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PACKAGING CONFIGURATIONS AND HANDLING REQUIREMENTS FOR NUCLEAR MATERIALS*

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SUMMARY

The basic safety concepts for radioactive material are that the package is the primary protection for the public, that the protection afforded by the package should be proportional to the hazard and that the package must be proved by performance. These principles are contained in Department of Energy (DOE), Nuclear Regulatory Commission (NRC) and Department of Transportation (DOT) regulations which classify hazards of various radioactive materials and link packaging requirements to the physical form and quantities being shipped. Packaging requirements are reflected in performance standards to guarantee that shipments of low hazard quantities will survive the rigors of "normal" transportation and that shipments of high hazard quantities will survive extreme severity transportation accidents.

Administrative controls provide for segregation of radioactive material from people and other sensitive or hazardous material. They also provide the necessary information function to control the total amounts in a conveyance and to assure that appropriate emergency response activities be started in case of accidents or other emergencies.

Radioactive materials shipped in conjunction with the nuclear reactor programs include, ores, concentrates, gaseous diffusion feedstocks, enriched and depleted uranium, fresh fuel, spent fuel, high level wastes, low level wastes and transuranic wastes. Each material is packaged and shipped in accordance with regulations and all hazard classes, quantity limits and packaging types are called into use. From the minimal requirements needed to ship the low hazard uranium ores or concentrates to the very stringent requirements in packaging and moving high level wastes or spent fuel, the regulatory system provides a means for carrying out transportation of radioactive material which assures low and controlled risk to the public.

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INTRODUCTION

At the dawn of the nuclear age in the 1940's, those involved in moving radioactive materials from place to place recognized the need for a coherent approach to assuring the safety of those materials during transportation. In an effort to provide that safety, the National Academy of Sciences was asked to put together a committee charged with the responsibility of developing a set of regulations to accomplish that safety objective. This committee developed regulations which formed the basis for the current movement of radioactive materials worldwide. Prior to discussing the materials and packages to be moved, it is important to look at the philosophy inherent in the development of the regulations. There were three philosophies of importance:

1. The protection of the public should be provided by the packaging into which the radioactive material is placed for subsequent shipment. Simply, the regulations would be developed on the basis that no special procedures would be required during transportation, no specialized transport equipment apart from the package would be necessary and no special personnel training or other skills would be necessary to provide adequate protection. Thus, all of the protection to be provided should be inherent in the packaging of the material itself.

2. The protection provided should be proportional to the hazard involved. Note particularly that this is not proportional to the risk involved, but to the hazard. Thus, we ship some radioactive materials in cardboard boxes and other radioactive materials in thick-walled, steel and lead containers. In specific terms, this early committee decided that there were four capabilities that had to be provided by the packaging in whatever depth was necessary to provide this proportional protection. First, the radioactive material must be contained. Second, the radioactive emissions from the material must be shielded to prevent undue exposure to transport workers and the general public. Third, if the radioactive material produces any heat, a method must be available to dissipate that heat without causing risk or injury to transport workers or the general public. Fourth, if the material being shipped is fissile (that is capable of supporting a sustained chain reaction) the material must be packaged in a way to prevent accidental criticality under any conceivable condition. Thus, each radioactive material is shipped in a package designed to provide these four protections as necessary, depending upon the hazard of the material involved. For low hazard materials, these capabilities are required for normal transport environments. For high hazard materials, these capabilities must also be maintained in severe accident situations.

3. The third philosophical basis for the regulation was that the packaging should be proven effective through either analysis, test or a combination thereof to a specified set of engineering conditions. These engineering conditions were defined at a level intended to produce damage to the packaging equivalent to what

might be experienced in an extremely severe transportation accident (accident resistant packages only).

In spite of the fact that these regulations represented the best engineering judgement of those members of the commitee involved, supported by subsequent engineering judgement of regulatory bodies worldwide, the ultimate question of their adequacy must rest upon the experience gained since their introduction. That experience is summarized in a recent study based on the Hazardous Material Incident Reporting (HMIR) system instituted in 1971 by the DOT. During the ten year period 1971 to 1980 inclusive, there were a total of 86,500 HMIR's filed with the DOT. Of these, 524 involved radioactive material. The HMIR system requires that the carrier file a standarized form giving information on any transportation accident involving hazardous materials where there is a death involved, a hospitalization of either the transport workers or a member of the public, where there is any property damage in the excess of $250, where there is some continued danger at the accident scene as the result of an accident, where there is the release of any hazardous cargo or where there is suspected radioactive contamination. In addition to the 524 HMIR's covering radioactive material incidents, during that same period there were an additional 135 incidents reported through the NRC's Agreement States system. This would bring the total number of reports for that ten year period to 659.

