DRAFT REVIEW OF REPORT

"Shipping Container Response to Severe Highway and Railway Accident Conditions"

Report Prepared by

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I. INTRODUCTION

The report "Shipping Container Response to Severe Highway and Railway Accident Conditions" by L. E. Fischer et al, Lawrence Livermore National Laboratories, has been reviewed from three aspects:

1. Approach: review of the basic premises on which the report is based; assumptions made in the course of the work; sources and quality of input data.

2. Execution: review of technical procedures and results.

3. Presentation: organization and readability; review of the report as a document whose function is to transmit information important both from the standpoint of regulatory needs and public interest.

The "bottom line" of the review is to answer the question: does the work as reported support the stated conclusions?

II. PEER REVIEW APPROACH

The review team at DRI consists of Myron Plooster, principal reviewer; James Butz, research engineer, and John Gilmore, research economist. It is with profound sadness that we report the death of John Gilmore on August 15, 1986. He had transmitted his comments for the review on the day preceding his death.

Each member of this review team has read the entire report several times for an assessment of its overall content, consistency, and readability, and for specific technical comments. Gilmore reviewed the accident data base and the public policy aspects, Butz the structural analysis and radiological hazards, and Plooster the thermal and probability analyses. In addition, a team at the Los Alamos National Laboratory has been engaged to review the use of the computer codes for structural response in this work, because of their extensive experience with the codes used by LLNL in this study, and because of the large proportion of the work which depends on the use of these codes. The Los Alamos report is expected momentarily, but is not in hand at the time of this writing.

This draft peer review report includes the work done at DRI to date. The attached copy of the LLNL report, with many corrections and comments throughout the text, is an integral part of the review. There are many more comments on the pages of the report itself than in this written review; this written review addresses only the major questions and problem areas.

III. CAPSULE REVIEW

In brief, the conclusions of the review effort are:

1. From a technical standpoint, the report is basically sound. No flaws have been found which cast any significant doubt on the major conclusions.

2. There is an apparent anomaly in the frequency distribution of thermal damage to truck casks. This anomaly may be due to a computational error, but even if it is, it should have little effect on the total estimated risk.

3. There are some questions about overall approach and the selection of accident data base, but these are more a matter of subjective judgment than of serious flaws.

4. The draft report is difficult to read, for several reasons:

   a) The order of presentation of the main topics is poorly chosen. There are too many implicit forward references - places where the reader is expected to be familiar with material that is defined or discussed later in the text.

b) There is an inordinate number of typographical errors in the text and, unfortunately, in numerical data.

c) There are numerous places where the text is obscure and difficult to follow.

d) In general, the annotation of tables and figures is inadequate.

Each of these points will be discussed in the following. An annotated copy of the draft report accompanies this draft review.

IV. DETAILED REVIEW

A. General Approach

1. The general methodology of the risk assessment approach is followed, using the same procedures as previous studies in this area, such as the 1976 Sandia report, "Severities of Transportation Accidents," and the 1977 Environmental Impact Statement, NUREG-0170. The results are thus directly comparable with previous work, which is an advantage.

2. The LLNL group used an analytical (instead of experimental) approach to the structural and thermal response of shipping casks to accident conditions. Given the analytical and computational capabilities available at LLNL, this choice is reasonable. An experimental study of equal scope would undoubtedly have cost much more. The analytical approach has the disadvantage that the reader cannot follow the detailed path between input and output, because of the number of complex computations connecting any input datum with the final results. This approach requires an implicit trust, on the part of the reader, in the quality of all of the computer programs used. Having said all this, some definitive

experiments, or reference to such experiments, would greatly enhance the credibility of the work.

3. The LLNL group consistently used a conservative (i. e., pessimistic) approach: whenever there was uncertainty as to whether an event would impair shipping cask performance, it was assumed that such impairment did occur. This is a reasonable approach, since a conservative estimate of risk is desirable. In this report, the conservative approach was used in lieu of any sensitivity analysis (i. e., an analysis of the effects of uncertainties in input data on the final assessment of risk). Some estimate of the sensitivity of results to changes in assumptions or input data would have been desirable.

B. Assumptions and Input Data

1. Representative cask selection. Question: does the choice of a single representative cask design, based on the use of lead as the gamma shield, in any way bias the analysis in such a way that some vulnerable feature of other cask designs is overlooked? No concrete example comes to mind. However, one wonders whether the choice of the lead cask, in itself, resulted in an analytical approach that emphasized the shortcomings of that design. Some current literature suggests that lead casks are on the way out. If this is so, then most of the work in this report will be obsolete when the next generation of shipping casks hits the rail/road. This is not a serious concern of ours; we just feel that more discussion of failure modes of the other cask designs would have been of use to the reader and for future reference.

2. API accident data. We question the use of the data from the American Petroleum Institute on overall accident rate per truck mile for this study. Telephone discussion with API staff indicate that their inputs are what member companies choose to report, and include no accident characteristics or details. The Office of

Technology Assessment, in their report, "Transportation of hazardous materials" (OTA-SET-304), July 1986), reports that the average trip length of a gasoline tanker is 28 miles. These data thus appear neither adequate nor applicable to the anticipated over-the-road haulage of nuclear wastes. There is thus no real justification for using them for this study. The fact that they give a "conservative estimate" is irrelevant.

