STATE OF NEVADA

AGENCY FOR NUCLEAR PROJECTS/ NUCLEAR WASTE PROJECT OFFICE

NWPO-TN--012-91

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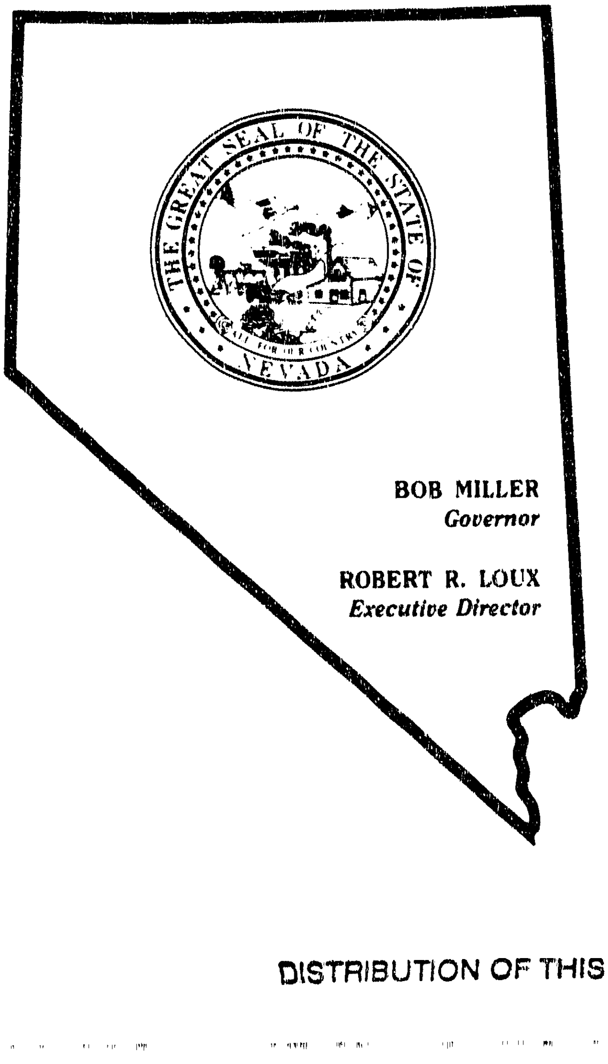
NWPO-TN-012-91

NUCLEAR CASK TESTING FILMS MISLEADING AND MISUSED

by

Lindsay Audin
Ossing, New York

October, 1991



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DISCLAIMER

The Nevada Agency for Nuclear Projects/Nuclear Waste Project Office (NWPO) was created by the Nevada Legislature to oversee federal high-level nuclear waste activities in the State. Since 1985, it has dealt largely with the U.S. Department of Energy's (DOE) siting of a high-level nuclear waste repository at Yucca Mountain in southern Nevada. As part of its oversight role, NWPO has contracted for studies designed to assess the socioeconomic implications of a repository and of repository-related activities.

This study was funded by DOE grant number DE-FG08-85-NV10461.

INTRODUCTION

In 1977 and 1978, Sandia National Laboratories, located in Albuquerque, New Mexico, and operated for the U.S. Department of Energy (DOE), filmed a series of crash and fire tests performed on three casks designed to transport irradiated nuclear fuel assemblies. While the tests were performed to assess the applicability of scale and computer modeling techniques to actual accidents, films of them were quickly pressed into service by the DOE and nuclear utilities as "proof" to the public of the safety of the casks. In the public debate over the safety of irradiated nuclear fuel transportation, the films have served as the mainstay for the nuclear industry. The author has personally heard many nuclear representatives proclaim, "I know it's safe. I've seen these films showing the casks can withstand the worst kind of crashes," or words to that effect.

The basic premise of the films is acceptable: the public should be apprised of government efforts to ensure safety in nuclear materials transportation. However, while initially produced as a semi-technical presentation, the original 14-minute "Accident Safe" was shortened to a 4-minute examination of "Five Full Scale Crash Tests" and excerpts later appeared in several other films. Although the scripts of all the films were reviewed by U.S.DOE officials before production, they contain numerous misleading concepts and images, and omit significant facts. The shorter versions eliminated qualifying statements contained in the longer version, and created false impressions. This paper discusses factors which cast doubt on the veracity of the films and the results of the tests.