The 659 incidents have been analyzed to separate those events which are considered reportable versus those events which actually involve an accident during transportation or during the handling phase of the transport activity. On this basis, it is found that those 659 incidents involve a total of 85 transportation accidents and 110 handling accidents. The 85 transportation accidents involved a total of 711 packages. Of these 711 packages, only ten were designed as accident resistant packagings to carry large quantity radioactive material shipments. The remainder involved packagings designed only to withstand the normal transportation environments (not accident resistant) which are used to contain small quantities of radioactive materials including, for the most part, such things as radiopharmaceuticals and similar low level radioisotopes.

The ten accident resistant packagings involved in actual transportation accidents all survived without failure of the packaging or subsequent release of contents.

Of the 701 non-accident resistant packagings involved in vehicular accidents, 660 of these packages suffered no failure or damage sufficient to cause release of contents. Of the remaining 41 packagings, 3 were damaged but did not release material and the remaining 38 packages were damaged to the point where radioactive material was released as a result of the accident. It should be noted that this type of packaging is not required to survive accidents because failure to survive the accident will not expose transport workers or the general public to levels of radioactivity above those encountered in naturally occurring situations. These 38 packages were involved in 5 separate vehicular accidents. Three of these accidents took place within cities in this country, and two of the accidents took place in rural locations. Perhaps the single most noteworthy of these accidents was the event in Colorado where a truck carrying uranium oxide (U_3O_8) in 55 gallon drums hit a horse on the highway and overturned spilling the drums causing 29 of them to fail and release "yellow cake" (natural uranium ore concentrate). A similar accident in Kansas released material from six drums. Thus, these two accidents account for 35 of the 38 releases involved. Again, let me reiterate that all of the failures in packagings for radioactive materials during that ten year period involved packagings which were not intended to survive accidents because their contents represented a low hazard. Thus, when reviewing the history during the period which we have accurate data, it would appear that the efforts of this National Academy of Science Committee in the mid-1940's have indeed been successful.

RADIOACTIVE MATERIAL REGULATORY CATEGORIES

Under the concept of proportional protection, the U.S. regulations have evaluated the hazard associated with various radioactive materials and have divided all radioactive materials into two broad forms referred to as normal-form and special-form materials. Since normal-form materials are all those which are not special-form, the definition is easiest if one concentrates on what constitutes a special-form radioactive material. According to the regulations, special-form materials are those which, if released from a packaging, might present a hazard due to direct external radiation. However, due to the high physical integrity of the material form, such material would present very little risk, if any, for inhalation or ingestion because of the very small probability of the release of contamination. As such, special-form materials include such things as massive solids not subject to easy abrasion or breakage and specially encapsulated radioactive materials where the encapsulation provides the barrier against the release of contamination. All other materials are normal-form materials.

Having made this broad generalization as to the hazard of radioactive materials, the normal-form category is further divided into seven transport groups. These seven groups, in the most general of terms, are shown in Table 1, which lists the types of radioactive materials contained in

Table 1. Transport Groups

1. Plutonium and Radiotoxic Transuranics
2. Mixed Fission Products and Some Radiotoxic Heavy Metals
3. Most Radiotoxic Materials
4. Broadest Group - Most Radioactive Materials
5. Most Uncompressed Radioactive Gases
6. Argon, Krypton and Xenon Gases
7. Tritium Gas

each transport group.* From this list, one can easily see that the more hazardous materials are at the top (low numbers) progressing to the least hazardous material, tritium gas, at the bottom. But, material form and specific radioisotopes are only part of the hazard picture. The other dimension on this matrix of hazards relates to the quantity of radioactive material involved. This dimension is easily understandable if one uses boundary limit type arguments which state that even plutonium, when found in small enough quantities, may represent an acceptable risk (since substantial quantities of plutonium already exist in the air). At the other extreme, if one were going to ship a very large quantity of tritium, the hazard involved there could be greater than the very small quantity shipment involving plutonium. Therefore, along this quantity axis, four further subdivisions have been established as shown in Table 2. The categories Exempt, Type A and Type B are definitions based on the total quantity of radioactive material included in the packaging. The remaining category, Low Specific Activity (LSA), is based upon the concept that

Table 2. Categories of Packaging by Form and Quantity

QUANTITY FORM		EXEMPT	LSA	TYPE A	TYPE B
NORMAL	1	QUANTITY	SPECIFIC ACTIVITY	QUANTITY	QUANTITY
	2				
	3				
	4				
	5				
	6				
	7				
SPECIAL					

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*Transport groups may be replaced in the future with A_1 & A_2 quantities for each isotope which accomplishes the same objective.

even though you might have substantial quantities of radioactive material contained in the packaging, if it is dilute enough (that is to say if the radioactive material represents a very small percentage of the total bulk of material involved), the hazard presented by such material is still low. Thus, the relationship displayed in Table 2 demonstrates the methodology behind the establishment of proportional protection for the various radioactive materials currently being shipped within our transport system. Obviously, Table 2 is incomplete in that there are numerical values associated with each transport group and each type of packaging. But, for the purposes of this discussion, those numbers are not significant except to say that they are an attempt to achieve a fairly constant risk level over a broad range of radioactive materials and packagings.

