emphasizes the sign messages of some activity that is going on. Disrespect for standard maintenance signs has some validity, because it is not uncommon for motorists to encounter such warning signs that accompany a total lack of maintenance activity at the specified distance. Directional flashing signs give motorists a genuine warning of the situation ahead.

We realized an added advantage of such devices during the actual setup of the barricade and zone taper. Although flagmen and flashing beacons on work vehicles have proved effective during this initial setup, the safety provided by the use of these flashing chevrons, coupled with the reduction in total time required for installing them, was significantly better.

SUMMARY AND CONCLUSIONS

In the preceding sections we attempted to evaluate, quantitatively, the effects of certain variables defined by sign size, type, and legend on driver response as measured by speed, conflict, and queuing parameters. Effects of flashing signs were also evaluated in terms of the above responses. The experiment was conducted at four locations on two-lane highways and on the Interstate system that required single-lane closures during maintenance. The seven conclusions that follow are based on the analysis and evaluation of the various responses using analysis of variance.

1. Motorists do respond to advance-warning signs, as was indicated by reduced speeds in the critical zone. However, this reduction is much more pronounced for two-lane roads than for the Interstate system.
2. The height of the sign does not indicate any statistical difference in any of the measured responses for either two-lane roads or for the Interstate system.
3. For two-lane roads there was a recognizable difference in speed reduction for the three sign sizes. However, the 0.76-m (30-in) sign yielded better response (greater speed reduction) than either the 0.91-m (36-in) sign or the 1.22-m (48-in) sign.
4. The significant difference in the dependent variables caused by location factor can be attributed to the traffic volume parameter, in addition to the driver's attitude toward signing in general.
5. At Interstate locations the 0.91-m (36-in) signs yielded better results than the 0.76-m (30-in) signs. The difference between the 0.91-m (36-in) size and the 1.22 m (48 in) was negligible.
6. Driver response to sign legend was statistically insignificant.
7. Flashing chevrons greatly enhanced the obedience of the driver to warning signs and also provided greater safety to the work force and the motorists during both initial sign installation and subsequent maintenance activity.

ACKNOWLEDGMENTS

We are grateful for the assistance and cooperation provided by the district maintenance engineers and their personnel during the study evaluation. Appreciation is also expressed to John Melancon and Veto Yoches, who managed this study during various phases, and to many other support personnel who helped in the successful completion of the study. The study was conducted under the Louisiana HPR program in cooperation with the Federal Highway Administration. The opinions, findings, and conclusions expressed in the paper are ours and not necessarily those of the State of Louisiana or the Federal Highway Administration.

REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, U.S. Department of Transportation, 1971.
2. W. M. Seymore, R. C. Deen, and J. H. Havens. Traffic Control for Maintenance on High-Speed Highways. TRB, Transportation Research Record 484, 1974, pp. 24-35.
3. Maintenance Traffic Control Handbook. Louisiana Department of Highways, 1973.

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Risk Assessment for Solving Transportation Problems

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Battelle, Pacific Northwest Laboratories, is currently conducting a research program sponsored by the Energy Research and Development Administration to assess the risk of transporting energy materials. The risk assessment model, although originally developed for use in analyzing shipments of radioactive materials, can be used to evaluate the risk of shipping any hazardous material. This paper briefly reviews the risk assessment method and describes how it can be used to solve hazardous materials shipping problems.

A clear understanding of the safety aspects is essential to planning and regulating the transport of potentially hazardous materials. Research programs are one method of improving the level of understanding.

Since 1972, Battelle, Pacific Northwest Laboratories (PNL), has been conducting a transportation safety studies program for the transportation branch of the Division of Environmental Control Technology of the U.S. Energy Research and Development Administration. The initial purpose of the program was to develop and use a model to assess the risk associated with the shipment of radioactive materials. Recently, this program has been expanded to include transport of all potentially hazardous energy-related materials, both nuclear and nonnuclear. Risk analysis was chosen for use in assessing safety because it allows us to predict the consequences of releases of hazardous materials in relation to how often accidents might be expected to occur.

A National Transportation Safety Board special study (1) pointed out the variety and inconsistency of current regulations governing the transport of hazardous materials via various transport modes. The desirability of determining the relative levels of risk for various commodities is clearly shown in this study.

BACKGROUND ON RISK ASSESSMENT

Risk, as used in the context of this paper, is defined as the magnitude of a possible loss multiplied by the expected frequency of loss occurrence. Two measures of risk are useful in assessment, (a) the total risk, obtained by adding up the risk associated with each particular loss, and (b) a risk spectrum (Figure 1).

