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Bibliography on Irradiated Fuel Shipping and its Shipping Casks

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Bibliography on Irradiated Fuel Shipping and its Shipping Casks

Summary

Present problems of the irradiated fuel shipping and its shipping cask, especially from the standpoint of its design and manufacture, are described in this report.

About 400 literatures of foreign and our countries, which were gathered for this work, are divided into 12 groups according to their own fields, and listed chronologically. In this bibliography, literatures published after 1959 are mainly collected, considering efforts and development works on these problems done by the IAEA and many countries in these several years.

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使用済み燃料の輸送と輸送容器に関する文献集

要　　旨

使用済み燃料の輸送問題についての最近の傾向を展望し，同輸送容器の設計上，製作上の問題点を紹介した．あわせて，この調査にあたって収集した約 400 の内外の文献を，その主題別に分け，年代順に掲載した．なお，本文献集にはここ数年間これらの問題に関してなされた国際原子力機関や多くの国の開発を考えて，主に 1959 年以降の文献を選択した．

1966 年 10 月

日本原子力研究所　東海研究所
動力炉開発計画部　沢　井　　定
技術情報部　志　知　大　策

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1. Introduction

The shipment of irradiated fuels from nuclear reactors is becoming important both in Japan and other countries day after day, as the number of nuclear stations increases. Many countries hope to establish world-wide regulations on the irradiated fuel shipping and also at the same time to determine the methods of testing and evaluating the integrity of irradiated fuel shipping casks, so that there may be no problems on this shipping, even internationally.

In these four or five years, the IAEA has made its efforts to establish the regulations on the irradiated fuel shipping by holding the international panel meetings many times, and it is expected new regulations will be proposed in autumn, 1966.

Many development works on the irradiated fuel shipping and its shipping casks, including fire experiments of the casks, cask drop tests and survey works, have extensively been made in the U.S.A., U.K., etc.[92], [201], [374], [375], [376], [377], [378], etc.

In the mean time, a great attention is now also given to this problem in Japan ; the research committee on the irradiated fuel shipping cask was organized in the Japan Society of Mechanical Engineers last winter, the irradiated fuels from the JRR-2 (Japan Research Reactor-2) were shipped to Idaho Chemical Processing Plant, U.S.A. last August and the Government hopes to make regulations on this matter in the special committee referring to the regulations of the IAEA and U. S. A.

In view of the above situations, we have made a survey of the irradiated fuel shipping casks from the standpoint of their design and manufacturing, and collected the literatures on the research and survey works of the irradiated fuel shipping.

2. Present status on the regulations on irradiated fuel shipping[5.1], [5.2], [5.11]

As this problem is very important from the standpoint of public and personnel safety, the IAEA issued the " Regulations for the Safe Transport of Radioactive Materials " in 1960 ; however the IAEA would like to make it more perfect and asked many experts of the member states to review this regulations on the basis of their actual shipping experiences and research and development works made since 1960. After having many meetings and discussions on this problem, the IAEA revised the above regulations in 1964,[54] to great extents. This IAEA's revised regulations made clear the safety standard, shipping cask design criteria and cask testing methods, although not much clear on such items as the model scale used for evaluating the cask integrity, shipping approval standards internationally, and so on,

The IAEA, therefore, had an international meeting on " Technical Safety Assessment of a Proposed Movement of a Loaded Irradiated Fuel Flask "[35], [36] in April, 1964 and its first international panel meeting on the " Design and Testing of Packaging for Large Radioactive Sources with Special Reference to Irradiated Fuel Casks "[46], [47], [48] in March, 1965,—both of which were held in Vienna—, to establish the regulations on the irradiated fuel shipping. With the results of the above panel meeting and the subsequent opinions by the member states experts, the draft regulations were proposed.[53], [54] The second international panel meeting[64] was then held in February, 1966 and the new revised regulations are expected to be issued in this fall.