For the purposes of a more complete understanding, it is important that each of these regulatory categories be described. The Exempt category (also referred to as limited quantity or small quantity) encompasses those radioactive materials of such a low activity level that release into the atmosphere would constitute no public health hazard. On the basis of that determination, these materials could be shipped through the U.S. mail, are exempt from marking and labeling requirements and need only be packaged in what are described as strong tight packagings (e.g. a cardboard box sealed with glass filiment tape). Limited quantity packagings must have no significant surface contamination on the outside of the packaging and should not emit radiation to a level greater than 0.5 mrem/hr at any point on the surface of the packaging. Examples of materials falling into this category would include such things as smoke detectors, luminous watch dials, luminous exit signs and other slightly radioactive manufactured products. While this category does not require external markings on the packaging, it is required to have the same shipping papers as the other categories of radioactive materials. It is doubtful that this category of radioactive materials is of any particular interest to most people even though such materials are shipped in common carriage with no special handling requirements.

The next category is the LSA materials. These materials include such things as mill tailings, uranium ore, natural uranium hexafloride, some low level wastes and even some transuranic wastes. The basic criterion here is that the material is very dilute; therefore making it extremely difficult to introduce significant quantities of the radioactive material into the biosphere through any conceivable means. Such materials, when packaged in strong, tight packagings, can be transported through the U.S. mail or by common carrier with no special handling requirements. The outside of each package must be marked "Radioactive LSA" and the shipping papers must include those specific instructions for shipping controls specified in the regulations. The radioactive emission level from LSA packages shall not exceed 1000 mrem/hr at a point 3 feet from the package. In addition, the radiation levels on the external surface of the railcar or truck body shall not exceed 200 mrem/hr nor shall it exceed 2 mrem/hr at any normally occupied position within the vehicle.

At this point, it is important to understand the difference between an emission level, a dose rate and an exposure. The emission level as used above indicates the level of radiation being emitted by the package.

A dose rate (similar to an emission level) means that the radioactive emissions are being absorbed by a human at the specified rate. Thus, an emission level is not necessarily a dose rate unless a human being is involved. Finally, an exposure is the sum total of the absorbed radiation in a human being. For example, the "emission level" from a package may be the maximum allowable 1000 mrem/hr at a point 3 feet from the surface of the packaging. If a conductor were to travel with the railcar carrying this material for a 12-hour period, he would be absorbing radiation at a "dose rate" of 2 mrem/hr (the maximum allowable dose rate at the occupied position), but his "exposure" would be 24 mrem.

It is assumed that the reader has some of concept the meaning of the terms used to describe radiation units. But, just for comparison purposes, the scenario described above which resulted in an "exposure" of 24 mrem to the hypothetical conductor would be equivalent in terms of the annual exposure of living in a brick house versus living in a wooden house or living in Denver rather than New York City.

The next type of packaging as we proceed across the categories shown in Table 2 is the Type A packaging. This type of packaging must meet somewhat more stringent requirements than either the exempt or LSA categories in that it must be capable of preventing the loss or dispersal of its contents when subjected to a hypothetical "normal" transport environment. This transport environment has been reduced to engineering terms and comes as somewhat of a shock to some people. The test conditions are applied in sequence as follows. The packaging must be exposed to direct sunlight at an ambient air temperature of 130°F until equilibrium is reached. It must also be exposed to an ambient temperature of -40°F in still air and shade until the package reaches equilibrium. The packaging must be capable of surviving exposure to a reduced pressure of half of the normal atmospheric pressure. It must survive the vibration conditions normally incident to transportation. It must survive a water spray heavy enough to keep the entire exposed surfaces of the packaging (except the bottom) continuously wet for a period of 30 minutes. Following this exposure to water spray, the packaging must survive a free drop for a distance of 4 ft onto a flat, unyielding horizontal surface striking in a position to create maximum damage. In addition, the packaging must survive a 1 ft free drop onto the same surface impacting sequentially on each corner of the package. And, a 13 lb weight, 1-1/4 in in diameter must be dropped from a distance of 40 in without puncturing the packaging. In addition, the packaging must be capable of being stacked five high without crushing. Next time you mail a Christmas package, you might do well to remember these "normal conditions" associated with transportation. On the other hand, should the package be involved in a vehicular accident, it is considered an acceptable hazard that the packaging be breached and all of the contained material dispersed into the surrounding area. Packagings in normal use meeting the Type A requirements would include cardboard boxes, wooden boxes and steel drums as shown in Figure 1. Most of the radiopharmaceuticals transported in this country and some of the low level waste are packaged in Type A containers. The packaging itself must have affixed to the outside of it, on two opposite sides, a radioactive label. Discussion of these labels will be covered later.

