A REVIEW OF THE EFFECTS OF HUMAN ERROR ON THE RISKS INVOLVED IN SPENT FUEL TRANSPORTATION

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INTRODUCTION AND SUMMARY

The Nebraska Energy Office requests answers to the following questions:

1. Does the transportation risk analysis in Appendix A of the Nuclear Waste Policy Act (Section 112) Environmental Assessment dated May, 1986, (hereinafter, EA) assume, over the 26 years of operation of the first national repository, that no human error will occur in the design, manufacture, maintenance and operation of transportation casks?

2. Is the information and reasoning in the Office's "Background To The Environmental Assessment Worst Case Transportation Analysis" accurate? (See Appendix C of this report.)

3. Does the history of cask design, manufacture, maintenance, and operations justify an assumption of no significant human error in similar activities to be pursued under the Nuclear Waste Policy Act?

4. How many cask designs certified for use by Department of Energy (DOE) licensees have been certified by the Nuclear Regulatory Commission (NRC)?

5. How many cask designs certified for use by NRC licencees have been certified by the NRC?

6. How many cask designs certified for use by DOE licencees have been rejected by the NRC?

7. How many casks have been produced using NRC certified designs?

8. How many of the casks in question 7. have been taken out of service?

9. If the same level of human error is experienced under NWPA as has occurred in the past, what difficulties might be anticipated and how extensive could the problem be knowing the number of casks expected under NWPA?

10. What kinds of human errors, manufacturing or design flaws or operational mistakes could lead to a release of radiation in a transport accident?

11. Does the discussion of risk analysis in section A.8.3.9 properly reflect the human error treatment in Section A.8?

12. Could the bottom line of the EA analysis be changed by uncertainties based on documented experience of human error in cask manufacture and operations in any of the following ways:

a.) the relative comparison of.the five repository sites;

b.) the absolute risks of spent fuel transportation, or

c.) the weight assigned transportation relative to other factors in reaching a decision on repository siting?

While all the above are answered in the text to follow, answers are summarized below.

1. The Environmental Assessment's Appendix A does not assume there will be no human error in maintenance and operation. Rather, it assumes (based on two reports, NUREG/CR-0743 and PNL-2588) that the impact will be too small to merit inclusion in risk calculations. By failing to utilize any analysis of design, manufacturing or incident handling errors, it assumes they will not occur or will also have too small an impact to merit inclusion in risk assessment.

2. The information and reasoning in the "Background" document (Appendix C of this report) is accurate except for one misconception. While different casks may fail under different accident conditions, federal standards require that all casks withstand a set of conditions considered by the NRC to equal or exceed stresses experienced in most accidents. Thus, while some casks may hold up better than others, none should succumb to a stress below a level set by federal rules, assuming proper fabrication.

3. The past history of cask design, manufacture, maintenance and operation does not justify an assumption of no significant error under the NWPA program, especially when the number of shipments of the past is compared to those expected under NWPA.

4. No cask designs certified initially by DOE have been later certified by NRC as of early 1986.

5. While over two dozen designs for spent fuel casks have been certified [illegible] licensees, only 9 were

designed for commercial reactor use. The others serve a myriad of research and submarine reactors. See Table 1.

6. NRC has rejected at least 10 cask designs for which DOE sought approval. See Table 2.

7. About 29 casks have been produced for service to commercial reactors.

8. Of that number, licenses have expired on 12 of them. Four of those with expired licenses were taken permanently out of service for having bowed inner cavities and/or defects in shielding and 2 others had excess internal or external contamination. Four other casks (still licensed) were placed under restricted service permanently for failed valves and temporarily due to a design error on the fuel basket. Two others were never in service and now are missing essential parts while two more are presently in service only in Europe. Only nine are available in the U.S. for unrestricted service.

9. If human error plays the same part under the NWPA program that it has in the past, it is possible that many radiation leaks will occur, many casks will be on the road in potentially dangerous condition and the large number of future shipments will yield opportunities for numerous near misses and a few very serious accidents. Changes in regulations, fuel condition and cask design will reduce or eliminate some past errors but other changes may lead to problems so far unforeseen. Effective inspection and

enforcement for NWPA shipments will require NRC staffing and budgeting in this area be greatly increased.

10. Some types of human errors leading to a release of radiation are discussed in the text of this report.

11. The May, 1986 version of Appendix A of the EA has no mention of human error in section A.8. The discussion of "uncertainties" (section A.8.3.9) does confirm the lack of attention to human error in the assessment.

12. The bottom line of the EA is affected by human error in these ways:

a.) some sites require more miles to be travelled, necessitating more casks with possible flaws and more miles of shipments during which accidents could occur; the risk differences between shipments to different sites, is not large, however, when compared to the uncertainties created by factoring in errors to all shipments;

b.) including error in the analysis increases the absolute transportation risks for all sites;

c.) since the absolute risk increases, so does the weight relative to other factors affecting repository siting. Uncertainties are also increased, however, so it was not possible to discern to what degree the increased risk would affect final site choice.

This analysis concludes that human error has the potential for increasing the probability and the consequences of both minor and major incidents. Overall risk is therefore increased and needs to be assessed more carefully to arrive at a more realistic understanding of the environmental impacts of spent fuel transportation.

STATEMENT OF THE PROBLEM

The dangers involved in transportation of spent nuclear fuel are primarily related to ways in which radiation could escape the shipping container, typically called a cask. While numerous precautions are built into the process of moving spent fuel, the main line of defense is the cask. If it leaks, serious contamination could result.

Nothing man-made is perfect, however, and since the cask is man-made a question arises concerning the consequences of imperfections in the fabrication and use of such casks due to human error. This problem has received far less attention than have the effects of impact and fire on a cask, partially because it is not as easily quantified or analyzed. Nevertheless, errors have occurred and only rarely have they been examined in the context of an accident to assess the effect they could have on that accident.

The general conclusion has been that the simultaneous occurrence of a serious human error and a severe accident is so remote that the probability approaches zero. Such a conclusion fails to take into consideration the types of errors that have been made as well as their ability to complicate otherwise uneventful shipments.

This study examines problems caused by obvious human error and includes attention to faults that could be interpreted as errors in judgement. Almost all are unaccounted for in NUREG/CR-0743 and PNL-2588. These two studies were used by the NWPA Environmental Assessment to show human error impacts to be too small to merit inclusion in risk calculations.

THE TRANSPORTATION PROCESS

Nuclear fuel is composed of uranium slightly enriched in its active form (U-235). Prior to irradiation, it is benign and gives off very little radiation. After approximately three years in a nuclear reactor, however, a small portion of the uranium has been converted into radioactive forms (i.e. isotopes) of many other elements, generally called fission products. At the same time, the fuel has become coated with a thin layer of radioactive metallic compounds formed from the breakdown of the walls of the reactor vessel. Often termed activation or corrosion products (or more simply "crud"), these compounds are made up of nickel, cobalt, iron and other metals.

Each year, fuel assemblies (composed of uranium pellets inside tubular zirconium alloy cladding held in metal frames) are moved around in the reactor core to achieve the most complete "burnup" of the fuel until their radiation level makes continued use a problem. The reactor is shut down and a third (or a quarter, depending on reactor type) of the fuel is removed and replaced with fresh fuel assemblies. All handling operations are done under water since water acts as both a coolant for the hot fuel and a shield against its radiation. The removed fuel is submerged in a storage pool near the reactor where it is cooled by circulating filtered water. All reactors have such pools, though some share a common pool. Storage pools also exist at federal and private labs and one commercial storage pool is in operation.

Such storage has become a nagging problem since the reactor pools were originally designed to hold only a year's worth of fuel but are now being forced to accomodate up to 10 years of discharges. To perform that task, the racks holding the fuel have been redesigned and the fuel often moved several times to make room in the pool. It will not be uncommon for some fuel to reside in pools up to 20 years before moving to a final repository.

Water storage will not be sufficient at many reactors, however, so transfer into dry storage casks or vaults outside the reactor building has already begun. Fuel will be kept in an inert atmosphere (such as helium) but not mechanically cooled. Some assemblies will self heat to temperatures between 600 and 700 degrees Fahrenheit if stored dry only 5 years out of the reactor.

Even this step may not be sufficient and DOE is testing procedures to take the assemblies apart and consolidate the fuel rods to allow even denser storage.

When finally ready for transport, the fuel will be loaded (again underwater) in a shipping cask that is then drained of fluid and filled with an inert gas. While past shipping casks have moved only one or two assemblies at a time by truck (about 10 or 20 by train), the next generation of casks will be able to pack twice the load because the fuel will have cooled for a much longer period prior to transport.

While in the shipping cask, the fuel gives off a small amount of heat, especially if it has been out of the reactor over 10 years, and will probably remain at less than 300 degrees Fahrenheit at its hottest point. When unloaded, again under water, the cask is cleaned, dried and returned to the reactor for another trip.

THE CASK INDUSTRY

The Cask Itself

While new designs for the next generation of casks have yet to be produced, the likely configuration will be similar to present designs in order to meet the same shielding and containment requirements that have been in effect since 1967.

The general design starts with the fuel basket, a metal framework and casting that holds the assemblies (and may absorb neutrons) and fits into the cylindrical cask. Surrounding the basket are concentric layers of shielding (lead, steel and/or depleted uranium, plus a neutron absorber) and a structural outer shell. No cooling system or heat radiating fins will be necessary, as on past casks, due to the lower heat generation of the older fuel. A lid at one end closes the cask and uses a metal and/or flexible gasket to seal the cask shut. The lid is bolted to the cask and may contain drain and vent valves, a pressure relief valve and/or a rupture disk to release internal pressure during a severe fire. To lift the cask, cylindrical protrusions (called "trunnions") are welded to the cask exterior and are designed to fit a special yoke connected to cranes at the reactor and repository. A drain line consisting of a thin tube welded to (and perhaps passing through) the cask body allows water to be removed after the cask is loaded or unloaded. Shock absorbers (called "impact limiters") are bolted at one or both ends to protect the cask in a crash.

Radiation can escape the cask in two ways: gamma and neutron emissions pass through the walls if shielding is damaged (e.g., lead leakage after fire and puncture), and particles, fluid or gas can be released through a crack or failed valve or seal. The radiation level within the cask remains constant unless, through collapse of the basket, the fuel assumes a configuration that leads to criticality (i.e., a sustained nuclear reaction). Radiation and heat would rapidly increase, possibly damaging the fuel and cask.

History

Three generations of casks have been produced:

1. those before standards were changed in 1967,
2. those produced between 1968 and 1979,
3. those produced in this decade.

The first generation casks followed general design guidelines and varied a great deal in the procedures used to demonstrate how they met federal criteria (at the time only loosely overseen by the now defunct Atomic Energy Commission). Drop and fire test requirements were different than those in effect today (e.g., withstanding a 60 minute fire instead of today's 30 minute fire). Very different designs were produced with very little federal oversight. Most casks were one-of-a-kind, designed to serve individual reactors.

The second generation had to meet more specific criteria and had the benefit of a "Cask Designers' Guide" to follow. This document, produced at Oak Ridge National Laboratory in 1970, offered a "cookbook" of accepted formulas and procedures to follow toward certification. Standard designs were developed and up to seven copies of one cask were produced, but the lack of a reprocessing industry blunted the need for mass production. As a result, one design was produced which resulted in only two copies of a cask. The designs utilized better analytical tools, however, and became less varied.

The third generation of casks was produced to handle very specific needs (such as moving the damaged Three Mile Island Fuel) rather than to serve commercial power plants having nowhere to send their fuel. Using more sophisticated analyses and benefitting from past experience had led to a greater assurance of safety in design and, in some cases, greater attention has been paid to proper manufacture. Very few casks have been produced, however, simplifying the task of inspection.

The next generation of containers will be markedly different, though. Economics will press for only a few designs and many more of each type will be needed (probably over 200 in total). The present NRC vendor inspection staff (about half a dozen people also responsible for inspecting manufacture of many other nuclear components) will need to be greatly expanded and better record-keeping and tracking systems installed <u>before</u> the first cask assembly line is set up.

Federal Oversight

Casks are designed according to nuclear and metallurgical principles and formulas. These designs are subject to varying degrees of review before a license is granted. Note that only designs are certified, not casks. The distinction is important because the sparse record of inspections during manufacture indicates that most federal attention is spent at the design level.

