Transportation Risk Assessments – A Review and Look to the Future

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SUMMARY

We have been performing risk assessments for the transport of hazardous materials for the last quarter century. What is the best use of transportation risk assessments? This paper suggests that it is not enough to perform a risk assessment that shows a hazardous material could be safely transported. A good transportation risk assessment can identify some key performance parameters that are major contributors to the risk. Measuring these parameters can be an effective monitoring instrument of actual transportation operations. A risk-based monitoring program not only can verify impacts are low but also identify ways to make transportation of hazardous materials safer. It can save lives.

HISTORICAL PERSPECTIVE

The reactor safety study, WASH-1400, issued in the mid 1970's, estimated the population risk associated with operating 100 commercial nuclear reactors in the United States. At that time there was a great deal of interest in determining whether the WASH-1400 methodology could be used to determine the transportation risks. Two forms of plutonium were being shipped around the United States at that time, plutonium oxide and liquid plutonium nitrate. The regulators were concerned about shipping a very toxic material around the country in liquid form but they had no evidence that the practice was unsafe.

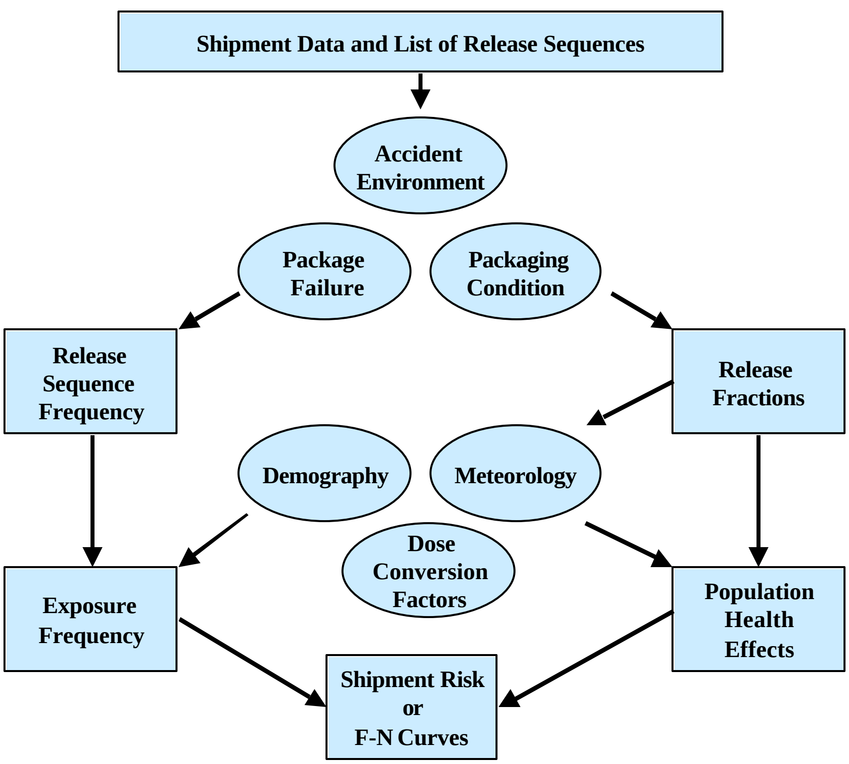

Figure 1. Initial Methodology for Performing Transportation Risk Assessments

Figure 1 shows the adaptation of the WASH-1400 methodology to transportation systems. This diagram is quite similar to the reactor safety study and contains all the elements that are part of a modern transportation risk assessment. It begins with the description of the system and identifies the scope of the analysis - in this case quantification of release sequences. The analysis evaluated the risk at a time when there would be several hundred truck shipments of plutonium oxide or liquid plutonium nitrate. In the mid-1970s, at the time the assessment was performed, plutonium shipments were less frequent. They were highly monitored and easily observed so any questions regarding the packaging procedures and condition of the package were easy to determine.

After the shipment parameters were specified, the severity of the accident environment was quantified. Sandia National Laboratories performed a study that characterized the truck, rail, and airplane transport accident environment (Clarke, et al.). Their report quantified the impact, fire puncture, and crush environments for each mode.

