin or tissue damage.

**irradiation** Exposure to radiation, as in a nuclear reactor.

**lethal dose** A dose of *ionizing radiation* sufficient to cause death. Median lethal dose (MLD or LD-50) is the dose required to kill within a specified period of time (usually 30 days) half of the individuals in a large group of organisms similarly exposed. The LD-50/30 for man is about 400–450 roentgens.

**licensed material** *Source material, special nuclear material,* or *by-product material* received, possessed, used or transferred under a general or special license issued by the Atomic Energy Commission or a state.

**maximum permissible concentration (MPC)** The amount of radioactive material in air, water, or food which might be expected to result in a *maximum permissible dose* to persons consuming them at a standard rate of intake. An obsolescent term.

**maximum permissible dose (MPD) (maximum permissible exposure)** That dose of *ionizing radiation* established by competent authorities as an amount below which there is no reasonable expectation of risk to human health, and which at the same time is somewhat below the lowest level at which a definite hazard is believed to exist. An obsolescent term. (See *radiation protection guide.*)

**mean free path** The average distance traveled by a particle, atom, or molecule between collisions or interactions.

**radiation source** Usually a man-made, sealed source of *radioactivity* used in teletherapy, radiography, as a power source for batteries, or in various types of industrial gauges. Machines such as accelerators, and radioisotopic generators and natural radionuclides may also be considered as sources.

**relative biological effectiveness (RBE)** A factor used to compare the biological effectiveness of different types of *ionizing radiation.* It is the inverse ratio of the amount of absorbed radiation, required to produce a given effect, to a standard (or reference) radiation required to produce the same effect.

**rem** (Acronym for *r*oentgen *e*quivalent *m*an.) The unit of dose of any ionizing radiation which produces the same biological effect as a unit of *absorbed dose* of ordinary X rays. The RBE dose (in *rems*) = RBE × absorbed dose (in *rads*). (Compare *curie, roentgen.*)

**rep** (Acronym for *r*oentgen *e*quivalent *p*hysical.) An obsolete unit of absorbed dose of any ionizing radiation, with a magnitude of 93 ergs per gram. It has been superseded by the *rad.*

**roentgen** [Abbreviation r] A unit of exposure to *ionizing radiation.* It is that amount of gamma or X rays required to produce ions carrying 1 electrostatic unit of electrical charge (either positive or negative) in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered X rays in 1895. (Compare *curie, rad, rem.*)

**scattering** A process that changes a particle's trajectory. Scattering is caused by *particle* collisions with atoms, nuclei, and other particles or by interactions with fields of magnetic force. If the scattered particle's internal energy (as contrasted with its kinetic energy) is unchanged by the collision, elastic scattering prevails; if there is a change in the internal energy, the process is called inelastic scattering.

**spontaneous fission** Fission that occurs without an external stimulus. Several heavy isotopes decay mainly in this manner; examples: californium-252 and californium-254. The process occurs occasionally in all fissionable materials, including uranium-235.

**thermal (slow) neutron** A neutron in thermal equilibrium with its surrounding medium. Thermal neutrons are those that have been slowed down by a *moderator* to an average speed of about 2200 meters per second (at room temperature) from the much higher initial speeds they had when expelled by fission. This velocity is similar to that of gas molecules at ordinary temperatures. (Compare *fast neutron, intermediate neutron;* see *fission.*)

# APPENDIX C
# DOT REGULATIONS

## Excerpts from

## *Tariff No. 23 - Hazardous Materials Regulations of the Department of Transportation* [7]

Gray areas apply specifically to californium.

**§ 173.389 Radioactive materials; definitions.** For the purpose of Parts 170-189:

(a) "Fissile radioactive material" means the following material: Plutonium-238, plutonium-239, plutonium-241, uranium-233, or uranium-235, or any material containing any of the foregoing materials. See § 173.396 (a) for exclusions. Fissile radioactive material packages are classified according to the controls needed to provide nuclear criticality safety during transportation as follows:

(1) Fissile Class I. Packages which may be transported in unlimited numbers and in any arrangement, and which require no nuclear criticality safety controls during transportation. For purposes of nuclear criticality safety control, a transport index is not assigned to Fissile Class I packages. However, the external radiation levels may require a transport index number.