A thorough examination of NRC's cask inspection records shows that very few (if any) casks were actually observed during production. Instead, NRC inspectors focussed on the paperwork history of manufacture. For example, the welders' professional credentials and success in performing welding on samples were checked rather than observing the cask welds as they occurred. While some weld radiographs (similar to an x-ray) were examined, such tests do not always find deficiencies when they exist. Reports attesting to other forms of weld testing (e.g., dye penetrants) were accepted without independent verification. When such records were missing, a claim of loss in a fire was accepted and the cask involved was assumed to match the approved design. Casks were usually examined after completion but only major discrepancies (e.g., valve missing) are discernible from such observations. In at least one case, the cask license was changed to match the cask when it had been constructed differently from the design drawings.

While some casks were designed by major engineering firms involved with the nuclear industry (e.g., Westinghouse, General Electric) they were almost exclusively made in specialty metal shops, some of them unaccustomed to fabricating to nuclear tolerances and dealing with federal paperwork demands. The record contains many deficiencies related to poor record keeping and failure to adhere to required quality assurance practices.

What Casks Have Been Produced

In the first generation, about twenty spent fuel cask designs (and casks) were made. None are useable for commercial fuel today, though several were used until 1975 after being re-certified to the upgraded standards.

The second generation saw approximately 30 cask designs and over 50 casks produced, over half of which could handle power plant fuel. Only a handful of third generation casks have been produced, all for special purposes (though some could be pressed into commercial service with minor changes).

The rest of this report focusses on the production of those second generation casks that utilized standard designs for handling commercial fuel and were produced in the United States. They represent the only real data base for extrapolating the way the next generation of casks will be handled.

TABLE 1.

Disposition Of Casks Using Designs Certified By NRC For Use In Shipping Commercial LWR Spent Fuel

Cask Name (Type)	No. Made	Disposition	No. Available In U.S., 1986
NAC-1/NFS-4 (normal wt. truck)	7	4 out of service due to bowing &/or shielding problem, 1 out of svc. due to exc. surface cont., 1 out of service due to exc. int. cont., 1 under restricted svc.	none-cask licensee allowed license to expire in 1984 & does not plan to renew
NLI-½ (normal wt. truck)	5	All still in service	5
TN-8 (over wt. truck PWR Fuel only)	4	Two used in Europe, Two in United States	2
TN-9 (over wt. truck BWR Fuel only)	2	Two in service	2
IF-300 (rail cask)	4	All under restricted service due to valve failure	4 (dry shipments only
NLI-10/24 (rail cask)	2	Neither ever used; baskets melted by owner to recover silver	none; license expired 7/31/86
Totals	24 made		13 available

TABLE 1. CONTINUED

Older Casks NRC Certified For LWR Spent Fuel

Cask Name (Type)	No. Made	Disposition	No. Available In U.S., 1986
IF-200 (over wt. truck)	2	No data; 1 used in Sandia rail crash test (train crash into truck); 1 was designed just for Indian Pt. #1 fuel; apparently used only up to 1971	None; license ran out in early 1970's
NFS-100 (rail cask)	1	Used for Big Rock Pt. & Humboldt Bay fuel (shut down in 1976) in early 1970's	None; license expired 1979
IF-100 (truck cask)	1 or 2	No data; 1 was used in Sandia truck crashes into wall	None; license ran out in early 1970's

WHAT COULD GO WRONG?

Care is taken in the design, manufacture, maintenance and handling of casks but the record is filled with unforeseen difficulties. Following is a list of problems that have either occurred in the past (see next section for examples) and/or are possible in the future. Others likely exist that have not been imagined or which could occur in groups, leading to different (and unforeseen) consequences.

Design Errors

1. Error in fuel basket analysis - possible buckling in crash, leading to criticality event, fuel damage and possible cask seal failure.

2. Most severe drop and puncture orientation not examined - a possible vulnerable spot is missed and cask could be breached by impact lower than assumed in standards.

3. Error in simulation input data - if unverified by large scale models, a computer simulation can yield reasonable, but erroneous, results in almost any aspect of the design thereby influencing the casks ability to withstand impact, puncture, or fire stresses in numerous ways.

4. Major mathematical error made - stress analysis could be flawed, creating vulnerability to impact or fire less than assumed in standards; criticality possible.

Manufacturing Errors

1. Installation of defective valves or rupture disk - normal transport vibration or accident impact could lead to opening an avenue for radiation release.

2. Use of Improper welding materials - vulnerability created in case of impact and/or fire; if stress is created that damages valve or vent line, contaminated fluid or gases could escape and air enter the cask leading to re-oxidation and release of particles; loss of lead shielding in a fire could lead to a large increase in radiation passing through cask walls.

3. Improper weld of cask end, drain line or valve mounting - vulnerability created in case of impact, leading to avenues of radiation release.

4. If lead shielding is unable to safely expand during a fire - overpressuring of cask body, leading to cracking of outer shell and/or damage to drain or vent valves followed by leakage of contaminated fluid gases; if valve failure results, air could enter and re-oxidization and radiation releae could occur.

5. Defective installation of shielding - vulnerability created in case of fire or impact, leading to increased exposure of emergency crew after accident.

6. Use of defective bolts - same as 2 above (but no shielding loss), or vulnerability to loss of cask impact limiter (see item 3 in "Loading Errors").

7. Use of defective seal material - same as 1 above.

8. Use of improper metal to correct deficient shielding - same as 2 above.

9. Use of defective steel in outer cask body - same as 2 above.

10. If depleted uranium shielding, failure to properly coat uranium with copper plating - formation of low melting point for shielding, leading to same result as 4 above.

Maintenance Errors

1. Failure to fully decontaminate externally - source of confusing radiation created, potentially complicating an accident; also possible source of contamination of cask or vehicle handlers and emergency personnel.

2. Failure to properly leak test - same as 1 in "Manufacturing Errors".

3. Failure to fully decontaminate internally - buildup of crud and perhaps fission products from leaking fuel, creating secondary source of contamination if failure of cask seal (or valves) occurs (even if fuel remains intact); also possible source of contamination of cask handlers.

4. No routine replacement of cask lid seal - same as 1 in "Manufacturing Errors"

5. Failure to check rupture disc loss of fluid neutron shield during transport leading to higher routine exposure and increased radiation dosage near cask involved in fire

(i.e., heat causes fluid to expand, leak and evaporate) or a crash (i.e., cask oriented to pour out liquid).

Loading Errors

1. The drain valve, vent valve or pressure relief valve is either defective or improperly closed, allowing fluid or particles to leak out and/or air to leak into the cask - depending on fuel rod condition and temperature, contaminated fluid and radioactive gases could escape, re-oxidation could result, and an avenue for a major radiation release become available.

2. All water is not removed from the cask - water vapor, possibly in the form of steam, could form and promote internal cask contamination if leaking fuel is present; it would also raise internal pressure during a fire.

3. Cask impact limiter improperly installed - limiter comes loose at impact, leaving cask vulnerable to shock that cracks outer shell and/or damages seal and stresses welds; potential release of fluid or particles, or loss of lead shielding in fire (causing large increase in radiation penetrating cask walls).

4. The inert cask atmosphere is contaminated with air - this could lead to re-oxidation (i.e., formation of a fission product dust) of fuel with damaged cladding.

5. The lid seal is defective or damaged during closure - same consequences as 1.

6. Lid improperly closed - same as 1.

7. The wrong fuel assembly (or assemblies) are loaded into the cask - this could lead to excessive internal temperatures, internal cask contamination if the fuel is leaking, and/or damage to the fuel basket; if low burnup or fresh fuel is mixed with high burnup, chances of criticality may be increased.

Accident Handling Errors

1. Improper assumption of leakage - misreading (or misunderstanding) geiger counter reading may lead to unnecessary suspension of fire fighting efforts in order to evacuate fire fighters, thereby prolonging length of severe fire beyond cask limits.

2. Immersion of damaged cask in water during fire-fighting - potential encouragement of criticality if water enters cask, creation of steam leading to removal of surface contamination or re-oxidized fuel.

Conclusions

Note that these errors fall into three categories:

1. those that apply to a single shipment
2. those that apply to a single cask (thereby affecting a number of shipments)
3. those that apply to a single cask design (thereby affecting a number of casks and potentially many shipments).

Past error analysis has examined only the first category of errors and thus logically assumed that such errors were randomly distributed among all shipments. The simultaneous probability of a random accident and a random human error affecting only one shipment led to the conclusion that human error provides no major impact on overall transportation risk. Unfortunately, some of the errors and deficiencies that have actually occurred involved generic problems that applied to an entire series of casks and are discussed later in this report.

PRIOR ERROR ANALYSIS

General

The Nuclear Waste Policy Act's Environmental Assessment's evaluation of human error for transportation relies on Chapter 4 of a study identified here by its number NUREG/CR-0743 or, for short, 0743. In this discussion, all tables and page references from NUREG/CR-0743 can be found in Appendix A of this study, which reproduces Chapter 4 in full.

Chapter 4 of NUREG/CR-0743 attempts to examine the effects of human error on transportation risk for all types of packages. Since the immediate interest of this report is spent fuel casks, most of the data is not relevant. The methodology is sound for most of the cask incidents in table 4-7 of that study but must be adjusted for the two other error categories previously outlined in this report. The "incident rate" factor must be altered to reflect those cases where an error applies not to one shipment but to a fraction of <u>all</u> shipments, as determined by the portion of shipping miles travelled by a single cask or group of casks. Numerous other factors intrude before the rest of the analysis could become acceptable, however.

Specific Problems

1. Assumed Cask Coolant Contamination Level

The basic assumption regarding human error (page 77 of NUREG/CR-0743) is that "the maximum result of a human error is the release of all contaminated coolant water in the cask." The level of contamination in cask coolant has been found to be higher in some cases than in table 4-8, p. 80, especially where fuel damage has occurred. The NAC-IE incident in which damaged fuel contaminated the cask interior also yielded coolant (actually residual water) with a level over 2000 times greater than the maximum in table 4-8. In that 9-5-80 incident, 300 ml of coolant was found to contain more radiation (in terms of rems if dispersed) than in the 418,000 ml of coolant in the hypothetical case of a full coolant release. It should be recalled that the NAC-IE had already been decontaminated several times at an experienced laboratory (Battelle Columbus Labs) and contained no spent fuel when this higher level was found in the coolant. (ref. 1).

2. Listing of Cask Incidents

The data base for table 4-7 is a survey done in 1978 by Battelle Northwest Labs and detailed in a report identified here as PNL-2588 (see Appendix B of this report). To use a survey so lacking in completeness and rigor as the basis of a "detailed error analysis" is seriously inadequate. Here are a few reasons why:

-the Battelle Pacific Northwest Labs (PNL) survey depended mainly on recollection, <u>not written records</u>, dating back over 8 years: not only are memories over such a span unreliable, but changeover in personnel in such a time period eliminates available information even if it were remembered.

-none of the participant companies or labs was a commercial power plant operating under stringent NRC rules of observation and reportage; 3 out of 5 were licensed by DOE, which does not exercise the level of oversight maintained by NRC.

-the survey includes an incident where a truck cask was found to be leaking upon arrival but ignores another incident involving a rail cask that was found to be leaking <u>en route</u> to one of the surveyed sites. The leak was stopped prior to arrival at the site (ref. 2); this fact raises serious questions about the completeness of the survey.

-the survey covers 1977 but a number of incidents in that year on record elsewhere are missing which involved one of the sites surveyed; three separate casks were found to have improperly installed vent valves and arrived with those valves open, and in another case a drain valve was found open and also may have been installed improperly; some of these events were not reported in the survey (ref. 3).

-the capability of that same site to detect and report excess surface contamination (item B.11 in the survey questionnaire) is open to question since at least seven shipments <u>left</u> the site contaminated excessively between 5/15/76 and 5/11/77 (ref. 4).

Use of Incident List

NUREG/CR-0743 misuses the PNL-2588 data in two important ways:

-while 3,939 shipments were surveyed, only 536 involved casks with impact limiters; since all casks now have impact limiters, it was erroneous to assume a rate of one failure to properly install a limiter out of 3,939 shipments. The proper rate would be one out of 536, which translates to over 7 errors per 3939 shipments if all had impact limiters.