OVERVIEW OF THE PROBLEM

The filmed portrayals of the tests mislead the viewer in three basic ways:

1. illusion - mistaken impressions are created that are not clarified, either by narration or subsequent scenes;

2. diversion - the viewer's attention is focused on characteristics and conditions that are not the most likely to yield a release of radiation;

3. censorship - important information is withheld, making an educated assessment of the film's validity nearly impossible.

For example, the tests (while spectacular to the unsophisticated eye) cover only a very narrow range of accident scenarios: no actual collisions occur between the cask and a reinforced body, like a bridge abutment. Instead, only end-on collisions with a flat surface were performed in which parts of the truck or cask enclosure absorb much of the impact. Depending on the cask design, a worse case could involve an impact at an angle with a rounded or irregular surface. Nor did the contents and internal conditions of the casks reflect reality at the time the films were made. At no time is the viewer informed about the physical and chemical mechanisms that could enhance, or make more likely, an accident-induced release of radiation. Cask designs had also changed, both before and after the films were made, making the tests potentially inapplicable to containers already on the road. In addition, the films avoided mentioning cask vulnerabilities revealed during the tests which, under actual accident conditions, could have significant health effects. Finally, the focus of the tests and the films was always on structural integrity, not the subtle leakage pathways more likely to yield a release. By never discussing the casks' seals, valves, and other vulnerable points, the films imply that there are no ways for a cask to fail other than major damage to its casing. These and other problems are detailed later in this paper.

BACKGROUND ON NUCLEAR FUEL AND SHIPPING CASKS

To fully understand the critique that follows, it is essential that the reader have a clear understanding of the basic materials and mechanisms at work during a severe transportation accident involving irradiated nuclear fuel.

Life Cycle of a Fuel Assembly

While taking the form of a solid ceramic encased in welded tubing, and not generally prone to leakage while in a reactor, nuclear fuel may react quite differently when exposed to impact and fire. When subjected to the high temperature and pressure in a reactor core, the fuel is submerged in water heavily treated to remove dissolved oxygen and other minerals. Sealed in the cladding (i.e., tubing), the pellets themselves are surrounded by helium, a gas that will not chemically react (i.e., it is "inert") with the fuel. During the nuclear reaction, the pellets become hot, but that heat is constantly drawn off by the reactor's circulating water moving across the cladding. Neither the rods nor the pellets ever come into contact with air while being heated in the reactor.

Similarly, the pressure in the core is uniform and the rods are held by springs in an assembly, so they are rarely subjected to bending stresses, physical shock or vibration. And since reactor conditions are controlled to maintain slow changes in temperature and pressure, fuel assemblies are not subjected to thermal shock, or rapid cycles of pressurization or decompression. After becoming spent, the fuel continues to be handled with care, which involves slow movements while immersed in conditioned and cooled water. When placed into a storage pool or shipping container, it is supported by metal baskets, again minimizing structural stresses.

Existing irradiated fuel casks (and those seen in the Sandia films) were designed to hold fuel only 5 months out of the reactor. As such, the fuel was extremely hot and very radioactive. To conduct this heat from the fuel to the cask's surface the casks were filled with water from the spent fuel pool. After commercial reprocessing was stopped in 1977, only power plant fuel that had cooled off for several years was being shipped, so casks were generally shipped dry, containing air instead of water. In 1984, six years after the Sandia films were made, problems with fuel degradation in the presence of air led to requirements that only inert gases, such as helium or nitrogen, be used when loading spent fuel casks.[1]

Hazards Presented by "Spent" Fuel

After several years of irradiation in the reactor core, nuclear fuel pellets and their surrounding cladding have experienced a number of changes. The cladding (usually a zirconium alloy) may have microscopic cracks and tiny pits that, under certain conditions, form pinholes open to the fuel. The cladding's surface will also be coated with a thin film of particles that have worn off the inside of the reactor pressure vessel. Commonly called "corrosion products," these particles contain radioactive forms (known as "isotopes") of cobalt, nickel, iron, and other metals; the film they form on the rods is called "crud." Past analyses have found that a fuel assembly may hold a significant radiological inventory in the form of dispersible crud, and it can flake off when exposed to air at temperatures reached in a sealed shipping or storage cask.[2] It could present a serious problem if released from a cask,[3] since it could then easily disperse throughout the environment.