(2) Fissile Class II. Packages which may be transported together in any arrangement but in numbers which do not exceed an aggregate transport index of 50. For purposes of nuclear criticality safety control, individual packages may have a transport index of not less than 0.1 and not more than 10. However, the external radiation levels may require a higher transport index number but not to exceed 10. Such shipments require no nuclear criticality safety control by the shipper during transportation.

(3) Fissile Class III. Shipments of packages which do not meet the requirements of Fissile Class I or II and which are controlled to provide nuclear criticality safety in transportation by special arrangements between the shipper and the carrier.

NOTE 1: Uranium-235 exists only in combination with various percentages of uranium-234 and uranium-238. "Fissile radioactive material" as applied to uranium-235 refers to the amount of uranium-235 actually contained in the total quantity of uranium being transported.

NOTE 2: Radioactive material may consist of mixtures of fissile and non-fissile radionuclides. "Fissile radioactive material" refers to the amount of plutonium-238, plutonium-239, plutonium-241, uranium-233, uranium-235, or any combination thereof actually contained in the mixture. The "radioactivity" of the mixture consists of the total activity of both the fissile and nonfissile radionuclides. All mixtures containing "fissile material" shall be subject to § 173.396.

(b) "Large quantity radioactive materials" means a quantity the aggregate radioactivity of which exceeds that specified as follows:

(1) Groups I or II (see paragraph (h) of this section) radionuclides: 20 curies.

(2) Groups III or IV radionuclides: 200 curies.

(3) Group V radionuclides: 5,000 curies.

(4) Groups VI or VII radionuclides: 50,000 curies.

(5) Special form material: 5,000 curies.

(c) "Low specific activity material" means any of the following:

(1) Uranium or thorium ores and physical or chemical concentrates of those ores;

(2) Unirradiated natural or depleted uranium or unirradiated natural thorium;

(3) Tritium oxide in aqueous solutions provided the concentration does not exceed 5 millicuries per milliliter;

(4) Material in which the activity is essentially uniformly distributed and in which the estimated average concentration per gram of contents does not exceed:

- (i) 0.0001 millicuries of Group I (see § 173.389 (h)) radionuclides; or
- (ii) 0.005 millicuries of Group II radionuclides; or
- (iii) 0.3 millicuries of Groups III or IV radionuclides.

NOTE: This includes, but is not limited to, materials of low radioactivity concentration such as residues or solutions from chemical processing; wastes such as building rubble, metal, wood, and fabric scrap, glassware, paper and cardboard; solid or liquid plant waste, sludges, and ashes.

(5) Objects of nonradioactive material externally contaminated with radioactive material, provided that the radioactive material is not readily dispersible and the surface contamination when averaged over an area of 1 square meter, does not exceed 0.0001 millicurie (220,000 disintegrations per minute) per square centimeter of Group I radionuclides or 0.001 millicurie (2,200,000 disintegrations per minute) per square centimeter of other radionuclides.

(d) "Normal form radioactive materials" means those which are not special form radioactive materials. Normal form radioactive materials are grouped into transport groups (see paragraph (h) of this section).

(e) "Radioactive material" means any material or combination of materials, which spontaneously emits ionizing radiation. Materials in which the estimated specific activity is not greater than 0.002 microcuries per gram of material, and in which the radioactivity is essentially uniformly distributed, are not considered to be radio active materials.

(f) "Removable radioactive contamination" means radioactive contamination which can be readily removed in measurable quantities by wiping the contaminated surface with an absorbent material. The measurable quantities shall be considered as being not significant if they do not exceed the limits specified in § 173.397.

