State of the Art Report 3

Addendum

Recent Advances in Hazardous Materials Transportation Research

An International Exchange

TRANSPORTATION RESEARCH BOARD
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Foreword

The papers in this addendum were presented at a Conference on Recent Advances in Hazardous Materials Transportation Research: An International Exchange held in Lake Buena Vista, Florida, November 10-13, 1985. Sponsored by the Federal Highway Administration and the Research and Special Programs Administration, U.S. Department of Transportation, the conference was planned under the guidance of a steering committee appointed by the National Research Council.

Most of the papers presented at the conference were published in *State of the Art Report 3*: Recent Advances in Hazardous Materials Transportation Research: An International Exchange in 1986. Four additional papers presented at the conference appear in this addendum to the report. Contractual arrangements with the U.S. Department of Transportation requiring delivery of a final report before review was completed prevented publication of three of the papers in the original report. The fourth paper that appears in this addendum, "The Transport of Non-Nuclear Toxic and Dangerous Waste in the United Kingdom," by P. J. Hills, although presented at the conference, was not previously published.

The Transport of Non-Nuclear Toxic and Dangerous Wastes in the United Kingdom

PETER HILLS

The hazards associated with wastes are less well-known and less easily controlled than those of the pure substances that they might comprise, precisely because wastes are rarely owned or valued by those who generate them. Furthermore, the scale and complexity of the problems of waste disposal increase as the output of chemical factories expands, and recent ecological disasters have underlined the need for concerted action by many nations to control these problems. This has prompted a study by nine member states of the European Community, under the aegis of the European Foundation for the Improvement of Living and Working Conditions, to collect evidence on the technical, operational, and legal aspects of transporting wastes. The findings of this study undertaken for the United Kingdom are summarized in this paper. The main report, presented to the European Foundation in July 1985, dealt with the transport of non-nuclear toxic and dangerous waste under six main headings: classification of wastes (Part I), packaging (Part II), means of transport (Part III), loading and unloading (Part IV), control and monitoring systems (Part V), and emergency measures (Part VI). Part VI contains a description of the potential for electronic data processing and monitoring equipment for transfrontier shipment of dangerous wastes (although this is not especially relevant to the United Kingdom). An evaluation of current practices in the United Kingdom and the various changes that are contemplated are presented in Part VIII. Most of these subjects are covered briefly in this paper but more detailed information can be found in the original report, which can be obtained from the European Foundation in Dublin.

Summarized in this paper are the findings of a study of the technical, safety, and legal aspects of the use of tankers, containers, and other modes of conveying hazardous chemical wastes in the United Kingdom.

The findings of the study, outlined broadly in this paper, are covered in a detailed report presented to the European Foundation in July 1985 *(1)*. This report is one of several commissioned by the foundation to provide an up-to-date assessment of the way European Community (EC) member states deal with toxic and dangerous chemical wastes. These separate reports will be brought together for discussion in the European Parliament and elsewhere concerning the need to adopt a common approach within the EC to the problems of hazardous waste disposal, which are growing in both scale and complexity in all the industrialized countries of Europe.

Department of Civil Engineering, Cassie Bldg., Claremont Rd., University of Newcastle upon Tyne, NE1 7RU, England.

WHAT IS SO SPECIAL ABOUT WASTES?

Although a large and growing volume of legislation exists on the handling of hazardous goods, much less attention has been given to the problems of hazardous wastes. The starting point in the United Kingdom was, perhaps, the Control of Pollution Act (1974) *(2)*, which interprets waste as "(a) . . scrap, effluent material, unwanted surplus . . . ; (or) (b) any substance requiring to be disposed of . . being broken, worn out, contaminated or otherwise spoiled."

By definition, therefore, these are materials of no value—or even negative value in that the waste producer must usually pay someone to take it away. Once this has been done, there is a temptation for the waste contractor to dispose of it as quickly and as cheaply as possible. This quick disposal is rarely in accord with the highest standards of public safety that people have come (quite rightly) to expect in dealing with these dangerous substances. In short, safe transport and satisfactory disposal of hazardous wastes cannot be left to the market.

DEFINITION OF A "SPECIAL" WASTE

The Control of Pollution Act goes on to define hazardous wastes and allows the secretary of state to make regulations under the act to deal with them. In particular, categories of special waste are any that

(a) (i) is dangerous to life; *or*
  (ii) has a flash point of 21°C or less, as determined by the methods and with the apparatus laid down by the British Standards Institution in BS 3900; *or*
(b) is a medicinal product, as defined in Section 130 of the Medicines Act 1968, which is available only in accordance with a prescription given by a medical practitioner.

Although the Control of Pollution Act (1974) *(2)* is the most important act covering waste disposal, two sets of regulations are in force under the Health and Safety at Work Act (1974) *(3)*, which also defines hazardous wastes. In the Classification, Packaging, and Labeling of Dangerous Substances (CPL) Regulations (1984) *(4)*, there is an approved list of substances regarded as dangerous for supply and conveyance by road. The wastes included in this approved list are given in Table 1. Another approved list is issued for use with the Dangerous Substances (conveyance by road in road tankers and tank containers) Regulations (1981) *(5)* and, so far as wastes are

TABLE 1 APPROVED LIST OF DANGEROUS SUBSTANCES

Name of Substance	Identification No.
Hazardous waste, containing isocyanates[a]	7022
Hazardous waste, containing organo-lead compounds[a]	7023
Hazardous waste, flammable liquid, flash point less than 21°C	7010
Hazardous waste, flammable liquid, flash point 20°C to 55°C	7011
Hazardous waste, flammable, solid or sludge[a]	7012
Hazardous waste, liquid, agrochemicals, toxic[a]	7021
Hazardous waste, liquid, containing acid	7006
Hazardous waste, liquid, containing alkali	7008
Hazardous waste, liquid, containing inorganic cyanides	7019
Hazardous waste, liquid[a]	7015
Hazardous waste, liquid, toxic[a]	7017
Hazardous waste[a]; also miscellaneous, packaged, including cylinders of compressed gas	7013
Hazardous waste, solid, containing inorganic cyanides	7018
Hazardous waste, solid or sludge, agrochemicals, toxic[a]	7020
Hazardous waste, solid or sludge, containing acid	7007
Hazardous waste, solid or sludge, containing alkali	7009
Hazardous waste, solid or sludge[a]	7014
Hazardous waste, solid or sludge, toxic[a]	7016

Note: As authorized for use with the Classification, Packaging and Labelling of Dangerous Substances Regulations (1984) *(4)*.
[a]Not otherwise specified.

concerned, is identical to the list in Table 1, except for waste in packages.

IDENTIFICATION OF HAZARDS

In principle, there is no difference between a hazard caused by waste materials and that arising from any other goods, products, or raw materials. The important difference is that the characteristics of the particular waste under consideration may not be fully known or the waste may have been contaminated with other substances, making it more dangerous or, at worst, potentially lethal. For these reasons, the physical and chemical properties of pure substances, although important, may only be of limited use when applied to wastes. Where a producer regularly has a large quantity of identical waste products, it may be worthwhile to investigate their properties. However, because this is costly, it is rarely done; the producer usually finds it cheaper to ascribe to his waste the worst attributes of its constituents and deal with it accordingly.

Solutions and mixtures of wastes transported in the United Kingdom and elsewhere may consist of almost anything, and those treated as special wastes may exhibit toxicity, corrosivity, flammability, or carcinogenity, or any combination of these. Where more than one dangerous property is manifested by a waste, the one likely to cause the greatest danger to life will be considered paramount. For example, a highly flammable but slightly toxic waste will be regarded principally as flammable and its toxicity, although noted, would be considered a subsidiary risk.

Using flammability as the example is appropriate because it is by far the most common characteristic for hazardous materials, though not for wastes. Figure 1 shows that, of all hazardous loads transported in the United Kingdom, the flammable ones account for 79 percent of overall tonnage. Even when petroleum is omitted from the figures, the flammable loads still account for 35 percent and are comparable with the next largest category—corrosives (44 percent). Explosive and toxic loads account for only about 26 and 13 percent, respectively, of tons with petroleum excluded.

Fortunately, wastes are confined almost entirely to liquids and solids, with the result that explosive and flammable hazards are rare. The problems center mainly on corrosives and toxic substances.

To identify the classes of risk present with any unknown substance, it is usually necessary to identify the chemical radicals present; although if the substance is believed to be, for example, corrosive it may be sufficient to test a small sample on the material with which it is likely to come into contact, such as the proposed container. Clearly, such a process is not possible when dealing with toxins or other substances harmful to human health. In such cases, some further analysis will be needed.

In many instances, where wastes are involved, the hazardous element will be dissolved in a solvent, perhaps aqueous but frequently organic. The solvent itself will need to be identified in the latter case, as it may present some risk to persons or to the environment. Surveys carried out in southeast England, in the County of Essex, which is one of the main areas of chemical waste disposal, have shown (Table 2) that paints and polymers, tars, phenols, and alkali wastes are common. The total tonnage of waste recorded in the survey (conducted in 1977) was 76,500 tons/year. Essex is believed to account for about one-third of all disposals in the United Kingdom. Thus, the annual total, allowing for growth of the chemical industry over the last 8 years, is likely to exceed a quarter of a million tons.

Although this may appear to be a large amount in absolute terms, it is less than 3 percent of all the hazardous loads being transported in the United Kingdom (140 MT per annum) which, in turn, is less than 3 percent of all freight being transported in the United Kingdom (1,900 MT). From this point of view, hazardous wastes represent an almost negligible proportion of the overall freight transport business. But, of course, the hazards themselves are potent and the risks cannot be ignored.

This should lead naturally to the question of risk-assessment. However, where many people are (rightly) skeptical of calculations based on average values derived from a small number of rare incidents, it is possible to assess risks for the transport of hazardous materials as a whole. But for wastes alone, it is not possible because in the United Kingdom, there has never yet been a death directly attributable to the transport of hazardous wastes. From 1970 to 1982, the average number of deaths per year due to the transport of chemicals by road was 0.46. This represents a total of only six deaths in 12 years (arguably too small to form a representative sample for risk-analysis) and, of these, three were believed to be the straightforward result of breaches of regulations. There is also the problem, for risk analysis of any kind, of distinguishing casualties resulting from collision of vehicles rather than from exposure to the loads they were carrying.

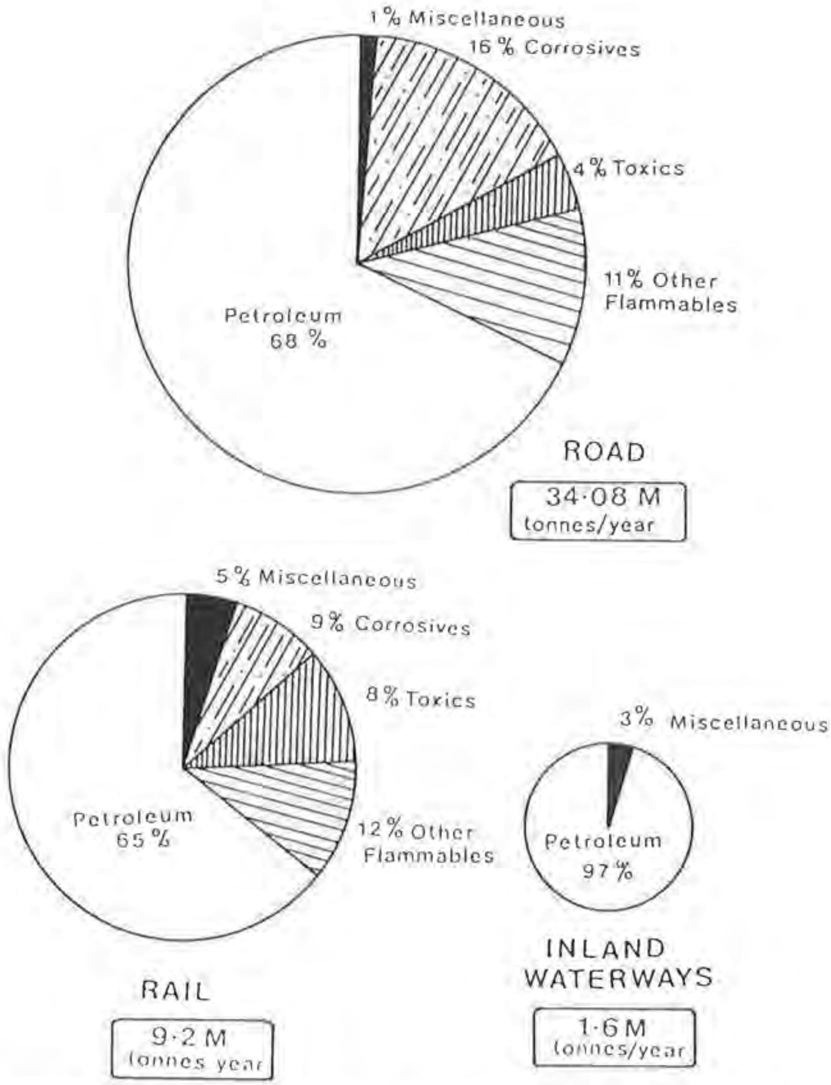


FIGURE 1 Transport of bulk hazardous chemicals in the United Kingdom by mode.

TABLE 2 HAZARDOUS WASTE DEPOSITED IN THE COUNTY OF ESSEX DURING 1977

Classification of Waste Materials	Bulk Gallons	Drummed Gallons	Equivalent Tons	Per-centage
Paints/polymers	3,689,350	717,238	15,470	19
Undefined miscellaneous	2,907,710	396,038	10,047	13
Tars/phenols	852,978	172,976	9,520	12
No worse than sewage/sludge	726,590	46,065	8,663	11
Plastic polymers	519,845	567,159	7,838	10
Alkaline wastes (no toxic metals)	7,030,850	74,282	7,543	9
Special hazard or nuisance	1,930,246	149,767	7,224	9
Oils	12,511,790	102,400	6,745	8
Pharmaceutical/laboratory chemicals	45,040	27,210	3,259	4
Neutral wastes (no toxic metals)	1,476,191	11,015	1,720	2
Non-notifiable	1,141,660	13,760	776	1
Cyanide wastes	1,703,737	37,755	667	1
Toxic metal waste (acid/alkaline)	4,108,558	4,193	657	1
Acid wastes (no toxic metals)	2,281,109	7,552	212	–
Solvents (nonhalogenated)	2,039,340	125,900	131	–
Solvents (halogenated)	813,450	22,706	75	–
Pesticides/herbicides/fungicides	273,957	5,564	38	–
Total deposited	44,055,400	2,841,582	80,512	100

INCIDENTS INVOLVING HAZARDOUS FREIGHT

Knowledge of the incidents involving spillage following collision of vehicles carrying hazardous substances is still not complete, even though a national survey of incidents involving hazardous freight moving overland in Britain has been conducted by the Scientific Advisory Branch of the Home Office *(6)*. This was based on a questionnaire, copies of which were sent to all the fire brigades in Great Britain. Each brigade was asked to complete one questionnaire for each chemical incident to which it had been called during the 12 months of 1980.

During 1980, there were 336 road transport incidents involving hazardous freight. Of these, 6 percent occurred on motorways, 36 percent occurred on A-class roads, 17 percent occurred on B-class roads, 9 percent occurred on unclassified roads, and 29 percent occurred off the highways; that is, in loading bays and parking areas. The cause of the incidents was an ordinary road accident in 36 cases (11 percent). The presence or absence of United Kingdom Hazard Information System (UKHIS) (devised by Cleveland constabulary) labels were recorded in 134 cases. The labels were present in 63 percent of the recorded cases but the details were correct in only three-fourths of these cases. Table 3 gives the number of recorded incidents involving chemicals by individual fire brigades and a breakdown of these incidents into static and transit types. The transport incidents are further categorized into those involving chemicals and petroleum but no fire, and those involving hazardous chemicals as well as fire. There were only two incidents involving fire and casualties as a result of the chemicals transported.

These data relate to all hazardous loads. Those involving wastes are always found under the "other" or "miscellaneous" categories. Thus, in view of the small number of accidents involving hazardous wastes, it would be difficult to conduct a meaningful risk-analysis for the United Kingdom. Because of difference in practices, data from abroad are often not relevant, and there is certainly nowhere near a representative sample of accidents available in the United Kingdom.