To illustrate, we will assume that the consequence of interest is the number of fatalities expected from accidents. The expected frequency of N or more fatalities is plotted as a function of N. The risks associated with two activities are truly similar if they have the same total risk (risk magnitude) and the same risk spectrum.

In the past, safety studies have used only historical data and previous accident-free experience to assess the safety associated with transport of potentially hazardous materials. The method we developed supplements this technique but does not replace it. Risk assessment techniques permit proper consideration of both past and possible accidents.

ASSESSMENT TECHNIQUE

PNL has already completed a number of risk assessments (2, 3, 4) to provide the background needed to demonstrate the usefulness of risk assessments. The technique developed for use in those studies will be reviewed, using examples from the studies themselves.

The risk analysis method comprises four steps: (a) system description, (b) release sequence identification, (c) release sequence (and severity) evaluation, and (d) risk calculation and assessment. The risk analysis model has been described in detail by Hall and McSweeney (2) and will be treated only briefly here.

Figure 1. Sample risk spectrum for plutonium shipment in early 1980s.

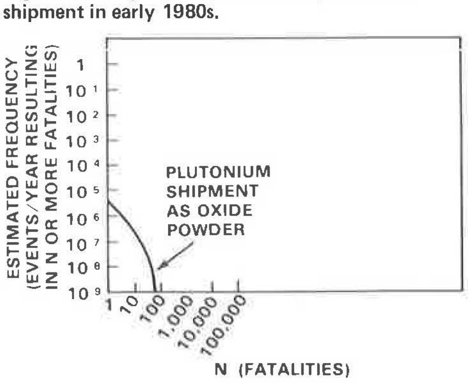

Figure 2. System description for plutonium shipment analysis.

WHAT: ______ PuO_2 POWDER

HOW MUCH: ____ 18 Mg OF Pu,
2.55 kg PER CONTAINER

WHEN: ______ 1980

AVERAGE SHIPMENT
DISTANCE: ____ 2372 km

HOW: ______ EXCLUSIVE USE, ESCORTED TRUCK
100 kg Pu PER TRUCK IN
39 6M CONTAINERS

Note: 1 Mg = 2200 lb and 1 km = 0.6 mile.

System Description

The system description can be considered the what, how, when, and where step. A risk assessment is no better than the kind of information known about the system through which the material is being shipped. Most of this information is already known or easily available. The seven components of a complete description of the system generally are

1. Quantifying projected industry characteristics;
2. Specifying amounts, origins, and destinations of materials to be shipped;
3. Specifying the material's basic characteristics;
4. Specifying the transport mode and carrier;
5. Specifying the container type and amount per container;
6. Calculating the number of shipments required; and
7. Specifying route and restrictions and population and weather zones.

A portion of the system description used in the risk assessment of plutonium shipment by truck is shown in Figure 2.

Release Sequence Identification

Materials become a safety concern only when the barrier(s) between them and people are breached. Hazardous materials are shipped in containers that isolate them from the human environment, so the first step is to identify the possible ways the materials could be released during transport. The components of the system description provide most of the information needed to identify possible release sequences. Although many techniques can be used to identify release sequences, the most complete listing is obtained by working backwards from a postulated release through the chains of events or failures that caused the breach. We used a deductive method called fault-tree analysis to identify release sequences because we felt that this method decreased the likelihood of overlooking any important sequence.

As an example, in the risk assessment of a plutonium shipment by truck, the system description specified that the material would be shipped in a closed van in a U.S. Department of Transportation (DOT) Specification 6M container (Figure 3). A release of material into the environment would therefore require a simultaneous breach of four barriers—the sample can, the 2R inner container, the outer drum, and the van, as shown in Figure 4.

These barriers are shown on the second level of a fault tree in Figure 5. The fault tree is further developed below this second level to a point where probabilities can be assigned to various events that take part in breaching the barriers. The fault tree therefore shows all the possible ways that each barrier can fail during transport.

As an example of how the risk assessment method determines the likelihood of events that have not occurred, we will consider the 2R container. No 2R (inner) container has ever failed during transport; therefore, no data exist on its failure probability. However, the probability of failure can be determined from other information. Let us consider, for instance, the likelihood that the 2R container will fail during an accident.

The probability that a truck will be in an accident is known from accident data, and the force required to cause failure of the 2R vessel can be found by testing. The probability that the accident forces will exceed that level can also be derived from analysis of accident data. By using the above information, we can then determine the probability that the 2R container will fail in an accident.

The same type of development is also used for other failure paths. In addition to accident-caused failures, releases caused by packaging errors or as the result of normal transportation forces, such as jarring and vibration, can also be analyzed.