-for reasons unmentioned, NUREG/CR-0743 truncated the list of human errors detected by the survey; casks requiring defective drain valve, vent valve, or pressure relief device replacement were eliminated from .0743's "summary of causes of cask incidents". These same items were utilized, however, in PNL's own analysis of cask leakage during an accident. When included, these items add 11 incidents to the list.

Together, these two adjustments more than double the incidents that should have been considered in 0743.

Subsequent Incidents

A survey of NRC documentation for the 7 years following the survey indicate the following:

-the frequency of exterior cask contamination is much higher than seen in the survey

-types of errors have occurred, not listed in the survey, or analyzed by PNL, that could cause failures of an equivalent, lesser or greater severity than indicated in the PNL accident analysis (e.g., improper cask fabrication leading to buckling of inner containment during impact).

-errors assigned a very low probability by PNL have already occurred (e.g., cladding failure during normal transport).

The last two items could affect the fractional occurrence of the maximum release [illegible] page 81 Appendix A) assumed in 0743. That figure is crucial in the effort to statistically dismiss human error as a risk factor.

Taken together, the above concerns lead one to the view that the basis for 0743's human error conclusions are not well founded. Not only are the human error rates too low, but missing errors and errors with consequences greater than the assumed worst case combine to yield a different spectrum of error to be analyzed. The probabilities derived by 0743 are incorrect, the consequences are incorrect and thus the risk analysis is incorrect.

THE REAL RECORD OF HUMAN ERRORS

This section provides examples found during private research over the last seven years. It is in no way intended to provide a boundary on the types of errors that have occurred and it is known to be incomplete. It is provided to show the breadth of human ability to circumvent detailed procedures, careful analysis and redundant safety mechanisms. The author is quite sure that, even if it were complete, this listing will be soon outdated when yet another unforeseen incident arises and yet another analyst says: "Wow! I never thought that would happen!"

Design Errors

Two types of errors have been observed: those affecting individual designs and those affecting all cask designs using standard practices.

Individual Cask Design Errors

IF-300 FUEL BASKET - Four IF-300 rail casks were produced in the early 1970's and separate baskets were designed and fabricated for PWR and BWR fuel. About 7 years into the use of these casks, an error was discovered in the structural analysis for the BWR fuel basket. A value of 3840 pounds was used for the weight of the basket instead of the correct value of 5675 pounds. According to the cask manufacturer, "substitution of the correct weight...results in a compressive stress which exceeds the critical buckling stress of the 2 1/4" diameter fuel basket tie rods when the cask is subjected to the hypothetical 30 foot drop test."

(ref. 5). Such buckling could have forced the fuel assemblies together in an orientation conducive to criticality. The net result could have been rapid overheating of the cask, severe disruption of the cladding, mixing of the fuel with the cask water, pressurization and opening of the relief valve, followed by dispersal (as steam) of the cask water and fuel into the environment. Fortunately, the original analysis had been so grossly simplified that this error was not large enough to overcome the limits of those calculations. A more sophisticated method (not used on most casks produced in the 70's) showed that the basket would be slightly damaged in a drop but would still hold the assemblies in place (ref. 6). This series of casks was used in nearly 400 shipments before this discovery was made.

MH-1A STRUCTURAL ANALYSIS - Two MH-1A casks were fabricated in 1971 and were used in 23 shipments to handle power reactor fuel for a U.S. Army power plant between 1974 and 1977. The reactor was shut down in 1976. Since such facilities were placed under DOE (then called ERDA) in 1975 when the AEC was dismantled, DOE had the option of using the cask for its laboratories. It chose to do so and upgraded the safety analysis prior to granting a new license in May, 1982. To allow NRC licensees to use the container, DOE requested NRC approval of the cask later that year. After examining the design, NRC responded with 5 pages of problems needing attention, including the need for a fire shield to avoid loss of lead shielding and numerous structural questions related to drop tests (ref. 7). DOE designed and installed a new fire shield, removed valves that could cause leakage in an accident and re-analyzed its structural design in late 1984. DOE then began shipments from Brookhaven National Laboratory on Long Island (near New York City) in January, 1985. Despite the cask alterations, NRC still questioned the design and, at a meeting in May, 1985, called upon DOE to answer its questions. When it was unable to do so, the U.S. Department of Transportation (which had the final say on container issues) ordered DOE to suspend use of the container (ref. 8). Thirteen shipments were made through New York City in 1985 before the suspension. Six months later, two other DOE labs evaluated the cask and found "that the package seal would be lost following the accident condition of the transport tests" (ref. 9). DOE intended to pursue re-licensing but, a year later, is still unable to show the cask would survive the 30 foot drop test. Loss of the cask seal at its lid could lead to release of the crud coating on the fuel elements (in this case, highly enriched, high burnup fuel plates from a research reactor) and possibly particles of damaged fuel (uranium alloy plates 1/16" thick and clad with only 1/64" coating of aluminum).

OTHER DOE CASKS -DOE has licensed at least another 10 spent fuel casks ,that have been refused NRC approval for various reasons. All are used to ship research reactor fuel. They are presented here to show how many potentially generic deficiencies in design have been allowed on America's highways. Unfortunately, NRC review was terminated on most of them in 1983 when DOE was unable to answer the problems cited by NRC. No third party verification was performed (as

TABLE 2.

Container	Date of Request For NRC Approval	Date Review Was Terminated	Dates Of Known Usage	No. Verified Shipments	Items In Question
HFBR	02/14/78	05/31/83	1968-1976	Over 100	Structure, Seal
Rover	09/26/75	01/22/85	1968-1972 (Approx)	No. Unknown	Structure, Thermal, Shield, Criticality
HNPF	08/02/78	05/31/83	1964-1971	No. Unknown	Structure, Seal, Criticality
			1978-1979	12	
HFIR	1979 Approx.	Still Pending	1978-1983	111	Unknown
ANL-402-SPM	04/02/79	05/31/83	1978-1983	34	Structure
ANL-390-SPM	12/30/77	05/31/83	1977	1	Structure, Seal
Paducah	11/17/82	05/31/83	1982-1983	8	Structure, Seal
Garden Carrier	08/24/81	05/09/85	1981-1985	11	Structure, Seal
Loop Transport	07/13/78	05/09/85	1978-1982	11	Seal
In Pile Capsule	07/31/78	05/31/83	No Shipping Record Available		Structure, Seal Thermal
MH-1A	09/07/82	Still Pending	1974-1977	23	Structure, Seal
			1985	13	

in the case of the MH-1A) to further support the claims of deficiency. Most of these containers are still available for use at this time. See Table 2 for delineation of the containers in question (ref. 10).

LLD-1 - While not a spent fuel cask, the LLD-1 is designed to carry large quantities of plutonium. It is presented here to show how a generic problem can be replicated in over 100 containers at one time. Weighing less than 150 pounds, each container holds about 15 pounds of plutonium and a typical shipment may involve 30 containers or more. DOE requested NRC approval 4-10-75 and NRC responded with questions on the cask's structural strength and seal. The container had been routinely used to ship powdered plutonium oxide (probably the most dangerous form) by plane to the U.S. and by truck through the center of Manhattan, the most densely populated area in the U.S. In May, 1980, following a new series of drop tests in which the container's support frame collapsed, NRC raised the possibility that (in a crash and a fire) many support frames could be damaged, leading to a nuclear criticality (ref. 11). Such an event might appear as a quick series of explosions as the sealed containers each rapidly heated and burst, dispersing the powder into the air. NUREG/CR-0743 (page 120) indicates that a 1Kg release (about 15% of one package) could yield thousands of latent cancer fatalities and billions of dollars in damage due to contamination. While plutonium oxide powder may no longer be shipped in the LLD-1 (due to a 1979 finding that it would leak during an accident even without a criticality event) solid plutonium metal (which burns on contact with air) is still shipped in this package. DOE terminated any further NRC review of the package on 5-31-83. About 5000 shipments have been made since 1970 (i.e., one truck moving 30 containers at one time equals 30 shipments), the most recent in June, 1984 (ref. 12). No answer was ever provided to NRC queries on criticality and structure.

Generic Cask Design Errors

As previously discussed, many casks were designed according to a guide written in 1970. Some of the formulae presented in it are based on empirical values derived from experience with similar shapes (e.g., stresses on large pipes). One equation shows the minimum thickness necessary to withstand the standard puncture test. Unfortunately, no full scale verification was performed on any casks in use today so there is no guarantee that the containers would actually survive the test. Federal regulations allow scale models or mathematical methods as proof instead. In 1980, more sophisticated analyses performed at Lawrence Livermore Laboratories concluded that "existing test data is inadequate and analytical methods, largely empirical, are crude and unreliable... The empirical formulae do not give designers the insight into puncture phenomena they need to produce a rational, safe design" (ref. 13). Subsequent work by a former NRC engineer verified these findings but no effort has been made to re-examine existing designs. New designs will hopefully utilize the improved analytical tools but this human error in choice of engineering methodology remains in effect for almost all casks on the road today. The consequences of a puncture failure could vary from a loss of fluid neutron shielding (with a slight impact primarily on emergency personnel) to a breech of containment, exposing to the air spent fuel also damaged by the puncture, or a criticality event due to the alteration of fuel pin configuration.

Manufacturing/Maintenance Errors

These two types are combined to avoid duplicating items that appear in both categories.

IF-300 PRESSURE RELIEF VALVE - As previously mentioned, four IF-300 casks were produced. Each cask has two pressure relief valves: one to relieve pressure in the cask and the other to relieve pressure in a water jacket surrounding the outer shell of the cask. The valves were designed to open, release steam and/or water and then close again. PNL-2588 lists 6 replacements of valves for the IF-300 prior to 1978 due to "defect with relief mechanism". These IF-300 casks were in service to the surveyed sites so apparently all the valves were replaced (two valves per cask x three casks = 6 valves). In June, 1981, the manufacturers of the valves informed General Electric Company (holder of the cask license) that there was "a generic problem affecting the six other valves which it fabricated in the 1970's...Tests on an identical valve found that it did not reseat with a leak tight seal following the venting" (ref. 14). In other words, cask coolant (and/or neutron water shielding) could continue to be released. Thus, defective valves <u>may have been used to replace other defective valves</u>. The valves were designed to open at 375 psi at a cask cavity temperature of 450 degrees Fahrenheit or at 200 psi in the water jacket. The cask's safety analysis indicated that, during the hypothetical 30 minute fire, the interior of the cask would not get hot enough to cause the valve to open. Such a fire would, however, cause the water jacket relief valve to open thereby causing a loss of neutron shielding. G.E. felt that since the interior cask valve would not open even during a fire, there was no hazard. Nevertheless, it informed the NRC that it would only use the cask for dry shipments until the problem was resolved.

Since all shipments at the time involved older, cooler fuel, there was no need for cask coolant water. However, another mechanism existed to force open a pressure relief valve in these earlier shipments still containing water. PNL-2588 (Appendix F) found that a collision between a water filled cask and a rigid structure such as the corner of a building or bridge abutment could cause water hammer (i.e., sudden water pressure) intense enough to open the valve. The velocity at impact could be less than 15 mph in the case of a side impact. It was therefore possible that a relatively low speed crash could force open the valve. It would remain stuck open due to valve failure and, if the cask had tilted on its side due to overturning of the truck, the coolant could pour out by gravity. Similarly, if a fire occurred, the cask need not even be on its side to lose coolant. While the interior of the cask would not reach boiling due to the heat shielding effect of the cask mass, it would still heat up leading to expansion of the water which could then flow easily through the open valve. The IF-300 holds almost 500 gallons of coolant so the potential release could be significant, especially if it was then vaporized by the fire into a respirable cloud. A less spectacular accident could involve only a fire that forces open the water jacket valve causing a loss of neutron shielding. This would cause a tripling (approximately) of the normally released neutron radiation. While not a major hazard, such an increase could affect fire fighters and cleanup personnel. It could also confuse them into believing that the cask was leaking, leading to an unnecessary evacuation or other turmoil. The IF-300 casks were apparently shipped wet in at least 375 shipments prior to June, 1981 (ref. 15).

WELDING ON THE 67 TON RAIL CASK - This container was a first generation cask fabricated in 1962. It was designed to different criteria than in use today, one of which was the ability to withstand a 60 minute fire (today's standard is a 30 minute fire). It had been taken out of service and in 1978 was used in a series of tests at Sandia Laboratories. One of these tests was an extended fire lasting almost two hours. About 100 minutes into the test, a white cloud was observed leaving the cask. The fuel supply was stopped and the fire went out at about 125 minutes into the test. Later examinations found that the outer shell had cracked open and the lead shielding had begun to vaporize. Two types of manufacturing errors were found:

1. no holes had been drilled into an interior cavity designed to allow the melted lead to expand into it; this created great pressure on the outer shell;

2. improper welding techniques had been used involving wrong materials and an excessive welding temperature (ref. 16).