This suggests that the safe disposal of wastes must be regulated by common-sense practices, carefully monitored in the

TABLE 3 UNITED KINGDOM HOME OFFICE SURVEY OF INCIDENTS INVOLVING DANGEROUS GOODS

Modes of transport	Road	250
	Rail	18
	Port	35
	Airport	1
(Total reported incidents)		304
Type of load	Bulk tank	98
	Packages	81
	Individual drums/containers	125
		304
Degree of spillage	None	44
	1 to 10 liters (2 gal)	109
	11 to 210 liters (45 gal)	109
	Over 210 liters	42
		304
Product hazard	Flammables	110
	Corrosives	107
	Toxics	55
	Other	29
	Nonhazardous	7
	Not identified	4
Casualties	Fatal	6
	Injuries (traffic accidents)	41
	Health impairment (chemical effects)	69
Vehicle labeling	Product name	181
	Hazard "diamond"	152
	Specialist advice telephone no.	89
	Tremcard/instructions	79
	Hazchem plates	47
	Other labels	45
	None	59
Specialist advice sought from	Consignor/consignee	91
	Local fire brigade	55
	Chemical companies (ex-consignment)	26
	Harwell	24
	Others	73
	None	73
		304

Note: Nine-month period, February 1, 1977–October 31, 1977.

public interest, rather than based on either a "socially acceptable" degree of risk or on some hypothetical economic optimum.

ORGANIZATION OF WASTE DISPOSAL

The method of eventual disposal of any waste in the United Kingdom is usually decided by each of the 165 waste-disposal authorities, which impose conditions on licensed sites, subject to the possibility of the secretary of state requiring the holder of a disposal license (or the disposal authority) to accept and dispose of specified special wastes. Because of the large number of waste disposal authorities, this had led to a wide variety of conditions, which is probably not in the best interest of either the waste producer or the community. Because landfill sites are usually cheaper than any other form of disposal, producers and haulage contractors may find it more economical to travel several hundred kilometers to a licensed site with a particular waste than to dispose of it, for example, by means of incineration at sea, even though such facilities may be nearby.

If a national policy relating to landfill sites was to be adopted (using classifications, if needed, for different risk categories) and a nationwide structure of sites set up, haul distances could be reduced, with a consequent reduction in the possibility of road traffic accidents. The Select Committee on Science and Technology of the House of Lords *(7)*, which reported in 1983, has proposed that waste disposal authorities be grouped into 11 waste disposal regions for the purposes of providing facilities, scientific services, and coordinating waste disposal plans. Eight of these regions would be based in geographical areas in England, and one each in Scotland, Wales, and Northern Ireland. The main advantage of a large region is that only one central pool of experts is needed. It is impossible for every small waste disposal authority to employ a highly qualified team of experts, but by appointing a team to each region, the services of a chemist or a toxicologist could be made readily available.

In central Scotland, three regional and district council groups have already been established to coordinate waste disposal, but the remainder of Scotland still operates on an informal basis. In Wales, three regional groups have been established to cover the north, southeast, and southwest. Northern Ireland, because of its compactness and the small volumes of hazardous waste generated, does not have a formalized structure, but disposal authorities do liaise with one another across the province. However, the government has so far opposed the idea of a new structure of regional groupings in England, where, in its view, the need for hazardous waste disposal can still be met by an informal process of regional consultation and coordination.

Disposal sites in the United Kingdom are licensed, subject to conditions imposed by the disposal authority, under special waste regulations. Once under the regulations, records must be maintained for all licensed landfill sites showing the location of each deposit of special waste on a site plan, which must be kept until the disposal license is surrendered or revoked and then sent to the disposal authority. This site plan is not needed, however, for liquid wastes discharged (without containers) into underground strata or workings, but a record must be kept of the quantity and composition of wastes discharged in this way. Another recommendation of the Select Committee *(7)* was that site operators should be required to monitor their sites during operation and for a given period afterwards. The government has accepted this recommendation and intends to provide guidance through the Landfill Practices Review Group, making the results of monitoring available to the public.

Important guidelines, published recently in the form of the Waste Management Papers of the Department of the Environment (DoE) *(8)*, urge industry to adopt production processes that minimize waste disposal problems. The guidelines point out, too, that waste disposal authorities will always provide technical advice on disposal. The government has agreed with the Select Committee *(7)* that landfill is the best practicable means for a wide variety of wastes, provided that the site is suitable. A long-term view of both the United Kingdom Government and the Select Committee is the desirability of classifying wastes according to their suitability for landfill, although variations in site conditions, as well as quantities and characteristics of wastes, mean that substantial flexibility must be introduced into the classification.

One material currently causing some concern in relation to its deposit in landfill sites is asbestos. Despite the fact that it is sufficiently safe to dispose of this material in landfill sites, getting rid of asbestos is an emotive issue and the mere mention of it appears to spark protests from residents anywhere near a site licensed for its deposit. Specific guidance on disposal of asbestos and other wastes is given in the *Waste Management Papers (8)*.

The Select Committee believed that, at the time of issuance of its report (1983), the degree of control over landfill sites needed to be strengthened. The special waste regulations at that time had not long been introduced, and the government considered that any action should be decided on after studying the first report of its Hazardous Waste Inspectorate *(10)*. This report indicated the Inspectorate's concern over the disparity of attitudes between waste producers, waste disposal contractors, and waste disposal authorities, which vary from "thoroughly professional" to "downright neglectful." The Inspectorate was also concerned that site licensing conditions can be breached without enforcement action being taken by the waste disposal authority. Although the report emphasized that many sites are run in accordance with current best practice *(10)*, it is important to correct malpractices in order to foster public confidence and acceptance. In particular it was believed that, if it were followed, the improved guidance on landfill sites published by the DoE *(8)* will result in better disposal practice.

Overall, the United Kingdom Government's response to the Select Committee's report on hazardous waste disposal, published in April 1985, has been less than adequate. Members of the Select Committee were disappointed that no conclusions were reached on three issues: (a) registration of hazardous waste producers, (b) quarterly returns on their production of wastes, and (c) licensing of professional handlers of hazardous waste. The government has stated that these issues are covered in the recently completed review of the special waste regulations scheduled (to take place after 12 months' operation of the regulations) and that, when the report of the review has been studied, the government will reconsider the issues in the light of this review and comments by interested parties.

Another source of disappointment to the committee was that, as a result of the Local Government Act (1985) (under which the Greater London Council and the other metropolitan authorities in England were abolished), waste disposal authorities could be fragmented in these major urban areas. The committee believes that the number of waste disposal authorities in existence (165), each with independent planning powers, is unlikely to produce consistent disposal patterns throughout the country.

PROCEDURE FOR DISPOSAL OF HAZARDOUS WASTES

The consignment procedure under the Control of Pollution (special waste) Regulations (1980) *(10)* requires the producer of special wastes to prepare consignment notes, usually six copies, one of which must be sent to the disposal authority for the area in which the waste is to be dumped. If this authority is different from that in which the waste is produced, then a copy of the consignment note must also be sent to the authority in whose area the producer operates. The precise form of the consignment note is set out in Schedule 2 of the regulations and is in five parts: Part A indicates where the material is to be collected, and Part B is a description of the material to be completed by the producer. Part C is to be completed by the carrier, and, in addition to certifying that he has collected the substance, the carrier must also certify the details in Part A and the general description and physical nature of the waste, as well as the quantity and size of waste. The producer must then fill in Part D, which certifies that the information in Parts B and C is correct. The fifth part of the consignment note is directed to the carrier, after completion of Part E, and also to the authority in whose area the special waste was produced. This "cradle to grave" system of documentation ought to have the effect of ensuring that all dangerous wastes are dealt with by properly authorized disposers at licensed sites.

PERFORMANCE-TESTING OF PACKAGES AND CONTAINERS

With regard to packaging, there is a duty under United Kingdom law for all consignors of dangerous goods to ensure that such goods are sent in packaging that complies with the requirements of the mode of transport selected. For road transport, the only relevant legislation applies to loads, exceeding $3m^3$ in volume, carried in tanks or tank containers. The Packaging Industry Research Association (PIRA) is at present the only body carrying out tests on packaging, but other bodies may also carry out tests by arrangement with PIRA. Effective January 1, 1985, only bodies accredited by the National Testing Laboratory Accreditation Scheme (NATLAS) were to be authorized to carry out tests leading to the issue of recognized United Nations (UN) certificates but implementation of this rule has been delayed. It is expected that, among other things, the issue of testing will be covered in the proposed Road Traffic (carriage of dangerous substances in packages, etc.) Regulations 1986 SI 1951.

It is expected, therefore, that by 1990 all packaging in Britain will be tested to UN standards. However, until that date, the requirements established by the British Standards Institution will continue to be met, in parallel with the UN specifications. British Standard 4826, in its various parts, delineates methods of testing for complete, filled, transport packages but there are also requirements for specific types of packages (e.g., 210-l steel drums) set out in other British standards.

LABELING OF DANGEROUS GOODS AND PLACARDING OF VEHICLES

Labeling of Hazardous Loads for Transport

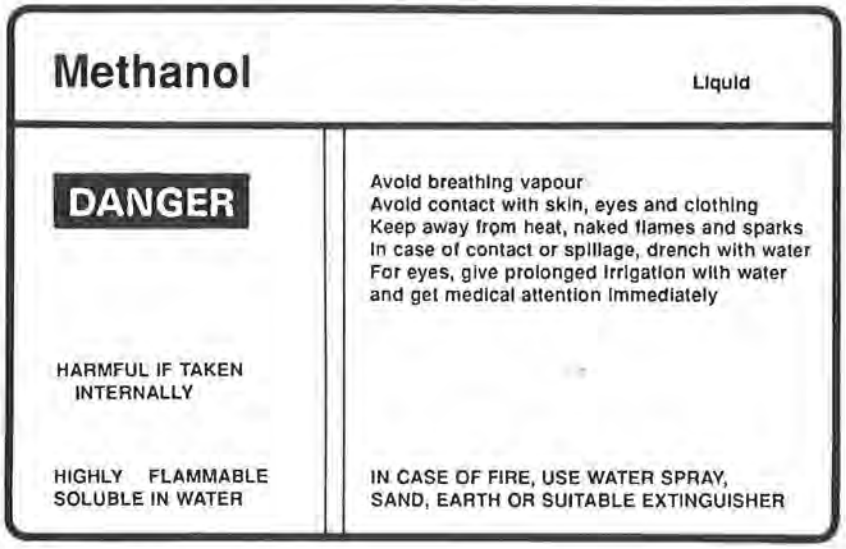
The law relating to the labeling of dangerous goods (including wastes) for overland transport is contained in the CPL regulations *(4)* and in British Rail's List of Dangerous Goods (LDG). Inland waterways are similarly controlled by the British Waterways Board's conditions, and the International Maritime Organization (IMO) has developed specifications, for the transport of dangerous goods in sea-going vessels, in the International Maritime Dangerous Goods (IMDG) code. Labeling now applies to individual drums and packages of hazardous goods (Figure 2), as well as to tankers and containers.

Placarding of Vehicles Carrying Hazardous Loads

Placarding in general follows the practices of European Agreement on Carriage of Dangerous Goods by Road (ADR) and Réglement de transport Internationalé Serro Ferro Viajre des Merchandise Dangereuses (RID), but with two important exceptions. The first of these is the use in the United Kingdom Hazard Information System of an action code in place of the Kemler number preferred in several other European countries. The Kemler number, which effectively echoes the hazard warning triangle, provides much less information to the emergency services than the Hazchem action code (Figure 3).

Incorporated into the Hazchem code by means of only a number between one and four and one other letter is sufficient information to enable the emergency services to use the correct fire-fighting medium and to wear the correct personal protection. Such a code would be unnecessary if the fire station computer could be reached by radio or data link to provide all the required information from the substance identification number, but this takes time and occasionally computers fail to operate. Radio links have also been known to break down. Arguably, any reliable information to help the man on the spot cope rapidly with an emergency must be worthwhile.

There is included in the approved lists for use with both the CPL and the tanker regulations a series of provisional substance identification numbers allocated by the United Kingdom specifically for wastes (see Table 1). These numbers range from 7006 (hazardous waste, liquid, containing acid) to 7023 (hazardous waste, containing organo-lead compounds, not otherwise specified). Although these wastes are all classified under the grouping of "other dangerous substances," they are nevertheless allocated a Hazchem code *(7)* on the tanker-approved list. In the pink pages of its LDG, British Rail uses the same provisional substance identification numbers for wastes but allocates them to Classes 3, 6, and 8 of the LDG covering the more important ones. This extension of the system of substance identification numbers, particularly when it is accompanied by the Hazchem action code, is to be strongly recommended.



It is recommended that manufacturers print their names, addresses and emergency telephone numbers at the bottom of these labels, which can be either self-adhesive or reversible tags incorporating the address to which empty containers are to be sent.

FIGURE 2 Chemical Industries Association package warning label.

REGULATION AND LICENSING OF OPERATORS

The need for a contractor to have an operator's license before he may use a large vehicle for the transport of goods for hire or reward, together with a Certificate of Professional Competence to be held by the transport manager, now means that there are very few "disreputable" haulage firms plying their trade on the roads of the United Kingdom. The license holder must be the person who uses the vehicle which, in the case of a one-truck firm, is the owner and in most other cases the person who employs the driver. There are nine traffic areas in the United Kingdom, and an operating license is required in each traffic area in which there is an operating center. Criteria that have to be fulfilled before a license may be granted include general fitness to manage, financial resources, and the suitability of the proposed operating center.

Regulation 21 of the Dangerous Substances (Conveyance by Road in Road Tankers and Tank Containers) Regulations (1981) *(5)* imposes a duty on the operator of a vehicle carrying a tank of more than 3000 liters, or a road tanker of any size, to ensure that the driver of such a vehicle has received adequate instruction on the dangers presented by the substance and the emergency action that should be taken, as well as the driver's duties under the regulations. The operator is also required by the regulations to keep records of instruction and training received by a driver during his employment and to make available to the driver a copy of such records. Training courses are provided by national schemes such as those set up by the Chemical Industries Association (CIA) and the Road Transport Industry Training Board (RTITB) or may be provided locally by individual operators for their own drivers or by a consortium of operators, when it would not be feasible for individual operators to set up their own courses.

In general, the training arrangements in Britain have improved in recent years and continue to receive priority on the grounds that in any incident the driver is (by definition) the first person on the scene and his trained response to an emergency will have considerable bearing on its outcome.

MONITORING MOVEMENTS OF HAZARDOUS WASTE

Increasingly, research in transport is concerned with the applications of information technology to freight operations. A typical project is that of Castle Rock Consultants of the University of Nottingham, who are engaged in research in the United States (the Crescent study) on a system of identifying a road vehicle by means of an electronic number-plate fixed underneath. This tracking method, known as the Oregon system, is at present monitoring heavy goods vehicles at state borders and specific points in between. The system relies on an inexpensive microwave generator on each vehicle, which has proved to be much more reliable than optical methods of identification *(11)*. The advantages of such a system applied to dangerous cargoes are self-evident, and firms are encouraged to use the system in order that they may know the whereabouts of each vehicle in their fleet. Drivers may resist initially but eventually they will probably accept it just as they have accepted the tachograph.

British Rail has developed a total operations processing

Compiled by the Cleveland Committee on Vehicle Placarding.

FIGURE 3 The United Kingdom hazardous information system.

system (TOPS), which uses a central computer in London to collect, process, store, and distribute information fed from all parts of the network. There are about 160 area freight centers located in the main areas of freight working, which report to the central computer all events involving freight traffic (such as movement, loading, unloading, repairs, etc.), as well as locomotive movements servicing and repairs. The LDG pink pages used in connection with the movement of hazardous goods has, for each substance, a TOPS commodity code, by which the precise location of all hazardous substances may be found instantly. The information stored by the TOPS computer is available to anyone who may need it and, although primarily a service to smooth the operation of the railway, can provide information to emergency services such as a full description of each wagon in any location, its load, and the load of any wagon nearby, whether or not they are part of the same train.

Although only a small proportion of hazardous waste is transported by rail, the TOPS system does demonstrate how a local or regional system of monitoring the movements of hazardous materials might be developed by electronic means.