In the U. S. A., 10-CFR-Part 72[14] "Protection against Radiation in the Shipment of Irradiated

Fuel Elements" was proposed in September, 1961 and 10-CFR-Part 71[29] "Shipment of Special Nuclear Material" in February, 1963; but both were revised (Draft)[44],[45] in November, 1964. Taking into consideration the IAEA's work mentioned above and also the developments and actual experiences on the radioactive material shipment new 10-CFR-Part 71[61] "Transport of Licensed Material" was proposed in December, 1965, which is very similar to the IAEA's regulations and revised in August 1966.[61-a]

These regulations were made based on the shipping experiences of the radioactive materials and many development works which have been made in the U. S. A., U. K. and so on. Many countries are going to make or establish their own regulations on the irradiated fuel shipping and its shipping casks, following the IAEA's regulations.

As the irradiated fuel contains not only fissile materials but also radioative substances, "Public Safety" and "Personnel Safety" are strictly required in designing its shipping cask and the shipment. The regulations in this connection are and have been made on the basis of this criteria, and the irradiated fuel shipping cask should be designed and manufactured under the conditions of containment of the fissile materials, type B packaging standard and the shipment of the large radioactive sources, according to the IAEA's regulations.

Each requirement in the regulations has its own significance which should be considered in the designing. For instance, "Hypothetical Accident Conditions" or "Test Procedures for Cask Integrity Evaluation" is derived by considering possible automobile collision accidents accompanied by a fire. It is reasonable to consider that the above hypothetical accidents do not represent any accident, and that if the cask could withstand the above accidents it would give good assurance for the cask performances in case of accidents, as written in 10-CFR-Part 71.[61]

However, it should be noted that the design conditions, such as shipping route, shipping method, etc., must be studied in each case including accidents, prior to the design of the cask. Another evaluation might be requested for the fire in a ship, and the requirements for the cask design may be influenced by the shipping route, if the route is restricted.

3. Problems in designing irradiated fuel shipping casks

The difficult problems in designing an irradiated shipping cask are the hypothetical accident conditions: these are "9m Drop", "Puncture Test" and "30 min. Fire". The development works on the irradiated shipping cask, therefore, are mainly concentrated on the solving of these items.

3. 1 Problems in the heat removal design

3. 1. 1 Decay heat[5.3],[5.5]

When making heat removal calculations for the irradiated fuel shipping cask, one must first estimate the decay heat from the irradiated fuels to be shipped. The decay heat is dependant upon the following,

(a) irradiated period or time of the fuel in the reactor,

(b) number of fissions per unit volume per unit time in the reactor,

(c) cooling period or time of the fuel after removal from the reactor.

The cooling time of the irradiated fuel is usually taken to be about 90 to 120 days, from

the standpoint of the reprocessing and its shipment. Some experiments and measurements[233),(263)] were made on the decay heat of irradiated fuels, and its estimation could be made by the equations such as (1),[401] (2),[233] etc., or by means of the work of the Oak Ridge National Laboratory, U. S. A.

$$P_s/P_0=5.7\times10^{-2}[T_s^{-0.2}-(T_0+T_s)^{-0.2}] \quad \cdots\cdots(1)$$

$$P_s/P_0=0.1\{(T_s+10)^{-0.2}-0.87(T_s+2\times10^7)^{-0.2}\}-0.1\{(T_s+T_0+10)^{-0.2} -0.87(T_s+T_0+2\times10^7)^{-0.2}\} \quad \cdots\cdots(2)$$

where P_s : decay heat
P_0 : thermal output of the reactor
T_s : cooling time (sec)
T_0 : irradiated time in the reactor (sec)

The heat removal calculation for an irradiated fuel shipping cask is usually done by assuming that all the decay heat of the irradiated fuel is generated within the fuel. When the cooling time of the irradiated fuel is 90 to 120 days, about half the decay heat is from the gamma photons, which means that some of the decay heat is produced directly in the shielding. If the heat generation in the shielding by the gamma photons can be estimated or calculated quantitatively, more irradiated fuels may be sent in one shipping cask, or the evaluation of its accidents may be easier, especially in the case of the coolant loss.