While this cask nevertheless survived a fire exceeding its 60 minute design limit, these errors raised serious questions about the ability to trust manufacturing processes not witnessed by federal inspectors. Such failures on other casks could also lead to cracking of the outer shell and loss of lead shielding in a fire. No breech of the cask interior or loss of seal would be needed to cause a release of radiation since loss of lead shielding could raise the level of radiation penetrating the cask walls from a few hundred millirem (relatively harmless over a short period of time) to a few hundred rem (very dangerous). Fire fighting would have to cease and no one within a hundred feet of the cask would be safe unless shielded. Examination of cask manufacturing records and NRC inspection reports shows that welding errors and failure to drill holes could occur and remain undetected for the life of the cask (as occurred in this case).

Welding problems have also shown up on other casks though their origin has not been studied closely. For example, half and quarter scale models of a British Magnox spent fuel cask were found to be cracked after drop tests were performed in 1983. The implications of the failure were not clear but the test resulted in suspension of the cask's license and a more rapid phaseout of the twenty year old containers. Nineteen of them were produced and used many times since Britain reprocesses spent fuel (unlike the U.S.). All new British casks use large castings and no welds in the area where the failure was observed (ref. 17). New U.S. shipping casks continue to use welded parts.

NAC-1 CASK IMPACT LIMITER - Another early cask (produced in 1959) was used in full scale tests in 1977 to examine its response to impact. It was dropped at an angle from 30 feet, with and without an impact limiter with a result that the absence of a limiter caused the outer shell to crack open. Another drop without a limiter, this time on one end, caused a second crack in a joint at the drain line, opening an avenue to the first crack that could allow coolant or damaged fuel to escape. While two drops are not required in order to pass today's standards, the orientation in this case could occur in an accident if the cask was to fall at a shallow angle (30 degrees) on one end and then bounce or fall further to impact vertically on its other end. A fall from a bridge or a road on a mountain side could present such an opportunity, for example. The consequences of failure to properly attach an impact limiter could thus be loss of lead shielding if a drop was followed by a fire or release of cask coolant and/or damaged fuel if a second drop occurred. The only recorded case of such an impact limiter problem was listed in PNL-2588's survey and involved the NAC-1 cask in September, 1975. At that time, it was found that only 2 of the 4 bolts normally used to hold the limiter were installed. The receiver of the cask (Nuclear Fuel Services) "maintains the opinion that under some combination of accidents not specifically analyzed, there could be a substantial reduction in the effectiveness of the cask with only two of the four impact limiter bolts installed" (ref. 18).

IMPROPER CLOSURE OF CASK - Two cases of spent fuel cask leakage were found in AEC documents:

1. In June, 1960, a rail cask passing through New York state began to lose coolant on its way to South Carolina. The fuel load included "some ruptured elements which had been encapsulated in aluminum cans". The leakage was observed at the vent line at the start of the trip but it quickly stopped, "Upon arrival at a large city, it was discovered the water was again dripping from the vents, and action was taken to confine the leakage to the car." Ground contamination near the railroad tracks was found and removed and the shipment continued to the next junction where 17 gallons of coolant water was drained before the leak stopped. It is estimated (by AEC) that "30 to 40 gallons of contaminated water leaked from the cask" (ref. 2). This small leak cost $24,000 (in 1960) to clean up. If a fire had aerosolized the coolant, the cost would be closer to several million dollars in an urban area (see graph 2 from NUREG/CR-0743).

2. On August 21, 1962 a cask carrying spent plutonium fuel leaked in transit. This incident required removal and burial of street pavement at one location. The form of leakage was not detailed so it is assumed that it was contaminated cask coolant (ref. 19).

The implications of such leaks, especially involving failed fuel, have been previously discussed. Since no cask damage was involved, it is assumed that the leaks were due to either improper loading or valve maintenance.

NAC-1 VALVE INSTALLATION - Five cases of open vent valves and one open drain valve were found between June 13 and June 29, 1977 involving three different NAC-1 casks (six were in service at the time). An NRC inspector concluded that the problem related to insufficient tightening of the valve packing which, when accompanied by the truck's normal vibration, caused the valves to come open en route (ref. 20). While tightening appears to have worked, the actual source of the problem (and the reason it afflicted at least 3 casks) was faulty valve installation instructions (ref. 21). Since these casks had been in use for several years, it is likely that this problem had occurred many times before. The license required testing of the valve only once every three months up until May, 1976 when the license was changed to require testing with each shipment. It is quite possible that many (if not all) tests were done by opening the valve, closing it and then testing it <u>before</u> the cask left the facility, thereby <u>never</u> witnessing the fact that it came open en route. There was never a requirement in the license that the valve be tested upon <u>arrival</u>. While the open valves were not sufficient by themselves to cause a major contamination (due to a cover plate and hose disconnect blocking coolant flow), a relatively mild accident could puncture the cover plate and open or damage the disconnect, allowing coolant release and a direct route to the spent fuel. See prior discussion for the implications. The three NAC-1 casks in question were used for about 150 shipments before the valve problem was corrected (ref. 22).

NAC-1 SHIELDING - The NAC-1 used lead shielding sandwiched between two concentric cylindrical shells that was poured into the space in a molten state. This is a tricky process, according to the Cask Designer's Guide, and needs to be checked carefully. When two NAC casks were manufactured, the casting didn't come out quite right so the lead shielding was thin in one or more spots. To increase the shielding, copper plates were welded to the outside of one cask in violation of the cask license. Neither condition was observed by NRC inspectors during their inspections at the manufacturing plant or at the reactor where the cask was in use. The condition remained unnoticed until a purchaser of one of the casks found that the inner cask cavity shell was bowed out of shape, also a violation (see next item). The casks were produced in 1974; the condition was found in April, 1979 (ref. 23). The presence of copper next to steel can lead to a low melting point where the two metals meet. Extra care is also needed in the choice and quality of welding filler materials to avoid impurities that could lead to cracking; it was improper welding material and technique in a copper-to-steel weld that was a cause of the crack in the outer shell of the 67 ton rail cask. None of these details had been reviewed by NRC during manufacture and much of the manufacturer's documentation was lost in a 1975 fire at his plant. As previously discussed [illegible] shielding can greatly increase the radiation leaving the cask wall even though no breach of the containment occurs. See the prior discussion for implications. The NAC cask in question was used for 84 shipments before the condition was discovered (ref. 22).

NAC-1 CAVITY BOWING - Two NAC-1 casks were found to have inner cask cavity shells bowed out of shape in March, 1979. NRC was informed of this fact 3/29/79 but did not suspend use of the casks until 4/6/79, during which time four shipments took place through the outskirts of Chicago with one of the deficient casks. The precise cause was never determined and NRC felt it was either a manufacturing error or a condition resulting from regular use. In either case, it apparently existed over all or a portion of the cask's lifetime since there was no record of any accident with either cask that could cause such a condition. Buckling of the inner cavity due to an impact could possibly damage the fuel rods and force open the pressure relief valve (if water coolant was present) until pressure was relieved. The casks in question may have been used for as many as 103 shipments before the condition was discovered (ref. 22). Two other NAC-1 casks were also suspended from use but never measured by their owners and may have been responsible for even more shipments with bowed cavities.

Loading Errors

INCORRECT CASK HEATING LOAD ANALYSIS - Perhaps the most serious blunder found in the literature involved the use of an incorrect equation to determine internal cask heat load.

In May, 1980, a damaged fuel assembly needed to be shipped from a Connecticut reactor to a lab in Ohio. Since the fuel had been cooling in a spent fuel pool for over a year, it was felt that it could be shipped dry (one of the conditions placed on all NAC-1 casks after the bowing incident) so a NAC-1 cask was chosen. A mathematical formula was used to determine if the heat generated by the assembly exceeded that allowed by the license for dry shipments (a maximum of 2.5 KW). A value of 2.09 KW was found using the formula so the assembly was loaded and sent on its way. The formula was later found to be an outdated (and not accurate) version of a similar one that yielded a value of 3.5 KW for the damaged assembly. As a result, the cask interior got hot enough to cause the fuel pellets exposed to air in the cask to re-oxidize and form a very fine powder that was distributed in the interior of the cask during the trip to Ohio. When the cask was opened under water, air bubbles were released that were coated on the inside with the fine powder. When the bubbles reached the surface of the water, they released the powder, contaminating the laboratory, the pool and the cask exterior. Lawsuits resulted, a worker received a dose of radiation far above his annual safe limit while cleaning up the area and the cask became too contaminated for future use. Even though the cask was decontaminated several times, it still had excessive surface contamination when shipped to a New Jersey reactor (where it was refused) and later to California. During both trips, the cask contained no spent fuel and was therefore not restricted to interstate highways nor was it necessary to avoid urban areas. When it reached California, the cask was found to still contain some of the powdered fuel suspended in residual cask water. The workers draining the cask (who were not qualified for the job) were contaminated, resulting in $125,000 in fines against the California reactor operator. The cask value loss was approximately $1,500,000. The lawsuits were settled out of court, for an undetermined sum kept secret by sealing the court record. The implications of this relatively minor error are staggering: dispersion of the fluid found in the cask could have led to a very serious contamination. Analysis of a 200-300 ml sample (about one cup of water) found a high level of isotopes and gave off very high radiation readings (over 300 r/hr). While the total amount of fluid and suspended powder was never determined, it was not unusual for several gallons to remain in the NAC-1. A release of 1/2 gallon of fluid such as that analyzed from the cask could, if vaporized in a small truck fire, lead to several hundred million dollars in cleanup costs, based on findings in NUREG/CR-0743 (pp. 58 and 59). The material could have escaped through an open or faulty valve (one drain valve on this cask was found to be defective just prior to the shipment and was replaced by a pipe plug) and been heated to steam by a small fire. Similarly the fluid could escape through an open valve and splash onto the road or nearby vehicles. In 1984, after prodding by both the author of this report and the Sierra Club, NRC reviewed the danger involved and changed the licenses of all commercial spent fuel casks to no longer allow air inside them (an inert atmosphere such as helium is now required). In its analysis, NRC concluded that a release possibly four times greater than that covered in NUREG-CR-0743 was possible (ref. 24). The 0743 analysis (which assumed only a crud release) concluded that several billion dollars in contamination damage, accompanied by a large evacuation to avoid health effects, could occur in an urban area. Note that the cask need not be breached, and neither a severe crash or a major fire is necessary. Many dry shipments with air atmosphere were made before NRC's decision to change the license was made, some involving damaged fuel. A major shipping campaign commenced in 1983 to empty the West Valley, N.Y. pool, which contained over 100 leaking assemblies. Most of those shipments were made (fortunately) after the NRC's April, 1984 decision to require an inert cask atmosphere instead of air. NRC's decision only applies to commercial spent fuel casks, however, and not to 9 other casks used to move research fuel. When the author requested that the restriction be made applicable to those other containers (in July, 1984) he was told there was no need because "...under authorized shipping conditions, there is not sufficient heat to present a concern..." (ref. 25). When it was pointed out that the prior oxidation incident occurred under <u>unauthorized</u> conditions, the NRC declined to comment. Those 9 casks are still available for use with damaged fuel in an air atmosphere.

EXCESS WATER IN CASK - All cask licenses require the container to be empty of water when shipped in a dry state or when shipped without fuel. In November, 1981 an NLI-1/2 cask (about the same size as the NAC-1) was shipped with 65 gallons of water in the cask cavity and no spent fuel (ref. 26). As indicated previously, a failed or open valve could release this fluid even without an accident though a small fire would help disperse the contents widely. If the coolant was contaminated to the level indicated in NUREG/CR-0743, the resulting cleanup would cost several million dollars. Health effects from inhaled coolant contamination could lead to lung problems due to radiation but probably not a high enough dosage to yield latent cancer fatalities. The record is not clear how often excess coolant is shipped, but larger casks (like the IF-300) often contain some residual water when shipped without fuel.