The most dangerous material in an irradiated fuel shipment is, of course, the contaminated fuel itself. After storage in a spent fuel pool for several years, the heat and radiation have decreased significantly, but unshielded exposure to it can still be lethal. Some of the pellets (enriched powdered uranium oxide pressed and heated into pellet form) may have swelled and cracked, and a small portion (about 2%) of their mass has been converted into isotopes of other elements, each having its own capacity for diverse chemical and physical reactions. Many of them have relatively short lives, and decay to less dangerous varieties in the first decade after removal from the reactor. A few become even more dangerous, however, converting to dispersable gases or long-lived forms of solids more readily absorbed by the human body or the environment. Thus, while the level of direct radiation and heat may drop significantly during the first decade of decay, the potential danger due to a dispersal from the fuel continues.

Some isotopes may be harmless on the surface of human skin but very dangerous if inhaled, while others are dangerous if ingested because the body will act to concentrate them in lethal doses. Even a tiny amount of dispersed contamination can have severe effects. For example, strontium 90 (Sr-90), when ingested on food or in water, can become part of teeth and bone, irradiating them and other nearby parts of the body. It takes only about .025 curies of Sr-90, absorbed into bone marrow, to yield 500 rems of damage.[4] In terms of physical mass, such a potentially lethal dose is only about .007 grams (i.e., 7 milligrams), or enough powder to fill in the zeroes in that number. A typical irradiated fuel shipment carries over 30,000 curies of Sr-90 (plus many curies of other dangerous isotopes). While it is part of the solid pellets that make up the fuel, and therefore not easily dispersed, a severe accident or series of human errors could cause a release of fuel and/or crud particles mixed with smoke accompanying a fire. They could then be inhaled or enter the soil and contaminate the food chain. Other isotopes that remain highly radioactive for decades are so hazardous that inhalation or ingestion of amounts too small to be seen can lead to cancer, radiation-induced disease and death.

Release Mechanisms from the Fuel

While contained in a sealed spent fuel cask, how could hard fuel pellets encased in metal tubes, or metallic surface corrosion, ever become airborne and escape? While there is practically no data on the reaction of irradiated fuel to the physical shocks that could occur in a serious transportation accident, some assemblies dropped accidently during handling (and receiving shocks not unlike a vehicle collision) have shown leakage. Tiny cracks and pinholes in the cladding are occasionally found that could create conduits for release of radioactive gases and small particles of fuel. These may result from defects in the tubing and swelling of the pellets, as part of the uranium is converted to gases and other elements during the nuclear reaction. The entrance of air through such cracks or pinholes can lead to gradual breakdown of the pellets, a process greatly accelerated by the heat given off by fuel even several years out of the reactor.

The severe shock and heat due to a transportation accident involving a flammable materials fire could loosen and disperse the crud layer and initiate several processes not normally experienced by uranium dioxide and zirconium alloy. At high temperatures in the presence of oxygen, both materials will change form. Uranium dioxide (UO_2) will "re-oxidize" and become U_3O_8 (its natural form), causing the fuel pellets to expand, crack and form a very fine powder, releasing gases previously held tightly inside the pellet. The powder contains all the isotopes in the irradiated fuel inventory and could be extremely hazardous if inhaled or dispersed into the environment.[5] At very high temperatures in the presence of air, zirconium can burn, vaporizing itself and the crud coating. In doing so, it gives off a great deal of heat, potentially initiating or enhancing other processes that require thermal input (such as uranium re-oxidation). Severe physical shock can also cause fuel pellets to shatter, returning them to the fine uranium powder involved in their manufacture.[6] Several of the isotopes formed in the nuclear reaction will also be affected by heat in the presence of air. Ruthenium, for example, will vaporize and combine with oxygen to form minute particles, while other elements, such as iodine, will be released as gases (some of which already exist in the spent fuel rods prior to an accident). Some of these reactions are in turn enhanced by the fineness of the powdering of the fuel, so these various release mechanisms can interact with each other. Finally, some isotopes will chemically combine with each other (both before and during an accident) to form additional compounds having their own unique characteristics.