3.1.2 Atmospheric conditions

The IAEA regulations specify the following;

(a) $-40°C$ and $70°C$ shall be considered,

(b) the temperature of the accessible surfaces of the package shall not exceed $50°C$ in the shade when fully loaded, assuming still, ambient air at $38°C$; and other ambient air conditions which correspond to envirinmental conditions of transport may be assumed upon approval by the competent authority; and if the package is transported as a full load the limit of $50°C$ above shall be raised to $82°C$.

However, the temperatures in the ship and atmosphere in the shipping route should be examined carefully, and also the solar heat along the route must be considered; these may affect the cask design temperature.

Many experiments on the solar heat have been done in the world[402], and the solar constant is taken about 1.94 cal/cm^2 min. As some of this energy may be absorbed in the air, about 0.9 of the total may be suggested to take.[259]

3.1.3 Fire

The irradiated fuel shipping cask is required to withstand the fire accidents during its shipment. The standard one hour fire designated in the ASTM, E 119-61 was at first considered for this accident evaluation. This standard one hour fire, however, is mainly stipulated for the fire in the building, and the probability of such a fire accident is probably larger in the case of vehicle collisions.

On the basis of the above evaluation principle, the IAEA took the open fire testing method (30 min., 800°), in which the following positions of the cask tested are suggested by considering the open fire characteristics, temperature distribution in the fire, the emissibity of the fire, etc.

(a) The package shall be supported so that the bottom of the package is 1 m above the bottom of the tank which will hold the fuel for the fire;

(b) The fire shall be such that all the sides of the package are exposed to a luminous flame not less than 0.7 m and not more than 3 m thick.

The burning rate of the fuel pool and the flame height were measured in U.S.S.R[92]; the former would be about 4 mm/sec when the diameter of the fuel pool was more than 1 m and the latter about 1.7 times as much as the diameter of the fuel pool which was over 2 m. Rough estimations could be made on the fire exposure time of the shipping cask using the results of such tests. In the case of vehicle collisions, however, the fuel may not flow out all at once and some fuel will also soak into the earth, which makes difficult to evaluate this accident precisely. The temperature of the flame may exceed 800°C in some parts, but it would be reasonable to make an evaluation tests of the shipping cask under the condition of being completely surrounded by the 800°C of flame, taking into account such fire phenomena in the vehicle collision accident.[56]

As the shipping cask is usually made of lead with steel lining. It would be important to know how the lead would behave in the case of the fire from the standpoint of the personnel radiation safety. Experiments were performed on this problem and there occured cavities in the lead shield after exposed to the fire in some case[247],[253] (Fig. 1). It was found that this could be

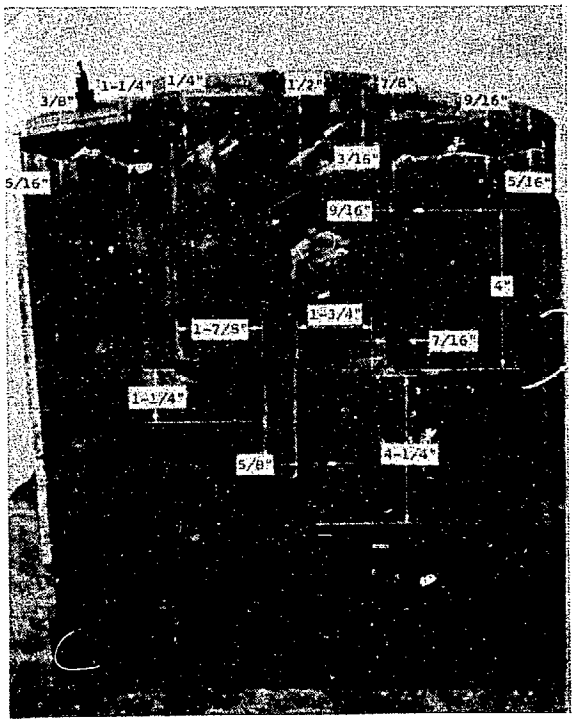

Fig. 1 [217] Cutway of cask after being exposed by fire

prevented by surrounding the cask with wood,[248],[374] however, this method is not considered satisfactory because of the heat removal of the irradiated fuel. Some suggestions and cask mock-ups were made including those in which depleted uranium metal or concrete with depleted uranium dioxide[110] was used instead of the lead, or some gaps were provided around the cask body for fire protection.