INFORMATION AVAILABLE IN EMERGENCIES

The crucial first step in any emergency is to know the nature of the hazardous material at each location. Following a spillage or other accident involving dangerous goods, the local fire brigade would be informed, either by the police or by the carrier. Fire brigades in the United Kingdom now invariably have the equipment and expertise to deal with an incident of this nature, as well as the technical backup needed for identification of chemicals and instructions as to the correct way of safely containing or dispersing the danger. By virtue of their training, firemen arriving at the scene of a spillage attempt to identify it by the substance identification number, or otherwise. Once the chemical has been identified, more complete information can be obtained from the fire station using the Chemdata system.

Most fire services in the United Kingdom now have the data they need at their fingertips, thanks to the Hazchem code and to a service provided by the National Chemical Emergency Centre (NCEC) at Harwell in Oxfordshire. The service, called Chemdata, is available on subscription and has detailed information on more than 30,000 chemical products. For more than 11 years Harwell has been the focal point for the provision of chemical information to the emergency services, when the manufacturer of a spilled product cannot be contacted. Originally set up by the central government in collaboration with the chemical industry as part of the Chemsafe industry scheme, the data bank was considered an essential part of the Chemsafe service but was accessible only to duty officers at Harwell. This data bank, at that time called Hazfile, was made accessible on an experimental basis to all United Kingdom fire brigades on a direct dial-in system. Because of recent advances in microcomputers, the data need no longer be stored on a mainframe, and Chemdata is provided to most United Kingdom fire brigades on hard disks. These disks are sent to Harwell for updating about three times each year. A similar system has also been set up in Belgium.

The Chemdata file may be searched using the chemical product name, a synonym or trade name where either the complete name (or even just the first few letters) are known, as well as by the substance identification (UN) number or the Chemdata document reference number. Once the chemical has been identified, the microcomputer prints out details such as the usual state of the substance, whether it is miscible with water, whether or not the vapor is heavier than air, and the risk that is presented to persons nearby. Another section of the printout provides detailed instructions on the degree of protection needed by those involved in dealing with the problem, how any fire should be extinguished, and how to deal with any contamination. There are also lists of precautions such as "keep the container cool if involved in a fire," "prevent the substance from entering watercourses and sewers," and "avoid vapor." At the bottom of the printout is a list of chemical companies that may be contacted in an emergency. In addition to English, Chemdata is now available in French, German, Italian, and Spanish.

CONCLUSION

In recent years, there have been many changes in legislation involving the transport of hazardous wastes in the United Kingdom. In particular, the Dangerous Goods Regulations are expected to become law next year and this one step will go a long way toward removing one of the major loopholes in United Kingdom legislation relating to road transport. Rail transport is well-regulated by British Rail's List of Dangerous Goods, which is continually being updated. For the small amount of dangerous wastes transported on inland waterways, comprehensive requirements are set out in the British Waterways Board's "Terms and Conditions for the Transport of Dangerous Goods." Most important of all, the government has agreed to reconsider the recommendations of the House of Lords Select Committee on Science and Technology *(7)* with respect to compulsory licensing for all professional handlers of hazardous waste outside the place of production.

Finally, it must be stated that, although no serious incidents have ever been recorded involving the transport of hazardous wastes in the United Kingdom, vigilance must never be relaxed. It would take only one major accident to set back public relations in this field to such an extent that the only way to restore public confidence would be by Draconian regulation. This could, in turn, lead to prohibitively expensive transport and disposal methods, all of which would add to the unit cost of industrial production, arguably for no further gain in social well being.

ACKNOWLEDGMENT

The author is indebted to his two colleagues, Peter Isaac and Tom Norton (both previously of the University of Newcastle upon Tyne) whose substantial contributions to this paper are gratefully acknowledged.

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The Transport System of Dangerous Products as a Risk Factor for the Future: The Computer-Aided Information Program on Hazardous Materials

W. J. GEYSEN

Over the past 5 years, the author has been contacted several times to provide information and expertise in the cases of accidents involving hazardous materials transportation. In examining the response role of the first intervention personnel, it has been found that the real information problem could be reduced to three basic issues—identification of the appropriate product, protection, and action. Close cooperation with the Geel fire brigade and the computer center of the Geel Polytechnic allowed the establishment of a computer-aided information program, with information on nearly 60,000 products. A permanent team of 10 members, 7 of which are chemists, provides a permanent 24-hr source of information. The basic principle was to make available to the response personnel in the event of an accident, immediate, clear, structured, and brief details about the course of action to be taken in the initial phase. The program is primarily an action-oriented tool, and as such, differs from the available data banks. The program has been built up in such a way that the information can be requested and dispatched in four different languages: Dutch, French, English, and German. In the near future, up to eight languages will be available. Access to the information system can be obtained by United Nations number, product name, or internal Belgium Information Center—Dangerous Goods (BIG) number. The computer returns with the corresponding hazardous chemical (Hazchem) code so that immediate action can be taken. Ten different information modules are available. To save time, the most important facts appear illuminated and flashing on the terminal screen. On the printed hard copy, the most important facts are indicated with an asterisk.

The aim of this paper is to acquaint the reader with the origin, development, contents, and use of a pilot-information system on dangerous products. Since July 1983, Belgium has been able to offer immediate assistance with dangerous goods incidents via emergency response personnel and a multilingual computer-aided data system.

AIMS

An information system for dangerous products may be very important but it remains only a part of the entire problem of the transport of dangerous products. It is therefore necessary to open the entire complex problem of the transport of dangerous products both nationally and internationally, from applied scientific and methodological points of view inherent in a multidisciplinary safety science. This "opening up" can be done in two ways: the whole system of the transport of dangerous products can be dealt with or only the subsystem "information" can be considered. In this paper the first approach is used.

No human activity can be conducted without risk. Even normal handling of dangerous products carries a certain risk. The accident risk increases considerably as a result of the transient situation. The most important danger lies in the unwanted escape of a dangerous product. Moreover, these escapes during transport cannot be localized beforehand and, in order to limit the consequences, they require flexible emergency planning that is often hindered by the given circumstances.

SYSTEM APPROACH

The entire "transport of dangerous products" system is represented as an MTE system (M = man, T = technology, E = environment) (Figure 1). On the one hand, the three elements are linked together functionally and as absolutely equivalent components. On the other hand, however, the element called technology is to be understood in the first meaning that the Van Dale Dutch dictionary assigns: "all the operations necessary to realize something in a certain part of industry." It is therefore obvious that not only the dangerous product itself, but also the vehicle, transport system, road followed, storage, and transshipment must be considered in this MTE-system as components of the technology element (see Figure 2). As can be seen, this important information system on dangerous products is only one part of a very complex system full of risks.

The consequences of accidents with dangerous products vary. They include pressure waves; fire; poisoning; toxicity; caustic action; radioactivity; and air, soil, and water pollution. The dangerous products themselves are of a different nature—they can be gaseous, liquid, solid, or liquefied by forced cooling or congealment. The transport may occur via road, rail, water, air, or pipelines (mostly underground), as shown in Figure 3.

Katholieke Universiteit Leuven, F.T.W.–DEP.E.E.–Safety Lab, Kardinall Mercielaan 94, B–3030 Leuvan, Belgium.

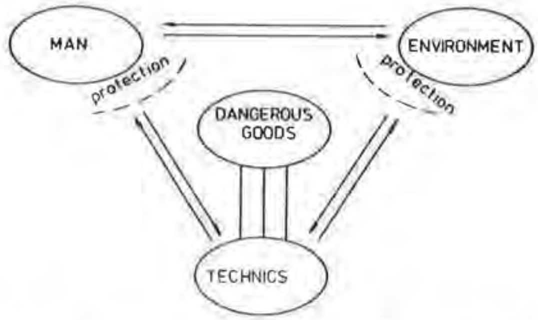

FIGURE 1 Dangerous goods in the MTE system.

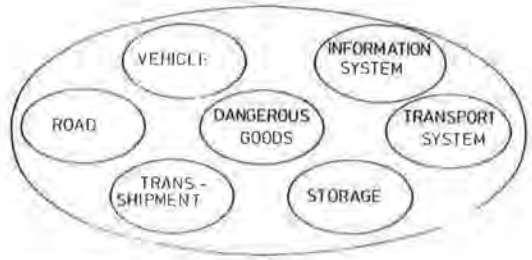

FIGURE 2 Subsystem technics.

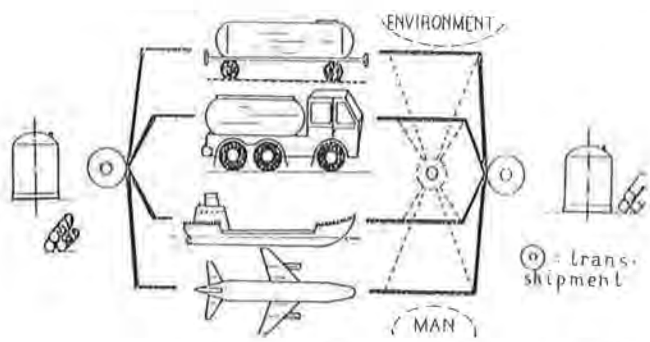

FIGURE 3 The MTE system transport of dangerous goods.

RISK CONCEPT

The risk concept in this contribution, meant as an objective risk, is the product of two equally important factors: accident frequency and gravity of the consequences. In this paper the problems of the subjective risk, risk perception, and risk acceptance are addressed. Accidents with dangerous products have a relatively low frequency but cause substantial damage and thus major consequences (see Table 1).

STATISTICAL RECORDS

Statistics show the proportional part of each means of transport. From the following table, it is clear that road transport comes first.

Means of Transport	*Total Accidents With Dangerous Substance (%)*	*Quantity of Substance (%)*
Road	74	18
Rail	5	33
Water	18	49

Source: Laboratorium Voor Algemene Systeemveiligheid en Forensische Ongevalsanalyse (1981).

In examining the proportional part of the various product groups in the number of road accidents given in the following table, it can be seen that oil products have the greatest risk potential.

Product Groups	*Total Road Accidents (%)*
Petroleum	49
Benzene	20
Solvents	7
Toxic substance	6
Acids and bases	6
Munition	4
Gas	3
Radioactive substance	1
Other	4

Source: Laboratorium Voor Algemene Systeemveiligheid en Forensische Ongevalsanalyse (1981).

Also interesting is the proportional division of the causes of accidents in road traffic. The influence of the human factor of "speeding" is clearly indicated in the following table.

Causes of Accidents	*Total Road Traffic (%)*
Speeding	40
Technical defect	12
Insufficient safety distance	8
Over-fatigue	7
Insufficiently secured load	7
Various causes	26

Source: Laboratorium Voor Algemene Systeemveiligheid en Forensische Ongevalsanalyse (1981).

For the entire road traffic, human influence factors are even more important in the total number of accidents as indicated in the following table.

Causes of Accidents	*Total Road Traffic (%)*
Faulty behavior of the driver	80
Faulty behavior of the pedestrian	9
Faulty influence of the means of transport	7
Technical defect	2
Various causes	2

Source: Laboratorium Voor Algemene Systeemveiligheid en Forensische Ongevalsanalyse (1981).

These sueveys indicate the direction in which improvement measures that could lead to risk reduction have to be developed.

TABLE 1 CHARACTERISTIC ACCIDENTS

Date	Place	Kind of Accident	Total Deaths	Total People Wounded
1967	Antwerp, Belgium	Fire in vinyl chloride installation	4	33
1972	Brazil	Explosion of butane cloud	38	78
1973	Lille, France	Explosion of propane gas tanker	2	16
1974	Flixborough	Explosion of cyclohexane	28	104
1974	Union of Soviet Socialist Republics	Ethylene explosion	14	79
1974	Heilbronn, Federal Republic of Germany	36 000 L benzine in canalization	–[a]	0
1975	Munich, Federal Republic of West Germany	Accident with radioactive material	–[b]	0
1975	Beek, The Netherlands	Propylene explosion	14	104
1976	Seveso, Poland	TCDB escape	–[c]	0
1977	Haltern, Federal Republic of Germany	Railway wagon with carbon dioxide explosion	–	–
1977	Columbia	NH_3 escape	30	22
1977	Piedmont, Italy	Tanker with CCl_4 turns over in Scrivia River	–[d]	0
1978	Munich, Federal Republic of Germany	2000 L toxic chromic acid escapes	0	23
1978	Los Alfaques, Spain	Tanker with propylene explodes	>200	–
1978	Schellebelle, Belgium	Railway wagon with C_3H_8 explodes	1	0
1978	Waverly, Tennessee, United States	Railway tankers with C_3H_8 are derailed	12	50
1978	Mexico City, Mexico	Tanker with butane explodes	11	200
1978	London, United Kingdom	Tanker with formaldehyde tears	2	50
1979	Mississauga, Canada	Tankers with C_3H_8 and Cl burn	–[c]	0
1980	Boston, Massachusetts, United States	Railway accident with PCl_3	–[c]	0
1980	Pont à Mousson, France	Tanker with liquid gas turns over	–[c]	0

[a]Explosion alarm.
[b]Radiation alarm.
[c]Evacuation.
[d]Water for 7 cities contaminated.
Source: Laboratorium Voor Algemene Systeemveiligheid en Forensische Ongevalsanalyse.

RISK CONTROL

These risk-reduction measures fall into three different categories: (a) safety legislation, (b) scientific safety approach, and (c) anthropology. They will be discussed in the following paragraphs.

Regulating Measures

The transport of dangerous products is conducted according to vast and complex national and international regulations whereby national legislation often proves to be intimately interwoven with international treaties and supranational regulations, and frequently is only a translated copy of the regulations. It is much worse, however, that neither of these types of regulations (national nor international) have yet been harmonized sufficiently. This can be accounted for, however, by the historical growth and the differences in composition, nature, and aims of the respective groups that study these regulations. In addition, continuous technical development requires continual adjustments to these regulations. In practice, this mostly results in exceptions, deviations, special conditions, or exceptional regulations which, in turn, have to be frequently modified or readjusted. Besides, there is evidence that specific areas are not or are inadequately regulated. As a consequence, the regulations reach a point at which they can no longer be surveyed, read, or even practiced even by the expert because in most cases, the unmistakable and clear definition proves to be impossible. This situation unavoidably leads to uncertainty that may result in incorrect interpretations and wrong decisions. Solid control is hardly possible and—at its worst—it may lead to only partial—or no application at all of the rules and regulations. In this way, the intended safety level is not reached.

All foregoing statements about the transport of dangerous products actually apply to the whole safety law. Moreover, it is evident that all these problems are not confined specifically to Belgium, but are of supranational dimensions. This is the reason that responsible authorities might well stimulate and encourage a complete and coordinated research program that strives to attain the following goals:

1. Coordination of all national and international study groups.
2. Harmonization of all existing regulations.
3. Uniform and optimal representation of the regulations.
4. Possibility of adequate and direct access to all regulations by computer use.
5. Development of effective control information and feedback systems.
6. Uniform, multifactorial, and expert analyses of all accidents with dangerous products and computer processing of all information on causes, damage to the MTE system and all necessary emergency measures.
7. Creation of a national and international pilot group for the coordination of all regulations concerning the whole system of transportation of dangerous products.
8. Concentration of all national safety regulations in one centralized computer system that is easily accessible to all interested parties.

Taking up the matter of the Accord Dangereuse Routier (ADR) and Reglement International Concernant le Transport des

Marchandises Dangereuses (RID) regulations on a supranational basis might well be a first priority. The regulations could be standardized and compiled in an orderly fashion, made accessible with keywords in a useful form to everybody specifically interested, and could incorporate all exceptions. Through this effort, all interested bodies, public authorities, transporters, recognized organizations, prosecution officers, and police commissioners might be well assisted in their difficult tasks.

A final result of this effort would be that all national and international transport would have the benefit of a uniform and standardized control system with specific checklists which, at the same time, would represent an adequate feedback element for the adoption of the regulations and the attainment of the intended safety level. Perhaps the obligatory insertion of the European Economic Community Directives concerning the risks of grave accidents with certain "industrial activities" of June 24, 1982, into the national legislation will be a positive contribution to this information struggle against the risks of dangerous products.

Scientific Safety Measures

The technical safety measures taken and imposed in Belgium are undoubtedly of a high standard. Nevertheless, accidents during transport of dangerous products remain possible and their consequences as to damage gravity may be important. Incidents at Martelange, Seveso, Los Alfaques, Missasauga, Toronto, and Schellebelle are still remembered.