3. <u>Highway environment data.</u> The section of Interstate 5 used to characterize bridge/overpass distributions and bridge heights and obstructions is dominated by the urban areas of Orange and Los Angeles counties. It is very unlikely that the many miles of the U. S. Interstate system that will be used for spent nuclear reactor fuel transportation are adequately represented by this one highway segment. There is the implicit assumption here that the United States as a whole looks pretty much like California. We question this assumption, to put it mildly. Similar comments can be made about the use of a single stretch of I-80 in California for roadside soil/rock distributions. These data can be used if the only goal is to get a conservative estimate. A more representative data set (i. e., one derived from a larger data base) would have given the report more credibility.

4. <u>Severe accident scenarios.</u> With two exceptions, cask impact studies assumed that casks always impact a flat surface. The exceptions were impacts by a steel I-beam and a locomotive train sill. We question whether another class of impacts should have been considered: the sideways impact of a truck cask with a massive structure, such as a concrete column or bridge abutment, whose lateral dimension is appreciably smaller than the length of the cask. Here, the impact force would be concentrated on only the central portion of the cask, and the ends of the cask could "wrap around" the structure. In such an impact, bending stresses severe enough to cause tensile failure and rupture of the cask might be achieved. Although the probability of column/abutment

impacts is small in comparison with other accident scenarios, this could be an example of a plausible accident with the potential for a major radiological hazard. If such scenarios were considered, they were not mentioned in the report.

C. Technical Procedures and Results

1. Accident characterization. Aside from the comments in IV.B.2-3, the determination of the probability vs. severity of truck and train accidents appears to be thoroughly and carefully carried out. The inhomogeneity and incompleteness of accident data bases makes this the greatest source of uncertainty in this study, in our opinion. The most severe accidents, the only ones with the potential for serious risk to the public, are out in the "tails" of the probability distributions, where statistical uncertainties are greatest. It is for this reason that we feel that some sensitivity analysis would have been highly desirable.

2. Representative cask selection. Beyond the questions already expressed in IV.B.1, the selection of representative casks is carried out in a reasonable manner. The description of the cask selection process is badly scrambled in the report, a point which will be discussed in IV.E.2.

3. Cask response state definition. The selection of response variables and the significant levels for categorization of the severity of cask response to structural and thermal loads is well thought out and executed.

4. Structural response analysis. This portion of the work has been reviewed both by DRI and a group at the Los Alamos National Laboratory. The Los Alamos review is concerned especially with the use of the finite-element codes DYNA and NIKE, since they have extensive experience with these codes. The Los Alamos review document will be separately attached to the review. DRI also

reviewed the structural response analysis, since it forms an essential part of the entire study. The remaining comments here were raised during the DRI review effort.

Tables 6.3 and 6.5 indicate that water is harder than rock, in that the S1 strain response level is reached at lower impact velocities on water than soil or rock. We realize that different analytical methods were used for water impacts. In any case, however, this result appears ridiculous, even if it does result in a "conservative estimate."

There are conflicting data in the tables and text of Appendix E concerning the static load at which the inner shell of the rail cask undergoes plastic yield. Section E.5 notes that the minimum static force to yield either cask (rail or truck) was 1.6 million lb, while earlier in Table E.5 the rail cask was listed as having a yield force of 260,000 lb in a sidewise orientation. This discrepancy should be eliminated or explained. This may be a simple misprint problem, but it is not clear that it is.

Beyond these comments, the structural response analysis appears to be competently and carefully carried out.

5. Thermal response analysis. The approach and execution of the thermal response analysis appears to be basically sound. The use of a one-dimensional heat transfer model for a cask engulfed by a fire, with radiative heat transfer as the primary heat transfer mode, gives a suitably conservative estimate of the time required for the contents of a cask to reach the defined response levels. We have constructed a very simple one-dimensional model analogous to that used by LLNL, using independent sources for engineering heat transfer equations and thermal properties of materials. With this model, which is simple enough to run on a desktop computer, heat transfer rates and response times essentially the same as those in the report were obtained. For example, for the

regulatory 1475F engulfing fire, the time taken to reach the T2 response level (600F at the midpoint of the lead gamma shield) was 1.41 hours for our model and 1.35 hours for the LLNL model. The extent of the agreement between the two models essentially confirms the validity of the thermal analysis approach used in the report. Several other runs were made with our model to test some of the other assumptions made by LLNL; in every case, the results in the report were supported.

6. <u>Probability analysis.</u> The approach and methodology used for the probability analysis appear to be sound. This is the crucial portion of the work where all the individual factors (accident probabilities, structural and thermal response functions, and distribution functions for impact velocities, cask and impact orientations, fire durations and temperatures, etc.) are brought together to determine the fraction of accidents occurring at each combination of structural and thermal response levels. This is a completely computational process with many inputs, not all of which are given in quantitative form in the report. Thus it is not possible to verify any of its outputs independently; one has only subjective judgment to rely upon in evaluating the results.

With one exception, the results of the probability analysis appear reasonable. The exception is found in the truck cask response matrix, and specifically in the R(1,2), R(2,2), and R(3,2) entries. These entries give the conditional probability, given an accident, that the temperature at the mid-point of the lead gamma shield reaches a maximum temperature between 500 and 600F, and simultaneously that the maximum strain in the inner stainless steel wall of the cask falls in one of the first three response states (i. e., the maximum strain is less than 30%). These probabilities appear too small, in comparison with the next two columns of the matrix. The entries in question indicate that the probability that the maximum cask temperature is between 500 to 600F is less than the probability of reaching either of the next two thermal levels (600 to 650F, or 650 to 1040F). Nothing in the data presented on the distributions of fire temperature, duration, or location, or on the relative times taken for the cask to reach any of these temperature levels, supports this unusual probability distribution. Moreover, the response of the rail cask shows no indication whatever of this behavior. We wonder if these seemingly anomalous low probabilities are due to an error in the computational procedures. We have contacted the LLNL team about this problem, and they are checking it out. It should be emphasized that the probabilities in question are small numbers, and even if adjusted to what we expect as "reasonable," they will result in only very small adjustments to the other values in the response matrix.