It is also important the gasket which would show good behaviours at the time of a fire or in the high temperature atmosphere.

3. 1. 4 Coolant loss

In this case, heat removal of the decay heat of the irradiated fuel is very important for safety. Since atmospheric air is the only coolant available in the cask (in this accident), the decay heat of the irradiated fuels is mainly dissipated by the radiation and one could not evaluate this heat removal precisely, due to the gamma heating in the shield, etc. Many experiments and measurements are thus necessary to establish the evaluation methods and to obtain the data for the evaluation. Some dried-type shipping casks (using no liquid coolant) are now used in the U. S. A.[153), (192)]

3. 2 Problems in the shielding design of the cask[(5. 3), (5. 6)]

The numbers of gamma photons emitted from the irradiated fuel decreases day by day after removal from the reactor ; which may be calculated by separating them into several energy groups.[(269), (270), (403), (404)] In the shielding calculation, however, the gamma photons of less than 0.8 Mev energy are rather insignificant, and one has to consider those with long half lives and high energies.[(115)] These nuclides would be found in the literatures.[(181), (403), (405)]

The comparative data of the shielding design values and their actual measured ones are much appreciated by the designers as well as manufacturers ; but there are available few data on this problem.

3. 3 Problems in the cask construction or structure[(5. 2), (5. 3), (5. 4)]

3. 3. 1 Acceleration and vibration received under normal shipment

It is necessary to have the data on the accelerations (Fig. 2) and vibrations suffering during

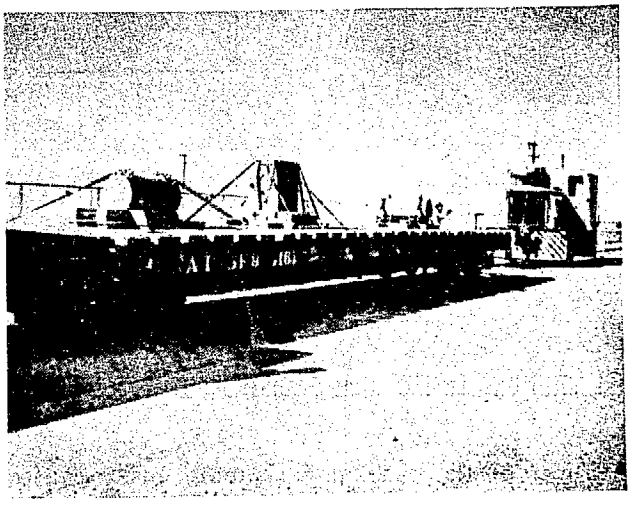

Fig. 2 Shunting test

the cask shipment, these are much affected by the nature of the route, including the road conditions and the method of transportation. In Table-1[(92)] are shown the results of studies made in the U. K. for this problem, which also has made studies on the testing methods, such as the

"Bump Test", "Vibration Test", referring to the testing methods of packages employed in the U. K. army.[92]

TABLE 1[92] Maximum accelerations of shocks in ordinary shipping conditions

Road	3 g	(anchored package suspension on rough road)
Rail	2 g	(rail joint)
	(10 g)	(shunting)
Sea	3 g	(slamming in rough weather)

3. 3. 2 Penetration check

The IAEA specifies the penetration check in its regulations, in which the cask is dropped from the height of 1 m to the target (15 cm±0.5 cm in diameter, 20 cm long). This testing is adopted by considering that the cask might collide with a protruding objects, such as the angle, etc., during its shipment, or that an automobile has a collision accident followed by the gasoline fire, which may cause the leak of lead out of the cask if the cask should be penetrated.