(g) "Special form radioactive materials" means those which, if released from a package, might present some direct radiation hazard but would present little hazard due to radiotoxicity and little possibility of contamination. This may be the result of inherent properties of the material (such as metals or alloys), or acquired characteristics, as through encapsulation. The criteria for determining whether a material meets the definition of special form are prescribed in § 173.398 (a).

(h) "Transport group" means any one of seven groups into which normal form radionuclides are classified according to their radiotoxicity and their relative potential hazard in transportation, and as listed in § 173.390.

(i) "Transport index" means the number placed on a package to designate the degree of control to be exercised by the carrier during transportation. The transport index to be assigned to a package of radioactive materials shall be determined by either subparagraph (1) or (2) of this paragraph, whichever is larger. The number expressing the transport index shall be rounded up to the next highest tenth; e.g., 1.01 becomes 1.1.

(1) The highest radiation dose rate, in millirem per hour at three feet from any accessible external surface of the package; or

(2) For Fissile Class II packages only, the transport index number calculated by dividing the number "50" by the number of similar packages which may be transported together (see § 173.396), as determined by the procedures prescribed in the regulations of the U. S. Atomic Energy Commission, Title 10, Code of Federal Regulations, Part 71.

(j) "Type A packaging" means packaging which is designed in accordance with the general packaging requirements of §§ 173.24 and 173.393, and which is adequate to prevent the loss or dispersal of the radioactive contents and to retain the efficiency of its radiation shielding properties if the package is subject to the tests prescribed in § 173.398 (b).

(k) "Type B packaging" means packaging which meets the standards for Type A packaging, and, in addition, meets the standards for hypothetical accident conditions of transportation as prescribed in § 173.398 (c).

(l) "Type A quantity" and "Type B quantity" radioactive materials means a quantity the aggregate radioactivity of which does not exceed that specified as follows:

| Transport group (see § 173.389(h)) | Type A quantity (in curies) | Type B quantity (in curies) |
|---|---|---|
| I | 0.001 | 20 |
| II | 0.05 | 20 |
| III | 3 | 200 |
| IV | 20 | 200 |
| V | 20 | 5,000 |
| VI and VII | 1,000 | 50,000 |
| Special form | 20 | 5,000 |

| Element[1] | Radionuclide[3] | Transport group I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|---|
| Tellurium (52) | Te-125m | | | | X | | | |
| | Te-127m | | | | X | | | |
| | Te-127 | | | | X | | | |
| | Te-129m | | | X | | | | |
| | Te-129 | | | | X | | | |
| | Te-131m | | | X | | | | |
| | Te-132 | | | | X | | | |
| Terbium (65) | Tb-160 | | | X | | | | |
| Thallium (81) | Tl-200 | | | | X | | | |
| | Tl-201 | | | | X | | | |
| | Tl-202 | | | | X | | | |
| | Tl-204 | | | X | | | | |
| Thorium (90) | Th-227 | | X | | | | | |
| | Th-228 | X | | | | | | |
| | Th-230 | X | | | | | | |
| | Th-231 | X | | | | | | |
| | Th-232 | | | X | | | | |
| | Th-234 | | X | | | | | |
| | Th Natural | | | X | | | | |
| Thulium (69) | Tm-168 | | | X | | | | |
| | Tm-170 | | | X | | | | |
| | Tm-171 | | | | X | | | |
| Tin (50) | Sn-113 | | | | X | | | |
| | Sn-117m | | | X | | | | |
| | Sn-121 | | | X | | | | |
| | Sn-125 | | | | X | | | |
| Tritium (1) | H-3 | | | | X | | | |
| | H-3 (as a gas, as luminous paint, or absorbed on solid material). | | | | | | | X |
| Tungsten (74) | W-181 | | | | X | | | |
| | W-185 | | | | X | | | |
| | W-187 | | | | X | | | |
| Uranium (92) | U-230 | | X | | | | | |
| | U-232 | X | | | | | | |
| | U-233[4] | | X | | | | | |
| | U-234 | | X | | | | | |
| | U-235[4] | | | X | | | | |
| | U-236 | | X | | | | | |
| | U-238 | | | X | | | | |
| | U Natural | | | X | | | | |
| | U Enriched[4] | | | X | | | | |
| | U Depleted | | | X | | | | |
| Vanadium (23) | V-48 | | | | X | | | |
| | V-49 | | | X | | | | |
| Xenon (54) | Xe-125 | | | X | | | | |
| | Xe-131m | | | X | | | | |
| | Xe-131m (uncompressed)[2] | | | | | X | | |
| | Xe-133 | | | X | | | | |
| | Xe-133 (uncompressed)[2] | | | | | | X | |
| | Xe-135 | | X | | | | | |
| | Xe-135 (uncompressed)[2] | | | | | X | | |
| Ytterbium (70) | Yb-175 | | | | X | | | |
| Yttrium (39) | Y-88 | | | X | | | | |
| | Y-90 | | | | X | | | |
| | Y-91m | | | X | | | | |
| | Y-91 | | | X | | | | |
| | Y-92 | | | | X | | | |
| | Y-93 | | | | X | | | |
| Zinc (30) | Zn-65 | | | | X | | | |
| | Zn-69m | | | | X | | | |
| | Zn-69 | | | | X | | | |
| Zirconium (40) | Zr-93 | | | | X | | | |
| | Zr-95 | | | X | | | | |
| | Zr-97 | | | | X | | | |