The underlying problem we see, applicable to any such computation-intensive analysis, is that if this problem is due to an error in the computer program, there is a non-zero probability that the program contains other errors as well.

7. Results and conclusions. This is the "bottom line" of the report and of this review. We find that the results and conclusions are presented in a straight-forward manner, and that they are supported by the approach and technical procedures employed.

D. Report Quality and Readibility

1. Overview. The quality of the technical effort described in this report is high. The quality of the report itself, as a document which is intended to be read and understood, is low. The problems are poor organization, uneven quality of writing, inadequate captions on tables and figures, and far too many typographical errors. These four categories of problem areas will be discussed in order, followed by some elaboration of the more important specific instances of problems.

To state the readability problem in a nutshell, the reader has two choices when encountering the report for the first time:

a) He can read the report straight through once, and stop there. He will have to skim over many parts, because of the forward references. However, at the end he will have a good general idea of the approach taken and the main conclusions.

b) He can delve deeper into the report, to try to understand the technical details. He will then become thoroughly frustrated by its labyrinthine order of presentation and many errors. The more closely one reads this report, the harder it is to follow.

2. Organization of report. The most serious problem with the report, from a readability standpoint, is the order in which the major subjects are presented. We are not referring here to material presented in the appendices, but only to the order of presentation in the nine main sections of the report proper. There are far too many "forward references:" references to material that is presented in a later section of the report. Worse, in too many places, such references are needed but missing; the reader is left on his own to find where to go for information.

The two most serious organizational problems are: a) the discussion of the structural and thermal response of the casks to accident conditions is fragmented, part of each being presented in each of the two chapters on first- and second-stage screening; and b) the probability analysis, which ties all the analyses together, is presented after the presentation of the two stages of screening. Figure 1-2, on page 1-9, purports to show how the report is organized. The actual organization does not follow the scheme shown on the figure.

A better order of presentation, which would have averted the need for many of the forward references, would have been:

Section 1.0. Introduction. The introductory section of the report is well written, for the most part, as it now stands.

Section 2.0. Accident Rates, Scenarios, and Loading Distributions. The discussion of accident characteristics and distributions can be carried out almost independently of the remainder of the technical discussion, and thus should be presented before the discussion of casks and their responses.

Section 3.0. Representative Cask Selection. A major point of confusion in the report, which is discussed in more detail later, is that there were two different definitions of a representative rail cask. Otherwise, this section is reasonably well presented.

Section 4.0. Cask Response States, Levels, and Regions. This section is very important for understanding of the remainder of the report, and it is presented quite clearly.

Section 5.0. Radiological Consequences of Cask Response States. The discussion of radiological consequences is fairly well presented, as far as it goes. For the general reader, we feel that there is a real need for more discussion of the relationship of the relative seriousness of the four different types of radiation hazards. This is discussed in more detail below.

Section 6.0. Structural Response Analysis. The structural response analysis should all be described in one coherent section. The fact that linear small-deformation analytical methods could be used for the first screening, while non-linear large-deformation methods were needed for the second screening, does not provide an adequate justification for splitting the discussion between two chapters. The output of the structural analysis process was a set of continuous curves of force, lead slump, and strain, which were then used as inputs to the probability analysis. Splitting this section of the work up makes it very difficult to follow the arguments leading to the final analysis. This is a major shortcoming of the report in its present form. It will be very difficult for a general reader, especially one who has neither the technical background nor the time that we have been able to spend in the review process, to follow the reasoning that leads to the final results.

Section 7.0. Thermal Response Analysis. The same comments apply here as in the preceding section. Here there is even less justification for splitting the discussion between two sections. A single analytical procedure was used to obtain all of the response distributions to thermal loads.

Section 8.0. Probability Analysis. This is the section that ties all the preceding work together. It definitely must be presented before the two-stage screening analysis, since it defines the distribution of accidents among the various response states. The first two figures in this section in the report as it now stands are essential to an understanding of the actual process by which the structural and thermal analyses were used to relate accident conditions, in terms of impact velocities, cask orientations, etc., to cask response states and radiological hazards. All of the preceding discussion should have been pointed toward showing how the various analytical methods were used to construct these families of curves. This is our most important criticism of this report. Without a clear picture of the goal of all the preceding work, one must continually go back and forth between sections in order to make coherent sense of the process. It would also have been extremely helpful to show a complete set of curves of this type for both the truck and train casks.

Section 9.0. <u>First-Stage Screening.</u> <u>Now</u> is the time to present the results of the first-stage screening analysis. The results of this process fall out of the probability analysis in a very natural way, and could be presented concisely and clearly.

Section 10.0. <u>Second-Stage Screening Analysis.</u> Ditto for the second-stage screening.