Although absolutely risk-free transport of dangerous products is unattainable because of failures in each of the subsystems (MTE), efforts should be made to reduce the occurrence of such accidents as much as possible, and to minimize the consequences of accidents that do occur by developing adequate emergency procedures. Because the dangers connected with the transport of dangerous products are both product- and surroundings-bound, thorough research in the following fields is necessary:

1. The basic principle that the increasing danger of the product must be met by an equally increasing strength of the packing or the container should be consistently carried out.
2. The volume of certain groups of products transported should be limited.
3. All system-bound risks appropriate to the transport of dangerous products should be analyzed.
4. The development of a complete intervention-oriented information system ought to be stimulated.
5. The necessary measures for optimal preventive emergency planning and centralization of power of decision should be studied.
6. A risk-register for the entire transport system should be drafted with special regulations for extremely dangerous products.
7. The dispersion problem of gases and vapors should be thoroughly investigated.
8. The static and dynamic stability of the transport systems used should be analyzed and checked.
9. All—and especially new—dangerous products should be studied and the danger limits defined.

Knowing that the reason for this presentation has been a partial pilot study of Item 4 of the previous list, the work still to be done becomes apparent. At present, safety-science disposes of adequate methods [fault tree-analysis, decision tables, environment-effect analysis, accident investigation analysis as management oversight and risk tree (MORT) analysis, etc.] which, in certain cases, may lead to the knowledge of the appearing difficulties, both qualitatively and quantitatively. These methods of risk analysis should be imposed for all complex systems with numerous and tightly interconnected components or for systems with an extremely high danger potential.

Regulating the Human Factor

Figures available show that approximately 50 percent of all accidents in the entire system of transport of dangerous products can be attributed to human failure. The need for thorough investigation into the safety-relevant influence factors of the subsystem "Man" that affect the whole system of transport of dangerous products is therefore obvious in order to reduce possible human failure. Investigation into the following fields is therefore suggested:

1. Special and permanent training for all personnel working in this field.
2. Licensing criteria for all contractors who play a part in this field.
3. Physical and mental health of all personnel with feedback to the admissible, general workload factors.

QUID NUNC WITH THE INFORMATION SYSTEM

The K.U. Louvain (Catholic University of Louvain, just outside Brussels) has often been called for information and advice in accidents or so-called "near misses" with dangerous substances. Over the past 5 years, the author, member of the engineering faculty of the K.U. Louvain, has been contacted several times by the Belgian authorities and asked to provide information and expertise in dealing with hazardous materials transport accidents. An overturned tanker, a leaking container on or off a truck, a damaged ship tanker after a collision, a broken glass container at the airport are all examples of accidents that demonstrate the need for an adequate information system.

It is partly from this experience that a decision was made to examine thoroughly, via a comparative study, the solutions to the problems in foreign countries. On the basis of this knowledge and thanks to a lucky coincidence of an existing interest at the Geel Fire Brigade and an existing infrastructure and computer know-how at the Geel Polytechnic (H.I.K.) and its computer center (M.I.K.), a pilot study was undertaken through a BTK project (Note: BTK refers to a temporary job service created by the government to reduce unemployment).

Initially, the purpose of the project was to set up a computerized information program as soon as possible that would be based on intervention and industrial needs, and that would be quickly accessible in emergency situations. To accomplish this the following features were incorporated:

1. The existing program was developed into a search program that could also provide answers to problems that involve limited or incomplete information, such as trade or partial names.

2. Information is simultaneously stored and matched up with other substances (new substances and trade names included).

3. The program simultaneously provides a permanent feedback from its data files via operational information cards.

4. The program is kept operational, which means that the information is accessible 24 hr every day of the year.

It is clear that these four features were necessary and for obvious reasons could only be implemented in Geel. After a certain time it was clear to every administrator that without state support, it would be impossible for the community of Geel to (a) host a long-term national or international center for dangerous products, (b) accommodate a specialized group of engineers for dangerous products, and (c) fulfill the role of a national crisis center. Due in large part to the efforts of the Minister of Home Affairs who recognized the need for such an information center and the capability of Geel to implement it, the center is now a reality. It goes without saying that such a center must be manned by excellent technicians to make and keep it operational. A permanent updating, a central control, and a fast and efficient transmission via a solid information system are absolute conditions for the continued success of the program.

As opposed to the various existing data bases, the Geel program also has international relevance not only because it is based on intervention (this also goes for the program in the English atomic center of Harwell) but because it is also multilingual (input as well as output). In fact, the information center at Geel is now implementing four new languages and has also started a 1-year project to implement the different legislations.

The developing and marketing of the possibilities of this pilot study give Belgium and the EEC a considerable start on information concerning dangerous products. A move toward a specialized intervention unit and a central crisis center appears a logical next step, although it would probably require a restructuring of some existing services. (The intervention unit in the Netherlands and the crisis center in France provide good examples.)

As stated previously, such an information system is only part of the total safety management, of which the intervention and emergency planning; all the nuclear problems; the communication difficulties; the training and retraining; and all the prevention problems for labor, traffic, spare time, and environment, form so many other main components.

It can be wondered whether it is not desirable to found an institution on English lines, a national "health and safety commission" combined with a solid regional restructuring of the safety corps, for competencies, as well as for abilities and training, around the existing provincial inspection services. No potential damage payer will mind the small sacrifices that may be made by some too-narrowly conceived municipal authority.

In a period of economic crisis, new initiatives are likely to be turned down with the argument that there is not enough money. More money may not be absolutely necessary. When coordinating the existing services in a solid way, much might be saved in the execution. There are enough funds available for the study within existing institutions and funds, providing that safety obtains the recognition of science and discipline and is treated equivalent to the other classic disciplines.

In the final analysis, industry is expected to follow the English example by contributing actively to the aspects of safety management for which they are responsible. Their information programs on the transport of dangerous products and especially the availability of their expertise would be a unique opportunity. Recent experiences in this matter have, unfortunately, been negative.

POSSIBILITIES AND CONTENTS OF THE PROGRAM

The information problem for dangerous products is not only a Belgian problem, but one for all countries. It is caused by a great diversity of products. For example, suppose an Italian tanker truck driver is transporting a French-manufactured chemical identified only by a trade name (no UN number) to the Federal Republic of West Germany and the truck overturns on a Belgian highway. In this example, three questions must be answered immediately:

1. What is the product?

2. What means of protection are required for the intervening personnel?

3. What must be done?

The intervention problem is connected with the wide range of possible accident situations and is considered to be the most critical one. Therefore, it was given priority in this project.

In this preliminary study, the available information systems (reference books, card systems, data bases) were investigated for content and operational value. Reference books and index cards were useful for "first-line" work but not for difficult problems (products without UN code, trade names, or with incomplete names). Available data bases (DABAWAS, ECDIN, TOXFILE) have not been set up for intervention purposes and, consequently, do not aid in solving this problem. They contain large amounts of irrelevant information while intervention information is, for the greater part, missing. Only a specifically established data base with an appropriate retrieval program can be utilized.

One of the objectives to be accomplished while developing this specific data base was to create a system which, besides its indispensable scientific and technical contribution, would primarily aid the emergency staff in action. The basic principle, therefore, is to provide immediate information about the course of action to be taken in the initial phase of an intervention in a chemical accident, without reference to books, inventories, or chemical scientists. The program is therefore a source of information that can be useful for all intervention services because assistance is immediately available.

Data Retrieval

How can data be retrieved in a relatively simple way? As a result of language difficulties experienced internationally in the exchange of data, a multilingual program proved to be necessary as opposed to selecting only one language (i.e., Dutch, French, English, or German). The program is now being extended to include four additional languages. There are then three possibilities for multilingual data retrieval: (a) by UN number, (b) by product name, and (c) by internal BIG number.

By UN Number

Several regulations exist for the international transport of hazardous materials according to the means of transport used. The following table gives the names of the regulating agencies and their corresponding jurisdictions (transport modes).

Agency	*Mode*
RID	Rail
ADR	Road
ADN(R)	Inland Navigation (Rhine)
International Maritime Organization (IMO)	Sea
International Air Transport Association (IATA)	Air

As a typical example, transport by road will be illustrated.

In these legislations, we are especially interested in the provisions that concern the identification of the product. On the front and back of a vehicle carrying a dangerous product, there must be an orange board with two numbers. The upper number is the danger code (Kemler number). The lower number has a 4-digit UN number identifying the product. This international UN number, which is also applied nationally, is used as an access code to the Geel system.

Product Name

A second possibility for data retrieval is via the chemical name of the product. To avoid faulty spelling and thus fail to have access to the data of the product, only the first two or three letters of the name need to be entered. All products whose names begin with those two or three letters will then appear on the screen. The exact denomination is then selected and all data are transferred.

BIG Number

BIG, which is Belgian Information Centre—Dangerous Goods, is a technical number used internally for the classification of the UN number; it is furthermore the access key independent of the UN number. When a product is retrieved via one of the three ways of access to the system, the information appears on the screen in the form of a "menu." The following message will be displayed on the screen:

- UN number (see above),
- BIG number (see above),
- Danger code, and
- HAZCHEM code.

The Kemler number, or the danger code, indicates the primary and secondary danger of the product (e.g., "633: 6 = toxic and 33 = highly flammable liquid"). The HAZCHEM (Hazardous Chemicals) code is an English fire brigade code for assistance at accidents involving dangerous products. The code can be passed on to the intervention team as a first piece of information. For example, the following message would be displayed on the screen:

3WE:3 = use foam
W = complete personal protection with breathing protection; keep leakage under control; a violent or explosive reaction is possible
E = evacuate people from the immediate surroundings of the accident

The principal names also appear on the screen in the various languages. The following message display shows a list of the program modules:

1. Type of hazard.
2. Emergency action, method.
3. Personal protection.
4. Properties, appearance + composition.
5. First aid: symptoms + measures.
6. General precautions.
7. Remarks.
8. Experts.
9. Literature.
10. Synonyms.

Contents of the Program Modules

See output document ACRYLONITRILE

1. Type of hazard
   - This part deals with the dangers that may appear when intervening.
   - The data provide insight into the applicable emergency action, the personal protection, and the general precautions.
2. Emergency action
   - Action to be taken to cope as efficiently as possible in case of accidents with dangerous products (fire, leakage).
   - Fire-extinguishing agents.
   - Clearing action.
3. Personal protection
   Protection measures for the intervention team in direct contact with the danger.
4. Properties + appearance
   - Physical condition + appearance.
   - Color.
   - Smell.
   - Large amount of physical data.
5. First-aid
   - Symptoms after:
     - Breathing the product,
     - Contact with the skin,
     - Contact with the eyes,
     - Swallowing the product.

- Measures after:
  - Breathing the product,
  - Contact with the skin,
  - Contact with the eyes,
  - Swallowing the product.

6. General precautions
   This part of the program is, among others, useful as a means of identification for other emergency services. The federal or local police, for instance, do not need to know the physical properties, but they should be able to take care of the safety in the accident area in an efficient way. This part of the program contains the general precautions to be taken, such as keeping up wind, blocking roads, guarding against naked lights or sparks.
7. Remarks
   It is important to know how the product is packed. In the future, this will be included in the program partly for identification purposes.
8. Experts
   Unlimited amount of data about experts:
   - Country,
   - Names of experts,
   - Manufacturers of the product,
   - Telephone numbers.
9. Literature
   Information about the literature of the given product and the relevant pages.
10. Synonyms
   In this file, all chemical and trade names are listed in different languages. With this file of synonyms, the information about a product can be retrieved even though only a trade name or a synonym of the product is known.

CONCLUSIONS

From these data, the following conclusions are drawn:

1. The risk of an accident with an escaping dangerous product (the word "risk" is defined as the product of accident frequency and damage gravity) is characterized on the one hand by a low accident frequency but on the other hand by a high damage consequence (damage to people, environment, and the plant involved).

2. It is the national and the supranational authorities' duty to steadily increase the safety level of the entire MTE transport system by constant reduction of danger potentials and of the risk as a whole. This can be realized if, for each of the MTE subsystems, the bottlenecks are adequately analyzed. For this purpose, the available data must be systematically organized and used in the best way. The risk control aimed at has not only a purely technical, but also an economic and socioecological significance, especially in the field of risk acceptance of catastrophes with low frequency.

Although universities are very often reproached for not being society-focused and engineers are often told only to be interested in the naked technologies, an attempt has been made, via a preliminary analysis of the entire MTE transport system for dangerous products, to get a provisional idea of all the bottlenecks and an attempt has also been made to formulate a first series of proposals on three separate levels—regulating, safety-scientific, and human—so as to come to a better risk control via a well-coordinated multidisciplinary approach.

The information system that has been developed in Geel is a first, humble, partial pilot study of a project. The international interest in it proves the importance of such safety realizations that try to reduce and control the dangers for mankind.

It is hoped that national and supranational authorities will react, each on his level, with a coordinated and deliberate safety-scientific research plan that can be realized at short notice.

Belgium has at its disposal a unique and multilingual computer-aided data system to tackle hazardous materials incidents. But the system itself is still incomplete and needs constant updating and correcting. Top priority additions to the program will include further data on trade names, chemicals without UN numbers, partial names, and industrial waste. The program is being continuously updated and developed. More material is being added to the information data base (such as mixtures and specific groups such as pesticides, explosives, etc.); the search program is continuously under development; four more languages will be implemented; and, within 1 yr, it is hoped that all transportation legislation will be input.

A completed system should not be regarded as the ultimate goal, however, but rather as just another useful tool in efforts to reduce hazardous goods transport risks. The question that immediately arises is whether this information system completely eliminates the problems of the entire system of transportation of hazardous chemicals. Can the industry quietly sit down and wait for the next major accident and limit its consequences by the use of the described information system? The answer is clear: No!

It must be clear to everyone that this information system, however important it is and whatever high priority it has, remains only a part of the total problem complex of the transportation of hazardous chemicals. This total problem complex will be the subject of a later project.

ACKNOWLEDGMENT

The author is grateful to the Minister of Home Affairs for his initiative in recognizing the BIG computer-aided information project and giving it living space for the following years.

A Validation Study of the INTERTRAN Model for Assessing Risks of Transportation Accidents: Road Transport of Uranium Hexafluoride

E. G. TOMACHEVSKY, C. RINGOT, P. PAGÈS, AND P. HUBERT

The INTERTRAN code was developed by the International Atomic Energy Agency in order to provide member states with a simple and rapid method of assessing the risk involved in the transportation of radioactive materials and one that was applicable on a worldwide scale. Before being used, this code must be validated and thus the Commissariat à l'Energie Atomique compared the results obtained with the conventional risk-assessment methods used by the Centre d'Etudes sur l'Evaluation de la Protection dans le domaine Nucléaire with those derived from INTERTRAN. The results of the studies conducted on road transportation of uranium hexafluoride in France are presented. The conventional accident risk-assessment method gave a figure of 8.84×10^{-4} deaths per year, whereas INTERTRAN obtained 1.78×10^{-2}. To these figures should be added 3.38×10^{-2} deaths per year, which is the intrinsic road risk whatever the goods carried. In relation to conventional estimates, the INTERTRAN forecasts are 5 times lower for the uranium risk and 20 times higher for the hydrogen fluoride risk. The chemical risk is indeed the most prevalent one in this case. Other comparisons are needed to validate this code.

In 1977 the Standard Advisory Group on the Safe Transport of Radioactive Materials of the International Atomic Energy Agency (IAEA) recommended that a risk-assessment program be launched in connection with the transportation of radioactive materials. The purpose was to develop a simple risk-assessment method that could be applied on a world-wide scale.

In 1979 the creation of the INTERTRAN *(1)* code was entrusted to a working group led by Sweden with strong U.S. participation, because the model is based on the RADTRAN II program produced by Sandia National Laboratories *(2)*. The CDC and the IBM versions of the code were sent to users in 1982 and 1983. After some slight reworking of the program, computer runs began at the end of 1984 at the Commissariat à l'Energie Atomique (CEA).

One of the first applications was the risk assessment of road transportation of uranium hexafluoride in France *(3)*, so that it could be compared with a study already conducted for the CEA by the Centre d'Etude sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN) *(4)*.

CEN-FAR, 60-68 avenue du Général-Leclerc, B.P. No. 6, 92265 Fontenay-aux-Roses, Cédex, France.

DATA

Material Transported

Depending on the uranium enrichment level, uranium hexafluoride (UF_6) is considered to be depleted, natural, or enriched.