Release Mechanisms from the Cask

But won't the cask block such releases? Casks are designed to withstand several tests that federal regulators believe emulate and exceed the worst conditions occurring in real life (see Appendix, Cask Testing Standards). Consisting of concentric layers of steel, lead and/or depleted uranium shielding, a cask is like a giant thermos bottle, capped at one end and closed with a heavy lid and flexible seal at the other. Both ends are usually protected by shock-absorbing covers (called impact limiters). Since casks are loaded under water, drain and fill valves were installed that can also relieve the high internal pressure that could occur during a fire, if the cask also contained water during transport. While the opening of such a valve could create a pathway for leakage, examination of the safety analysis reports for the casks used most often found little or no discussion of the potential for release of loosened crud or leaked fuel particles mixed into the escaping steam and water. While shifting to gas-filled casks eliminated the possibility of a steam-borne release during a fire, doing so did not completely eliminate the potential for re-oxidation, since a failed valve or seal could still allow the inert gas to escape and air to enter.

Rail and truck accidents often involve impacts that create shocks, and (sometimes) fires, aided by vehicle fuel and/or flammable cargoes. While a large majority of such accidents are relatively minor in nature, severe conditions nevertheless <u>do</u> occur. One such extreme case occurred in 1982 when a gasoline tanker truck was involved in a collision with a stalled car in the Caldecott Tunnel, near Berkeley, California. The tunnel contained the fire's heat while also providing a constant supply of combustion air by pulling it into the tunnel, as hot gases from the fire exited at the opposite end. The fire lasted over two hours, nearly 45 minutes of which was at temperatures equal to or above the 30-minute regulatory standard. This accident involved a <u>single</u> tanker: today's relaxed trucking rules allow <u>double</u> tankers. A more recent case involved a leaking natural gas line in the

Soviet Union. As a train passed nearby, its sparks ignited the gas, causing a massive explosion and a high-temperature fire that lasted several days.

Note, however, that casks are not always constructed or maintained as they were designed. The history of spent fuel transport is replete with errors in manufacturing and maintenance and, in a few cases, even of design.[7] Human errors have been made that, if combined with a minor accident, could have created opportunities for releases of radioactive materials. Valves, for example, have been installed backwards and come open during transit. Others designed to open momentarily to relieve pressure during a fire were found to be defective, and failed to re-close. Casks were found, upon close analysis, unable to maintain a proper seal when subjected to high temperatures that could occur during a chemical fire. Several such containers were certified by DOE, using lax standards and review procedures. Hundreds of shipments were made with these faulty containers, many of them through urban areas.[8]

An excellent example of the potential for such human errors occurred in 1980 when fuel with cracked cladding re-oxidized from its own heat while en route to a laboratory in Ohio, due to a human error during loading. It formed a fine powder that escaped from the cladding and dispersed throughout the cask in a matter of hours. When the cask was opened - under water - the fine powder escaped inside the air bubbles leaving the cask, contaminating the storage pool area (and later one worker).[9] An uncontrolled release of such material during a fire could yield a wide dispersal concealed in the fire's smoke. A failed seal, open valve, or cracked drain line could all create an open pathway for air to enter and for contaminants to exit. A clear pathway could also allow loosened surface crud to be released, even if the fuel rods themselves remained undamaged. There would be no need for a puncture or crack in the cask's steel skin (which is the mode assumed by most government-sponsored accident analyses).

All such factors must be kept in mind as one examines the portrayal of the casks in the Sandia films, which echo the limited nature of past accident analyses.