The technique described above is the key to the entire risk analysis. Estimates of risk can be made for events that have never happened, and each possible release sequence is detailed in a way that provides the specific conditions required for a release. This detailed analysis of each release sequence is, as we shall see later, very helpful in analyzing transportation safety.

Release Sequence Evaluation

The third step in risk assessment is determining the severity of each individual release sequence. Since the severity of each sequence will be different, estimates of the amount of material that will be released in each postulated release sequence must be made. For instance, in shipping gasoline, a release sequence involving a leaking valve will probably release significantly less material than one in which the entire side of the tank is damaged. Where there are no accident history data, we can instead analyze the behavior of the hazardous material under the conditions of the postulated release sequence.

Risk Calculation and Assessment

The final step in the analysis is determining the consequences of each postulated release sequence, relating it to its respective occurrence rate, and combining these individual risks to obtain an indication of the total risk system.

In order for a particular material to be injurious to people, it must reach them after it is released. This might be a matter of a few feet (as in a gasoline spill) or several miles (as in an airborne release of a powder). Therefore, any evaluation of the consequences of a release should include such aspects as weather, population distribution near the release site, and the health effects of the particular released material. After all of the individual sequence risks have been combined, a risk spectrum can be determined.

APPLYING THE TECHNIQUE

A basic result of the risk assessment procedure is the determination of the overall risk. Comparisons of the relative safety of an activity can be made by expressing alternatives in terms of risk. For example, PNL has been analyzing plutonium shipments via truck (2), rail (3), and air (4).

In each case, the system description was the same except for mode of transport. This way each mode could be assessed and compared with the others to determine relative safety. The results (Figure 6) showed that the

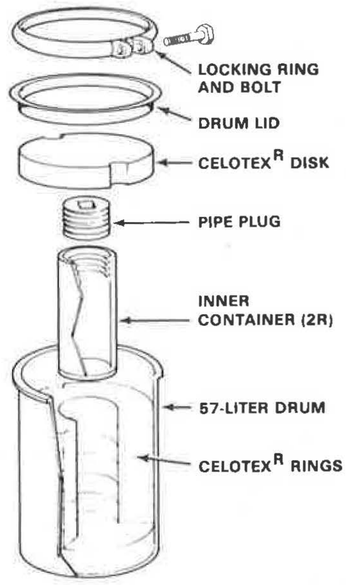

Figure 3. Specifications for 6M container.

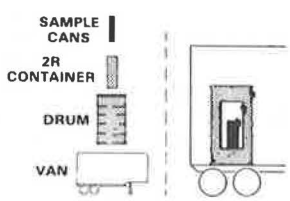

Figure 4. Barriers to plutonium release from van.

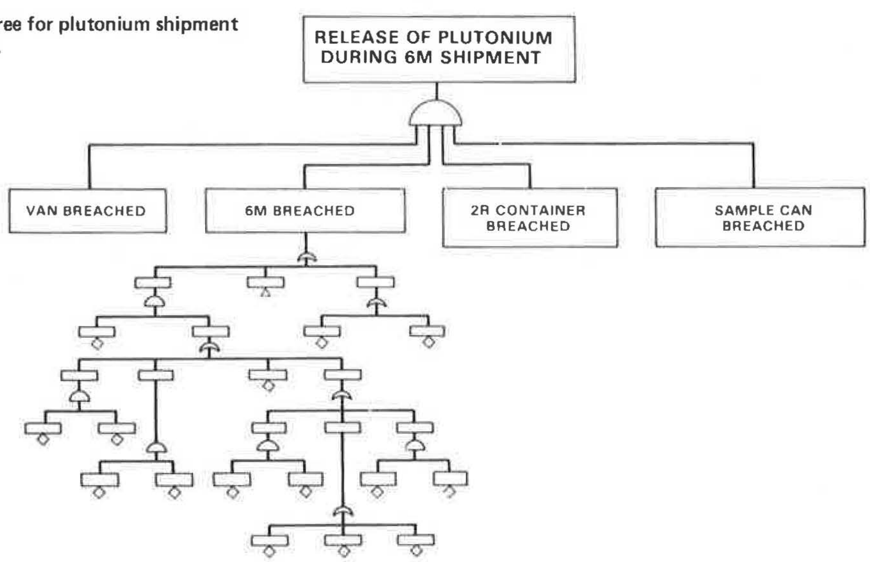

Figure 5. Fault tree for plutonium shipment release sequences.