Next, the response of the packaging in the accident environment was analyzed. Mechanical analysis codes were used to determine the behavior of the packages in the accident environment. Receivers of the packages were asked a series of questions and the results were used to determine the actual condition of the packaging during shipment. This enabled packaging errors and actual shipment conditions to be included in the accident analyses. This triad of information was evaluated using fault tree analysis and the result was a set of accident sequences. Since the desired outcome was F-N curves similar to the reactor safety study, two separate analyses were performed on the accident sequences identified by the fault tree analysis. The rectangles on the right and left hand side of Figure 1 show the separate probability and consequence analyses performed on each accident sequence. The availability of experimental release fraction data (Mishima, 1966) was a key factor in the success of the program.

Shipment risk estimates were developed next. Maps were used to determine the number of miles traveled in four regions of the country and within each region, in urban, suburban, and rural areas. Census data was used to determine the population density in each region and zone. Standard United States meteorology was used to model the plume dispersal from a postulated release. The rectangles on the bottom left and right hand side of Figure 1 depict this calculation step. The probability and consequence evaluations for each accident sequence were maintained as separate calculations and then combined to produce the F-N curves shown in Figure 2. The risk spectrum curves are for plutonium transportation projected into the mid-1980s.

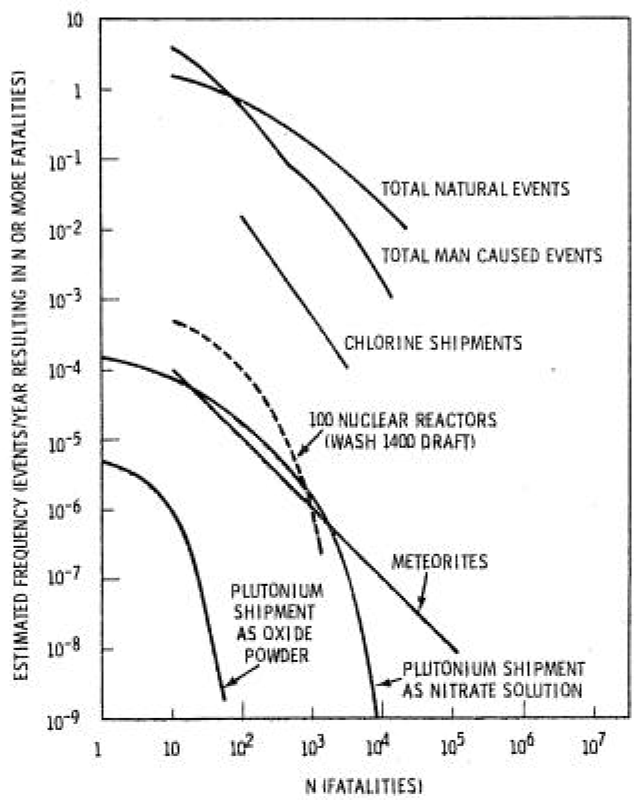

Figure 2. Risk Spectrum for Plutonium Shipments for the Entire United States

The decision to perform the first quantitative transportation risk assessment on plutonium oxide and liquid plutonium nitrate shipments was a wise choice. The packaging was relatively simple so their behavior in the accident environment could be quite easily modeled. The packages were being shipped routinely so it was possible to observe the loading and unloading operations. Most importantly, the quantity of material released from a damaged package could be estimated from experimental data.

However, the real strength of the analyses was not in the presentation of the risk curves but, instead, in the sensitivity analyses performed on the accident sequences. Packaging errors were not a significant contributor to the risk. However, the behavior of the loose vermiculate was a significant risk contributor. Stabilizing the vermiculate in the L-10 package used to ship liquid plutonium nitrate was shown to lower the plutonium nitrate shipment risk curve two orders of magnitude, making it comparable to the risk curve for the plutonium oxide shipments. It is believed that these results contributed to the withdrawal of the certification on the L-10 and with it, the ability to ship liquid plutonium nitrate solutions in the United States.

FOLLOW-ON-STUDIES

The initial study of plutonium truck shipments was so successful that follow-on studies were performed, first for air transport of plutonium oxide and then for several other hazardous and radioactive material shipments. Many of the materials were not being shipped at the time so observing the shipments was not possible. This made it impossible to base some of the accident sequence probabilities on actual shipment experience. Furthermore, more and more of the assessments only presented the risk results and concluded that they were acceptable. Two decades ago, sensitivity and uncertainty analyses were not easy to perform. Today, there are analysis tools that make performing such analyses almost automatic. Unfortunately, there is little evidence that their benefit or power is recognized.