Section 11.0. <u>Results and Conclusions.</u>

3. <u>Unclear writing.</u> There were numerous places in which the meaning of the text was unclear, or where blocks of text just plain didn't say anything. In a report of this size, it is understandable that the flow of words must have seemed endless to the writers, and that the goal finally became one of just getting it over with. Fuzzy or superfluous passages have in most cases been marked or corrected in the report copy being sent back along with this review.

One particular example of unclear notation is the use of the "E" notation to denote multiplication by a power of ten (e. g., 1.1E-4=0.00011). This notation is ubiquitous in computer output. It is not generally used or accepted in published papers or reports except for verbatim reproductions of computer output. People not conversant with computer usage will be confused or mystified by this notation. It should be used only sparingly in this report, if at all, and its meaning should be explained in a footnote whenever it is used. It should <u>not</u> be used in a table column heading or the axis label on a figure to denote the numerical factor by which the displayed data are to be multiplied (as is done, for example, in the figures showing the relative probabilities of accident scenarios, Figs. 3-2, 3-3, and 3-4).

On the subject of obscure writing, Appendix G, "Probability Estimation Techniques," is exceptional: it is unintelligible.

Everyone who reviewed the report concurred in this assessment. This appendix is addressed to someone who is already a specialist in the field, and uses as few words as possible. This style is out of keeping with the rest of the report. It is not appropriate for a report which will be read by people with a wide diversity of backgrounds. Some readers would be able to follow and benefit from this section if there were just a small attempt to explain why this approach was taken and how it works. When the terse text is combined with numerous misprints in equations, the result is a total loss for the reader. This appendix should either be fixed or scrapped.

4. <u>Annotation of tables and figures.</u> In any refereed technical publication, it is a general requirement that tables and figures should be self-explanatory. Their captions and other annotation should allow the reader to extract the essential information therefrom without having to refer back to the text. Figures and tables in this report are almost uniformly substandard in their annotation. In addition, many contain erroneous captions, or do not display the information that is promised in their captions or the accompanying text. Again, we have noted such problems in the accompanying copy of the report.

5. <u>Typographical errors.</u> The draft report was not adequately proofed. There are simply too many typos. Many errors in the text were relatively easy to identify; errors in numerical data, whether in the text or in tables and figures, have required more effort. In many cases, numerical errors were found by direct calculation, where adequate source data was available, or by using other information; for example, that the sum of the entries in a table of probabilities must add up to 1. We have found numerous errors by checking tables in this way. Unfortunately, there are many other places where we do not have enough information to verify numerical data. The report needs a very thorough proof-reading before it is ready for publication. Typographical errors are

identified or corrected in the copy of the report accompanying this review.

E. Discussion of Specific Problems.

There are numerous items in the report which merit separate comment, whether for their technical content or their impact on the readability of the report. The order in which these items are discussed in the following is not related to their relative importance.

1. Discussion of radiological hazards. The introduction discusses, in passing, allowable dosage rates for radiation shielding. Further references to radiation effects throughout the report discuss radiation in curies (equivalent quantity of radioactive material) rather than rems or rads (dosage units). This is confusing at best and deceptive at worst, in that the biological effects are proportional to exposure levels, not quantities of radioactive material. The clarity of the report would be greatly enhanced if the four categories of radioactive releases defined in Section 5.0 (Figs. 5-7 and 5-8) were described in terms of dosages and severity of exposure. As an absolute minimum, the relative seriousness of the radiation hazards of these four categories should be described. As it is, there is no really clear discussion of the fact that the releases of krypton-85, although generally largest in terms of the number of curies, present less of a health hazard than vapors or particulates. Without such a discussion, a reader not familiar with the details of radiation hazards could be unduly alarmed by the size of these numbers.

   As an example of the frustration and clumsiness of using the curie units, a discussion is presented in Section 9.0, Results and Conclusions, in which the results of this study are compared to those of NUREG-0170. There is a problem in making the comparison since the LLNL study included particulates as a release category, and NUREG-0170 did not. This is addressed by including a "fudge factor" that "adjusts" the value for particulate materials to account for its much more serious health effect on a per curie basis. The discussion goes on to note that the more serious consequence of particulate radioactive releases is mitigated by the much smaller quantities (in curies) of particles released in comparison with vapors. The vapors and "adjusted" particulate quantities are then combined and compared favorably, several paragraphs later, with the vapor release levels predicted in NUREG-0170. Wouldn't it be simpler, more useful, and certainly more informative to express release levels in units that directly relate the radiation exposure levels to the consequent threat to human health?

NUREG-0170 goes into considerable detail to explain the nature of exposure to radioactivity, as well as the standard units of measure for exposure. A strong recommendation is to include a similar (although condensed) discussion in this report.

2. "Representative" cask definition. It was found that there were actually two different sets of rail cask dimensions labelled as "representative." One was used for the preliminary analysis of cask response to static loads, in the process of determining which gamma shield material to use; the second was used for dynamic analysis and determination of structural and thermal response levels. This switch from one design to the other was not discussed explicitly in the text, and it was only through following a perceived discrepancy in the dimensions of the rail cask that the implied existence of different designs was discovered. In the accompanying report copy, we have changed the wording so the the first (static analysis) cask designs are labelled as "preliminary" designs, to distinguish them from the "representative" designs used for the bulk of the analyses. This, however, is probably still not enough to ensure clarity; the text at the outset should state clearly that two sets of cask dimensions were used, and tell when, where, and why the change was

made. The confusion on this point is equally as great in Appendix E as in Section 2.0.