DAMAGING FUEL DURING LOADING OR TRANSIT - Aside from the re-oxidation incident, two other cases of fuel damage due to shipping were found among shipments in the U.S. (five others were found outside the U.S.) (ref. 27). The degree of damage was not clear but if it involved cladding, the loss of an inert atmosphere through a faulty valve could lead to release of crud or damaged fuel suspended in the gas by truck vibration. The consequences would depend heavily on the degree of fuel damage.

Incident/Accident Handling

FAILURE TO PROPERLY ASSESS LEAKAGE - While not directly related to spent fuel casks, the potential exists for human error to interfere in a cask incident and make it worse. In March, 1977 a train carrying cylinders of uranium hexafluoride, a mildly radioactive substance that becomes gaseous on exposure to heat and open air, was involved in a derailment and fire. The containers are close to the size and weight of spent fuel casks. Fire fighters were trying to put out the fire surrounding the cylinders when an Army explosives team arrived to assist. Using geiger counters, they measured radiation and suspected a leak. The area near the containers was evacuated and fire fighting continued only near some explosive chemicals. Over two hours passed while the fire continued to contact one of the containers. It was then found that the radiation reading was erroneous, though the cause of the error was never determined. The firemen then extinguished the fire near the cylinder (ref. 28). This error significantly increased the time the container was being burned. The assumption of a 30 minute fire (in the cask standards) is based upon effort to put out a fire, not avoid it. The error could thus cause a cask to undergo greater stress than assumed, possibly leading to loss of cask coolant and even (according to PNL-2588) cladding rupture, fuel re-oxidation, seal failure and dispersal of powdered fuel outside the cask. A severe fire would have to occur but the consequences of this error are far beyond the spectrum of those analyzed in the 0743 error analysis. In February, 1978, a spent fuel cask was involved in a truck accident in which the trailer bed buckled. A State Police team measured 4 rems per hour coming from the cask (4 times the allowable limit even in a serious accident) but twenty minutes later it was found the police misread the scale (it was actually 4 mrem per hour) (ref.

29). While no fire was involved, this incident demonstrates how easily such mistakes are made.

FAILURE TO PROPERLY ROUTE HAZARDOUS MATERIALS - The most severe vehicular fire ever recorded was made worse by improper routing. In April, 1982, a single gasoline tanker ruptured in a collision in a tunnel, caught fire and exploded. The confined tunnel conditions created an intense inferno that may have exceeded the 30 minute fire test (today's double tanker trucks would yield an even worse situation). While the likelihood of such a fire occurring while a spent fuel truck is also in the tunnel is small, the fact remains that an error was made by the trucking firm in sending the truck on that route. According to the accident analysis by the National Transportation Safety Board, another route was available that compared favorably with the tunnel route and would not violate federal routing rules for hazardous materials (as does the tunnel route) (ref. 30). The trucking company erred in its route analysis, thereby contributing to a severe fire condition.

FUTURE CONSIDERATIONS

Several other items need further exploration to better assess the cask concerns involved.

1. Number of Casks

Depending on the site, the number of casks needed could vary from 130 to 165 (this range could also vary due to the mix of rail and road shipments). At either extreme, industry must produce in the next 15 years about ten times as many casks as it made in the last 15 years. The implications for inspection and quality assurance (QA) are significant in light of the problems with previous cask assembly line attempts. The largest of these was the NAC-1 effort. At on point (after producing five casks) the cask owners concluded that it had problems implementing its own QA program with its cask fabricator. The multiple problems of valves, bowing and shielding on five containers out of 7 are enough to raise questions concerning the manufacture of over 150 containers. If past history is any indication, the number of casks needed could easily double to account for those taken out of service from time to time due to manufacturing/maintenance problems. The differences in cask demands by the three sites then begins to have a larger effect on industry's ability to supply the needed containers: the less accessible sites necessitate more casks or, conversely, greater pressure to use worn or questionable containers to meet schedules.

2. Availability of Qualified Vendors

It is unlikely that current cask owners will be willing to re-enter the production market without federal guarantees they will have an easier time than the last decade. One of the largest, National Lead Industries, (NLI) became so frustrated that it tried to sue the federal government when the decision was made not to reprocess fuel since that eliminated the need to produce more casks. NLI later closed its fabricating shop, melted down its fuel baskets to sell the silver in them and sold its cask business to a company that makes health foods. It was the one shop able to cast and machine the large depleted uranium shield sections needed for rail casks. It is noteworthy that the generic cask designs shown in DOE's assessment are shielded with depleted uranium. This important past experience will thus be missing from the next generation of cask fabricators.

3. Inspection and Enforcement

A similar question concerns NRC's ability to monitor, inspect and control such a rapidly expanding industry. It had only a half dozen inspectors when only a half dozen casks were in production and they failed to catch major mistakes. In this era of diminished regulation, how will it attain the staffing to handle the load? In the past, the casks have been on the road before the welding radiographs were checked by NRC.

4. Changes To Cask Designs And Fuel Storage

Shipping 5 year old fuel in a dry cask filled with helium eliminates some of the scenarios previously analyzed. It also reduces the radiation level occurring when shielding is lost. On the other hand, new casks will contain twice as much fuel in each shipment, thereby increasing the amount of available crud or damaged fuel that could be released in a severe accident. Fuel will have been stored at higher temperatures in dry storage casks where, over a span of time, stresses could affect cladding and increase the chances of cladding failure in a severe crash. Taken together, these changes could create new types of human error (in fuel loading, storage, examination, etc.) just as they eliminate some old mistakes. A careful analysis of forseeable errors unique to the new casks is needed to assess their impacts on risk prior to the first shipping campaign to a repository.

PERSPECTIVES ON HUMAN ERROR AND PROBABILITIES

The previous discussions of error indicate a high level of uncertainty exists in determining the impact of human error. To define the limits of that uncertainty is risky but necessary in order to constructively proceed with an acceptable environmental assessment.

The fault tree probabilities outlined in PNL-2588 could be altered, for example, to account for the types of errors discussed in this report (supplemented by expanded research) and the increased consequences that could result. Appropriate changes to account for dry shipment (after dry storage), changed cask designs, routing corridors, etc. would be necessary but a consensus on such parameters is possible. The results would provide improved (and perhaps acceptable) inputs into the overall EA risk analysis.

A "rough cut" approach could also be taken by assuming that human error increases probabilities and consequences by certain numerical factors and then performing sensitivity analyses to assess the overall impact. For example, various studies on nuclear reactor safety have developed probabilities for certain reactor events using the methodology later copied by PNL-2588 for cask events. A comparison between known reactor events and the probability calculations performed before those events occurred is instructive when seeking a limit on such factors. The Three Mile Island accident, for example, involved several simultaneous events estimated individually to occur only once in 1000 to 30,000 reactor-years of operation (a reactor year is a measure of the experience involved in operating one reactor for one year). Since the likelihood of the total series of events is the product of those probabilities, one would expect a TMI-type meltdown only once in several million reactor-years. It occurred, however, after only 500 reactor-years of commercial operation, due to the intervention of human error. A "human error factor" could then be developed to adjust the mathematical value to a more realistic number. In this case, human error made the event at least several thousand times more likely, so perhaps adjusting the risk of nuclear transport by three to five orders of magnitude may be acceptable.. A similar result is obtained by examination of the Chernobyl event: an incident that was estimated to occur only once in ten million years occurred after only about 300 reactor-years of Soviet operations. Again, a human error factor for worst case scenarios of 5 orders of magnitude may be acceptable to even the most severe critic. If applied to present analyses, spent fuel transport would then still create a lower risk to life than that of airplane travel, when averaged over the U.S. population. Such an average, when redefined for communities or states bearing most of the risk, may not be considered acceptable by them, however. The above is only an example and should not be construed as indicating a position of the author or of any participant in the environmental assessment process.

A somewhat different approach would translate the impact of human error on accidents into economic effects instead of health effects. While the economic impacts of the more dramatic but less probable worst cases have been approximated, it would be instructive to do so for the less dramatic but more probable events as well. An annual "accident management bill" could then be developed for comparison to the available insurance. While it is likely that expanded Price-Anderson coverage will be adequate for most incidents, it would be useful to gauge the "dollar risk" taken by states and communities responsible for accident handling and cleanup costs not reimbursed by Price-Anderson. Perhaps the development of such figures could lead to additional financial structures that would reduce the concerns about managing mishaps in transit. In more serious cases, however, it would be difficult to arrive at a consensus on the real value of (for example) a community severely contaminated by radiation, even if all inhabitants escaped unharmed.

It is possible that approaches similar to the above may create a "meeting ground" for most of those concerned with the handling of spent fuel and the siting of repositories. This discussion is provided to foster such a dialogue since it is essential to avoid either a dangerous impasse or a pyrrhic expression of federal power.

CONCLUSION

There are many scenarios involving human error that are not covered in NUREG/CR-0743 and therefore not examined in the NWPA EA. Many involve errors affecting hundreds of shipments, a fact not analyzed in any federal study. A few yield consequences rivaling or exceeding the worst cases assumed in a severe accident. Almost all errors serve to increase the risk of spent fuel shipping by raising the consequences of incidents otherwise not serious (e.g., faulty valve releasing cask coolant as a vapor due to a small fire) or by increasing the probability of a serious accident (through design or manufacturing errors that weaken cask integrity). The overall effect of past blunders needs to be assessed more carefully with an eye to tailoring the analysis to route and cask specifics so a more realistic judgement can be made of the dangers involved in shipping spent nuclear fuel.

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Note: Numerous other documents (over 150) were utilized to develop data for this report but are not listed due to their non-controversial nature (e.g., trip reports for shipments, descriptions of routine cask operations). References for all such details are available from the author.

Appendix A:

Chapter 4,

NUREG/CR-0743

NUREG/CR-0743
SAND79-0369

Transportation of Radionuclides in Urban Environs: Draft Environmental Assessment

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4

ENVIRONMENTAL IMPACTS FROM HUMAN ERRORS AND DEVIATIONS FROM ACCEPTED QUALITY ASSURANCE PRACTICES

Human errors and deviations from accepted quality assurance (QA) practices can produce environmental impacts similar to those produced by vehicular accidents, i.e., through loss of shielding, loss of containment, or through delay of the shipment. The detailed incidents selected for analysis in this chapter are those specifically related to the transport process and include problems in packaging, labeling, handling and stowage of the radioactive material. Human errors which result in vehicular accidents are treated as such (Chapter 3). Deviations from accepted QA practices include both failure to adhere to normal procedure and lack of quality control.

Records of actual incidents involving radioactive material transport in urban areas reported to governmental agencies were analyzed to estimate the probability of occurrence of an incident on a per-shipment basis. Since quality assurance practices vary depending on the package type (e.g., Type A packages are controlled differently from spent fuel casks), the probability of occurrence of an incident is estimated as a function of package type. A separate analysis estimates the probability of occurrence of an incident involving a spent fuel cask since there have been no reports filed with the appropriate agencies for this shipment type.

Package-dependent incident probabilities are used in the radiological consequence code METRAN, operating in a special mode, to estimate the contribution of human error or QA deviations to the risk of transporting radioactive materials in urban areas. The definition of estimated value of radiological risk, given in the introduction of Chapter 3, applies here also.

From a systems point of view, human error occurs when there is a reduction or potential reduction in system reliability or safety, e.g., failure to perform the necessary task, performance of a required task out of sequence, or inaccurate marking of the transport index on the package.

4.1 Transportation

Radioactive materials are not unique in the complexity of the transport process. Operations specifically related to transportation in which human errors could occur include packaging and labeling of the shipment; temporary stowage of packages, handling, securing, stowing, and routing operations prior to initial movement of the material; in-transit transfers; and movements of the shipment by the receiver to its final destination. Incident reports, examined in this analysis, describe several of the previously listed error types and form the basis for determination of occurrence rates for human errors and deviations from accepted QA practices as a function of package type.