Tremendous strides in the development of risk assessment tools have been made in the last two decades. A very simple population density model was used in the initial transportation risk assessment. Today, an analyst can use INTERLINE and HIGHWAY for rail and highway route selection. These two codes select the route based on link impedances chosen by the user and for each selected route determine the number of miles, or kilometers, traveled in each state in each of 12 population density ranges. These 12 density ranges are usually collapsed to urban, suburban, and rural travel fractions. Saricks and Tompkins (Saricks, 1998) have published state-specific accident data for truck and rail transport. Release fraction data for many materials have advanced to the point where they have been codified into an ANSI Standard.

Models are now available for estimating the release fraction for spent fuel involved in severe transportation accidents, replacing the initial studies that were largely based on expert judgment. In 1986, the Modal Study (Fischer, 1986) presented the first comprehensive modeling of spent fuel shipment risk. This was followed in 2000 by an even more comprehensive study (Sprung, 2000).

Analytical tools have advanced significantly as well. RADTRAN5 is the fifth version of the first integrated transportation risk assessment code. RISKIND provides valuable spent fuel transportation risk assessment information as well. These codes both use standard radioisotope data to convert consequences of a release to exposure estimates. Validated mechanical analysis codes use massively parallel networks to model the behavior of large, heavily shielded shipping casks used to ship spent nuclear fuel.

There have been advances in the hazardous material risk assessment area as well. For many classes of hazardous material, the volumes shipped are large enough to measure the annual shipment risk using actual accident data, (Greenberg, 2001). This study again showed the value of sensitivity analyses. The hazardous cargo is not the dominant contributor to risk. However, sensitivity analyses showed that rollover accidents involving flammable materials were frequently fatal, probably because of the much higher incidence of fires and explosions following such accidents. The Department of Transportation and the shipping industry are evaluating ways of reducing the rollover risk.

It is unfortunate that risk assessments frequently add detail in the wrong places. Some assessments have made milepost risk estimates and then added all the risks per mile to get the overall shipment risk. Using average accident rates for the route would have resulted in the same risk level. Such studies fail to recognize that potential applications of the risk assessment results are far more important than adding more detail to the risk assessment calculation.

Some fundamental weaknesses remain. One is accident causation. Transportation risk assessments still cannot include causal factors and without causal factors it is difficult to identify effective preventative safety measures. Both transportation accident databases and transportation risk assessments typically begin with a transportation accident or an accident rate. A significant advance will have to be made in transportation risk assessment before causal factors can be included in risk assessments.

Estimating the frequency of accident sequences that have an expected frequency of less than once every 100 years is another limitation. Unlike natural hazards analyses, having 100 years of data would not be useful for a transportation risk assessment because the transportation system has changed so much over the time period. The analyst must choose either to use scant current data or data compiled over a longer period that may no longer represent the current transportation system. The choice is not an easy one to make.

While weaknesses will remain, transportation risk assessments can still be used to identify the risk dominant parameters associated with a planned or operational transportation system. In the case of the plutonium nitrate shipment evaluation, the sensitivity analysis identified that stabilizing the vermiculate in the L-10 container would reduce the risk by two orders of magnitude. Lives can be saved if the transportation risk sensitivity and uncertainty analyses are used in the operational period to identify areas where cost effective improvements can be made.

VISION OF THE FUTURE

Because of the rapid advances in computing power, risk assessments can now be performed routinely. Most of the data needed to perform a transportation risk assessment are now at one's fingertips. Future studies must lead us to some rudimentary understanding of causal factors and their contribution to transportation risk.

Where does all this take us? Shippers and carriers of hazardous material can now perform meaningful transportation risk assessments. This is where the real benefits of transportation risk assessments will be discovered, as was the case with the liquid plutonium nitrate shipments. How many other simple fixes go undetected because no risk assessments that monitor actual operations are being performed? Good business practices will drive companies in this direction. Fewer accidents and fewer lawsuits will increase a company's competitive edge in an extremely competitive market place.

In summary, data limitations will remain with us. The current data limitations will be replaced in the future with new limitations because safety and risk analysts will want to extract more and more information out of the data. The computing power will continue to increase. Carriers of hazardous materials will recognize the importance of monitoring the performance of their drivers and vehicles. Shippers will want to monitor carriers as well. The best use of transportation risk assessments, monitoring and improving the performance of actual transportation systems, will attain its proper place. Lives will be saved.

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