3. Accident probabilities. The accident probability data charts (Figs. 3-2, 3-3, and 3-4) suffer from two problems. First, there are numerous errors in the probability values, which are corrected in the accompanying report copy. Second, there are errors in the probabiity column headings. Both for the truck accident chart (Figs. 3-2 and 3-3) and rail chart (Fig. 3-4), the units for the probabilities (second column from the right) are given as "E-3." This is confusing in its own right; the "E" notation should not be used in this way. More seriously, the rail cask probabilities are not in these units; they are given in percent (or "E-2"). It is strongly recommended that both charts use percent, and that they label the units as "percent" and not as "E-2."

4. Train sill data presentation. We believe that there is an inconsistency in the data presented in Tables 6.3, 6.5, 7.1, and 7.2. These tables give the impact velocities required to reach a given strain response level, for both truck and rail casks, as a function of the surface or object being impacted and of the cask orientation at impact. The inconsistency concerns the train sill impact orientation. For all of the other entries in the table, the orientation angle is the angle between the axis of the cask and the surface being impacted. We suspect that this is not the geometry associated with the train sill impact data. Train sill impacts are discussed only in Appendix E. Train sill impacts there all appear to be side-on, that is, the longitudinal axis of the train sill is perpendicular to the cask axis. In a 0-degree impact, the train sill strikes the cask "dead-center," with sill and cask axes in the same horizontal plane. In a 45-degree impact, the sill hits the cask above or below center, but their principal axes are still at right angles. A 90-degree train sill impact, we surmise, will be a grazing impact, in which no force is transmitted to the cask. The first point of this criticism is

that the different interpretation placed on the 45 and 90 degree impacts with the train sill should at the very least be noted in the tables. Of more concern is the question, was the angular orientation of the train sill treated in the probability analysis in the same manner as the impacts on soil, water, or rock? That is, was the same distribution function for cask orientation used for all impacts, even though the meaning of the "orientation angle" is totally different for the train sill? We can't find any mention of the way train sill impacts were included in the probability analysis; the subject seems to be in limbo.

5. Appendix D. This Appendix seems to be an outlier in this report, in that it was written by a subcontractor in a language totally removed from the rest of the work. Some of the terms used (e. g., "bents") are not defined. Figures D-1 and D-2 list some quantities which are not defined or explained in the text. Figure D-3 is totally obscure, since it apparently refers to the usage of a computer program which is not described at all. Finally, some of the terms in the few equations presented are not defined; we can't tell if this is due to omissions or misprints.

6. Appendix E. This Appendix has some problems with figures and tables. Table E.5 contains the previously mentioned point of confusion concerning the yield strength of casks under sideways loading. Visual interpretation of figures E-6 through E-9 is difficult, primarily because the units on the ordinate of E-8 differ from the others by an order of magnitude. Table E.7 has some confusing entries; how do you define a linear force, in units of lbs/ft, when you are pushing on the end of a cask? Figures E-12, E-14, E-16, and E-18 all show two curves, none of them labelled; their captions only mention one curve. Moreover, the little triangles and squares strung along the curves for identification purposes appear to be reversed on E-16, when compared to the other three.

7. Appendix F. The typography of the equations on the first few pages of this appendix is poor. At one point the typist apparently used a typeface intended for subscripts or superscripts when greek letters were called for. The result is that some terms in the equations look like superscripts, some look like exponents, and some look wrong. We started to mark in the corrections, but gave up. This is a job for the author.

8. Funny figure. Figure 5-3 is impossible as drawn. It looks like a cumulative distribution plot of breached fuel rods vs. deceleration force, but with the axes interchanged. However, it shows that at a single value of the force, both 10 and 100% of the fuel rods (and all values in between, for good measure) are breached, which is absurd when you stop to think about it. However, the stepwise line that has been drawn in does describe the fraction of fuel rods breached as used in the probability analysis. At least this line is consistent with the text, which is more than can be said for the figure in its original form.

9. Etcetera. There are many more points which could be discussed here, but for which we refer the reader to the annotated copy of the report accompanying this document. The annotated copy is an integral part of this review, not just an appendix. Many points requiring the attention of the sponsor and/or the team at LLNL are identified on its pages. As a general rule, red marks in the report copy represent explicit changes or corrections. Blue marks are questions or comments, sometimes suggesting changes more extensive than can be made just by locally editing the text or data.

Table 1 accompanying this review lists the page numbers, by section, on which comments or corrections are marked. These page numbers refer only to DRI review team comments. The report copy we received already contained numerous comments and changes inserted at NRC. We agree with these comments and changes, and support their inclusion in the revised and corrected report. We have not listed their page numbers in Table 1.

V. RECOMMENDATIONS

As we see it, there are two ways to proceed from here with this report, and the choice depends on the priorities of the NRC. The options are: 1) Make the corrections indicated here, clean up all the typos, but otherwise leave the report basically in its present form, and prepare a summary report, more carefully written than this report, to present the essential conclusions and to provide a "road map" for those who wish to delve deeper into this report; or 2) commission a major rewrite to eliminate the confusion and disorganization that pervades the current version.

The report as it now stands needs to go through a major quality control process. We have found a fairly large number of errors. It is a certainty that we have not found them all. We were still finding numerical data errors in the last week of this review effort. Every number in this report needs to be checked against its original source. In our opinion, these are things that should have been done before the report was sent out for review. Any scientific journal or publisher receiving a document in this condition would have rejected it out of hand.