The Franklin Institute[207][222][219] has studied this problem systematically, using specimens (Fig. 3) composed of lead and steel liners just like the wall of an actual shipping cask and

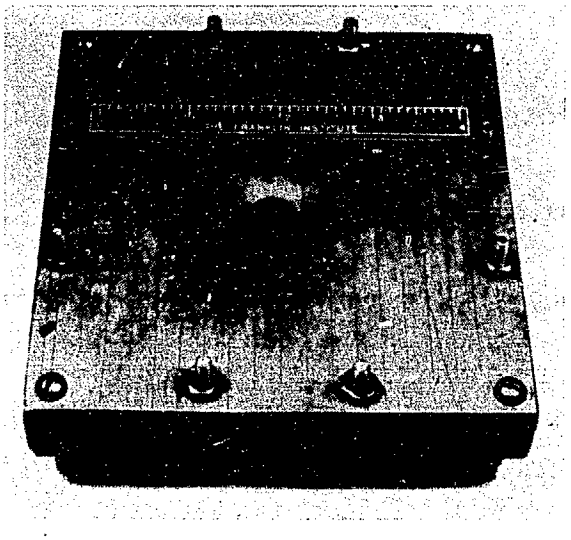

Fig. 3[222][219] Penetration test specimen

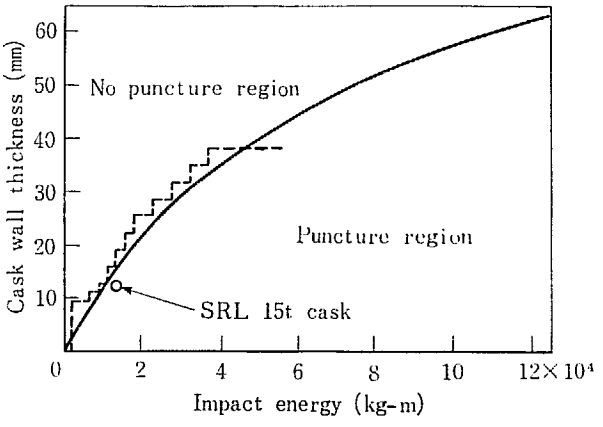

Fig. 4[222][219] Puncture design curve
dotted line : proposed value specified in 10-CFR-Part 72 draft (1964)

also analyzing the actual shipping cask testing data. They obtained the following results or conclusions.

(a) The outer steel liner of the cask may be more easily penetrated by the target with the flat surface than by the one with the spherical surface.[206]

(b) The ordinary steel may be more easily penetrated than the high-tension steel.

(c) Penetration limit may be roughly guessed from Fig. 4.[222][219]

The depth of penetration is found not to be proportional to the scale factor, however, the penetration limit through the wall could be estimated rather precisely by the sample or specimen testing method developed in the Franklin Institute. This specimen testing method may, therefore,

be considered useful for this purpose.

The usual shipping casks are weak against this penetration as was shown by the Savannah River Laboratory's experiments.[215] Then a multilayer shipping cask (steel-lead-steel—steel)[222] was proposed for preventing the leak of lead out of the cask in the collision accident accompanied by a fire. This multilayer shielding cask was shown to be stronger than ordinary casks (steel-lead-steel) in the penetration.

3.3.3 Shock and drop tests

The IAEA also specifies the 9 m drop test in the regulations for evaluating the cask integrity, considering such accidents during the shipment as the vehicle collision, derailment of the train car, falling down from the bank or crane, etc. The height of 9 m was taken by considering the height of the crane was loaded on the ship, the speed of the vehicle (50 km/hr), and so on. It is very difficult to evaluate this accident precisely only by analysis and calculation, and moreover the full scale testing would be very expensive. Therefore, the model drop testing is now attracting much interest in the world. Recently many irradiated fuel shipping casks are shipped with the crush bars around the cask (Fig. 5), so that the crush bars may be broken and the cask be protected when the cask received a big shock in the accident.

Fig. 5 JRR-2 irradiated fuel shipping cask

The shock or deceleration of the vehicle collision depends on the type of collision and kind of vehicle. This accident was measured experimentally in the U. S. A., and one example is shown in Fig. 6.[307]

The drop tests of the shipping cask have been made extensively in the U. S. A., at Savannah River Laboratory,[215] (15 ton cask, Fig. 7), Oak Ridge National Laboratory (four 1.4 ton casks and two 6 ton casks), Franklin Institute,[219] Hanford Laboratory, etc. The general conclusions and tendencies are as follows:

(a) in the drop test of the lead ball, the strain is proportional to the impact velocity and is not influenced by the ball size.