[1] Atomic number shown in parentheses.
[2] Uncompressed means at a pressure not exceeding 14.7 p.s.i. (absolute).
[3] Atomic weight shown after the radionuclide symbol.
[4] Fissile radioactive material.

(b) Any radionuclide not listed in the above table shall be assigned to one of the groups in accordance with the following table:

| Radionuclide | Radioactive half-life: 0–1,000 days | 1,000 days to $10^6$ years | Over $10^6$ years |
|---|---|---|---|
| Atomic number 1–81 | Group III | Group II | Group III |
| Atomic number 82 and over | Group I | Group I | Do |

NOTE 1: No unlisted radionuclides shall be assigned to Groups IV, V, VI, or VII.

(c) For mixtures of radionuclides the following shall apply:

(1) If the identity and respective activity of each radionuclide are known, the permissible activity of each radionuclide shall be such that the sum, for all groups present, of the ratio between the total activity for each group to the permissible activity for each group will not be greater than unity.

(2) If the groups of the radionuclides are known but the amount in each group cannot be reasonably determined, the mixture shall be assigned to the most restrictive group present.

(3) If the identity of all or some of the radionuclides cannot be reasonably determined, each of those unidentified radionuclides shall be considered as belonging to the most restrictive group which cannot be positively excluded.

(4) Mixtures consisting of a single radioactive decay chain where the radionuclides are in the naturally occurring proportions shall be considered as consisting of a single radionuclide. The group and activity shall be that of the first member present in the chain, except if a radionuclide "x" has a half-life longer than that first member and an activity greater than that of any other member including the first at any time during transportation; in that case, the transport group of the nuclide "x" and the activity of the mixture shall be the maximum activity of that nuclide "x" during transportation.

**§ 173.391 Small quantities of radioactive materials and radioactive devices.** (a) Radioactive materials in normal form not exceeding 0.01 millicurie of Group I radionuclides; 0.1 millicurie of Group II radionuclides; 1 millicurie of Groups III, IV, V, or VI radionuclides; 25 curies of Group VII radionuclides; tritium oxide in aqueous solution with a concentration not exceeding 0.5 millicuries per milliliter and with a total activity per package of not more than 3 curies; or 1 millicurie of radioactive material in special form; and not containing more than 15 grams of uranium-235 are exempt from specification packaging, marking, and labeling, and are exempt from the provisions of § 173.393, if the following conditions are met:

(1) The materials are packaged in strong tight packages such that there will be no leakage of radioactive materials under conditions normally incident to transportation.

(2) The package must be such that the radiation dose rate at any point on the external surface of the package does not exceed 0.5 millirem per hour.