The last of the categories of packagings indicated in Table 2 is the Type B packaging. It has the most stringent of the packaging requirements and is intended to be utilized for transporting larger quantities of radioactive material or materials with a higher radiotoxicity level. Type B packagings must be capable of preventing the loss or dispersal of their contents when subjected to hypothetical accident environments. In actuality, these environments are a series of engineering tests designed to create damage to the packaging equivalent to that which it would see in severe transportation accidents. Those engineering test conditions include the sequential exposure of the radioactive material packaging to, first a 30 foot free fall onto an unyielding target. While the 30 foot drop only produces an impact velocity of approximately 30 mph, the unyielding character of the target (an engineering feature) produces damage to packages equivalent to impacts at two to three times that velocity on more realistic targets. Second, a packaging is subjected to a 40-inch drop onto a 6-inch diameter steel pin. This test, intended to duplicate puncture of the packaging by other cargo or debris involved in the accident, was intended to threaten the subsequent survivability of the packaging during fires. Third, the packaging must survive a one-half hour exposure to a fire with a radiating temperature of 1475°F. This fire is to be totally engulfing and free of soot. While there are fires that last longer than 30 minutes and there are fires that are hotter than 1475°F, it was the opinion of the committee (subsequent expeience has proven them right) that actual fires rarely exceed the total heat input of this test. Fourth, if the packaging is carrying fissile materials, it must withstand an 8-hour immersion in a minimum of three feet of water in order to evaluate the effect of water leakage into the package and possible subsequent criticality. At the conclusion of these four tests, the packaging is to maintain its shielding integrity, its containment with minor exceptions, its heat rejection capabilities and its sub-criticality. Worldwide experience has shown that these test conditions do cause damage to the packaging more severe than the damage experienced in actual transport accidents. Still there are those that feel uncomfortable about various provisions of these tests and thus harbour some doubt as to their effectiveness. Efforts have been made to address such doubts by comparing the test conditions to the realities of transport accidents.

One example of such a comparison is the 30 ft free fall onto an unyielding surface. Many people are uncomfortable that the impact velocity is a mere 30 mph and that many vehicles transporting radioactive material travel at velocities between 60 and 90 mph. In an effort to evaluate the test conditions, Sandia National Laboratories conducted a series of tests during 1974-76 in which two identical lead and steel spent fuel shipping casks were subjected to free fall drops onto two entirely different surfaces. Other types of packages were also subjected to impact tests at various velocities into a variety of surfaces.

The result of this test program was the determination that if one were to substitute normal, reinforced concrete structures for the unyielding target, the impact velocities would have to go up by at least a factor of two to produce the same damage that the unyielding target produces. Furthermore, if the target were as soft as fully compacted earth, the impact velocity would have to be greater than three times that required for equivalent damage on the unyielding target. Thus, while the test conditions appear to be unrealistic to some, they do produce damage equivalent to high velocity impacts encountered during transportation. Similar comparisons were made for the other test requirements and in each case the test requirements were found to be effective in providing the required protection.

Type B packagings come in basically two categories. The most familar category is the spent fuel shipping cask or high level waste shipping cask. These casks are large, rigid, heavy, thick-walled structures capable of sustaining immense insults without producing significant structural damage. Figure 2 shows one of these spent fuel shipping casks mounted on its railcar.

There is also another category of Type B container. These containers, known as overpacks, contain no shielding and are intended to provide the necessary protection to Type A or other packages carried inside the overpack to assure survival when subjected to the Type B qualification tests. An example of such a Type B overpack would be the Super Tiger™ shown in Figure 3 or the TRUPACT, currently being developed for transporting transuranic wastes to underground repositories. A model of this system is shown in Figure 4. Type B packagings are used for transporting spent fuel, high level radioactive wastes, enriched uranium hexafloride and transuranic wastes. These packages must be labeled on two opposite sides and further require that the vehicle be placarded as well. The same radiation limits on the external surfaces of the package and on the outside of the railcar or trailer apply for Type A, Type B and LSA packagings. It is important to note that whereas all the contents of exempt, LSA and Type A packagings can be released and dispersed following an accident, Type B packagings must not release their contents following an accident. It is permissible for the emission level from a Type B packaging to increase following an accident.