BACKGROUND ON THE TESTED CASKS AND THEIR CONTENTS

Three different casks were used in the filmed crash and fire tests. Two were versions of the same model truck cask, while the other was designed for shipment by rail. The first was used in two head-on collisions between a truck and a reinforced concrete wall. The second was struck in a sideways position by a train, while the third was crashed into the same wall and later burned in a fire. In the truck crash tests, the casks were mounted on open flatbed trailers, while the rail cask was held in a box-framed steel harness.

All three casks transported spent fuel up to 1967, when cask design and testing standards were upgraded by the Atomic Energy Commission, predecessor to the existing NRC and DOE. Under the prior standards, the casks were designed to withstand stresses different from today's standards, including a one-hour high-temperature fire, instead of today's 30-minute requirement. Additional rules were added and the casks in question were not recertified, requiring that they be taken out of service in 1967, ten years before the Sandia tests.

OBJECTIONABLE CHARACTERISTICS OF THE FILMS

Public Portrayal of the Films as "Proof" of Cask Safety

Some transport experts have been critical of the film because, without any grasp of nuclear hazards or cask construction, an audience could easily interpret what it sees as "evidence" of cask safety. For example, by avoiding any discussion of the fabrication and handling of the casks, the film implies that the casks can be manufactured and maintained perfectly, though one National Transportation Safety Board (NTSB) official stated that "the Safety Board's accident experience suggests that this is not a valid assumption."[10] The extremely limited scope of the tests prompted this additional criticism by a NTSB official:

> "It is the misuse of these films to represent that the casks are safe that is objectionable . . . The high speed collision tests represent only two of a larger number [of] accident scenarios that need to be analyzed to assess the safety of spent fuel cask transportation."[11]

By focusing all the attention on the cask as the main line of defense against radiation leakage, the film may also mislead the average viewer into believing that other methods to reduce risk (e.g., emergency preparedness) are unnecessary.

Shortly after their release, the films received nationwide television coverage[12] and magazine exposure,[13] and were used by many speakers representing nuclear electric utilities. Single frames from the film were made into a brochure used to sell casks[14] and for thwarting efforts to pass local legislation regulating irradiated fuel transportation.[15] According to one industry study of nuclear transport, the films "did more to help the nuclear shipment safety image than anything else in recent years."[16] Over one thousand copies of the films have now been distributed worldwide.[17] Subsequent use of the film clips from the tests (in the late 1980's) made fewer safety claims, but the earlier versions were never withdrawn. Over ten years after their production, they continue to circulate and mislead the public.

As detailed in the sections to follow, modifications made to the casks and their contents make these tests, and the films featuring them, a little like a magic act where the audience has no idea that special props will be used to create an illusion.

Misleading Visuals

The viewer is shown a cask mounted on a trailer, while a technician using a geiger counter checks for radiation before a test. The trailer holding the cask is labeled with warning signs reading "RADIOACTIVE" in large letters, implying a hazard. One is led to believe that the casks to be crash tested contain highly radioactive material and are being shipped with such cargo to the test site. No clarification is made that the fresh fuel used in the test (and in the cask shown) was only one-millionth as radioactive as irradiated fuel during shipping, had no surface crud since it had never been in a reactor, and that there was very little likelihood of detecting radiation from the fresh fuel even if the cask on screen had been breached, unless the geiger counter was placed directly over the crack.

The film opens the discussion of cask testing by showing several drop tests (both with and without impact limiters) performed at Oak Ridge National Laboratories in Tennessee, utilizing an obsolete model not used in the crash or fire tests. In the second drop without a limiter (seen on the film), a crack formed along a weld leading directly to the cask's inner cavity where the fuel is held, creating a potential pathway for leakage.[18] While such multiple drops are not part of a regulatory requirement, they could occur if a cask were to bounce on pavement during a crash. During the train-truck crash shown in the film, the cask left the flatbed trailer and bounced twice,[19] but neither this fact, the crack that occurred in the drop test, nor their implications are mentioned in any version of the film.