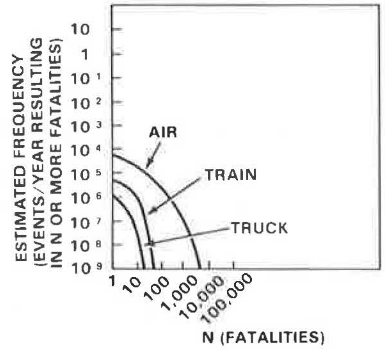

Figure 6. Risk spectra for plutonium shipments by three modes in early 1980s.

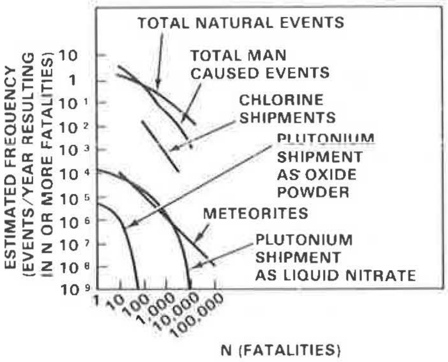

Figure 7. Risk spectra for plutonium shipments by truck in early 1980s.

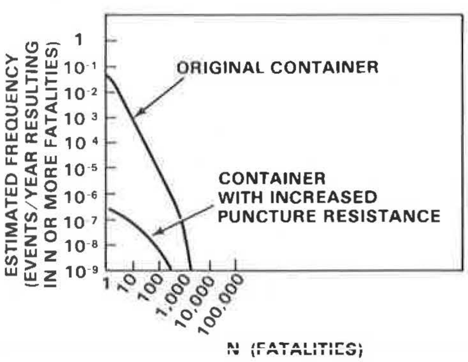

Figure 8. Risk comparison between old and redesigned containers.

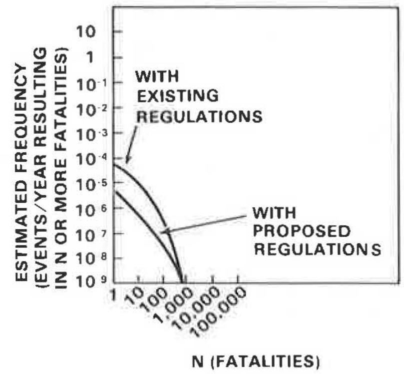

Figure 9. Risk comparison between existing and proposed regulations.

risks of shipping plutonium on trucks and trains were about equal and that the risk by air was higher although still very low. Using risk assessment technique in this manner would show the shipper of hazardous material the safest possible mode.

Risk in the shipment of a hazardous material can also be compared to other risks to which human society is exposed. As an example, the risk of shipping plutonium is compared with other known risks in Figure 7. As can be seen, the risk of transporting plutonium at 1980 shipping levels is much lower than that of shipping chlorine.

It is also possible to compare the relative safety of shipping the hazardous material in different physical forms (solid, liquid, gas) by using the same method. Other things such as route changes, changes in the type of container used, and amounts per shipment can be analyzed as well.

A second important feature of the risk assessment technique is that the main contributors to overall risk can be identified. During the analysis, every possible release sequence (combination of events leading to a release) is outlined, and each element of the sequence is assigned a probability. We can then state the probability that a sequence will occur. At the same time, release fractions (the amount of material released during a particular sequence) and consequences are determined for each release sequence. If we multiply release sequence probability by its consequences, we can get an indication of that particular sequence's contribution to overall risk. The release sequences that make the greatest contribution to overall risk can thus be identified. These contributors can then be used to signal areas where modifications to reduce overall risk and increase safety could possibly be made. Combining this with other information on costs and benefits can lead to the best ways to increase the safety of hazardous material shipment.

For example, analysis might reveal a puncture of the container as the highest risk contributor. Then a redesigned container that is more puncture resistant could give new failure thresholds for reevaluating risk (Figure 8). A new risk spectrum showing the effect of the new container would indicate a decrease in overall risk.

The technique can also evaluate proposed changes in safety regulations. The merits of proposed regulatory changes can be assessed before implementation in terms of the overall transportation risk of a particular material. This is done by first finding the risk involved in shipping the material in the conventional manner. Next, a second risk analysis is made by using the proposed rule change (for instance, a requirement for greater wall thickness in containers). A comparison of the risks can then show what effect the new regulations will have on shipment safety (Figure 9). If the new regulation is found to significantly reduce risk, then further consideration should be made to implement it. By using the risk assessment technique, regulatory changes can be made on the basis of reduction in risk.

By comparing the risk spectra of various transportation modes, we can see whether one mode is being over-regulated in relation to others. The differences in safety of the various modes can also be compared.