(3) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(4) The outside of the inner container must bear the marking "Radioactive."

(b) Manufactured articles such as instruments, clocks, electronic tubes or apparatus, or other similar devices, having radioactive materials (other than liquids) in a nondispersible form as a component part, are exempt from specification packaging, marking, and labeling, and are exempt from the provisions of § 173.393, if the following conditions are met:

NOTE 1: For radioactive gases, the requirement for the radioactive material to be in a nondispersible form does not apply.

(1) Radioactive materials are securely contained within the devices, or are securely packaged in strong, tight packages, so that there will be no leakage of radioactive materials under conditions normally incident to transportation.

(2) The radiation dose rate at four inches from any unpackaged device does not exceed 10 millirem per hour.

(3) The radiation dose rate at any point on the external surface of the outside container does not exceed 0.5 millirem per hour. However, for carload or truckload lots only, the radiation at the external surface of the package or the item may exceed 0.5 millirem per hour, but must not exceed 2 millirem per hour.

(4) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(5) The total radioactivity content of a package containing radioactive devices must not exceed the quantities shown in the following table:

| Transport group | Quantity in curies: Per device | Per package |
|---|---|---|
| I | 0.0001 | 0.001 |
| II | 0.001 | 0.05 |
| III | 0.01 | 3 |
| IV | 0.05 | 3 |
| V or VI | 1 | 1 |
| VII | 25 | 200 |
| Special form | 0.005 | 20 |

(6) No package may contain more than 15 grams of fissile material.

(c) Manufactured articles, other than reactor fuel elements, in which the sole radioactive material is natural or depleted uranium, are exempt from specification packaging, marking, and labeling

(h) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(i) Except for shipments described in paragraph (j) of this section, all radioactive materials must be packaged in suitable packaging (shielded, if necessary) so that at any time during the normal conditions incident to transportation the radiation dose rate does not exceed 200 millirem per hour at any point on the external surface of the package, and the transport index does not exceed 10.

(j) Packages for which the radiation dose rate exceeds the limits specified in paragraph (i) of this section, but does not exceed at any time during transportation any of the limits specified in subparagraphs (1) through (4) of this paragraph, may be transported in a transport vehicle (except aircraft) assigned for the sole use of that consignor, and unloaded by the consignee from the transport vehicle in which originally loaded.

(1) 1,000 millirem per hour at 3 feet from the external surface of the package (closed transport vehicle only);

(2) 200 millirem per hour at any point on the external surface of the car or vehicle (closed transport vehicle only);

(3) 10 millirem per hour at 6 feet from the external surface of the car or vehicle; and

(4) 2 millirem per hour in any normally occupied position in the car or vehicle, except that this provision does not apply to private motor carriers.

(k) When radioactive materials are loaded by the shipper into a transport vehicle assigned for the sole use of that shipper, the shipper must observe all applicable requirements of Part 174, 175, or 177, as appropriate.

(l) Packages consigned for export are also subject to the regulations of the foreign governments involved in the shipment. See §§ 173.8 and 173.9.

§ 173.394 Radioactive material in special form. (a) Type A quantities of special form radioactive materials must be packaged as follows:

(1) Spec. 5B, 5D, 6A, 6B, 6C, 6J, 6K, 6L, 6M, 17C, 17H, 42B, or 42C (§§ 178.82, 178.84, 178.97, 178.98, 178.99, 178.100, 178.101, 178.103, 178.104, 178.107, 178.108, 178.115, and 178.118) metal drums.

(2) Spec. 21C (§ 178.224) fiber drums.

(3) Spec. 14, 15A, 15B, 15C, 15D, 19A, or 19B (§§ 178.168, 178.169, 178.170, 178.171, 178.190, and 178.191) wooden boxes.

(4) Any Spec. 12 series (§§ 178.205 through 178.212) fiberboard boxes, 200-pound test minimum, or Spec. 23F or 23H (§ 178.214 or § 178.219) fiberboard boxes.