UF_6 (depleted, natural, or enriched to less than 1 percent) is transported in DV08 containers (American designation, 48 Y). These are industrial-type cylindrical casks 1.20 m in diameter and 3.80 m long. They are made of 16-mm-thick steel and weigh 14.9 tonnes when filled to their maximum capacity of 12.5 tonnes of UF_6, that is, an equivalent of 8.4 tonnes of uranium.

UF_6 enriched to more than 1 percent is transported in DV05 containers (American designation, 30 B) equipped with an FS 50 protective shell (American designation, 21 PFT). These are B(U)-type cylindrical casks 0.76 m in diameter with an overall length of 2.05 m. They are made of 12.7-mm-thick steel and when equipped with their protective shell, their diameter is 1.10 m and their length 2.21 m. They weigh 2.9 tonnes when filled to their maximum capacity of 2.5 tonnes of UF_6, an equivalent of 1.4 tonnes of uranium.

Quantity Transported

Details of the UF_6 shipments are given in Table 1.

Route

The majority of UF_6 traffic in France is between the Pierrelatte plant and Le Havre, covering a distance of 900 km (see Figure 1). In reality, nearly all this traffic is by rail, but for the purposes of this assessment attempt, all traffic was considered to be by road. Elsewhere, the CEPN has given the risk per package per kilometer for both methods of transport (rail and road) *(4)*.

Type of Hazards

In a moist atmosphere, uranium hexafluoride breaks down into UO_2F_2 and hydrogen fluoride (HP). The risks are therefore both chemical and radioactive.

TABLE 1 UF_6 SHIPMENT DETAILS

Type of UF_6	Weight of Uranium (tonnes)	Reciprocal Activity (gm/Ci)	Transported Activity (Ci)	No. of Packages per Transport	No. of Transports per Year	Weight of UF_6 Transported (tonnes/year)
Depleted	8.1	2×10^6	4.05	1	120	1,000
Natural	8.1	1.42×10^6	5.70	1	120	1,000
Enriched	1.4	4.91×10^6	2.85	5	72	500

HF is a toxic gas. In the long term, fluorine can metabolize and cause bone damage. The danger is that of inhalation of hydrofluoric acid, which is likely to have an immediate effect. Without consideration of any effects leading to irreversible lesions, only lethal effects corresponding to an inhaled-dose threshold are dealt with.

The effects of UO_2F_2 are due both to the fluorine and to the activity of uranium. A difference can be determined between the early fatalities and the latent effects. The values adopted by the CEPN are as follows *(4)*:

1. HF, early fatality: threshold level at 50 mg inhaled,
2. UO_2F_2, early fatality: threshold level at 150 mg of U inhaled (172 mg of UO_2F_2), and
3. UO_2F_2, latent effects: 2×10^{-2} effects per man-sievert (i.e., 1.2 radiation-induced cancers, 0.4 genetic effect in the first two generations, 0.4 genetic effect in the following generations), 3.6 Sv/g of enriched U inhaled, 0.9 Sv/g of natural U inhaled, 0.56 Sv/g of depleted U inhaled.

In the INTERTRAN code, the dose of dispersible products inhaled by an individual is calculated. This does depends on the radionuclides concerned and the organ affected. Radionuclide characteristics (activity, photon energy, decay period, etc.) and the 10 types of organs are defined in the code itself and cannot be modified in the data stream.

The evaluation of chemical hazards resulting from a traffic accident under the INTERTRAN code *(1)* is based on the UF_6 dose-effect values given in Table 2.

DESCRIPTION OF INTERTRAN CODE

The INTERTRAN code is a method of assessing the risk involved in the transportation of radioactive materials under normal conditions and accident conditions. The INTERTRAN model *(5)* is associated with a breakdown of the assessment procedure into modules describing the conventional sequence

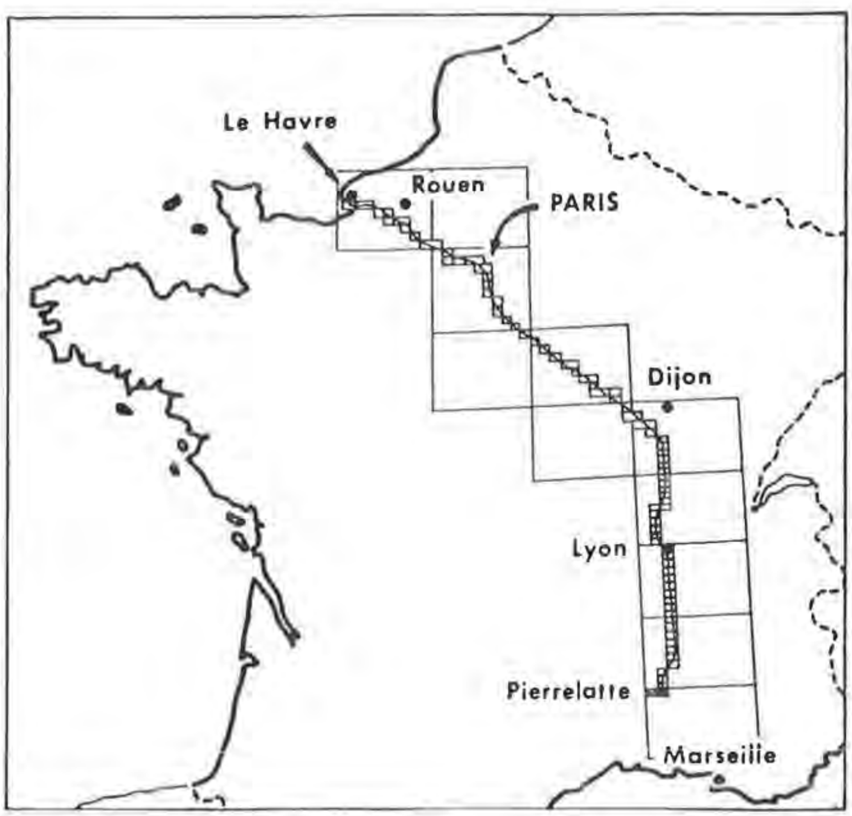

FIGURE 1 Route studied and identification of the fine grid pattern affected (large meshes = 10 000 km^2; fine meshes = 100 km^3).

TABLE 2 DOSE-EFFECT VALUES FOR URANIUM AND HYDROGEN FLUORIDE

Uranium		Hydrogen Fluoride	
Amount Inhaled (mg)	Probability of Fatality	Concentration Inhaled[a] ($mg \cdot m^{-3}$)	Probability of Fatality
800	1.00	800	1.00
500	0.95	500	1.00
300	0.80	300	1.00
200	0.70	200	0.95
170	0.50	170	0.75
140	0.30	140	0.50
100	0.20	100	0.30
70	0.10	70	0.10
50	0	50	0

[a]Exposure of 1 hr.

of operations required, for example, with regard to accident conditions:

1. Accident parameters and probability of occurrence,
2. Fracture rule,
3. Source term,
4. Dispersal rule,
5. Individual and collective exposure, and
6. Associated health effects.

The preceding steps lead to accident or fracture probabilities per kilometer traveled by a package and (in given transport conditions) to the assessment of the consequences of a given type of accident (for example, release of a certain quantity of radioactive material). By combining these steps with the models describing the actual conditions of the transport envisaged (method, route, etc.), in particular the demographic data for the regions traversed, the (health) risk assessment associated with a given transport program is reached (Figure 2).

Two types of data are generally required for each step in the procedure. The first concerns the parameters of the models used, for example, the occurrence probability values for the various accident scenarios or the various levels of seriousness of an accident. These values are generally considered internal

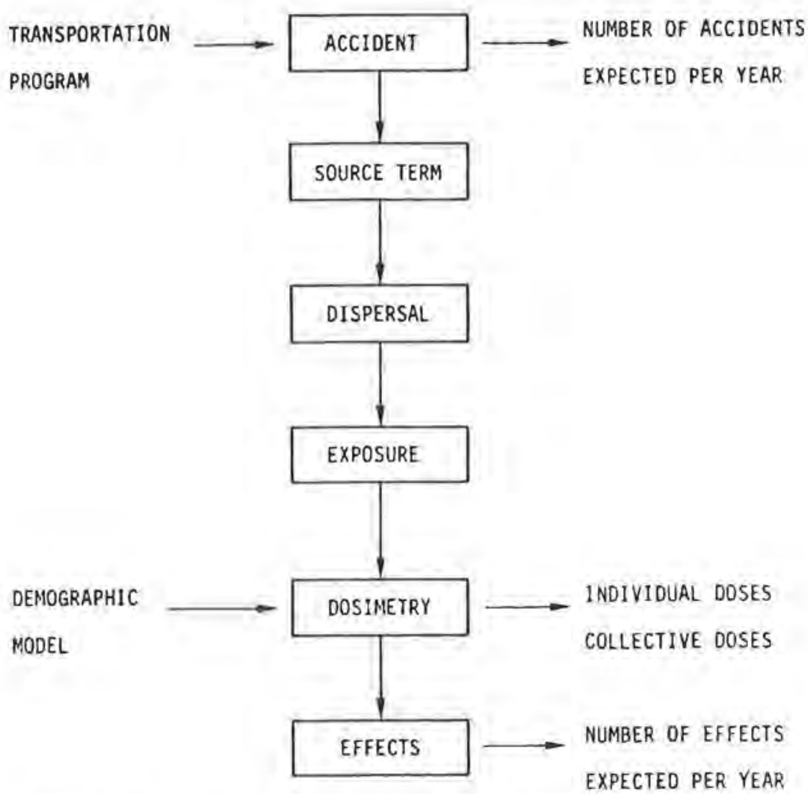

FIGURE 2 Accident risk-assessment model in INTERTRAN.

to the program and can only be modified at the code level (programming problem) and of course only after the possible implications of all these modifications on the results have been examined (modeling problems). In general, these data result from statistical analyses or theoretical calculations, which must be valid for all envisaged applications. The default values contained in INTERTRAN cannot be accepted without a certain number of precautions. The second type of data, however, is peculiar to the case examined and enables the methods or the values for certain characteristic variables of the package concerned to be specified, for example, method of transportation, type of route, type of package, and so on. This latter type of data can only be the responsibility of the user and must be very generally covered by a code and a data analysis for the case examined.

DESCRIPTION OF CEPN METHOD

The methodological approach can be broken down into two parts: (a) the creation of a physical model that takes into account all pertinent variables of the transportation system and is aimed at providing a risk assessment as accurate as possible given the data available and the techniques used, and (b) the setting up of a decision-making assistance model by using the results of the previous model and allowing comparison between various safety policies.

The method used in the physical model to evaluate the risk involved in the transportation of radioactive materials is based on a sequential breakdown of the problem into four steps:

1. Analysis of the transportation system to highlight the variables relevant to the problem;
2. Determination of the probability, given that an accident has occurred, of its being of a certain type and a certain severity;
3. Examination of the opening of the container in various accident conditions and determination of the consequences on the environment; and
4. Risk assessment.

This process is shown in Figure 3. The sequencing of the various steps is not automatic and the programs are adjustable.

Figure 4 shows the calculation stages for the health consequences of an accidental atmospheric transfer.

COMPARISON OF DATA

The data common to both studies *(1, 3, 4)* are as follows:

1. The method of transport (road);
2. The weights transported and the number of packages times kilometers per year (see Table 1);
3. The population density:

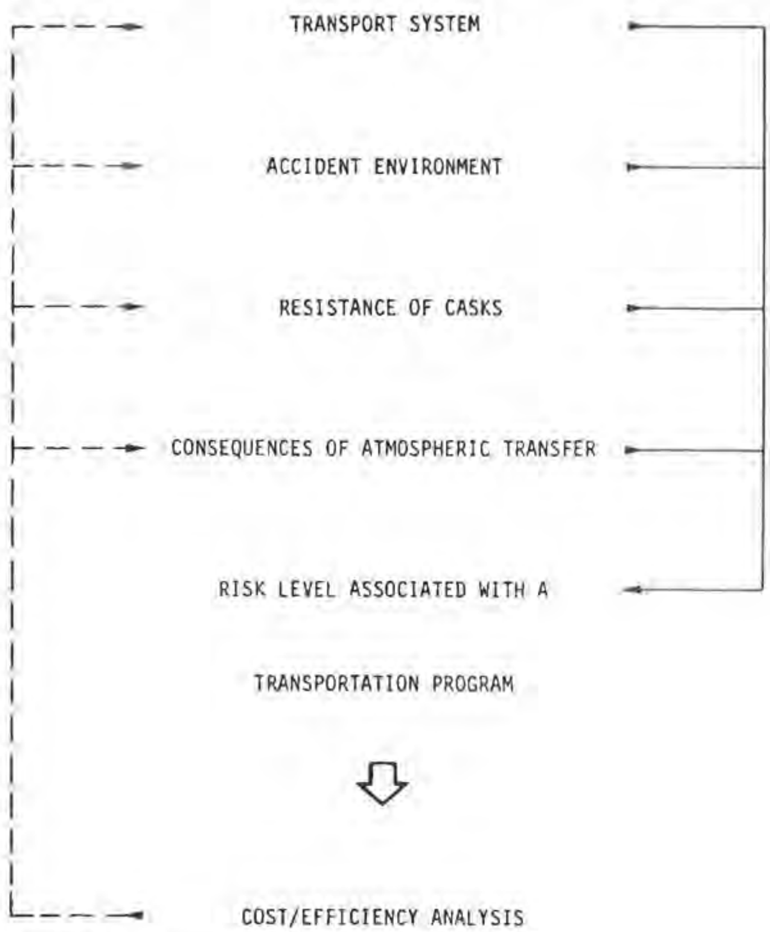

FIGURE 3 Assessment steps.

a. For INTERTRAN, the following distribution is calculated as a function of the route *(6)*: rural area with 54 inhabitants/km^2, 64 percent; suburban area with 700 inhabitants/km^2, 32 percent; urban area with 6,800 inhabitants/km^2, 4 percent; giving an average of 531 inhabitants/km^2;

b. CEPN calculations gave an average of 530 inhabitants/km^2;

4. The accident rates on the roads are practically the same:
   a. 1×10^{-6} km^{-1} for INTERTRAN;
   b. 0.9×10^{-6} km^{-1} by CEPN determined on the basis of analysis of the reports from the Interministerial Committee on Transportation of Dangerous Materials (CITMD); and

5. The meterological conditions adopted in the CEPN studies are the DOURY DN1 and DN10 categories *(7)* (normal diffusion conditions, windspeed 1 and 10 m/sec), very similar to PASQUILL category D, which, for INTERTRAN, led to the adoption of meteorological conditions D and F (neutral and high stability conditions, windspeed 4 and 1 m/sec), whose respective probability levels are 0.85 and 0.15 and whose characteristics are as follows: D = neutral stability condition, windspeed 4 m/sec; F = high stability conditions with low turbulent dispersal and windspeed 1 m/sec.