If the report is to stand on its own, it needs a major revision. It needs re-ordering of the major subject areas, and it needs to present a clear outline at the very beginning to help guide the reader through the presentation of a genuinely complex process. It also needs to highlight the important results and conclusions. The old three-step outline for giving an effective speech is equally applicable here:

Step 1. Tell 'em what you're going to tell 'em;
Step 2. Then tell 'em;
Step 3. Then tell 'em what you told 'em.

TABLE 1

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D	3 7 8 11 12 13
E	7 8 9 10 12 14 17 22 30 32 33 35 37 38 40 41 55 57 58 67 73 75 87
F	1 4 5 6 7 10 12 14 19 21

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12 September 1986

Mr. William Lahs
Risk Analysis Branch
Division of Reactor System Safety
Office of Nuclear Regulatory Research
Nuclear Regulatory Commission
5650 Nicholson Lane
Rockville, MD 20852

Dear Bill:

Yesterday I received the review from Los Alamos on the structural response analysis section of the Livermore report. I am enclosing this review, which should be attached to ours. I am pleased with the Los Alamos review because it complements ours and covers a number of topics that we could not properly address.

Their review went into more detail than I expected, in view of the rather small level of funding that we had to offer for this work. I think that they have made a number of very good points, although there are a couple of spots where they're off the wall (such as the reference to the cask possibly being filled with liquid).

Their most important point is the need for references to experimental data. (We also noted this point early on, but we were not acquainted with the literature in this area as they obviously are.) If the Battelle and Los Alamos scale model experiments are correct in showing that closure and weldment failure are the most probable structural failure modes, then the foundation of the Livermore analysis, and the use of strain as the response variable, is in question.

All in all, I think that this is a very competently executed piece of work, containing a number of important points for the review. I haven't had time to evaluate its impact on the overall quality and credibility of the Livermore study. Perhaps this is a question for NRC to decide; in any case, we need to give Larry Fischer, et al., a chance to consider these comments and respond to them.

I'm sure I'll be hearing from you when you have had a chance to ponder over this addendum to the review. Until then, take care.

Sincerely,

Myron N. Plooster
Sr. Research Physicist

MNP:JW

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

August 22, 1986

Q-DO/TR-86-110

Energy Division

Myron N. Plooster
Laboratories for Applied Mechanics
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Dear Dr. Plooster:

The enclosed report is in response to the University of Denver purchase order No. 88532 to Los Alamos National Laboratory. Staff members from both WX and Q Divisions have written the report.

If you have any questions or comments about the report, please do not hesitate to contact me (505/667-9820), Wilbur Birchler (505/667-9361), or any of the three authors.

Sincerely yours,

Harold Sullivan
Program Manager for
Terrestrial Reactors

HS:ke

Enc: a/s

cy: W. D. Birchler, WX-4, MS G787
J. G. Bennett, Q-13, MS J576
CRM-4, MS A150 (2)

A REVIEW OF THE STRUCTURAL ANALYSIS SUPPORTING THE REPORT "SHIPPING CONTAINER RESPONSE TO SEVERE HIGHWAY AND RAILWAY ACCIDENT CONDITIONS,"

by

Joel G. Bennett
Thomas A. Butler
William A. Cook
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

I. INTRODUCTION

This document will serve to record the observations and conclusions from a partial review of the draft report "Shipping Container Response to Severe Highway and Railway Accident Conditions," by Fischer, et al., of the Lawrence Livermore National Laboratory. This review was performed by personnel at the Los Alamos National Laboratory at the request of the Denver Research Institute and was restricted to an evaluation of the work and conclusions reporting the structural dynamic response of the shipping casks. This report will give an overall evaluation where possible while pointing out specific criticisms.

The general approach used by the authors of the subject report is considered sound and the conclusions are relatively well founded, though the analysis and presentation can be improved as will be discussed. The comments and criticisms that will be expressed in this document are put forth in the spirit of contributing to that improvement and presumably can be addressed by the authors in the final report.

This report is organized into a review of Appendix E by topic, followed by a partial review of the main body of the report and overall comments. Finally, a concise summary of Appendix E is given for the reader who needs to refresh his memory of the subject report.

II. REVIEW OF APPENDIX E

The primary basis for all structural response related material in the report is taken from Appendix E, "Structural Analysis."

A. Material Property Selection

Section E.2 dealing with material properties used in the analyses is well organized but is subject to some general criticisms. For example, using ASME Code Properties for stainless steel may not be the best choice for evaluating a generic cask. Code values are usually minimum values which, though useful in design, can be considerably lower than actual values. For instance, the .2% offset yield value at which the report defines as end of the S1 level of response range is based is closer to 40 ksi for most A304 stainless steels. The yield strain value in the report is taken to be 0.9% strain corresponding to 25 ksi. Use of a lower yield value may or may not be conservative. Peak forces will be less with lower yield, but peak strains should generally be larger. In addition, not including strain rate effects on yield value will contribute to lower forces acting on the cask.

Uranium properties can vary significantly with molybdenum content (with which it is commonly alloyed) and the percent molybdenum considered should be specified. However, no amount of Mo can account for the low yield stress for the uranium as given in Table E.3. This value appears to be an order of magnitude too low.

The lead properties appear to be too stiff. Reference 1 indicates an elastic modulus of $E = 140$ ksi, and a hardening modulus of $E_H = 20$ ksi as opposed to 2,220 ksi and 45 ksi respectively.