(5) Spec. 55 (§ 178.250) metal-encased shielded container. Additionally authorized for not more than 300 curies per package, for domestic shipments only.

(6) Spec. 7A (§ 178.350) Type A general package.

(7) Foreign-made packagings which bear the symbol "Type A" may be used for transportation of radioactive materials from the point of entry in the United States to their destination in the United States or through the United States en route to a point of destination outside of the United States.

(b) Type B quantities of special form radioactive materials must be packaged as follows:

(1) Spec. 55 (§ 178.250) metal-encased shielded container. Authorized only for not more than 300 curies per package. Authorized for domestic shipments only (see also § 178.394 (a) (5).

(2) Spec. 6M (§ 178.304) metal packaging.

(3) Any Type B packaging specifically approved for such use by the Department.

(c) Large quantities of radioactive materials in special form must be packaged as follows:

(1) Spec. 6M (§ 178.104) metal packaging. Radioactive thermal decay energy must not exceed 10 watts.

(2) Any Type B packaging which meets the standards in the regulations of the U. S. Atomic Energy Commission (Title 10, Code of Federal Regulations, Part 71), or the 1967 regulations of the International Atomic Energy Agency, and which has been specifically authorized for such use by the Department under Part 170. In applying for Departmental authorization of packages for large quantities of radioactive materials to be used in shipments by the U. S. Atomic Energy Commission, or one of its contractors or licensees, a copy of the license amendment or other approval issued by that Commission will be accepted in place of the package structural integrity evaluation.

§ 173.395 Radioactive material in normal form. (a) Type A quantities of normal form radioactive materials must be packaged as follows:

(1) Spec. 5B, 5D, 6A, 6B, 6C, 6J, 6K, 6L, 6M, 17C, 17H, 42B, or 42C (§§ 178.82, 178.84, 178.97, 178.98, 178.99, 178.100, 178.101, 178.103, 178.104, 178.107, 178.108, 178.115, and 178.118) metal drums.

(2) Spec. 21C (§ 178.224) fiber drums.

(3) Spec. 14, 15A, 15B, 15C, 15D, 19A, or 19B (§§ 178.165, 178.168, 178.169, 178.170, 178.171, 178.190, and 178.191) wooden boxes.

(4) Any Spec. 12 series (§§ 178.205 through 178.212) fiberboard boxes, 200-pound test minimum; or Spec. 23F or 23H (§ 178.214 or § 178.219) fiberboard boxes.

(5) Any Spec. 3 or 4 series (§§ 178.36 through 178.44 or §§ 178.47 through 178.58) cylinders.

(6) Spec. 55 (§ 178.250) metal-encased shielded container.

(7) Spec. 7A (§ 178.350) Type A general package.

(8) Foreign-made packagings which bear the symbol "Type A" may be used for transportation of radioactive materials from their point of entry in the United States to their destination in the United States or through the United States en route to a point of destination outside of the United States.

(b) Type B quantities of radioactive materials in normal form must be packaged as follows:

(1) Spec. 6M (§ 178.104) metal packaging. Authorized only for solid or gaseous radioactive materials which will not decompose at temperatures up to 250° F.

(2) Any Type B packaging specifically approved for such use by the Department.

(c) Large quantities of radioactive materials in normal form must be packaged as follows:

(1) Spec. 6M (§ 178.104) metal packaging. Authorized only for solid or gaseous radioactive materials which will not decompose at temperatures up to 250° F. Radioactive thermal decay energy must not exceed 10 watts.

(2) Any Type B packaging which meets the standards prescribed in the regulations of the U. S. Atomic Energy Commission (Title 10, Code of Federal Regulations, Part 71) or the 1967 regulations of the International Atomic Energy Agency, and which has been specifically authorized for such use by the Department under Part 170. In applying for Departmental authorization of package for large quantities of radioactive materials to be used in shipments by the U. S. Atomic Energy Commission, or one of its contractors or licensees, a copy of the license amendment or other approval issued by that Commission will be accepted in place of the package structural integrity evaluation.