The risk assessment technique can be valuable for solving a variety of transportation safety problems, of which we have presented a few of the more significant ones.

REFERENCES

1. Risk Concepts in Dangerous Goods Transportation Regulations. National Transportation Safety Board, U.S. Department of Transportation, Rept. No. NTSB-STS-71-1, 1971.
2. R. J. Hall and T. I. McSweeney. An Assessment of the Risk of Transporting Plutonium Oxide and Liquid Plutonium Nitrate by Truck. Battelle, Pacific

Northwest Laboratories, Richland, WA, BNWL-1846, Aug. 1975.
3. R. J. Hall. An Assessment of the Risk of Transporting Plutonium Oxide and Liquid Plutonium Nitrate by Train. Battelle, Pacific Northwest Laboratories, Richland, WA, BNWL-1996 (draft), June 1976.
4. T. I. McSweeney and J. F. Johnson. An Assessment of the Risk of Transporting Plutonium Oxide by Cargo Aircraft. Battelle, Pacific Northwest Laboratories, Richland, WA, BNWL-2030 (draft), July 1976.

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Abridgment

Transport of Hazardous Materials and Docket HM-112

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HM-112 is a serial docket number assigned to an omnibus regulatory action on several hundred different subjects pertaining to the U.S. Department of Transportation's (DOT's) regulations on the safe transport of hazardous materials. The principal matters addressed in the action are

1. Consolidation of DOT's hazardous materials regulations into a single volume;
2. Allocation of one part addressing hazardous materials communications, documentation, marking, labeling, and placarding;
3. Realignment of the regulations applicable to certain hazardous materials that are consumer commodities;
4. Elimination of all regulations pertaining to certain materials;
5. Complete reissuance and restatement of the modal regulations pertaining to transport of hazardous materials by air, rail, and water;
6. Addition of four new classes of materials, or other regulated materials (ORM), to be subject to certain regulations when transported by air or water or both;
7. Requirement that all materials classed as class B poisons and those materials in other classes also meeting the definition of class B poisons be labeled to identify their hazards even in quantities previously exempt from labeling requirements; and
8. Many other changes necessary to unifying and clarifying DOT's hazardous materials regulations.

This amendment is probably the most significant action taken over the past 60 years. It is important because it brings all the department's regulations together into a single volume. It also improves the safety regulations pertaining to the safe transport of hazardous materials by making them as intermodally compatible as practicable. All persons concerned with the department's regulations—shippers, carriers, or emergency, regulatory, or enforcement personnel—will agree that this is an important rule-making action.

The impact of HM-112 is best judged by the people affected by the regulations adopted under the Docket, who agree that consolidation is a benefit. Now they need only deal with a single volume when they class a material, determine its required packaging, marking, and labeling, prepare shipping documents, and identify transport vehicles regardless of the mode or modes to be used.

The new hazardous materials table set forth in Section 172.101 applies to four modes of transport for the first time in 60 years of regulation. Furthermore, consolidation eliminated more than 700 pages of federal regulations and thereby the need to wade through three different volumes to find the applicable requirements on transport of hazardous materials. Of further benefit was the elimination of requirements that were incompatible for movement between modes. In the past, regulations addressed requirements in different places and not only were inconsistent in several areas but also failed to recognize intermodal movements.

For example, there were different placarding requirements for rail and highway for 40 years. When a tractor semitrailer moved to a rail yard, the placarding on the trailer was not appropriate for its transport aboard a rail car. Worse yet, though, was the situation for intermodal transport involving carriage aboard vessels. The system failed to recognize intermodal container movement, which has become a very important form of transporting all kinds of goods in commerce. Under the new system, the shipper knows how to label the package, mark the contents on the outermost packaging, prepare documentation, and apply placards to freight containers that will be transported by one or a combination of modes. These requirements are now set forth in part 172 of DOT's hazardous materials regulations.

Another important fact is that now the labeling and placarding system can be considered consistent with the international standards and provisions for the additional communication required by some international regulatory bodies, such as the Intergovernmental Maritime Consultative Organization.

It has been estimated that more than $60 billion worth of retail consumer commodities sold annually in the United States fall within the hazardous materials definitions set forth in the regulations. All aerosol products and such products as nail polish, aftershave lotion, paints and related materials, and many cleaning compounds are classed as hazardous under the regulations.

In 1972, a notice was published in the Federal Register requesting public participation and comment on whether some form of adjustment should be made in the regulations as they apply to these materials. Many responses supporting the contention that these materials were in some ways overregulated were received. Comments along these lines were also received from the president of the New York City Fire Fighters Union; this suggested that certain adjustments should be made, par-