It is recognized that some judgment must be exercised in modeling a real material with an elastic, strain hardening material. However, the conservative or nonconservativeness of the choices commented on above, are not readily apparent, particularly when two materials are combined in a structural model. Thus, a general comment on this section is that the entire report could be made stronger by demonstrating a brief sensitivity study showing how peak inner surface strains vary with σ_y for stainless steel and the effect of different choices for the lead properties.

A final general comment on this section is that no weld or heat affected zone properties are mentioned. In this regard, References 1 and 2 accumulated a fair amount of experimental evidence from drop tests on model shipping containers. In these tests, failure (leakage) was never caused by excessive strain in the parent material but rather at welds or because of excessive deformation at seals. Neither area is addressed by varying material properties.

B. Representative Cask Selection Process

This same issue of failure mode should be addressed in the representative cask selection process, Section E.3. Use of the minimum overall cask yield force as a criterion for "worst case" shielding material assumes failure is constituted by maximum plastic strain. As pointed out in Reference 1, when failure on test containers did occur, the mechanism was closure failure, not maximum plastic strain. The difference can be significant in picking a generic cask since closure failure may be more dependent on peak impact force. Peak impact forces would be larger for the "harder" shielding materials, such as uranium. (The harder materials also exhibit other failure modes such as brittle fracture that could lead to radiation shine paths.) Other failure modes that should be addressed are failures of local closures and appurtenances (piping, valves, etc.). It is recognized that these items are discussed in Section 2.4 of the report. The question we are raising is whether use of a max plastic strain criteria really encompasses these failures as Section 2.4 would imply. Perhaps this choice should be justified in this section.

C. Quasistatic Loads Due to Minor Accidents

The assessment of these accidents is well done and we generally agree that the results of the evaluation are reasonable. In Table E.7, a "4 x 4 Column" should be clarified (i.e., clearly not 4 inches by comparing total force for common objects).

D. Impacts on Unyielding Surfaces

The statement that lead slump will not occur if the axial force is less than 40 g is unclear and should be discussed. For example, will quasistatic loads equal to 40 times the weight of the cask cause lead slump? Also, peak loads can vary rapidly depending on cask orientation. Moreover, Reference 1 reports a 1% lead slump for a 15 ft. drop (20 mph impact) of a container onto an "unyielding" surface. What cut-off of slump is used for 40 g?

As a general comment, benchmarking both NIKE/DYNA and IMPASC computer codes would be better done against the experimental data of Ref. 1. Nonetheless, it is not clear that Table E.11 demonstrates adequate benchmarking of IMPASC. IMPASC overpredicted the endwise impact calculation for a truck cask from NIKE by 17%, yet underpredicted the rail cask by 20%. It is not clear that the point intended was at all demonstrated.

There are apparently errors (we believe) in both Tables E.9 and E.11. The plots shown in Figures 6.5 (pages 6-14) and 6.8 (pages 6-21) of the main report do not agree with these tables. Again, we point out that choosing 0° and 90° impact orientation as the bounding cases are dependent on selecting max plastic strain as a comparison criteria rather than maximum impact force.

E. Elastic Plastic Response by Cask

The finite element mesh used in this analysis uses 2 continuum elements through the thickness to model the steel shells that contain the lead shielding. For DYNA calculations, this is 2 integration points which is far too course to warrant the strain contour detail shown in Figure E-17. In this regard, the mesh used is not very efficient since the same degree of element gradation is used throughout, yet all "action" occurs near the impacting end of the cask. The reviewers believe a much better mesh could be developed for this analysis.

As a general comment, the figures in this entire section are poorly labeled and nearly unusable for one interested in the quantitative details of the result. Examples include contour levels in Figures E.13 and E.17. Figures E.12, E.14, E.16, and E.18 all contain two unidentified curves that presumably represent lead and steel response at an unidentified location on the model. Also, these figures do not seem to accurately reflect the discussion in the text. It is worrisome, for example, that maximum lead slump in Table E.12 is given as 12.3 inches and yet, the axial displacement of the lead (curve "B" in Figure E.12?) is 15.5 inches and increasing with a significant slope. Has the calculation been completed? Is there some elastic rebound to account for the difference?

The method and assumptions for calculating the "average" (spatially, temporarily, both?) innerface force in Tables E.12 and E.13 is not presented and should be.

In the section on sidewise impacts, some of the same criticisms expressed above can be made of both the plane strain mesh used and the figures presented. The authors do a good job of showing the adequacy of using the plane strain analysis for sidewise impacts, however.

One general criticism, which the authors also point out but do not adequately discuss, is that the models do not include the cask contents or their effects. If the contents are liquid (incompressible) the physical behavior calculated does not seem possible. The reviewers are not sure that the conservativeness of the assumption of neglecting the contents can be adequately defended.

A final comment on this section is that the argument for analyzing only the edgewise and endwise cases as bounds and linear interpolation to determine results for other angle impacts only holds for a maximum strain criterion. If failure of closure is considered, local (nonuniform) deformation due to corner impacts have not been shown to be covered by these extremes and in the reviewers opinions cannot be (particularly in light of test results in Reference 1).

F. Impact on Real Objects

The assumptions for the equivalent damage technique should be better presented and discussed. For example, the assumption of constant deceleration (or constant impact force as opposed to "deceleration force") truly hold only for; (1) end-on or side-on impacts, (2) elastic-perfectly plastic materials, and (3) lead and steel yield at approximately the same point in time. Perhaps an argument can be made based on the calculational results that the models used do approximately show the assumption to be true.