4.2 Methodology for Risk Assessment

;k from human errors and deviations from accepted QA practices are expressed as expected health effects as a function of the type of package in which the material is shipped. In general terms, the risk may be formulated as follows:

$$R = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} N_{j,k} \cdot PPS_{j,k} \cdot RF_{i,j} \cdot K_k \cdot SPY_{j,k} \cdot C_{i,j} \quad (1)$$

where

R = total annual risk from human errors and deviations from QA practices (expected number of human health effects)

i = index over severity categories

a = number of severity categories (= 3 for casks; = 8 for all other package types)

j = index over package types

b = number of package types

k = index over materials

c = number of materials

$N_{j,k}$ = curies per package for kth material shipped in jth package type

$PPS_{j,k}$ = packages per shipment for kth material shipped in jth package type

$RF_{i,j}$ = release fraction for jth package in accident of ith severity

K_k = health effects conversion factor for kth material (expected health effects per curie released or exposed)

$SPY_{j,k}$ = shipments per year of kth material in jth package type

$C_{i,j}$ = incident rate for ith severity incident involving jth package type

Severity-dependent fractional occurrences for human errors were developed from the data provided in the DOT and NRC incident reports and are reflected in Table 4-5. Release fractions consistent with the accident analysis are used for package Types A, B, LSA, and drum. A separate section of the chapter is devoted to fractional occurrences, release fractions, and incident rates for cask transport.

Sources of information on the number and type of incidents involving radioactive material shipments have been developed with the assistance of the Task Group on Transportation of Radioactive Material in Urban Environs. Several members supplied contacts within their own organizations or have suggested individuals, agencies, or groups that led to relevant information.

Unfortunately, most potential data sources have not maintained records that could readily be applied to this study. Frequently, applicable data could only be extracted from the actual reports of investigations made by the regulatory agencies. Regulations require that a detailed incident report be submitted to the Department of Transportation (DOT) within 15 days if death, injury, fire, breakage, spillage, or suspected radioactive contamination occurs as a result of transportation of radioactive materials.[1] Similar reports must be filed with the NRC for any instance in which there is substantial reduction in the effectiveness of any authorized packaging during use.[2] If a local (city, county, state) surveillance agency exists, that agency will usually make and file a report of an incident investigation. False alarms or insignificant events are rarely reported to the federal level but do remain a matter of record at the local level for short periods of time. Reports of incidents thought to be newsworthy are also generally filed and thus made a part of the record.

4.2.1 DOT Incident Reports

DOT reports on incidents involving transportation of radioactive materials in urban areas are available for the period 1 January 1971 through 3 August 1977. These investigative reports, which describe the events as reported at the time of the incident, are summarized in Appendix H. Of the 251 incidents for that period, only the 153 occurring in urban areas are included. Other information derived from the detailed reports, such as the probable cause of the incidents and transport mode affected, are summarized in Table 4-1. Human errors or deviations from accepted QA practices were found to affect 141 of the total 153 incidents. Incidents were about equally divided among air and surface modes of transport.*

The probable causes of the incidents studied include the following:

- Stowage -- Shipments are blown off vehicles, crushed by following vehicles, run over by forklifts, damaged by other freight, fall from vehicles, or suffer water damage as a result of insecure or ineffective placement on a vehicle or within a terminal area.
- Handling -- When dropped or punctured, shipments lose package integrity through damage to internal containers or external packaging material.
- Packaging -- Shipments lose integrity by failure of external containers, omission of internal padding, defective valve closures, corrosion, improper packaging, welding failures, or drum rupture.
- Theft/Loss -- Radioactive materials are stolen or misdirected in shipment.

*The events charged to air shipments usually occur as a result of actions performed during ground operations before or after flight (a package falls off a loading dock, faulty tiedowns, etc.).

- Disposal -- A damaged radioactive material container is discarded in an unauthorized fashion.
- Labeling -- Improper label or radiation level is given on package.

As shown by Table 4-1, stowage, handling, and packaging account for the bulk of the human error incidents. Traffic accidents are not considered, and theft is considered a purposeful act rather than a human error. This set was further reduced to include only those for 1975 before the incident rates were calculated.

Table 4-1

Department of Transportation Investigative Reports on Radioactive Material Incidents in Urban Areas -- 1971-1977

Incident Cause	No. of Reports	Percent of Total	Human Error/Deviations from QA	Percent of Total
Stowage	51	33.3	51	36.2
Handling	39	25.5	39	27.6
Packaging	50	32.7	50	35.5
Theft/Loss	4	2.6		
Unknown	9	5.9	1.0	0.7
TOTAL	153		141	

Transport Mode	No. of Reports	Percent of Total
Air	78	51.0
Road	72	47.1
Train	2	1.3
Water	1	0.6
TOTAL	153	

4.2.2 NRC Incident Reports

Transportation incident reports for 1975 were provided by the NRC from its five regional offices. Reports pertinent to urban areas are synopsized in Appendix I. As summarized in Table 4-2, 8 of the 19 incidents contained in the NRC files which occurred in urban areas (excluding those also reported by DOT) can be attributed to human errors. As in the case of the incidents reported to the DOT, packaging, handling, and stowage account for the majority of human errors or deviations from accepted QA practices.

Additional information was obtained from the NRC for incidents reported by its agreement states for the period July 1976-July 1977. These reports are summarized in Table 4-3. Of the 23 incidents related to transportation, 7 involved human errors of the types in the other incident reports.

Table 4-2

Nuclear Regulatory Commission Regional Office Reports of Transportation-Related Radioactive Material Incidents in Urban Areas, 1975

Incident Cause	No. of Reports	Percent of Total	Human Error/ Deviations from QA	Percent of Total
Stowage	2	10.5	2	25.0
Handling	2	10.5	2	25.0
Packaging	3	15.8	3	37.5
Procedure	1	5.3	1	12.5
Theft/Loss	4	21.1	-	-
Unknown*	7	36.8	-	-
TOTAL	19		8	

*Could not be directly attributed to human error.

Table 4-3

Nuclear Regulatory Commission Agreement States Reports on Incidents Related to Urban Transportation of Radioactive Materials 1976-1977

Incident Cause	No. of Reports	Percent of Total	HumanError/ Deviations from QA	Percent of Total
Stowage	2	8.7	2	28.6
Handling	4	17.4	4	57.1
Procedure	1	4.4	1	14.3
Theft/Loss	9	39.1	-	-
Equipment Failure	1	4.4	-	-
Unknown	6	26.0	-	-
TOTAL	23		7	

.2.3 Other Data Sources

Other data sources have been investigated in order to obtain a better perspective on the types of human error and general error rates in shipping to be expected.

Studies performed in nine states plus New York City, and collated by Los Alamos Scientific Laboratories, indicate that the same procedures are usually followed at terminals for all types of shipments, including radioactive materials.[3] No special procedures, special stowage, or special loading are consistently applied to radioactive material shipments.

Additional information necessary to this analysis is actual shipment frequency by package type. The 1975 shipment data base is coupled with the incident reports for 1975 to estimate the incident rates by package type.

4.3 Estimation of Urban Incident Rates

Equation 1 requires an incident rate as a function of radioactive material shipment type. Data described in the previous sections indicate that few incidents have occurred which involved a small fraction of the hundreds of different isotopes shipped annually. Therefore, a reliable incident rate by isotope cannot be calculated directly from the data. The package type employed may be a more significant parameter affecting the occurrences of errors, since only a few package types are typically employed. Thus, the available data can be used to estimate incident rates as a function of packaging.

The incident rate per package for package Type k may be expressed as

$$E_k = \frac{\text{Total No. of incidents involving package Type k}}{\text{Total No. of packages of Type k shipped}} \quad (2a)$$

Since the incident reports do not normally indicate package type, the total number of incidents for a particular material in a given package type is estimated as follows:

$$\begin{bmatrix}\text{Incidents involving}\\ \text{isotope X in Type A}\\ \text{packages}\end{bmatrix} = \begin{vmatrix}\text{Total incidents}\\ \text{involving X}\end{vmatrix} \cdot \begin{vmatrix}\frac{\text{Total Type A packages for X}}{\text{Total packages of X}}\end{vmatrix} \quad (2b)$$

Thus the expression for E_k in Equation 2a can be replaced by

$$E_k = \frac{\sum_{j=1}^{N} B_j F_{jk}}{\sum_{j=1}^{N} n_{jk}} \quad (3)$$

where

B_j = total urban incidents per year for isotope j

F_{jk} = fraction of isotope j shipments made in Type k packages

n_{jk} = number of Type k packages of isotope j shipped per year

N = total number of isotopes in the shipment model

Note that for those materials with no reported urban incidents, the value of B = 0. However, the sum expressed in the denominator of Equation 3 equals the total number of shipments of Type k packages per year. Nonzero values for B have been obtained from the summarized urban incident reports in Appendices H and I and combined with the data from Reference 4.

Values obtained for the terms in Equation 3 are given in Table 4-4. The calculated urban incident rates are per package shipped on a nationwide annual basis. Other incident rates can be calculated using all 1975 incidents (DOT and NRC) if an evaluation of a national average and not of an urban-specific set is desired. The estimated urban incident rates by package type are as shown in Table 4-5.

The release fractions by severity and package type are summarized in Table 4-6. DOT and NRC incident reports indicated that in 71% of the cases, no measurable release to the environment occurred. For a Category 1 accident, the probability of occurrence was set at 0.71. The remaining seven probabilities of occurrence were scaled in comparison with the fractional occurrences for vehicular accidents discussed in Appendix A. The resulting set of occurrence probabilities are given in Table 4-6. Hypothetical descriptions are also provided for the severity categories used in the analysis.

4.4 Analysis of Cask Incident Rate

Data from Reference 5, Table 7.2 indicate the following information:

- Total number of cask shipments (rail and truck) — 3939
- Number of incidents which could be traced directly to a human error or deviation from accepted QA practices -- 16

A tabulation (by cause) of these human error or quality assurance incidents is given in Table 4-7.

The 16 occurrences in 3939 shipments result in an overall rate of 4.1×10^{-3} incidents per shipment. It is assumed that the maximum result of a human error is the release of all contaminated coolant water in the cask. Reference 6 provides information on the quantity of material that could be released. This information is summarized in Table 4-8.

It is recognized that inert gases and traces of tritium and iodine would also be released from the perforated rods. Using the assumptions in Reference 7, the quantity of these materials in the cask during "normal" transport is approximately 12 curies. As in the accident analysis, these materials would contribute negligibly to the overall population dose, hence they are not considered further (see Section 3.3 in Chapter 3). Additionally, the conservative assumption is made that all of the material in Table 4-8 is cobalt 60. Reference 6 indicates that for the "normal" transport situation, 90% of the activity in the coolant is cobalt (dissolved "crud" material) and 1% is cesium (leached from fuel rods). Thus, the assumption that all contamination is Co-60 is not unreasonable. The health effects coefficients (rem per µCi values -- see Appendix H) used for the "human error" cask incident are those for Co-60.