Contents of the Casks

While designed to hold several full-sized nuclear fuel assemblies, none of the casks contained irradiated fuel during any of the tests. Such fuel could (depending on its age and condition) produce heat, pressure, and loose irradiated particulate matter. Instead, each contained a single (and much smaller) clean, cold unirradiated fuel assembly from the defunct nuclear merchant marine ship, S.S. Savannah. Since it was never used, such fresh fuel had no crud layer, nor had the rods and pellets been subjected to the usual radiological degradation. The cladding on the fuel was stainless steel rather than zircaloy, the material used in nearly all commercial nuclear reactor fuel at the time the film was made. After several years in a nuclear reactor, zircaloy can become more brittle than stainless steel. As a result, an independent evaluation of the tests by a consulting firm hired by the NRC described them as "interesting, but inapplicable for irradiated zircaloy" fuel assemblies.[20] Almost all commercial irradiated fuel shipments made in the past and to be made in the future will entail zircaloy clad spent fuel.

The casks were pressurized to a lower level than could occur with fuel recently removed from a reactor. While some water-filled casks could have pressures exceeding 130 psi,[21] only 26 psi was maintained in the tested casks.[22] The higher pressure level could more easily open pressure relief systems during a severe impact.

Additional Protection Added

The truck casks were protected by impact limiters, added solely for these tests, and not part of the casks' original designs, which were developed to withstand impact without the use of such devices. The casks also utilized radiative cooling fins, not present on most of today's casks, which served to absorb much of the shock when they were deformed by impact. They were therefore potentially more crash-resistant than casks in use today, or planned for use in the future, since none have been designed with this "belt and suspenders" approach.

At the time the film was made, it was common to secure casks to the back of wooden flatbed trailers with chains. The tie-downs used in the crash tests, however, were of a superior design, much stronger than chain connections. The tie-downs used in the tests held the cask in a position that maximized absorption of the impact by the truck, instead of the cask.

Portrayal of the Crash Tests

In the head-on truck crash tests, the casks hit the wall only after striking the rear of the truck cab, which reduced the shock to the cask. Concluding that this indicates the casks can withstand impacts at the velocity of the truck is "dangerous," according to an NRC official who went on to say that "it was the truck that had the impact."[23] While the truck had been traveling at 62 miles an hour, the cask struck the wall at only 29 miles an hour, having been slowed during the collision by the shock absorption of the truck. Many scenarios for impact do not involve such ideal head-on collisions, so it is unlikely that one could depend on the truck's cab to act as such an absorber.

Different Cask Shielding

While alterations were made to their contents and exterior protection devices, the obsolete casks used in the tests were also structurally different in some ways than those used in the recent past (and planned for the future). All the tested casks used lead shielding, though depleted uranium shielding is used more often.[24] One nuclear industry study stated that "care must be taken not to portray [i.e., apply] the results of these cask tests to other generic types of casks, such as those with depleted uranium shielding".[25] Depleted uranium behaves differently from lead under impact, puncture and fire. It does not absorb force by easily deforming like lead, but instead passes on any force applied to it. Such shielding could have created significantly greater stresses on the cask lid's seal and structure.

Failure to Clarify Releases

After each test, the soundtrack states that no radiation would have been released, but two of the crash tests did cause leakage of water from the cask. In one case, about 100 cc (about half a cup) was released.[26] Had the fuel cladding been damaged or the surface crud loosened, the fluid could have been seriously contaminated (as occurred during the previously detailed 1980 shipment),[27] the internal pressure would have been higher (as previously discussed), and the pathway that allowed the 100 cc release would probably have released a much greater volume of fluid in the form of steam, had the accident involved a fire. During the fire test, the buildup of pressure inside this cask caused its pressure relief valve to open, venting steam to the environment. Both the opening of this valve, and the potential for steam or water to be contaminated with fuel crud or particles, remained unmentioned. Such events could have had serious health consequences, especially to emergency personnel near the cask.

Important Details Excluded from Fire Test Sequence

In the fire test, the train cask was held in a special steel harness that acted as a "shield between the cask and the heat source" which can "significantly affect the amount of heat input"[28] to the cask. Most train casks used today do not utilize such a harness. The cask in question was also designed to withstand a one-hour fire, rather than the half-hour fire required in today's standards.[29] The film emphasizes that the cask in the fire test showed no damage during a 90-minute period, but fails to mention that 10 minutes later the outer shell cracked open in two places, the lead shielding began to vaporize, and the test was stopped as a result. A later postmortem on the cask found that the cracking was due to faulty manufacturing techniques and improper welding materials,[30] neither of which were detected during federal inspections. The film never mentions these human errors or their potential for worsening a cask accident.