The reviewers do not believe that the results presented in this section serve to benchmark the equivalent damage technique. First, the comparison of 5.4% strain calculated for a real cask impacting a real concrete surface when compared to 14.3% estimated by the equivalent damage technique is so poor that some explanation is needed. Second, in Table E.16, the equivalent damage technique appears to predict identical results as the calculation for a real cask impacting an unyielding surface. In short, the reviewers believe that if these results are correct, the equivalent damage technique does not appear to be the best method to use for estimating the effects of impacting real surfaces.

The discussion of the remainder of Section E.7 including the water impacts and train sill impact study is adequately presented and well done in the reviewers opinion.

III. PARTIAL REVIEW OF MAIN REPORT BODY

The reviewers do not believe a sufficient argument is made for the choice of strain measure as a surrogate measure for damage. Despite the fact that closure systems (bolts, seals, lids, valves, etc.), are meant to be designed to not compromise the gross integrity of the cask, tests such as in Reference 1 show that if failures (radiological releases) will occur, these are the most likely areas. Such a conclusion could imply that; (1) maximum impact forces (harder materials, uranium shielding), and (2) angle impacts (large local deformations around closures, loss of closure, etc.) should be included in the bounding study. The point is that once this choice is made in Section 2, the remaining results are totally influenced by it.

Chapter 6, "First Stage Screening Analysis," does an adequate job of reflecting the results of Appendix E with the exceptions of some disagreement between Tables E.9, E.10, and Figures 6.5 and 6.8. The discussion of Table 6.5 could be improved by including a discussion of the 150 mph limiting impact velocity for the 90° train sill case. This value seems out of line.

Chapter 7, "Second Stage Screening Analysis," appears to do an adequate job of using results of Appendix E to evaluate strains higher than 0.2% on the cask shell inner surface as a function of impact velocities. However, the results should be evaluated with the review of Appendix E above in mind.

IV. OVERALL COMMENTS

The credibility of the structural response calculations supporting this work can be improved if;

(1) sensitivity studies using different choices for material properties were done, effects of welding or heat affected zones could be included here.

(2) benchmarking calculations against actual experiments. (Saying that Sandia used a code similar to NIKE 2D to calculate the response of full-scale casks used in crash tests is a rather weak substitute for benchmark calculation!) Experimental data from References 1 and 2 could be used for such a calculation,

(3) a calculation that includes the effects of cask contents, and

(4) 3-D calculations that include modeling of closure responses to "corner" drops.

In general, the reviewers believe that the overall probabilistic conclusions from this study will not be changed significantly by any issues raised in this review, but do believe that the supporting analyses can be stronger.

V. SUMMARY OF APPENDIX E - STRUCTURAL ANALYSIS

The structural analysis (Appendix E) section tabulates material properties for stainless steel (304), lead, uranium, and balsa wood. This appendix considers six cask designs, three shielding materials (lead, uranium, and steel), each used for a truck cask design and a rail cask design. Two static analyses of each cask design showed the lead shielding was the most vulnerable to failure (worst case) so it was chosen as the shielding material for a representative truck design and a representative rail cask design.

Several accidents are evaluated. These included minor accidents, crush, puncture, and impact. Using equivalent static loads, it is shown that minor accidents and crush are less severe than impact. Also described is how puncture is less severe than impact. This was demonstrated with a DYNA3D computer code calculation of a high (kinetic) energy-density I-beam impacting a cask. The authors refer to this problem as the worst possible puncture problem. They conclude this is less severe than impacting a cask with a train sill, so the "worst case" loading condition is impacting a cask with a train sill.

Impacts on unyielding surfaces were studied in two categories, elastic with the computer code IMPASC and elastic-plastic with the NIKE and DYNA computer codes. The elastic-plastic analyses with NIKE and DYNA computer codes consisted of analyzing both the truck and rail representative cask designs for impacts of 30, 60, and 90 mph and for both end and side impacts. A comparison is made of side impact problems with the plane strain assumption and a three-dimensional analysis of the same problem. These calculations demonstrate the plane strain assumption to be accurate.

Equivalent damage technique is defined and validated. Using this technique, a study of the representative casks inpacting on hard rock, soft rock, and soil is made. The equivalent damage technique is used to analyze the impact of these casks at several orientations as they impact on the water.

The final portion of this appendix describes calculations of the representative truck cask design impacting a train sill. This is the worst case accident and two DYNA computer code calculations are made. One is a center impact and one is an off-center or oblique impact. These results are used to estimate the response for the representative rail cask design.

"A NOTE OF CAUTION"

> Sometimes in this report a "worst case" assumption is used, for example, in deciding which shielding to use and which loadings are most severe. Other times "best estimate" assumptions are used, such as soil conditions. These ideas need to be used to keep the job manageable and yet must be remembered so that the reader can follow the reasoning by the authors.

VI. REFERENCES

1. Hadden, J. A., and Burian, R. J., "Sclae Model Drop Tests to Evaluate Impact Response of Lead and Uranium Shielded Radioactive Material Shipping Containers," Battelle Columbus Laboratory report, BMI-2039, September 30, 1979.

2. Butler, T. A., "The Effects of Drop Testing on Scale Model Shipping Containers Shielded With Depleted Uranium," Los Alamos National Scientific Laboratory report, LA-8120-MS, February 1980.

I have reviewed these and will include commentary on them in my report.

— L.A.