As was indicated above, Type A and Type B packagings must have radioactive labels on them located at positions on opposite sides of the packaging so that the label is visible from either side. These labels are used to inform those handling the package and loading the vehicles of the relative radiation level of the packaging. Three types of labels are currently prescribed. The first of these, as shown in Figure 5 is called the White I label and is used on packages with a surface emission level of less than 0.5 mrem per hour and an emission level of zero at 3 feet from the packaging. This label covers most radiopharmaceutical shipments and is probably of little concern to the carrier. The second label called a Yellow II is shown in Figure 6. This label is used on packages which emit more than the level required for White I type labels but less than 50 mrem per hour on the surface of the packaging and less than one mrem per hour at a distance of 3 feet. Packages falling into this category are often more dependent upon the type of packaging used than the material involved.

A third category of label is the Yellow III designation shown in Figure 7 for packages having a surface emission level of up to the 200 mrem per hour limit and exposure levels of less than 10 mrem per hour at a distance of 3 feet. These labeling requirements are summarized in Table 3. Two additional pieces of information are noted in this table. The first of these is that any railcar or trailer carrying a package with a Yellow III label on it must also carry an external placard.

Table 3. Radioactive Packaging Labels

	EMISSION LEVEL	
LABEL	SURFACE OF PACKAGING	3 FEET FROM PACKAGE**
WHITE I	0.5 mr/hr	zero
YELLOW II	50 mr/hr	1 mr/hr
YELLOW III*	200 mr/hr	10 mr/hr

*Requires vehicle be placarded
**This value determines and is equal to transport index

Second, the emission level at a distance of 3 feet from the package determines its transport index. This transport index, shown on the shipping papers, is the radiation level in mrem per hour at a distance of 3 feet rounded up to the next one tenth (a measurement of 1.05 mr/hr at 3 feet would produce a transport index of 1.1). This transportation index is used to limit the number of radioactive packages carried on any one railcar or trailer. At this point, there is a factor of confusion which creeps into the minds of those who deal with radioactive packages. There are those who confuse the transport groups 1 through 7 with the three packaging labels, White I, Yellow II and Yellow III, and with the transport index. If this were not enough, there is yet another class of packagings involving fissile materials (reactor fuels) in which these materials fall into Fissile Classes I, II or III. The fissile classifications are intended to meet additional requirements involved in transporting materials whose primary hazard is not radiation, but criticality.

Another factor involved in the transport of radioactive materials are those general handling requirements imposed upon the carrier. First of all, the carrier should not accept for transport packages with radioactive labels on them (White I, Yellow II or Yellow III) in which the information on the label has not been completed. You will note from Figures 5, 6 and 7 that each label has two pieces of information required. First, the contents of the packaging should be stated on the label. These contents refer to the radioisotopes contained therein. Second, the amount of radioisotopes, described in Curies, is required to be entered on the label. On the Yellow II and Yellow III label, there is an additional box to be filled in as shown in Figures 6 and 7. This box is supposed to contain the transport index as determined by the shipper.

In addition to the labeling requirements, the carrier must not accept radioactive material packages for shipment unless the shipping papers accompanying that package include: (1) the proper description and classification of the material involved and (2) the certification from the shipper that the packages have been properly represented and are fully in compliance with DOT regulations. The standard certificate to be typed onto the shipping paper is:

> "This is to certify that the above named articles are properly classified, described, packaged, marked and labeled and are in proper condition for transportation according to the applicable regulations of the Department of Transportation."

After accepting the shipment and assuring that the shipping papers and labeling are proper, the carrier must observe certain prohibited loadings or storage conditions. Radioactive materials must be handled in such a way as to preclude the loading or storage with explosive devices including low explosives or black powder, Class A explosives or propellents, blasting caps with or without safety fuses, ammunition for cannon and small arms, incendiaries, illuminating projectiles on shells or rockets, explosive projectiles, bombs, torpedos, hand grenades, jet thrusters or detonating fuses Class A with or without radioactive components. In addition, the radioactive materials must be handled in such a way as to preclude loading or storing yellow labeled packages closer than 36 feet from undeveloped film or closer than 7 feet from locations that are continuously occupied by personnel.