Table 4-4

Determination of Urban Incident Rates for 1975 DOT and NRC Data

Radionuclide	B_J	F_A	B_{JA}	F_L	B_{JB}	F_L	B_{JL}	F_{LSA}	B_{JLSA}	F_{LQ}	B_{JLQ}	F_{NS}	B_{JNS}
C-14	5	1.0×10^{0}	5.0×10^{0}	-	-	3.8×10^{-3}	1.9×10^{-2}	-	-	-	-	2.8×10^{-4}	1.4×10^{-3}
Cd-115m	1	1.1×10^{-1}	1.1×10^{-1}	8.9×10^{-1}	8.9×10^{-1}	-	-	-	-	-	-	-	-
Co-57	1	9.1×10^{-1}	9.1×10^{-1}	-	-	8.5×10^{-2}	8.5×10^{-2}	3.5×10^{-3}	3.5×10^{-3}	-	-	-	-
Cr-51	1	1.0×10^{0}	1.0×10^{0}	-	-	-	-	1.0×10^{-3}	1.0×10^{-3}	-	-	1.8×10^{-3}	1.8×10^{-3}
H-3	3	9.8×10^{-1}	2.9×10^{0}	1.4×10^{-2}	4.1×10^{-2}	5.9×10^{-3}	1.8×10^{-2}	1.7×10^{-3}	5.0×10^{-3}	-	-	1.9×10^{-4}	5.7×10^{-4}
I-125	2	8.5×10^{-1}	1.7×10^{0}	-	-	1.4×10^{-1}	2.9×10^{-1}	9.1×10^{-4}	1.8×10^{-3}	-	-	3.5×10^{-3}	7.0×10^{-3}
I-131	6	9.8×10^{-1}	5.9×10^{0}	1.4×10^{-3}	8.1×10^{-3}	1.2×10^{-3}	7.3×10^{-3}	2.0×10^{-5}	1.2×10^{-4}	-	-	1.9×10^{-2}	1.1×10^{-1}
Ir-192	2	1.8×10^{-1}	3.5×10^{-1}	8.1×10^{-1}	1.6×10^{0}	9.8×10^{-3}	2.0×10^{-2}	-	-	-	-	1.9×10^{-3}	3.7×10^{-3}
Mo-99	3	9.7×10^{-1}	2.9×10^{0}	2.5×10^{-2}	7.5×10^{-2}	6.0×10^{-4}	1.8×10^{-3}	-	-	-	-	-	-
Pu	2	5.1×10^{-1}	1.0×10^{0}	3.9×10^{-1}	7.8×10^{-1}	6.5×10^{-2}	1.3×10^{-1}	7.1×10^{-3}	1.4×10^{-2}	6.1×10^{-3}	1.2×10^{-2}	2.4×10^{-2}	4.7×10^{-2}
Ra-226	1	1.5×10^{-1}	1.5×10^{-1}	3.9×10^{-1}	3.9×10^{-1}	2.8×10^{-2}	2.8×10^{-2}	-	-	-	-	4.3×10^{-1}	4.3×10^{-1}
Tc-99m	2	9.9×10^{-1}	2.0×10^{0}	-	-	-	-	7.2×10^{-5}	1.4×10^{-4}	-	-	1.2×10^{-2}	2.4×10^{-2}
Th	2	6.5×10^{-1}	1.3×10^{0}	5.3×10^{-3}	1.1×10^{-2}	9.0×10^{-3}	1.8×10^{-2}	3.4×10^{-1}	6.7×10^{-1}	-	-	1.7×10^{-3}	3.4×10^{-3}
U	2	4.1×10^{-2}	8.[illegible]$\times10^{-2}$	1.1×10^{-1}	2.3×10^{-1}	1.2×10^{-2}	2.5×10^{-2}	8.3×10^{-1}	1.7×10^{0}	4.8×10^{-3}	9.6×10^{-3}	1.2×10^{-3}	2.5×10^{-3}
Xe-133	1	9.9×10^{-1}	9.9×10^{-1}	-	-	-	-	-	-	-	-	5.7×10^{-3}	5.7×10^{-3}
Fissile Mat'l	1	7.3×10^{-2}	7.3×10^{-2}	9.3×10^{-1}	9.3×10^{-1}	-	-	-	-	-	-	-	-
Nonspecified	2	9.8×10^{-1}	2.0×10^{0}	-	-	-	-	1.7×10^{-2}	3.5×10^{-2}	-	-	-	-
Waste Mat'l	3	3.8×10^{-1}	1.1×10^{0}	4.9×10^{-3}	1.5×10^{-2}	3.7×10^{-3}	1.1×10^{-2}	5.9×10^{-1}	1.8×10^{0}	5.0×10^{-4}	1.5×10^{-3}	2.1×10^{-2}	6.4×10^{-2}
$\sum_j b_{jk}$ Totals													
where $b_{jk} = b_j F_{jk}$			2.9×10^{1}		5.0×10^{0}		6.5×10^{-1}		4.2×10^{0}		2.3×10^{-2}		7.0×10^{-1}
$\sum_{j=1}^{n} n_{jk}$			1.71×10^{6}		1.04×10^{5}		4.35×10^{4}		6.24×10^{5}		3.45×10^{3}		2.21×10^{4}
Incident Rate, I_k			1.7×10^{-5}		4.8×10^{-5}		1.5×10^{-5}		6.7×10^{-6}		6.7×10^{-6}		3.2×10^{-5}

Table 4-5

Urban Area Incident Rates by Package Type

Package Type*	Urban Incident Rates (per package shipped)
A	1.7×10^{-5}
B	4.8×10^{-5}
L	1.5×10^{-5}
LSA	6.7×10^{-6}
LQ	6.7×10^{-6}
NS	3.2×10^{-5}

*L = limited (formerly exempt) shipments
LSA = low specific activity shipments
LQ = large quantity shipments
NS = package type not specified in Reference 4.

Table 4-6

Probability of Occurrence

Category	Description	F_i	Release Fractions by Package Type (RF_{ij}): A	B	LSA
1	No measurable release	0.710	0	0	0
2	No significant release	0.232	0.01	0	0.01
3	For fragile packaging--partial release of contents	0.045	0.1	0.01	0.1
4	For fragile packaging--total release of contents	0.010	1.0	0.1	1.0
5	For sturdy packaging (e.g., Type B) total release of contents	0.0018	1.0	1.0	1.0
6	↓	0.00071	1.0	1.0	1.0
7	↓	5.5×10^{-5}	1.0	1.0	1.0
8	↓	9.7×10^{-6}	1.0	1.0	1.0

Table 4-7

Summary of Causes of Cask Incidents

Cause	No. of Incidents
Impact limiters not properly installed	1
Higher external radiation readings than permitted	5
Closure bolts not properly torqued	6
Missing closure bolts	1
Closure seal leaking*	1
Vent valve not closed	2
TOTAL	16

*This was the only recorded case where a release to the environment was documented.

Table 4-8

Levels of Contamination in Cask Coolant

Transport Situation	Level of Contamination (μCi/ml)	Source of Contamination	Total Quantity[a] of Material (Ci)
"Normal"	0.1	Dissolved "crud" material and cesium leached from perforated fuel rods	0.042
"Maximum Contamination"[b]	3.0	Dissolved "crud" material and abnormal levels of cesium from additional perforated fuel rods	1.25

[a]This calculation assumes 4.18×10^5 cm^3 of coolant, characteristic of the NFS-4 or NAC-1 truck cask.

[b]This level occurred in 1 shipment out of 800.

In order to apply the METRAN model to human errors involving the special case of spent fuel casks, release fractions and fractional occurrences must be determined. Information from Table 4-7 reveals that in 94% of the incidents, no release to the environment occurred. The information from Reference 5 is used to subdivide the remaining 6.25% (1 incident out of 16) between categories of nominal release to the environment and a maximum release to the environment. This information is also summarized in Table 4-9.

Table 4-9

Fractional Occurrences and Release Fractions for Human Errors/Cask Incidents

Occurrence Categories	Description	Fractional Occurrences	Release Fractions of Co-60
A	No release to environment	0.94	0
B	Minimum release	0.06	0.034
C	Maximum release	7.8×10^{-5}	1.

For the cask exposure case, it is assumed that a human error or deviation from QA practices would not create the kinds of forces necessary to cause a circumferential crack in the cask wall (this is the assumption used in the accident release fraction determination). Thus the release fractions for all severities for cask exposure are set to zero.

4.5 Environmental Impacts of Human Errors or Deviations from Accepted QA Practices

Equation 1 contains a term $C_{i,j}$ which represents the probability per year of a human error of severity i for package Type j. Since the incident rates are only a function of package type, C_{ij} may be expressed as follows:

$$C_{ij} = F_i \cdot E_j \qquad (4)$$

where

F_i = probability of occurrence of a human error or deviation from accepted quality assurance practices of severity i

E_j = package type j incident rate

Table 4-10 summarizes the results of the application of the METRAN consequence code with the human error incident rates and occurrence probabilities replacing the similar accident-related parameters (accident rates, etc.).

Table 4-10

Package-Type Contributions to Expected Risk Values from Human Errors or Deviations from Accepted QA Practices[a]

Package Type	Time of Day:	Expected Number of Latent Cancer Fatalities per Shipment Year 1200	1630	2400
A[b]		4.1×10^{-5}	3.6×10^{-5}	5.1×10^{-6}
B[b]		2.4×10^{-5}	1.2×10^{-5}	3.9×10^{-6}
Drum[b]		1.0×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
Cask[c]		1.8×10^{-3}	1.4×10^{-3}	1.4×10^{-3}

[a]Values are presented only for expected number of latent cancer fatalities since the breakdown for expected numbers of genetic effects is quite similar with totals of 2.0×10^{-3} at 1630 hours, 2.5×10^{-3} at 1200 hours, and 2×10^{-3} at 2400 hours.

[b]Calculated using DOT HMIR data for incident rates (see Section 4.3).

[c]Calculated using data from Reference 5 (see Section 4.4).

As in the accident case, there is only a small variation between the time of day runs; thus a single set of values to estimate the radiological risk is used. Specifically, the time 1630 is chosen, with a 4-m/s south wind. For this set of data, Tables 4-11 and 4-12 present the breakdown on the basis of end use and transport mode.

Results of the analysis are expressed as total expected health effects as in the vehicular accident case. Again, the expected risk values are per shipment year; however, in this instance the most meaningful breakdown is on the basis of package type.

Major contributions to the total expected risk are from casks, Type A, and Type B packages. Examination of the economic risks from human errors or deviations from accepted QA practices reveals that the major contributors to the total of $\$2.9 \times 10^4$ are medical-use shipments (92%) and shipments in Type A packages (75%), with Type B packages contributing an additional 18%. Shipments having at least part of their transport by truck constitute 99% of the economic risk.

Table 4-11

End-Use Category Contributions to Expected Number of Latent Cancer Fatalities from Human Errors

End Use	Expected Number of Latent Cancer Fatalities
Medical[a]	1.3×10^{-5}
Industrial[a]	6.4×10^{-6}
Fuel Cycle[b]	1.4×10^{-3}
Waste[a]	1.2×10^{-8}
TOTAL	$\sim 1.4 \times 10^{-3}$

[a] Calculated using DOT HMIR data for incident rates (see Section 4.3).

[b] Calculated using DOT HMIR data from Reference 5 (see Section 4.4).

Table 4-12

Transport-Mode Contributions to Expected Number of Latent Cancer Fatalities from Human Errors

Transport Mode	Expected Number of Latent Cancer Fatalities
Truck[a]	1.4×10^{-3}
Air[b]	3.5×10^{-8}
Air and truck[b]	7.7×10^{-6}
Barge[b]	2.7×10^{-7}

[a] Calculated using DOT HMIR data for incident rates (see Section 4.3).

[b] Calculated using data from Reference 5 (see Section 4.4).

4.6 Summary

Contributions to total expected radiological risk from human errors has been evaluated using urban incident rates by package type. Expected health effects are $\sim 1.4 \times 10^{-3}$ latent cancer fatality and $\sim 2 \times 10^{-[illegible]}$ genetic effect. These results a-- obtained using the accident consequence portion of METRAN and represent a servative estimate of the effects of human errors, since it is assumed that the error results in release and dispersal of materials in a manner similar to a vehicular accident, i.e., release fractions and aerosol fractions are assumed in most cases to be the same as in the accident analysis. In reality, the aerosol fractions (and possibly release fractions) would probably be smaller than estimated, but in the absence of better data, the conservative assumptions have been utilized. As mentioned earlier, human errors resulting in accidents are not included in this analysis. Although there are possible synergisms that would connect the human error with a vehicular accident, the two were considered separable for this treatment. The results should be interpreted carefully since the source of the initial data for the determination of incident rates were vastly different.

NOTES

[1]49CFR171.15.

[2]10CFR71.61.

[3]U.S. Nuclear Regulatory Commission, Summary Report of the State Surveillance Program on the Transportation of Radioactive Materials, NUREG-0393, Washington: NRC, March 1978.

[4]BNWL-1972.

[5]Battelle Pacific Northwest Laboratories, An Assessment of the Risk of Transporting Spent Nuclear Fuel By Truck, PNL-2588, Richland, WA: PNL, November 1978.

[6]Personal communication from K. Eger, General Electric, Morris, Illinois, 25 June 1979.

[7]WASH-1238.

Appendix B:

Chapter 7,

PNL-2588

PNL-2588

UC-71

An Assessment of the Risk of Transporting Spent Nuclear Fuel by Truck

November 1978

Prepared for the U.S. Department of Energy
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Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-2588

7.0 CONDITIONS OF SPENT FUEL CASK DURING TRANSPORT

To perform a detailed risk analysis of spent fuel transport, it was necessary to determine the package condition during normal transport. A survey was conducted of companies and government laboratories which have received spent fuel for storage or processing. The survey was performed to obtain a data bank of conditions of the cask during transport for use in the risk analysis. The results of this survey are presented in this section.

7.1 SCOPE OF SURVEY

The initial step in developing the survey was to determine the information which was needed for the data bank. Determination of the package condition information required was carried out simultaneously with development of the release sequence evaluation fault trees shown in Section 8.