(b) the deformation is proportional to the scale factor,

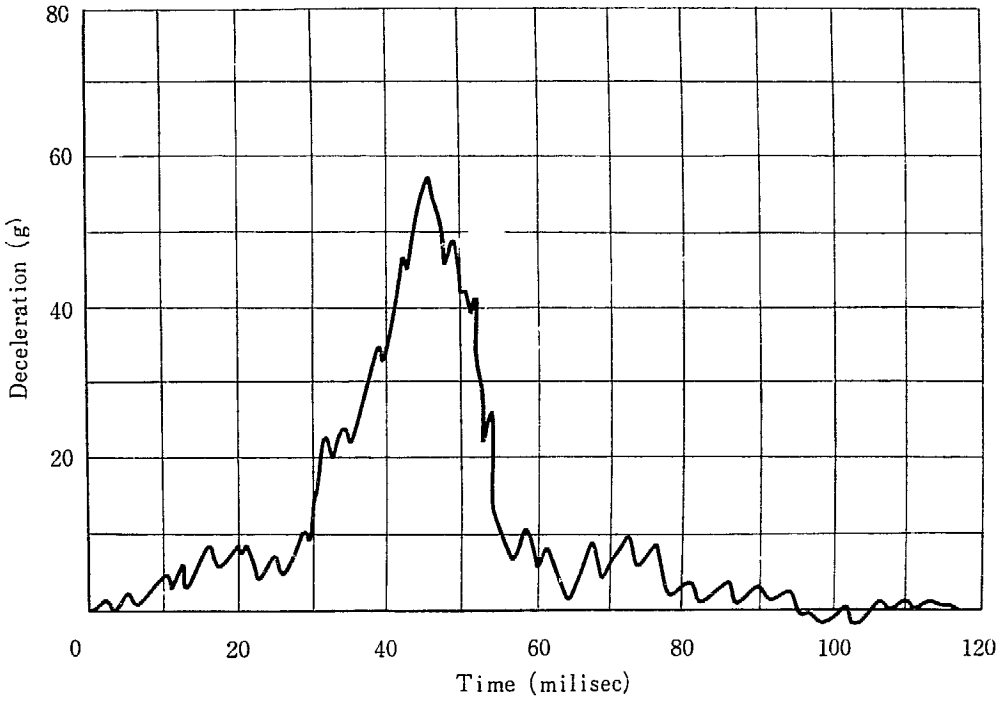

Fig. 6[307] Typical deceleration at head-on collision
(Truck-to-truck, each vehicle traveling 53 km/hr)

Fig. 7[215] Drop test of 15 ton DuPont cask

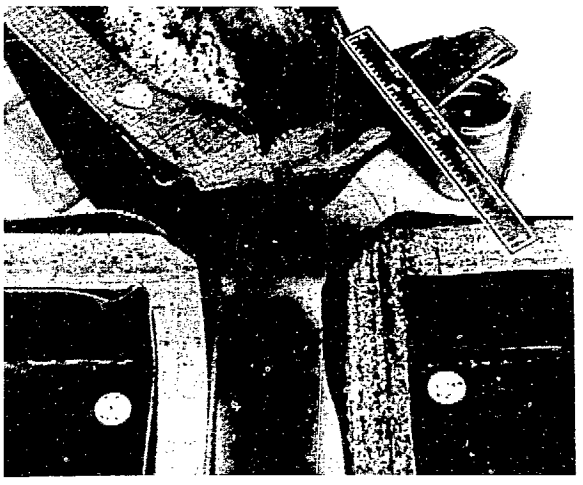

Fig. 8[219] Corner drop test

(c) one example of the deceleration in the drop test is shown in Fig. 9[215] and much deceleration may be expected in small cask.