The carrier, in addition, is responsible for placarding cars containing radioactive materials under certain conditions. For example, any railcar bearing a Yellow III label or carload lots of materials in the LSA, Type A or Type B category must be placarded externally on both sides of the vehicle. Should there be an accident, a fire, an unusual delay or loss of a shipment containing radioactive materials, it is the responsibility of the carrier transporting that shipment to: (1) immediately notify the shipper and the DOT and (2) in the case of an accident, to restrict access to or occupancy of cars, buildings, areas or equipment where radioactive materials have been spilled. This occupancy restriction can be removed when the situation has been recovered to the point where there is no removable radioactive surface contamination and all packages have either been removed or shown to be within the original specifications defined above.

SOME SPECIFIC RADIOACTIVE MATERIALS

This description has been given from the standpoint of defining the regulatory classifications of radioactive material packagings. Most of the time though, when the radioactive material package is submitted to a carrier, the carrier is told more about the material involved than the regulatory classification involved. In an attempt to cross relate these two categories, Table 4 has been prepared. You will note that this table drops the exempt category and addresses special-form LSA, Type A and Type B materials. Furthermore, it takes the more common radioactive materials from the nuclear power cycle which are being transported and shows which classification into which each of those falls. Table 4 also defines the principal hazard involved in each of these material categories. A few pertinent facts are evident from a study of this table. First, when one looks at mill tailings, uranium ore, natural UF_6, enriched UF_6 and fresh fuel, you will note that the principal hazard involved in every

Table 4. Comparison of Regulatory Categories and Material Categories for Some Radioactive Materials of Interest

REGULATORY CATEGORY / MATERIAL CATEGORY	SPECIAL FORM	LSA	TYPE A	TYPE B	PRINCIPAL HAZARD
Uranium Ore		X			Chemical
Mill Tailings		X			Chemical
Natural UF_6		X			Chemical Corrosion
Enriched UF_6				X	Chemical Corrosion Criticality
Fresh Fuel	X*				Chemical Criticality
Spent Fuel				X	Radiation Criticality Chemical
Low Level Waste		X	X	X	Chemical Radiation
Transuranic Waste		X	X	X	Chemical Radiation
High Level Waste				X	Radiation Criticality Chemical

*Unirradiated uranium fuel in pins qualify as a special form container and, thus, is transported in simple overpacks.

case is chemical or one of maintaining subcriticality. None of these materials presents a particular radiation hazard. Although, enriched UF_6, because of the criticality problem, must be shipped in a Type B packaging, fresh fuel is considered special form because of its inert form and high quality cladding. The remaining four materials: spent fuel, low level waste, transuranic waste and high level waste do present some radiation hazard, although, in the cases of low level wastes and transuranic wastes, that radiation level varies over such a broad range, that in some cases, these materials can be shipped as LSA materials.

The remainder of this paper is devoted to a brief description of each of these material categories and some of the features of the packagings used to transport each of these.

Uranium Ore

Uranium ore is designated as LSA material in DOT regulations. It requires no special packaging when shipped in bulk carload quantities where the entire boxcar or flat car is exclusively used for transporting radioactive material. Ore from a mine is generally delivered to a mill in dump trucks. The trucks may be owned by the mine operator or contracted from local trucking companies. After milling, uranium ore concentrate (yellowcake) is then shipped in 55 gallon steel drums from the uranium mill to facilities where it is processed into uranium hexafluoride (UF_6). Each drum contains about 800 pounds of concentrate. Rail transport is used frequently for yellowcake shipments. If there is no rail siding at the uranium mill site, the containers of uranium ore concentrate are usually trucked to the nearest rail facility. Usually, lots containing 110 drums are transported in sole use railroad boxcars.

The mining and the milling of uranium ore at or near the mine to produce uranium ore concentrate $(U_3)_8)$ or yellowcake, is the starting point of many activities in the nuclear industry. This commodity provides the feedstock to fuel nuclear reactors for both electrical power generation and defense purposes. Yellowcake is a powdery, material whose primary hazard is its potential for heavy metal poisoning of life forms through ingestion of significant quantities.

Mill Tailings

Mill tailings are the residues that remain after the extraction of uranium from the mined material. Tailings are generated in very large volumes and contain very low concentrations of naturally occurring radioactive materials. Mill tailings are currently divided into two categories according to their status: (1) tailings at active sites and (2) tailings at inactive sites. Tailings at active sites are handled by the milling companies and are not being transported because they are being disposed of at the site location. However, tailings that were not completely reclaimed prior to the abandonment of the sites in the 1940's and 1950's are currently classified as remedial action wastes. The largest quantity of these materials are included in the DOE Uranium Mill Tailings Remedial Action Program (UMTRAP). The Uranium Mill Tailings Radiation Control Act of 1978 authorized DOE to undertake the stabilization and control of mill tailings in a safe and environmentally sound manner and, where appropriate and practical, to reprocess existing tailings to extract residual uranium and other mineral values. The Act also specifies remedial actions as required on properties in the vicinity of tailings sites. All material movements are specified to occur prior to 1989. These shipments would use bulk container vehicles (probably covered hopper cars) with care taken to minimize leakage and wind blown dispersal of materials.