The data that can be different for both studies are as follows *(1, 3, 4)*:

1. Level of gravity of the accidents
   a. INTERTRAN gives a grid of 11 accident severity levels, taking into account the duration of the fire, on the one hand, and the impact force, on the other. The limits given correspond to the IAEA tests plus an excess zone.
   b. In the CEPN study, the possible scenarios were identified and probabilities of occurrence were attributed to them. The various levels of kinetic energy and their probable distribution were estimated. The failure rules for 48 Y and 30 B casks were extrapolated on the basis of observations of the behavior of liquid hydrocarbon road tankers. With regard to fire at 800°C, the explosive rupture levels are 60 min for 48 Y and 90 min for 30 B, values that are based on calculations and tests conducted by the CEA.
   c. The comparison between the probable occurrence of the various types of loading is as follows:

Loading	*INTERTRAN*	*CEPN*
Mechanical only	0.9930	0.9820
Thermal only	0.0064	0.0100
Mechanical and thermal	0.0006	0.0080

2. Failure fraction

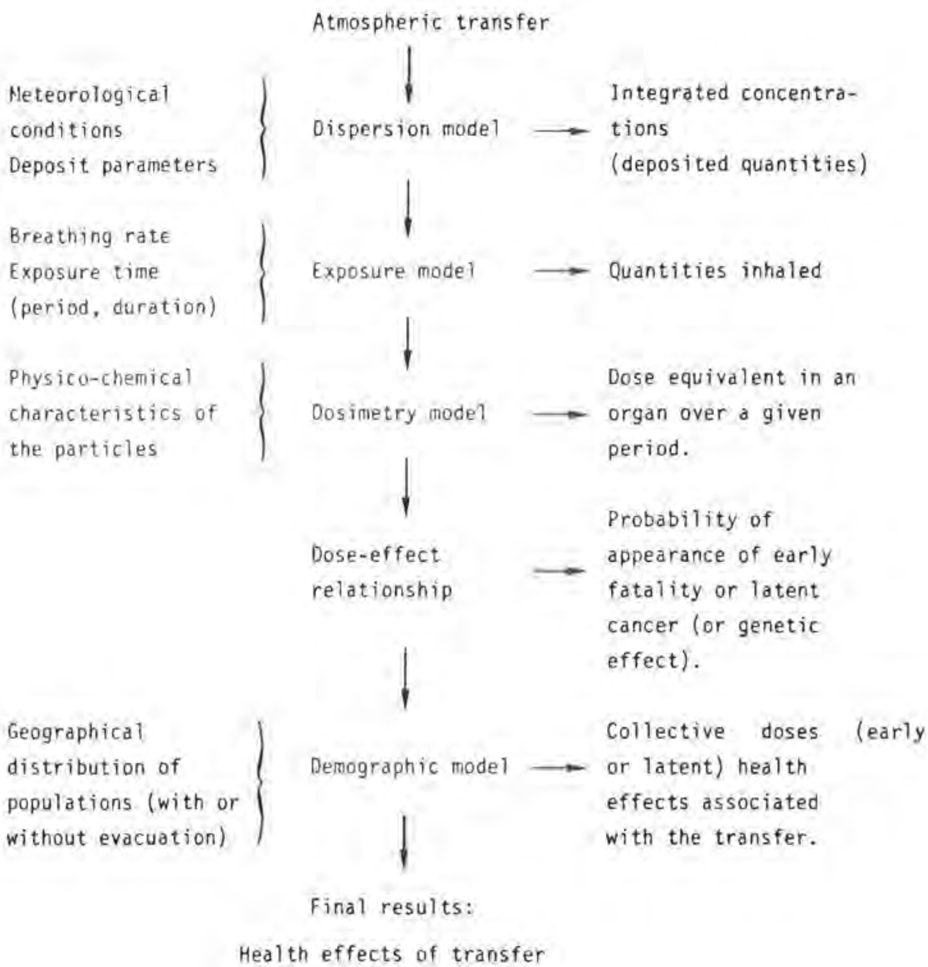

FIGURE 4 General calculation model for consequences of atmospheric transfer.

TABLE 3 SUMMARY OF ESTIMATES OBTAINED WITH INTERTRAN OF NUMBERS OF FATALITIES PER YEAR

Type of UF_6	U Risk	HF Risk	Total Risk
Depleted	9.07×10^{-6}	6.95×10^{-3}	6.96×10^{-3}
Natural	7.62×10^{-6}	6.95×10^{-3}	6.96×10^{-3}
Enriched	5.90×10^{-6}	3.91×10^{-3}	3.92×10^{-3}
Total	2.25×10^{-5}	1.78×10^{-2}	1.78×10^{-2}

Note: Radiation hazard, 0; chemical hazard, see Table 4.

a. In INTERTRAN, the following failure fractions are considered:

Duration of Fire (min)	*48 Y*	*30 B*
0–30	0.1	0
30–60	1	0.1
> 60	1	1

b. By using actual complete rupture data, CEPN only reaches 1 for 48 Y after a fire of 60 min.

3. Dispersal
   a. In INTERTRAN, the dispersal model is the PASQUILL model in which the standard deviations of the basic formula depend on a windspeed category and the distance from the release point.
   b. CEPN uses the DOURY model in which the standard deviations depend on the actual transfer time.

In both cases the model is Gaussian. Comparative calculations have shown a high level of correspondence between the two types of categorization for average weather conditions, that is, PASQUILL C and D and DOURY DN2 to DN5 (7,pp. 403–448).

4. Radioactivity-induced effects: The CEA is currently conducting a special assessment of the INTERTRAN code with regard to the problem of radiological protection.

RESULTS

A summary of the estimates obtained with INTERTRAN of numbers of fatalities per year is given in Table 3 and that of the estimates obtained by CEPN in Table 4. It can be seen that in relation to those obtained by CEPN, the estimates obtained with INTERTRAN are 5 times lower for the U risk and 20 times higher for the HF risk. In both cases, the chemical risk is greater than the radioactive risk. (The current study on the radiological aspects of INTERTRAN may provide an explanation for this difference.)

Given that the number of fatalities indicated by the CITMD

TABLE 4 SUMMARY OF ESTIMATES OBTAINED BY CEPN OF NUMBERS OF FATALITIES PER YEAR

Type of UF_6	U Risk	HF Risk	Total Risk
Depleted	0.45×10^{-4}	2.90×10^{-4}	3.35×10^{-4}
Natural	0.48×10^{-4}	3.08×10^{-4}	3.56×10^{-4}
Enriched	0.26×10^{-4}	1.68×10^{-4}	1.94×10^{-4}
Total	1.09×10^{-4}	7.66×10^{-4}	8.85×10^{-4}

Note: U, radiation and chemical hazard; HF, chemical hazard.

TABLE 5 EXPECTED FATALITY RATE DUE TO ROAD ACCIDENTS

Type of UF_6	No. of Shipments	Distance Covered (km)	Fatality Rate (km^{-1})	Road Risk
Depleted	120	900	1.2×10^{-7}	1.30×10^{-2}
Natural	120	900	1.2×10^{-7}	1.30×10^{-2}
Enriched	72	900	1.2×10^{-7}	0.78×10^{-2}
Total	312	900	1.2×10^{-7}	3.38×10^{-2}

files is 12 per 100 accidents *(4)*, the expected fatalities due to road accidents should be added to the previous estimates (Table 5). It can be seen that the risk inherent in road transport is nonetheless higher than the total risk inherent in the material transported (twice as high for INTERTRAN and 50 times higher for CEPN).

As indicated earlier, nearly all UF_6 transportation in France is by rail. The CEPN study *(4)* shows that rail transport is 100 times safer than road transport.

CONCLUSION

A single assessment comparison is insufficient to validate a code. This is why other comparisons will be made with other products transported and other methods of transport. Other users of the INTERTRAN code will carry out the same work and will make their contribution to the common effort.

Depending on whether one has an optimistic or pessimistic outlook, the results obtained with a conventional study will appear either relatively close or remote from those obtained with INTERTRAN. However, because the code models used are not yet perfect, one can hope to achieve the objective set, that is, to create a fast risk-assessment method that can be used by those involved in safety analysis.

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Modifying the Regulation for Small Radioactive Package Transit Through the Mont Blanc Tunnel—Assessment of the Health and Economic Impact

P. PAGÈS, P. HUBERT, P. GILLES, J. HAMARD, AND E. TOMACHEVSKY

The purpose of this study is to illustrate how a probabilistic risk assessment can be applied to a regulatory problem—specific reference is made here to the determination of an authorized limit for the transit of radioactive materials through the Mont Blanc Tunnel. The latter is 12-km long and is situated under the highest mountain in Europe. Hazardous materials are subjected to much more stringent regulations than are required by international regulatory agreement (by the Accord Dangereuse Routier and International Atomic Energy Agency). The transportation of small amounts of dispersible radioactive material is currently permitted for a truck content that is only one-third of the activity limit, A_2, that is applicable to a single package in the general traffic. The consequences and occurrence probabilities of an accident have been investigated. The economic impact of an accident was found to be quite independent of the transported activity. The mathematical expectation of the economic losses (post-accident radiation monitoring, shutdown of the tunnel, and decontamination work) currently amounts to \$6 a year. The health impact is a result of either the immediate effects of radiation or the delayed effects (cancers and genetic effects). The expected number of such effects is very low: 3.10^{-8} per year. In the event that an accident has occurred, this impact was found to increase in proportion to the transported quantity. With respect to the decision-making problem, the following feature is important: Because the number of transits decreases when the allowed quantity for each passenger increases, so does the probability of an accident. The mathematical expectation of the risk therefore decreases (economic effects) or is constant (health effects) when the limit is loosened. This decrease does not allow for deriving a limit from this criterion. Other criteria have been envisioned. A comparison with road accident victims and other allowed hazardous materials proved that the present level, or even a higher level, is still acceptable. Looking at the consequences of the worst case accident, some thresholds were found above which a fatal consequence is plausible (300 times the present limit) or a morbidity effect (30 times). Keeping below a limit that is twice the present value would, in any case, avoid the need for decontaminating a large portion of the tunnel, thus creating a major nuclear event in the country, whatever the actual consequences might be. These are only indicative figures and the choice of an appropriate limit therefore remains linked to subjective weighting of these criteria. The present study, however, allows for enlightening the basis for decision making in this field.

P. Pagès and P. Hubert, CEPN, 92260 Fontenay–aux–Roses, Paris, France. P. Gilles, J. Hamard, and E. Tomachevsky, CEN-FAR, 60–68, avenue du Général–Leclerc, B.P. No. 6, 92265 Fontenay–aux–Roses, Cédex, France.

SCOPE OF THE STUDY

As is the case for many road tunnels, important restrictions apply to the transit of hazardous material cargo through the Mont Blanc Tunnel. Only very small amounts (e.g., 50 kg of liquefied petroleum gas) are permitted to pass through this 12-km-long tunnel, which has been burrowed under Europe's highest mountain and is one of the most important routes between France and Italy. The transportation of small quantities of dispersible radioactive materials is allowed on the European roads, according to the IAEA standards *(1)* in the "A package," up to a certain limit in activity for a single package (the "A_2 limit," which depends on the radionuclide). Above this limit, a stronger package (called Type B) is required. But when crossing the tunnel, the total cargo of a truck can be only one-third of this A_2 limit. Eighteen years after the opening of this thoroughfare, the question of the suitability of such stringent standards for this traffic, which consists mainly of sources for medical application, has been raised. More precisely, the issue was to determine at which activity level should the standard for the tunnel be set.

The purpose of this paper is to describe the analyses that support a decision in this field, under the constraint that the solution must be in compliance with IAEA standards. First the transportation system is described and the consequences of potential releases are assessed. This implies numerous assumptions on the tunnel environment (traffic, etc.) and the use or development of various models (air transport of radioactive particles, health effects of inhalation, etc.), that cannot be fully described here [see Hubert and Pagès *(2)* for details]. Then the decisional issue is addressed first with a probabilistic assessment of the risk under various assumed values for the authorized limit. A classical cost-benefit approach is attempted, taking into account and weighting the advantages and disadvantages in raising (or lowering) the present limit. As a result of the specificities of nuclear transportation incidents, and of the transit of hazardous materials through tunnels, it appeared that the analysis had to be developed further, and the problem of acceptability was therefore dealt with. These two approaches proved to be complementary when grounding decisions of this kind. Also, the fact that the analyses were mainly of a comparative nature (comparing two solutions for the same traffic or two hazardous materials) was a key factor for ensuring the validity and the meaningfulness of the results.

THE TRANSPORTATION SYSTEM

This system is characterized by the nature of transported materials, the packages and vehicles in use, and the intensity of the traffic. However, the environment which, in this case, means the conditions that are encountered while driving through the Mont Blanc Tunnel should be described.

Traffic of Isotopes

There are three weekly transits through the tunnel, two of which are made on the same day. The vehicle in use is generally a light truck. Its cargo content, expressed in actual activity, averages to 54 Ci, ranging from one-half to twice this figure. It is made up of various radioisotopes. In Table 1, the percentages of the total activity are given, as is the A_2 limit that applies to the various isotopes. The higher the limit, the less harmful is the isotope. For example, it can be said that 5 Ci of Technetium 99 m are equivalent to 1 Ci of Iridium 192. Nonetheless, most of the activity (99 percent) is a result of the transportation of Technetium generators. This device contains both Molybdenum 99 and Technetium 99 m. The first one has a longer half-life period (66 hr) and is transformed gradually into the second one having a shorter half-life (6 hr). Generators of this kind can be used for approximately 1 week to provide Technetium for visualization of various organs in medical scanning.

A yearly traffic of approximately 10,000 of these packages is performed through the tunnel, giving rise to approximately 150 crossings. The present study will focus on this generator, leaving aside the other products whose traffic appears to be negligible.

TABLE 1 AVERAGE CONTENT OF A SHIPMENT *(1,4)*

Main Isotope	Activity (Ci)	Total Activity (%)	A_2 Limit (Ci)
Molybdenum 99	28	52	100
Technetium 99 m	25.5	47	100
Phosphorous 32	.24	0.45	30
Iridium 192	.08	0.15	20
Iodine 131	.10	0.25	10
All others	.08	0.15	-
Total	54	100	-

Technetium Generator

The contents of the ORIS Industry generator can vary from 50 mCi to 500 mCi of nominal activity, that is, of the Technetium activity guaranteed to the customer on the date of delivery (note that the actual activity is about 4 times higher 3 days before this date). However, the generator itself, known as Elumatic III, is always the same. It contains, within a parallelepipedic plastic box of about 20 cm, a system to extract the required solutions of Technetium out of a small glass column in which both isotopes are contained. Because of γ radiation, this column is inside a biological shielding of 13 kg of lead (see Figure 1). During transportation, the generator is inside a drum and enclosed in a polystyrene jacket to prevent it from suffering the consequences of impact. This assembly pertains to the "Class A" container for liquid radioactive materials. Accordingly, it has to fulfill important testing requirements such as surviving a 9-m drop, a 1.7-m drop on a probe, and a 1-hr sprinkling of water.

Tunnel Environment

It must first be stated that traffic through the tunnel is quite heavy; 1.4 million vehicles cross it every year with trucks

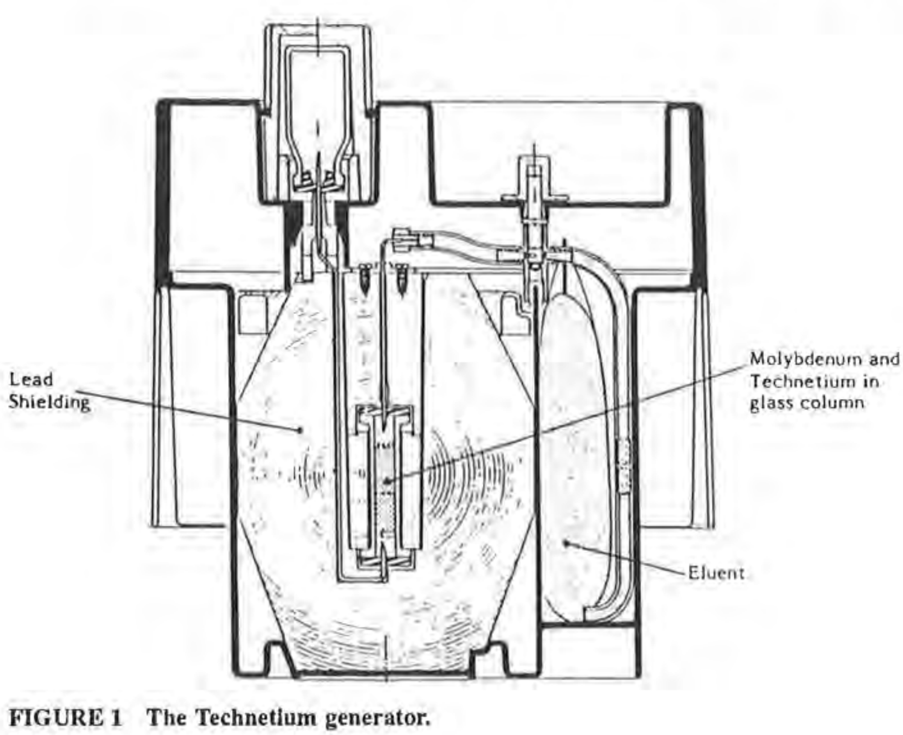

FIGURE 1 The Technetium generator.

accounting for one-third of the total traffic. In addition, there are seasonal traffic peaks; 250,000 tourist vehicles drive through the tunnel during August. For commercial traffic, the peak occurs in March and has reached 3,000 trucks for a single day *(3)*. The total length of the tunnel is approximately 12 km with one lane in each direction. Although the nominal speed is limited to 80 km/hr, the actual speed is approximately 50 km/hr from France to Italy and 90 km/hr from Italy to France because of an average grade of 0.9 percent.