(d) more strain may be produced when the cask is filled with water than when it is not.

3. 3. 4 Compression test of cask

The compression test of the cask was also made in the Savannah River Laboratory as

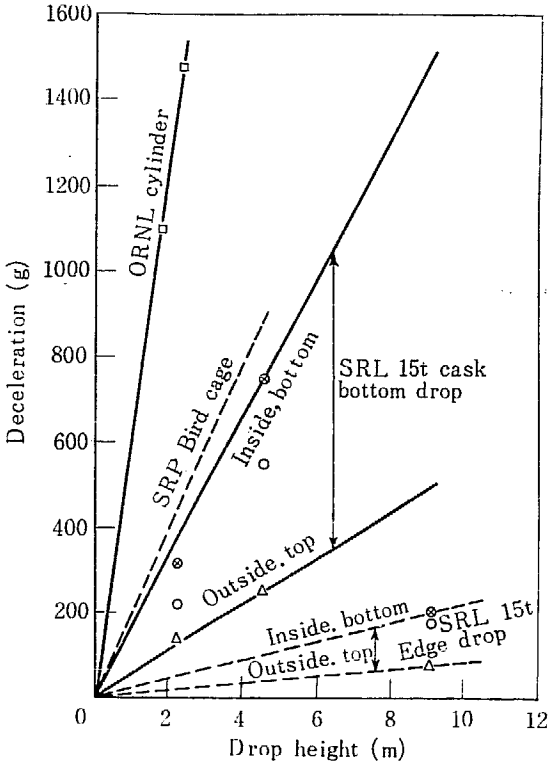

Fig. 9[215] Comparison of decelerations recorded in drop test

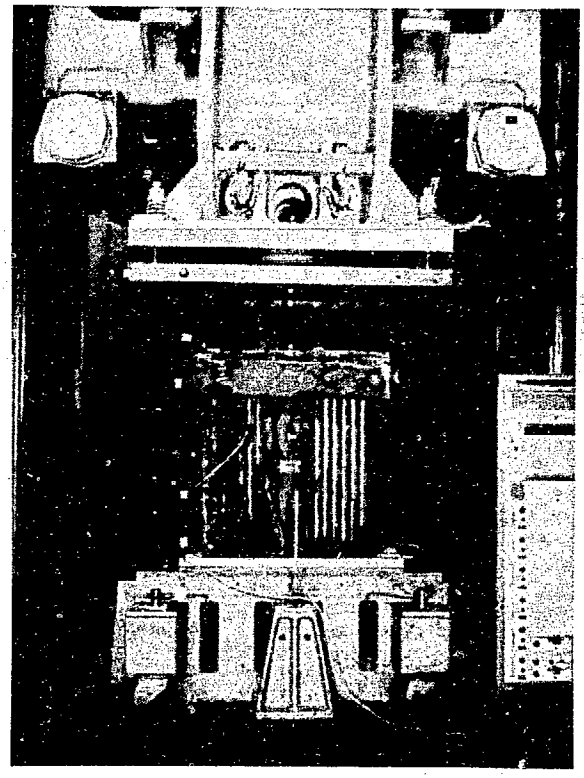

Fig. 10[215] Compression test of 15 ton DuPont cask

shown in Fig. 10, and it is found that the cask is weaker when the compression is applied diagnally.[215]

3. 4 Water decomposition

The pressure within the cask (wet type) may increase due to the water decomposition caused by radioactivity of the irradiated fuel and chemical reaction between the water and cladding materials. This problem is serious when the magnox fuel is shipped and the pressure in the cask may sometimes increase at the rate of as much as 0.2 to 0.4 $kg/cm^2/day$.[115]

Therefore, when the magnox fuel of the Latina was shipped from Italy to the U. K., the refrigerators were provided in the ship so that the water temperature of the cask might be maintained about 10°C during the shipment[120]

4 Miscellaneous

Many other items should be studied including statistical analysis[291],[295],[5.7] of the accidents, filters, cask standardization from the standpoint of receiving facilities in the reprocessing plants, fission products release at cladding failure, and so on.

Acknowledgement

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