Natural Uranium Hexafuoride

Uranium hexafluoride (UF_6) is a chemical compound of uranium which, in gaseous form, can be processed to concentrate one isotope of uranium (U-235). For uranium to be used as a fuel in present U.S. nuclear power plants, the U-235 isotope concentration must be increased by a factor of about seven (to a total of three to four percent of the uranium present). Uranium ore concentrate or yellowcake (U_3O_8) is converted to uranium hexafluoride (UF_6) at a conversion plant and then shipped to an enrichment facility (where U-235 is concentrated, or "enriched").

Uranium hexafluoride is a highly reactive material, which rapidly reacts with water, most organic compounds and other metals. UF_6 does not react with oxygen, nitrogen or dry air, and it is sufficiently inert with aluminum, copper, Monel and nickel that these materials can be used in a UF_6 environment without excessive corrosion. At room temperature, UF_6 is a white, volatile solid. The UF_6 is placed in a reusable shipping container under pressure as a liquid at about 200°F, after which it is cooled to ambient temperature and solidified before shipment.

Natural uranium hexafluoride qualifies as radioactive LSA material, but its packaging standards are set by the chemical hazard of the material rather than by its radioactive properties. Natural UF_6 is shipped in 10-ton or 14-ton capacity steel cylinders. Special cradles and tie-downs are used to secure the cylinders to the transport vehicle. The transport vehicle is (usually) a flat car modified by permanent installation of the cradles and tie-down equipment. Because the packagings used to transport the material are reusable, the return shipment of empty containers must be added to the commodity shipments to define the total potential shipment volumes.

Enriched Uranium Hexafluoride

As uranium hexafluoride (UF_6) is enriched, the U-235 isotope becomes concentrated in part of the original material and depleted in the balance. The enriched UF_6 is shipped from the enrichment facilities to plants where it is fabricated into fuel for nuclear reactors while most of the balance of the material (depleted UF_6) is stored indefinitely at the enrichment facility. Small quantities of depleted UF_6 are shipped to some manufacturers who produce such items as aircraft counter weights and other metallic uranium products.

Enriched UF_6 is the same chemically as natural UF_6, but the greater concentration of the U-235 isotope increases the hazard of a "criticality" accident or uncontrolled nuclear chain reaction. A nuclear explosion would not result, however, the heat and radiation produced could harm the package and/or nearby personnel. Therefore, large quantities of enriched UF_6 are transported in packagings that can withstand transportation accidents. This increases the size and weight of the packaging relative to the payload of the commodity shipped. Since the containers with protective overpacks are reusable, the return shipment of empty packagings must also be considered.

Fresh Fuel

At the fuel fabrication plant the enriched uranium hexafluoride (UF_6) is converted to uranium dioxide (UO_2) and then fabricated into sintered uranium dioxide pellets. The pellets are placed into metal (zirconium alloy) tubes which are arranged together to form fresh fuel assemblies for nuclear reactors. These fresh fuel assemblies are used by either pressurized water reactors (PWR's) or boiling water reactors (BWR's) located throughout the country.

The uranium fuel assemblies are considered a special form which meets transportation requirements without an additional containment overpack. Also, there is no significant radiation source from fresh fuel. The assemblies are usually enclosed in a plastic bag that is enclosed in a protective outer package (overpack) designed to prevent damage to the fuel in transit. Typically, two fuel assemblies are placed in an overpack. While these overpacks are usually shipped to the reactor by truck, 12 containers of PWR fuel or 36 containers of BWR fuel could be placed on a rail flat car. Do not confuse these overpacks with "Type B" packagings as they are not designed to be accident resistant.

Spent Fuel

After use in a nuclear reactor to generate power up to its useful economic limits, spent nuclear fuel contains residual uranium, plutonium and large quantities of radioactive fission products. The radioactive decay processes of some of these materials also generate large amounts of decay heat. The spent fuel elements (similar in external appearance to fresh fuel) are stored at the reactor a minimum of 120 days (in reality more like 7 to 10 years) to allow radioactivity and heat generation levels to decrease before they are transported. The properties of spent fuel include large gamma and neutron radiation emission levels, large heat generation rates and an assembly length of typically 15 feet. These factors combined with the constraints of the transportation regulations, place stringent requirements on the spent fuel transport packaging (casks).