COMPARISON TO A SIMILAR BRITISH FILM

Six years after the Sandia films were completed, the British Central Electricity Generating Board (CEGB) was confronted with citizen concerns over rail shipments of spent fuel between its reactors and a fuel reprocessing facility. To allay fears, CEGB staged a rail crash test similar to that done previously at Sandia and produced a short film about it. This production provides an interesting contrast to the Sandia film.

Unlike the Sandia presentation, CEGB shows the cask in production at a foundry and lets the viewer know how it is constructed (i.e., like a large box with a lid, forged from a single contiguous piece of steel). Slow- motion films of drop tests highlight an apparent problem with the cask: for a very brief moment the lid's seal is pushed aside and a small quantity of water mist is released before the seal reseats.[31] This candor reflected in the British film is completely absent from the Sandia films, or any similar DOE productions that have followed. Since some of the problems with American casks have been related to their more complex construction (involving lead castings, numerous welds, and poor quality controls), a similarly honest approach by DOE would necessarily have to reveal such items to American citizens. An honest discussion of cask performance issues might, however, increase rather than diminish demands for stronger safety measures.

CONCLUSION

By such critical omissions, the Sandia presentations withhold and distort information showing that the consequences of transportation accidents could be significantly more severe than claimed by the DOE and the nuclear industry. Such productions can be fairly called "propaganda" and are clearly out of place in an honest debate over nuclear transportation safety.

REFERENCES

1. "Research Information Letter No. 139, Potential Oxidation of UO_2 in Irradiated Fuel and Its Regulatory Implications," John G. Davis, U.S. Nuclear Regulatory Commission, Washington, D.C., March 5, 1984.

2. "Comments on Fuel Crud as a Safety and Operational Factor of Independent Spent Fuel Study Installations," NUREG/CR-0163, U.S. Nuclear Regulatory Commission, Washington, D.C., November 1978.

3. "Transportation of Radionuclides in Urban Environs: Draft Environmental Assessment," NUREG/CR-0743, Finley et al., Sandia National Laboratories, Albuquerque, N.M., July 1980.

4. Ibid., Appendix G.

5. Uranium Dioxide: Properties and Nuclear Applications, edited by J. Belle, U.S. Atomic Energy Commission, Washington, D.C. 1967.

6. "An Assessment of the Safety of Spent Fuel Transportation in Urban Environs," SAND82-2365, Sandoval et al., Sandia National Laboratories, Albuquerque, N.M., June 1983.

7. "A Review of the Effects of Human Error on the Risks Involved in Spent Fuel Transportation," L. Audin, Nebraska Energy Office, December 1986.

8. Ibid.

9. "Airborne Contamination Released During Underwater Unloading of a Failed PWR Spent Fuel Assembly," R.W. Klingensmith, Battelle Columbus Laboratories, Columbus, OH, Proceedings of PATRAM '80, 1980.

10. Personal communication to L. Audin from Ludwig Benner, chief of Hazardous Materials Branch, National Transportation Safety Board, Washington, D.C., May 1979.

11. Ibid.

12. "U.S. Chronicle," WNED-TV, Washington, D.C., November 1981.

13. "Devilish Deeds for Nuclear Safety," Fortune magazine, Vol. 97, p. 148, June 5, 1978.

14. "Specialists in Transportation Systems for Radioactive Materials," National Lead Industries sales brochure, Wilmington, Del. 1980.

15. "Briefing Paper for Atlanta City Council Members on Radioactive Materials Transportation," Nuclear Assurance Corporation, Atlanta, Ga., February 1979.

16. "Proceedings of the Nuclear Materials Transportation Program Development Seminar," SAND79-2262, Sandia National Laboratories, Albuquerque, N.M., April 1979.

17. "The U.S. Department of Energy's Nuclear Materials Transportation Technology Development Program," R. B. Chitwood, paper presented to the Sixth International Symposium of Packaging and

Transportation of Radioactive Materials, Berlin, W. Germany, November 1980.