The analysis traced the steps of package loading and closure and the normal transport environment to identify all conditions that could affect package containment integrity. Based on the information identified in the analysis, questionnaires were prepared for use in the survey of the nuclear industry. The survey covers the time period from 1970 to 1977 with most of the available data in the period 1973 to 1976.

7.1.1 Packages Included in Survey

The purpose of this survey was to provide the broadest possible data base to evaluate packaging conditions during transport. Thus a broad class of spent fuel shipping casks were covered in the survey including both truck and rail casks. Most commercial spent fuel casks will accept either PWR or BWR spent fuel by using different fuel baskets, however, some are designed only for a particular type of fuel. Table 7.1 gives information about commercial shipping casks that are currently licensed and available for LWR spent fuel shipments in the United States.

TABLE 7.1. Licensed and Available Shipping Casks for Current Generation LWR Spent Fuel

Cask Designation	Number of Assemblies PWR	Number of Assemblies BWR	Approximate Loaded Cask Weight, MT	Usual Transport Mode	Shielding Gamma	Shielding Neutron	Cavity Coolant	Maximum Heat Removal kW	Status
NFS-4 (NAC-1)	1	2	23	Truck	Lead and steel	Borated water antifreeze	Water	11.5	6 casks available
NFS-5	2	3	25	Truck	Uranium and steel	Borated water and antifreeze	Water	24.7	SAR submitted
NLI 1/2	1	2	22	Truck	Lead, uranium and steel	Water	Helium	10.6	5 casks available
TN-8	3		36	Truck[a]	Lead and steel	Borated solid resin	Air	35.5	Licensed
TN-9		7	36	Truck[a]	Lead and steel	Borated solid resin	Air	24.5	Licensed
IF-300	7	18	63	Rail[b]	Uranium and steel	Water and antifreeze	Water	76[c]	4 casks available
NLI 10/24	10	24	88	Rail	Lead and steel	Water	Helium	97[d]	2 casks available

(a) Overweight permit required.
(b) Truck shipment for short distances with overweight permit.
(c) Licensed decay heat load is 62 kW.
(d) Licensed decay heat load is 70 kW.

Since the number of commercial cask shipments that have occurred in the United States has been limited, the survey included other noncommercial casks that have been used to ship spent reactor fuel. The material shipped in these casks were similar to commercial fuel. The type of packaging and handling of the casks were also similar. The results presented in this study include the entire survey, both commercial and noncommercial fuel shipments. When differences occurred in the data, if possible, that data relating to commercial fuel was relied on more heavily than the noncommercial fuel. By including as much data as possible, a broader data base for the survey could be obtained.

Specific commercial spent fuel containers covered in the survey are: NFS-4, NLI 1/2, IF-100, and IF-200 truck casks and the IF-300 rail cask. The survey includes noncommercial casks used by government laboratories and the Naval reactors program.

7.1.2 Sites Included in Survey

The companies and laboratories asked to participate in the survey included:

General Electric Company
Morris Operation
Morris, Illinois

Allied Chemical Corporation
Idaho Chemical Programs
Operation Office
Idaho Falls, Idaho

U.S. Energy Research and
Development Administration
Pittsburgh Naval Reactors Office
West Mifflin, Pennsylvania

Nuclear Fuel Services, Inc.
West Valley, New York

E. I. duPont de Nemours
Savannah River Laboratory
Aiken, South Carolina

7.2 RESULTS OF SURVEY

A copy of the questionnaire with overall results of the survey is shown in Table 7.2. The total number of shipments covered in the survey from 1970-77 is 3,795 shipments. This includes 3,581 truck and 214 rail shipments. It should be emphasized that in the experience sampled by the survey, a complete loss of packaging integrity of a spent fuel cask has never been observed.

There have been several accidents involving spent fuel casks; however, no radioactive material has been released in these accidents.[1, 2] The survey does not include data on any casks that were involved in accidents. Supplementary information obtained from the survey respondents used in the analysis is provided in the comments section of Table 7.2.

Even though the information obtained in the survey provides a reasonably good base for the risk assessment model, certain limitations should be recognized. First, for the most part, the observations were made by personal recollections. Consequently, the time period of the observations were not entirely certain. Secondly, in the years since 1971, Quality Assurance (QA) and Quality Control (QC) requirements have been strengthened by the NRC resulting in a significant reduction in packaging errors. Considering these factors, the results presented in Table 7.2 are believed to represent the best available data on present day spent fuel handling and packaging conditions.

TABLE 7.2. Spent Fuel Cask Shipping Survey Results

	Total No. of Truck and Rail Shipments	Truck Casks	Rail Casks
A. Shipments of Spent Fuel Received			
1977	399	384	15
1976	532	482	50
1975	613	594	19
1974	453	429	24
1973	541	522	19
1972	489	470	19
1971	371	350	21
1970	397	350	47
Pre-1970 (If Available)	144	0	144
Total 1970-77	3,795	3,581	214
Total	3,939	3,581	358

	Truck and Rail Shipments	Truck Casks	Rail Casks
B. General Condition of Shipments (1970 - 1977)			
1. What was the maximum cask internal pressure on arrival?	0-35 psig (1)	18 psig	35 psig
2. Number of casks received with coolant pressure above normal operating range	0	0	0
3. Number of casks designed with impact limiters received with impact limiters not installed.	0	0	0
4. Number of casks designed with impact limiters received with impact limiters not installed correctly	1 of 536 (2)	1 of 536 (2)	0
5. Number of casks received with cask hold-down broken or failed during shipment	9 (3)	9 (3)	0
6. Number of casks received with cask hold-down not safety wired at time of shipment	0	0	0
7. Number of casks received with low fuel cooling water level (not shipped dry)	0	0	0
8. Number of licensed "dry" shipments of spent fuel casks	98	55	43
9. Number of casks received with low neutron shield water levels (casks which have neutron shield water).	0	0	0
10. Number of casks containing spent fuel subjected to freezing with damage caused by freezing.	0	0	0
11. Number of casks received with higher external radiation readings than permitted on shipment release survey	5	5	0
12. Number of casks received with shipping damage incurred in route. (Note damage which was incurred in comments section.)	0	0	0
13. Number of casks dropped during handling procedure. (Note details of any damage in comments section.)	0	0	0

(1) If accurate numbers are not available, approximate values or estimates based on best recollections can be used and are requested. If you have any questions about completing this form, please contact H. K. Elder, Battelle-Northwest, Richland, Washington 99352 (509) 946-3530 FTS 444-7411 (Ext. 946-3638)

(2) Please identify any casks listed here in the comments section

TABLE 7.2. (contd)

	Truck and Rail Shipments	Truck Casks	Rail Casks
C. Cask Lid Condition			
1. Number of casks received with closure bolts not properly torqued (overtorqued/undertorqued)	6[4]	6[4]	0
2. Number of casks received with missing closure bolts	1	1	0
a. Number of closure bolts missing	1[5]	1[5]	0
3. Number of casks received with closure bolts damaged in transit	0	0	0
D. Closure Seal Condition			
1. Number of casks received with closure seal damaged in transit	0	0	0
2. Number of casks received with closure seal not installed properly	0	0	0
3. Number of casks received with incorrect closure seal installed	0	0	0
4. Number of casks received with closure seal leaking	1	1	0
E. Cavity Penetration Conditions			
1. Number of casks received requiring defective drain valve replacement	2[6]	2[6]	0
2. Number of casks received requiring defective vent valve replacement	2[7]	2[7]	0
3. Number of casks received requiring defective pressure relief device replacement	7[8]	1[8]	6[8]
4. Number of casks received with drain valve not closed.	0	0	0
5. Number of casks received with vent valve not closed	2	2	0
6. Number of casks received with drain valve not installed properly	0	0	0
8. Number of casks received with pressure relief device not installed properly	0	0	0
9. Number of casks received with cavity penetration damaged during transit (Note details of damage in comments section.)	0	0	0
10. Number of casks received with drain valve requiring replacement due to wear	10	10	0
11. Number of casks received with vent valve requiring replacement due to wear	5	5	0

(Additional information or details on survey are shown below.)

Comments:

(1) Pressure in casks ranged from 0 to 35 psig.

(2) 1 of 536 truck casks designed with impact limiters was received with impact limiter not installed correctly.

(3) 9 truck cask shipments had loosened tiedowns on shipment arrival. No failures of tiedowns occurred.

(4) 6 truck cask shipments had bolts which were undertorqued.

(5) Cask with bolts missing had 6 bolts total on the cask.

(6) 2 drain valves were replaced due to leakage which occurred when testing before shipment.

(7) 2 vent valves were found defective after pressure testing before shipment and were replaced.

(8) 1 truck cask pressure relief valve replaced after testing; 6 rail cask pressure relief valves replaced due to defect with relief mechanism.

REFERENCES

1. J. W. Langhaar, "Transport Experience with Radioactive Materials," Proceedings of the International Symposium on the Management of Wastes from the LWR Fuel Cycle, CONF-76-0701, Denver, Co, July 1976.

2. A. E. Grella, "A Review of Five Years Accident Experience in the U.S. Involving Nuclear Transportation (1971-1975)." International Symposium on the Design, Construction and Testing of Packaging for the Safe Transport of Radioactive Materials, IAEA-SR-10, Vienna, Austria, August 1976.

Appendix C

Background to the Environmental

Assessment Worst Case

Transportation Analysis

ATTACHMENT ONE

Background to Environmental Assessment Worst Case Transportation Analysis

The Environmental Assessments analyses of the consequences of a "very severe" transportation accident to an individual (p. A-21) and to a large population (p. A-23) both rely on Sandquist, et al., Exposures and Health Effects From Spent Fuel Transportation (1985). Sandquist's study for its most essential terms, that is, the basis from which it estimates radioactive releases from casks in accidents of varying severity, relies on Wilmot, Transportation Accident Scenarios for Commercial Spent Fuel (1981), hereinafter Wilmot, Scenarios. Wilmot's 1981 report in turn relies on descriptions of what kinds of releases for what kinds of accidents were "credible" to a group of "blue ribbon" experts -- 21 government and industry experts and 13 Sandia Laboratory employees who participated in a workshop sponsored by Sandia and summarized by Wilmot in Report on A Workshop on Transportation Accident Scenarios Involving Spent Fuel, May 6-8, 1980. (1981), hereinafter Wilmot, Workshop.

One objective of the 1980 Workshop was to "decide on a consensus scenario to be used as a reference for environmental impact statements." (Wilmot, Workshop, p. 1). Although the group rejected the idea that a single worst case scenario would be adequate, it did reach agreement on the following points:

1. A credible accident might be more severe than that described by the NCR's performance standards. Specifically, the experts proposed standards for a longer and hotter fire, replacing the NRC's 30 minute, 800 degree C. fire with a two hour fire at 1000 degrees C. (Wilmot, Workshop, p. 4).

2. The points at which casks fail and radioactive materials are released into the environment "are generally not known" and "are very dependent on cask design" (Wilmot, Scenarios, p. 19 and Wilmot, Workshop, pp. 10-11). Therefore, differently designed casks, all of which passed the NRC's "performance standards" test might fail and release radiation to the environment under different accident conditions.

3. A breach larger than one square inch in a cask of any design was considered not credible, regardless of the impact geometries or flame temperatures of an accident. (Wilmot, Workshop, pp. 1, 4, 10).

4. The Workshop report makes this comment on human error:

   Other pathways [from the cask cavity to the environment] exist and were suggested, but were not considered in detail. These might include human error (e.g., incorrectly torquing head bolts) and sabotage. (Human error has been considered in detail in the Urban Study as had sabotage). [Reference to Finley et al., Transportation of Radionuclides in Urban Environs: Draft EA, NUREG/CR-0743 (1980)]

This point and reference are repeated in Wilmot, Scenarios, p. 13.

The "Comment Response Document", Appendix C of Volume II of the Environmental Assessments makes this comment on human error in the EA transportation analysis:

C.2.4.1.23 Potential for human error

Issue

Some commenters stated that the potential for human error in the transportation of radioactive waste is not treated adequately in Appendix A.

Response

The DOE has considered the potential for human error in the assessment of transportation risks. A study prepared for the Nuclear Regulatory Commission (NRC, 1980) [NUREG/CR-0743] analyzed detail incidents of human error and deviations from accepted QA practices are extremely small (i.e., 0.00012 latent-cancer fatality per shipment-year for packages tested to accident conditions), and thus it is not meaningful to include these risks in the radiological risk analysis for transportation.

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