It should be noted that tank truck transportation of any hazardous materials is prohibited. Only small quantities can be transported. For example, the maximum permissible quantity for products such as hydrogen chloride and phosphorus trichloride is 3 kg. There are two categories for the permitted transits. For the first one, there are no special restrictions other than that each vehicle must maintain a distance of 200 m from the previous vehicle. For the second category, the speed is restricted to 60 km/hr and the nature of the product must be declared at the toll. In addition, the tunnel management can dictate specific rules such as restricted hours for transit or it can provide the vehicle an escort, although this is not the case for the products under study.

The physical parameters of the tunnel are its shape and its ventilation system. The cross section is the typical horseshoe; however, the air ducts are underneath the roadway (see Figure 2). The section that is devoted to the circulation is 46 m^2 and the width of each lane is 3.5 m. Because the mountain range above the tunnel is extremely high (ranging from 1000 to 2400 m), intermediate shafts to the surface were virtually unfeasible, therefore the ventilation has to come from the portals and two fan houses that were built at the ends of the tunnel. Each plant (Italian and French) provides and extracts air from its half of the tunnel. Four different fresh air ducts provide air to the four different sections of each half-tunnel (each section is about 1450 m long). One single duct is intended for the extraction of the air collected from the ceiling every 300 m.

At present, there are two ventilation modes. In the first mode, all the ducts, including the one previously designed as an exhaust duct, are used for discharging fresh air, and the exhaust air flows out through the portals. This system can be called the "normal operation system" and, in this case, 300 m^3/sec are provided to each half-tunnel. When an event such as a fire takes place, or when there is severe air pollution, the system is reversed. Then the exhaust duct can extract 150 m^3/sec of polluted air, while the supply ducts still provide 300 m^3/sec of fresh air. The reversal time takes from 1 to 2 min.

It is important to depict the survey and emergency response system. There is a continuous monitoring of the parameters relative to air pollution (carbon monoxide and opacity) and of the traffic conditions. A television camera is positioned every 300 m to monitor the roadway. An alert, in case of an accident, can also be given with the help of the emergency phones that are located next to the emergency parking areas (every 600 m) in glass-enclosed safety rooms. Fire extinguishers are available every 100 m, and the first response to an emergency is a motorbike equipped with a fire extinguisher. These precautions have proven to be effective for 13 of the 14 fires that have occurred in the tunnel. An emergency vehicle is located at each portal and is equipped with more powerful extinguishers and breathing apparatus. In more severe cases, the fire brigades would have to come from Chamonix in France, or Courmayeur in Italy. With regard to radiation hazard, there is no monitoring device available at the tunnel. The decontamination teams would have to come from Lyons, which is 200 km from the tunnel *(3, 4)*.

CONSEQUENCES OF AN ACCIDENT

Properties of the Products

The two radioisotopes that are transported are very likely to remain together in the case of an accident. According to the circumstances of the accident, either the Molybdenum or the

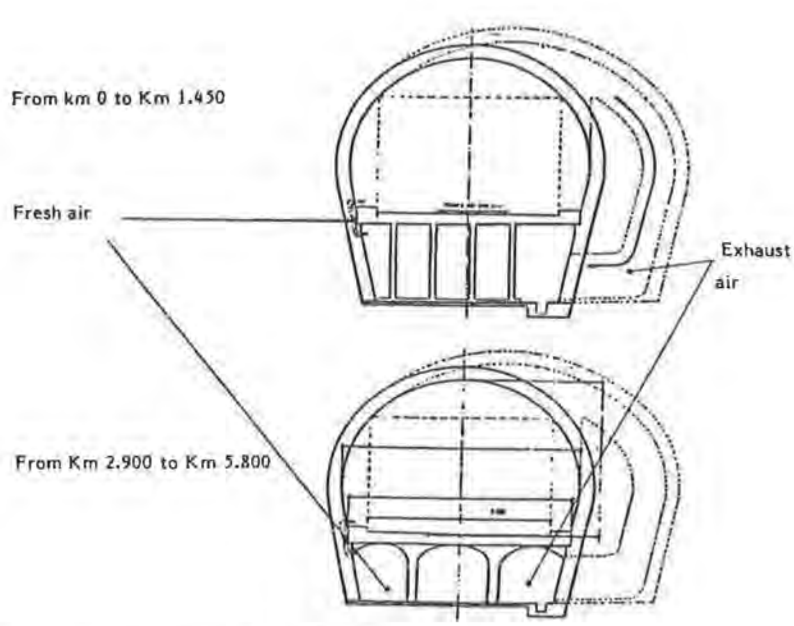

FIGURE 2 Cross section of the tunnel.

Technetium could prove harmful. A radiation incident can result in external irradiation, or in internal irradiation as a result of inhalation of the material. Ingestion can be reasonably discarded here. Table 2 gives data on the potential harm of the isotopes in different conditions. The result is the absorbed dose expressed in sievert (Sv).

When close to the source (10 cm), the dose rate can be quite high, but one should be aware that it is mainly due to β rays. This means that only the skin is likely to be damaged, and light troubles begin to appear at about 1 Sv. In addition, almost any material can considerably reduce this dose. At 1 m, both isotopes would contribute to the dose, which is now a γ dose, and can therefore be considered to involve the whole body. The aim of the 52-mm lead shielding that is around the small column containing the active products is to protect against these γ rays. Lastly, inhalation of the products, especially of Molybdenum, results in doses to the different organs of the body. (Note that the lower intestine and the lungs are the most exposed body parts.) These doses can also be expressed as a whole body dose, which weights the organ doses for the purpose of computation of genetic effect and cancer induction rate. When examining external irradiation hazards, both isotopes are at the same level, while Molybdenum is the important factor in atmospheric dispersion scenarios.

Possible Events and Nature of the Consequences

In accordance with the aim of this study, the impacts of potential accidents are assessed in relation to the quantity of transported material. At this stage, however, the probabilistic aspect is not yet considered. There are two main categories for the possible consequences of an accident—the economic impacts and the health effects of irradiation. The economic impacts can be the cost of the control of radioactivity, the cost of decontamination, and the loss of earnings as a result of shutting down the tunnel. The radiation health effects can be either short-term effects or a long-term stochastic effect. For very high doses to an individual, death can occur. For lower doses, down to 0.5 Sv to some organs, reversible morbidity effects can be observed in which severity is dose dependent. What will be computed here is, assuming that the package has been destroyed, the probability that a passerby in the tunnel might be subjected to such a high dose. At low doses, there is only a stochastic effect, that is, an increased incidence of cancer and of genetic effect that is linearly connected to the dose (2.10^{-2} effects per Sv). Here, the collective dose, that is, the sum of the doses to the individuals within the tunnel, will be computed. This index allows for the derivation of the mathematical expectation of delayed effects in the whole exposed population with the help of the previously given dose-response relationship.

The following table gives data on the main impacts of an accident that involves the loss of package contents and the indices used to quantify them.

Impact	*Quantitative Indices*
Immediate death	Probability of occurrence
Morbidity	Probability of occurrence
Late radiation effects	Collective dose
Shutdown of tunnel	Monetary unit
Radiation control	Monetary unit
Decontamination	Monetary unit

The impacts are not of the same importance. Some are very unlikely to occur, others almost certainly will occur. If an incident occurs to the truck, many scenarios are possible. First, it can be safely assumed that it is a minor incident and that nothing has happened to the container. In this case, there might be no impact at all, or a slight delay in the traffic. In the case where there is even a small chance that a package has been damaged, it is almost certain that a radiological control team will be called in. This results in (a) a loss of earnings for the tunnel society because the tunnel will be closed, and (b) the control team having to be reimbursed for its expenses. If the package has been damaged, the cause may be due to the pyrex column having been expelled from its shielding. When cautiously handled, this situation does not imply consequences. However, it is possible that people unaware of the danger will also handle it; therefore, radiological health consequences cannot be totally discarded. The worst case is when there is a dispersion of the content, which can turn into powder as a result of impact or heating as proven by a recent train accident and a fire test performed by the French Atomic Energy Commission (private communication with C. Ringot). Then, atmospheric dispersion can occur leading to skin contamination and inhalation doses. This last case is the most severe as the health effects are generally more important and the removal of ground contamination may be necessary.

Computation of Radiological Health Effects

External Irradiation

To assess the consequences of a loss of shielding or dispersion of the material, various models must be implemented that compute the dose rate at a given distance and the atmospheric transfer, and that assess the number of people in the tunnel. In the following models, the basis will be the nominal activity of the package. Because the packages are transported 3 days before the day corresponding to this nominal figure, the actual activity is 2.1 Ci in Technetium and 2.3 Ci in Molybdenum for 1

TABLE 2 THE RADIOLOGICAL EFFECT OF THE PRODUCTS PER UNIT OF DISPERSED MATERIAL (1 Ci)

	Dose Rate at 10 cm (Sv/hr)	Dose Rate at 1 m (Sv/hr)	Whole Body Dose (Sv per inhaled Ci)	Lung Dose (Sv per inhaled Ci)	Thyroid Dose (Sv per inhaled Ci)	Lower Intestine Wall (Sv per inhaled Ci)
Molybdenum 99	30	7×10^{-4}	36	159	–	203
Technetium 99 m	16	7.5×10^{-4}	.3	1	2	

Ci of nominal activity. For external irradiation, it will be assumed that the contribution to the collective dose is negligible. What will be computed is the area in which the 0.5-Sv and 5-Sv threshold might be attained by somebody who would stay in the tunnel for 30 min. These are very small areas and they are linearly related to the activity by Equation 1.

$$\text{Morbidity } S_M = A \times 10^{-2}$$
$$\text{Lethal effects } S_L = A \times 10^{-3} \quad (1)$$

Where A is the activity in Ci, and S is the surface in square meters. The surface in which morbidity effects can occur ceases to be negligible for 100 Ci (and is then 1 m^2), while it is necessary to have a loss of biological shielding for 1,000 Ci to derive a significant area where lethal effects are possible.

Inhalation

The release and air transportation of dispersed material implies a need for more sophisticated models. For distances larger than approximately 50 m downwind (there is indeed a longitudinal wind in the tunnel due to the ventilation), a box model has been implemented to compute the inhaled fraction of a given release. The half-tunnel has been divided into 20 boxes 300 m long, corresponding to the distance separating the ceiling exhaust shafts. Then, given the flows of fresh and extracted air, the evolution of concentration with time was modeled (see Figure 3). The two ventilation modes have been taken into account, and various durations of stay in the tunnel were considered.

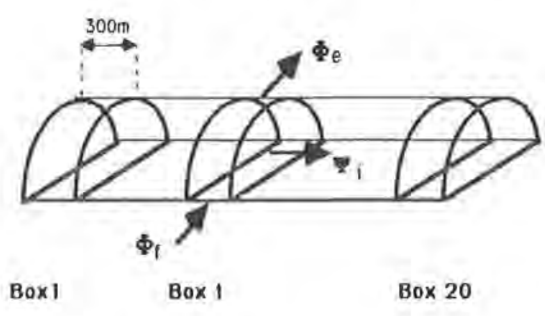

FIGURE 3 The box model for tunnel ventilation.

The two half-tunnels are independent. Due to the ventilation system, a neutral point with no longitudinal wind is established in the middle of the tunnel. If a release occurs on the French side, all the airborne contamination will go downwind through this same side to the French entrance. In Table 3, as an example, the inhaled fractions are provided, according to the place of the release and the position of an individual. In this example, the ventilation works in its emergency mode, and the individuals stay in the tunnel for 30 min. Should people stay in the tunnel for an indefinite time, the average figure would be doubled, although it would be almost unchanged for people near the release point because most of their dose is inhaled within a few minutes after the accident.

TABLE 3 INHALED FRACTION IN CASE OF AN AIRBORNE RELEASE

Position of the Individual (tunnel section)	Position of the Release (tunnel section)			
	1st	2nd	10th	20th
1st	1.4×10^{-5}	0	0	0
2nd	3.6×10^{-6}	1×10^{-5}	0	0
10th	1.2×10^{-8}	9.5×10^{-9}	2.9×10^{-6}	0
20th	4.5×10^{-11}	3.2×10^{-11}	7.2×10^{-12}	1.5×10^{-6}

The quick decrease in the inhaled fraction, when one is far downwind from the release point, must be noticed. It is still important, but not so dramatic, when ventilation is in the normal operating mode: from the first to the twentieth section, it is depleted by 1,000 instead of 1 million. With this model, the most irradiated organ of the most exposed individual receives a dose of 6×10^{-3} Sv per Ci of nominal activity released. At up to 100 Ci, immediate effects are unlikely to be observed. Above this value, a problem would occur because in the near field, the model is not conservative. Similarly, effects that are lethal might be observed for a release of 1,000 Ci.

With respect to the collective dose, only the average inhaled fraction of the release must be considered. This figure was averaged both on the accident location and on the individual location. This fraction is quite insensitive to the ventilation mode and the duration of stay in the tunnel and 2×10^{-7} is representative of most situations. Knowing the dose per inhaled Ci (Table 2) and the actual activity per nominal Ci, the risk, expressed as a collective dose, can be computed by using Equation 2.

$$H = n \times A \times (1.7 \times 10^{-5}) \quad (2)$$

where

- H = Collective dose (man-Sv),
- n = Number of people in the half-tunnel, and
- A = Released nominal activity (Ci).

Again, this risk is linearly connected with the carried activity.

The last situation to examine is atmospheric transportation near the source, for example, in the case of a fire. It has been assumed that the release will behave as a Gaussian puff and then will become homogeneous when reaching the lining of the tunnel. This process is very short and takes approximately 15 sec, which represents between 5 to 100 m according to the location of the release. On these bases, surfaces that correspond to the possibility of lethal or morbidity effects can be computed by using the following expressions (Equation 3):

$$S_M = 0.1\,A \text{ (morbidity area)} \quad (3a)$$

$$S_L = 0.01\,A \text{ (lethal effects area)} \quad (3b)$$

where A (Ci) is the nominal activity, and S is the surface expressed in square meters.

Here again, the dependency on the activity is linear. The areas are more important than the one calculated for external irradiation, and they do not depend on the time spent around the source so that it is more realistic to imagine somebody caught in the puff than staying near the source for 30 min. On the other hand, a total airborne release is linked to very severe accidents whose probability is lower.

Expected Risk

The second part of this analysis requires the assessment of the number of people within the tunnel downwind of the accident. The basic raw data are the average number of people per vehicle (1.7) and the annual traffic equivalent to 2.8 vehicles per minute (note that this figure might be four times higher on peak days at rush hours). An average speed of 60 $km \cdot h^{-1}$ allows the average number of vehicles in the tunnel at a given time (about 34) to be derived. Assuming that the flow of traffic might be stopped in 5 minutes, 7 more vehicles would have time to enter the tunnel from each side. Altogether this results in 48 vehicles more or less closely involved in the accident, out of which 8.5 should be deduced because they are both upwind and going away from the contaminated "half-tunnel." From those assumptions it could be deduced that about 66 people are involved. This figure is finally increased by 30 percent to take into account the fact that the shipments are not evenly distributed in time: 2 of the 3 weekly transits take place at daytime, when traffic is higher. This figure allows the computation of the collective dose by using Equation 2 and leads to Equation 4

$$S = 1.5 \times 10^{-3} \times A \qquad (4)$$

where

S = collective dose (man-Sv),
A = nominal activity (Ci).

To estimate the probability of nondelayed radiation effects, it has been supposed that the cars would remain at the beginning trapped in line behind the truck; the length occupied by an automobile (≈ 4.7 m) and the width of the tunnel (≈ 8.5 m) allows to derive a "density" (about 5 people for 100 m^2). So the probability of having to deal with a nonbenign contamination is around (Equation 3a) $(5 \times 10^{-3}) \times A$, a figure that might be lower when few people are crossing the tunnel, but not higher during rush hours. This is also slightly pessimistic because the cars offer some shielding. The probability of having lethal or very serious effects (Equation 3b) is thus $(5 \times 10^{-4}) \times A$. The numerous hypotheses that support these models must be underlined. First, these figures are related to the fraction of the content that would actually get out of control should an accident occur. In the case of scenarios with airborne isotopes, this would result from severe fire conditions. With regard to the transport models themselves, the box model aims to be a best-estimate approach. It might lead to pessimistic results only if a stratification of the atmosphere within the tunnel takes place, and this so far remains an open question. For example, opacity measurements have shown that the air in the exhaust duct was not more polluted than in the tunnel. On the other hand, the short-range analysis is more conservative, and it is mainly intended for purposes of comparison.