Spent fuel casks as Type B packagings must be able to withstand the specified regulatory tests to assure survival in case of accident. Radiation shielding, heat removal and criticality considerations during normal operation are also important. These features make the casks very large with a low ratio of payload to gross package weight. Spent fuel casks are usually transported on dedicated vehicles with special cradles and tie-downs required. Some casks have active cooling systems as an operational convenience for the shipper. Such cooling systems may require some attention during transport (e.g., refueling diesel generators). Additional attention not result, however, the heat and radiation produced could harm the package and/or nearby personnel. Therefore, large quantities of enriched UF_6 are transported in packagings that can withstand transportation accidents. This increases the size and weight of the packaging relative to the payload of the commodity shipped. Since the containers with protective overpacks are reusable, the return shipment of empty packagings must also be considered.

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Low Level Waste

Most nuclear-related activities in medicine, industry and power generation create a certain amount of trash that is contaminated with radioactive materials. Low level wastes are defined as all radioactive wastes that are not high level wastes, that contain less than a specified concentration of elements with an atomic number on the periodic table greater than uranium (called transuranic nuclides) and that are not mine or mill tailings. Low level waste consists of anything from waste paper to contaminated ion exchange resins to contaminated scrap piping. Some waste may require radiation shielding and other waste will not. The primary hazards of these materials range from the potential for ingestion of radioactive or chemical toxins to overexposure to ionizing radiation. This material must be transported from generation (some amount is produced in every state) to disposal sites where it is buried. However, recent federal legislation indicates that states will be responsible for their own low level radioactive waste and encourages formation of interstate compacts of neighborig states to dispose of these materials. Beginning in 1986, states not participating in compacts can be prevented from disposing of low level wastes within the boundaries of states participating in interstate compacts. This regionalization of disposal sites is not anticipated to reduce the number of projected waste shipments but will reduce the average shipment distance.

Much low level waste meets the requirements of LSA material, requiring strong, tight industrial packaging when shipped in carloads containing only radioactive materials (sole-use vehicles). Fifty-five gallon drums have been widely used for such shipments. Low level waste containing larger or more concentrated quantities of radioactive material (or waste not transported in sole-use vehicles) must be shipped in containers meeting the requirements of more stringent DOT specifications.

A variety of DOT specification metal drums, plywood boxes, fiberboard boxes and fiberboard drums have been determined to meet these requirements. The majority of low level wastes to be shipped do not require protective overpacks during transport and make a one-way shipment in a truck or box car.

Some low level wastes, however, contain sufficient quantities of radioactive materials or high enough surface radiation dose rates that a protective overpack is required. These protective overpacks are reusable and are usually carried on a flat car or flat bed truck.

Transuranic Waste

Transuranic (TRU) Waste is similar to low level waste, except that it contains greater concentrations of elements having an atomic number greater than uranium. This results in an increased potential toxicity of the waste if it were to be ingested. In addition, the period of time the wastes remain radioactive is significantly longer than for non-TRU wastes. Disposal of these wastes would occur by placing them in underground geologic formations.

Most transuranic wastes are generated by the reprocessing of spent fuel and the fabrication of materials or fresh fuel using the plutonium removed from spent fuel. Since only small amounts of spent fuel from commercial reactors have been or are expected to be reprocessed in the near future, the bulk of transuranic wastes comes from defense-related activities.

These wastes would be transported in reusable overpacks which would be required to withstand hypothetical accident conditions, and when emptied would be returned to their points of origin.

High Level Waste

High level waste is created from the reprocessing of spent fuel when highly radioactive waste products are separated from uranium and plutonium using chemical extraction cycles. The uranium and plutonium are recycled for useful purposes and the waste products are eventually solidified (usually in a glass) in disposable waste canisters. The waste canisters can range in size from 1 to 2 feet in diameter and 10 to 15 feet in length. Solidified high level waste has radiation and heat generation properties that are similar to spent fuel and would be transported in casks that are nearly identical in appearance and characteristics to spent fuel casks. The hazard is similar to spent fuel although less transuranic material is present. The casks are reusable and would be shipped empty back to the point of origin.

CONCLUSION

The NRC has recently closed a rulemaking activity which began by starting the Environmental Impact Analysis on the Transportation of Radioactive Material by Air and Other Modes. The final version of that document (NUREG-0170) was used as the basis for NRC's decision that the transport of radioactive material presented a low risk to the public and that no additional regulation was needed. This decision is supported by the record of zero deaths and injuries in the nuclear material transportation industry over the past thirty years which is unequalled by any other material classified as hazardous by the DOT.