18. "The Obsolete Cask Program: Drop Tests of the HWCTR Cask," Oak Ridge National Laboratory, Oak Ridge, TN, 1978.

19. Press release no. 77-82, U. S. Energy Research and Development Administration, Washington, D.C., May 1977.

20. "A Scoping Study of Spent Fuel Transportation Accidents," NUREG/CR-0811, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1979.

21. "An Assessment of the Risk of Transporting Spent Nuclear Fuel by Truck," PNL-2588, Pacific National Laboratory, Richland, WA, November 1978.

22. "Full Scale Simulations of Accidents on Spent Nuclear Fuel Shipping Systems," R. Yoshimura, Sandia National Laboratories, Albuquerque, N.M., 1978.

23. "NRC Scrutinizes Safety of Nuclear Waste Transport," <u>Greenville News</u>, Greenville, S.C., December 2, 1978.

24. "Current Status and Future Considerations for a Transportation System for Spent Fuel and Radioactive Waste," OWI/SUB-77/42513, Allied-General Nuclear Services, Barnwell, S.C., February 1978.

25. "Capabilities of U.S. Domestic Transportation Systems for the Shipment of Radioactive Wastes," Y/OWI/SUB-77/22330, Nuclear Assurance Corporation, Atlanta, Ga., September 1977.

26. "Crash Testing of Nuclear Fuel Shipping Containers," SAND77-1463, Sandia National Laboratories, Albuquerque, N.M., February 1978.

27. Inspection and Enforcement Report No. 50-206/80-26, U.S. Nuclear Regulatory Commission, Washington, D.C., November 1980.

28. "Modelling of Pool Fire Environment Using Experimental Results of a Two Hour Fire Test of a Railcar Cask System," Sandia National Laboratories, Albuquerque, N.M., November 1980.

29. "Full Scale Simulations of Accidents on Spent Nuclear Fuel Shipping Systems," R. Yoshimura, Sandia National Laboratories, Albuquerque, N.M., 1978.

30. "Postmortem Metallurgical Examination of a Fire Exposed Spent Fuel Shipping Cask," SAND79-1424, Sandia National Laboratories, Albuquerque, N.M., April 1980.

31. "Operation Smash Hit," film by Central Electricity Generating Board, London, England, 1984.

APPENDIX

Cask Testing Standards

Irradiated fuel shipping casks are designed to withstand severe accident stresses. To simplify the design analysis, the U.S. Nuclear Regulatory Commission requires that a cask design be subjected to 5 theoretical tests, in this order:

- a 30-foot drop onto a flat, unyielding surface
- a 40-inch drop onto the end of a 6-inch diameter flat steel stump
- a 30-minute engulfing fire at 1475° F
- an 8-hour immersion in water 3 feet deep
- an 8-hour immersion (of a second container) in water 50 feet deep.

Equations are used to simulate effects of each test. Scale models (but never an actual cask) are also used to verify the response of the design to one or more of the test conditions. Full-scale testing is not done, ostensibly because of the cost involved (the smallest casks each cost over a million dollars).

While a 30-foot drop may not seem very severe (an impact from that height would occur at a speed of only 30 miles per hour), the theoretical concept of an "unyielding surface" forces all the impact energy to be absorbed by the cask, instead of sharing it between the surface and the container, as would occur in real life. The resulting theoretical impact is roughly equivalent to an actual impact with a reinforced concrete surface at 55 to 60 miles an hour.

The same logic applies to the second and third tests: each attempts to replicate forces that may occur in real life. The fourth test verifies that the spent fuel remains in a configuration that cannot spontaneously initiate a nuclear reaction (called "criticality") even when all neutrons escaping it are reflected back onto it, as would occur if the cask were surrounded by water. The more extended immersion is designed to show that the seals and valves would not be opened even when subjected to sustained pressure from relatively deep water.

While other requirements must also be met by casks (e.g., weight, external temperature), these 5 theoretical tests form the basis of all cask safety analyses.

END

DATE
FILMED

9/17/92