Economic Impacts

Loss of Toll Fees

The loss of toll fees is directly linked to the duration of the closure of the tunnel. Depending on the hour and day on which the accident occurs, the losses can vary from $500/hr (lower season, nighttime) to $5,000/hr (high season, daytime). Of the three trucks crossing the tunnel weekly, one crosses at night and the other two cross at noon. An average figure of $2,000/hr will be assumed. An accident with nonradiological consequences cannot lock the tunnel for more than 1 hr. In 1969, it took that time to reopen the traffic after the turnover of a heavy semitrailer.

Radiological Monitoring Costs

Should there be any doubt about the integrity of the cargo, a radiological survey team would be called in. It consists of a small truck with two engineers and ten technicians. Their task would be to control the cargo and, if necessary, all the cars behind it and some of the ones that would have been crossing the other way. This implies that these vehicles would be prevented from getting away and would be kept in single file, in the same order, at the entrance of the tunnel. In addition, the roadway and walls are to be monitored. These costs are almost insensitive to the amount of damage to the packages. This work will last approximately 4 hr because it would take 2 hr for the team to get to the tunnel location. The total cost, including the loss of earnings at the toll, would amount to approximately $11,000, but the commercial loss remains the main component.

Decontamination Cost

The previous calculations performed with the box model allow the ground contamination to be computed by replacing the breathing rate with a deposition velocity. The parameter for quantifying this impact is the length of the contaminated portion. Its assessment requires the definition of an acceptable level of ground contamination. Theoretically, a figure of 50 $mCi \times m^{-2}$ of Molybdenum should be acceptable for a location that is not a work place. The results are shown in Figure 4. As for the other impacts, the parameter is the fraction of nominal activity that is submitted to air transport. The interesting feature is the appearance of a threshold, below which only a few meters downwind would have to be cleaned up. The probability reaches 1 at about 500 Ci, while above this level, many sections would be affected should the accident occur near the middle of the tunnel.

If the contamination is very slight (small release, or simple loss of biological shielding), it can be assumed that the control team might handle the problem within 1 hr. This implies 1 hr more of tunnel shutdown, and approximately 1 hr more for the team expenses. When one 300-m section is to be decontaminated, an additional team becomes necessary and the operation takes approximately 8 hr. Thus, 8 hr more of shutdown can be expected, and 16 hr more for the radiation intervention teams. All the associated costs are given in Table 4.

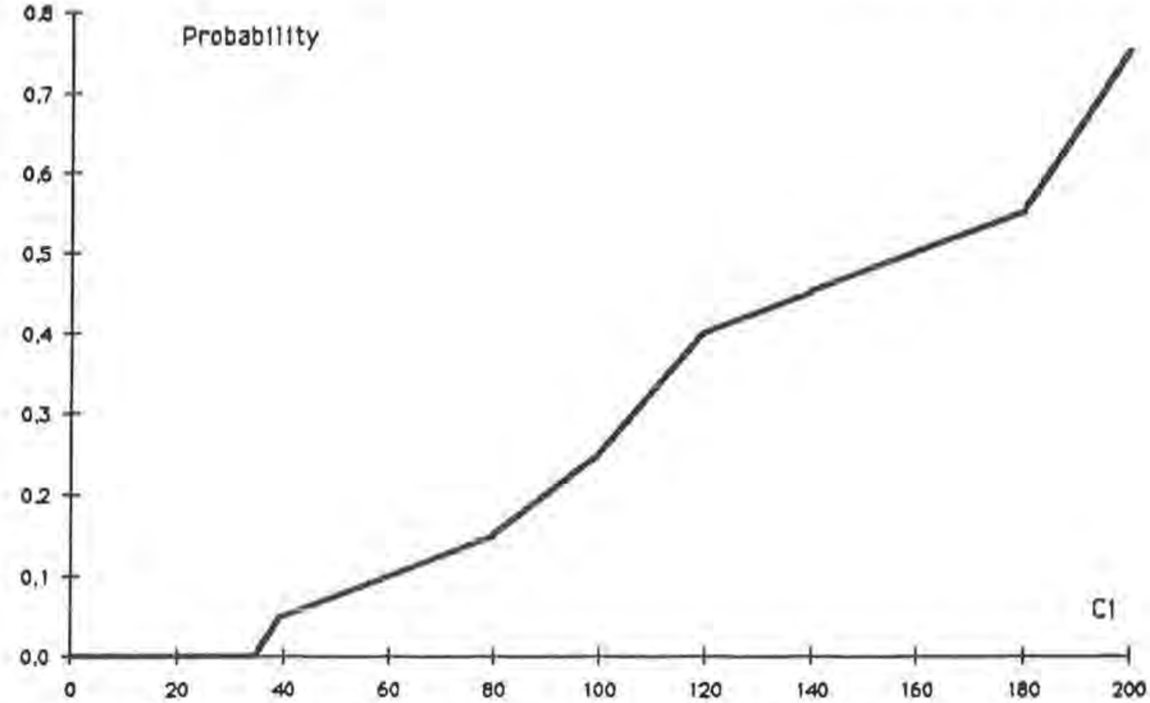

FIGURE 4 Probability of having a 300-m section to decontaminate related airborne nominal activity.

Summary of the Impacts

The various impacts are summarized in Table 4. The economic and health impacts are the most important, the risk of irradiation as a result of lost sources has been neglected. It would require that an unaware bystander pick up the source, which is unlikely to occur because the tunnel is under close control. The tunnel operator knows when the truck is crossing and what its content is. The scenarios listed here are not of equal probability. Some important points must be emphasized. First, an actual loss of the properties of the packages does not drastically increase the cost of the accident, nor, in most cases, does the quantity transported alter the economic impact. It is only when an airborne release is assumed above a certain threshold, that the amount of isotopes is of importance. Second, the health impacts are quite low; in the improbable case in which 100 Ci are released, 5.3×10^{-2} deaths can be expected. This figure is close to the death rate in any road accident. The comparison with economic impacts necessitates assignment and use of a monetary value on human life. In this extreme case, economic and health impacts are comparable when a figure of $0.5 million is adopted. These figures are subjected to many uncertainties, however. What must be stressed is that the immediate health impacts result from relatively conservative assumptions, while it is not the case for the collective dose.

For the economic impacts, the assessment is rather optimistic. When dealing with such events, public opinion must be taken into account and very often massive decontamination has been undertaken, well below the limits that are generally considered as admissible in the nuclear industry. In the present case, such an approach would lead to approximately one full day of decontamination for the smallest release.

In any case, computation of the data from Table 4 is only a first step when choosing the permissible levels for the transported activity. The data only provide an assessment of the consequences of hypothetical events. Some of them are quite probable, others are highly hypothetical. The next step necessitates use of a probabilistic approach.

ELEMENTS FOR THE DECISION-MAKING PROCESS

Probabilistic Assessment

At this stage the aim is to assess the risk (mathematical expectations of health or economic impacts of any kind). It requires

TABLE 4 IMPACTS OF VARIOUS ACCIDENT SCENARIOS

	Cost of Traffic Interruption ($)	Cost of Control ($)	Cost of Decontamination ($)	Probability of Morbidity	Probability of Mortality	Collective Dose (ManSv)
Trivial Accident	2,000	–	–	–	–	–
Suspected Loss of Content	8,000	3,000	–	–	–	–
Actual Loss of Biological Shielding	10,000	3,000	1,000	–	–	–
Actual Airborne Release	10,000 + (16,000 x Pc)	3,000 + (6,000 x Pc)	1,000 + (6,000 x Pc)	5.10^{-3} A.f	5.10^{-4} A.f	$1.5\ 10^{-3}$ A.f

Note: Pc = Probability of having a section become contaminated (see Figure 4), and A.f-released fraction of nominal activity.

data on the package failure modes, on the stresses likely to be generated in an accident, and on the probability of an accident. The parameter under study that is the allowed quantity for one shipment is connected only with the accident probability. The higher the limit the lower is the expected frequency, because shipments are to take place. Once again the dependency is linear.

The possible stresses on a package in a road accident and the response of the packages must be established. Here, the accuracy of such data is lower than in most probabilistic risk assessments of the transportation of radioactive materials. First the tunnel is not representative of an average French road so that the road statistics *(5, 6)* do not apply easily. Second, the Type A packages are not submitted to a deep analysis of their behavior, because the consequence of their failure is small.

Although some statistics are available on Type A package behavior in accidents *(7, 8)*, they are not specifically on Technetium generators. An interesting crush and fire experiment has, however, been performed with a light truck containing a mixed cargo of Type A and B packages in the U.K. Amersham Center where another type of Technetium is produced *(9)*. Among other conclusions, it proved that the impact speed is not the key parameter, as a result of the many interactions between the packages. Another interesting feature was the short time that was necessary for a fire to encompass the whole vehicle. Ignited with 40 l of petrol on the ground, the fire melted the lead shieldings in the small cans within 12 min. In addition, it resulted in a quick atmospheric dispersion.

There is some specific data on the French Elumatic Technetium generator. These are the results of the AIEA regulatory tests, the analysis of a train accident that occurred in France, and the destructive fire test performed in June 1985. From the regulatory tests, it can be concluded that a 9-m drop does not damage the package. In the railway accident 2 years ago in which two generators on a small trailer across the track were impacted by a train, the packages did not resist the 90 km/hr impact. Both columns were ejected from their biological lead shielding. One of them was found undamaged, but mechanical dispersion of the isotopes occurred with the content of the second column. The engine and the clothes of 20 people were found to be contaminated, although at a low level. Thus, the possibility of atmospheric dispersion after an impact cannot be discarded. This accident was equivalent to an impact on a rigid target, and the forces were consequently much higher than the ones encountered in a vehicle collision at the same speed. The last study—the fire experiment—showed a great sensitivity of these packages to fire (approximately 800°C). The drum opened in less than 2 min, and all the lead melted within 15 min. The flammable nature of the polystyrene jacket greatly accelerated this phenomenon. The pyrex vessel containing the column was found apparently intact after 30 min. However, it was weakened and broke very easily when removed and a light powder was released. The following assumptions are therefore stated for the problem, which is simplified by the fact that no side-on collisions are possible in the tunnel:

1. Light crash would result in no loss of shielding,
2. Frontal collision (i.e., approximately 120 km/hr) would result in loss of shielding and 1-percent airborne release of material,
3. Short fire would result in no loss of shielding, and
4. Strong fire (i.e., destroyed vehicle) would result in loss of shielding and 75-percent airborne release of material.

The survey of tunnel accident records provides quantitative figures for these accident types. Although they do rely on small numbers, the following probabilities can be set up.

The probability of a light crash is 3.5×10^{-6} at each crossing of the tunnel, half of them serious enough to require monitoring. This probability is 4×10^{-7} for a collision, 8×10^{-7} for a light fire, and 5×10^{-8} for a severe fire. The annual risk would vary with the allowed activity. However the actual risk of today's situation, with a yearly traffic of 150 trucks carrying 12 nominal Ci on the average, can readily be assessed as follows.

Accident probability	6.9×10^{-4}
Total expectation of economic impacts	\$5.6
Expected collective dose	1.11×10^{-7} Man Sv
Probability of a fatal effect	3.4×10^{-8}
Probability of reversible effect	3.4×10^{-7}

The level of risk appears to be low, and this is not just because of the small amount of traffic. For instance, the number of health effects is 1,000 times lower than the expected number of deaths that would result from the traffic accidents themselves *(10)* and, in addition, it is not attributable to catastrophic events associated with many victims.

The Cost Benefit Analysis

The issue here is to determine whether there is an optimum in the allowed nominal activity for the Technetium generators. One must therefore look over the costs and benefits of an increase in this level. The benefits arise from the reduction in the number of shipments, which would therefore result in a reduction in the cost of transport. The cost of the measure was expected to be an increase in the risk level. In principle, there should be an optimum when balancing these figures. As a result of other constraints such as radiation protection of the drivers, compliance with other transportation regulation (Transport Index), and delivery schedule, it does not appear possible to imagine options that can lead to transporting more than 100 Ci at a time. This might set the boundary of the analysis.

It has already been stressed that most of the costs of the accident were not dependent on the carried activity per shipment, and that the health effects were linearly connected with it. Increasing the allowed limit means decreasing the number of shipments and therefore the accident probability. The conclusion, shown in Figure 5, is that the expected number of health effects that would result from a spill remains constant, while the monetary cost of the accidents decreases.

This is a typical situation in which cost-benefit analysis does not lead to an optimum level because the cost of the potential detriment and of the transport are decreasing together. The limit must thus be searched for among the constraints that apply to this kind of transportation. The analysis was, however, of some interest. It illustrated the orders of magnitude of the health effects and of the monetary impacts. It can be noticed that equating the weights of the health impacts with the eco-

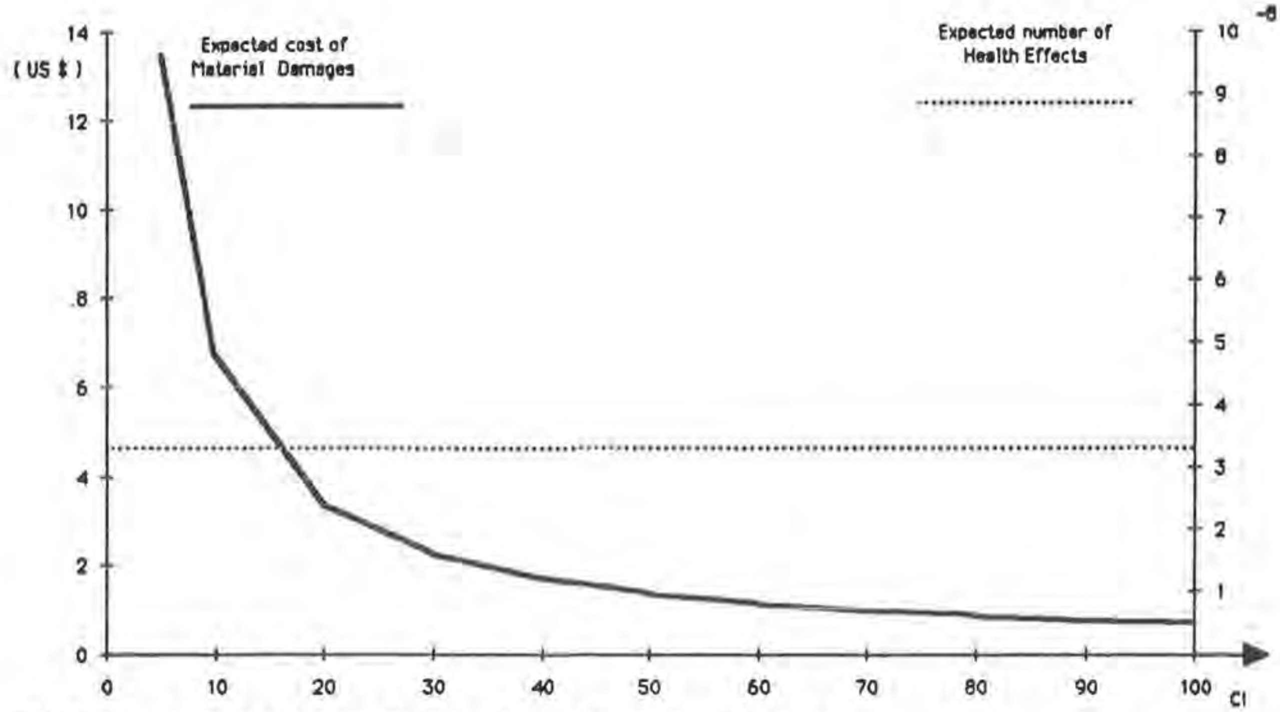

FIGURE 5 Evolution of the cost of the detriment with the increase in activity.

nomic impacts results in giving an implicit value to human life of at least $100 million. The analysis also showed that increasing the limit is sound, both from a monetary point of view and when the approach is purely grounded on the health effects. At the same time, lowering the limit would result in an increase in risk. This implies that it is not possible to use the risk, (i.e., the mathematical expectancy of the damages) as a unique criterion.

Other Criteria

It is necessary to look at the constraints that can limit the transported activity, as well as to search for other criteria based, for instance, on the consequences of the accidents. The main regulatory constraint that has an effect on the choice of the cargo limit is related to radiation protection. Increasing the activity to values higher than approximately 50 Ci of nominal activity appears difficult because of the weight of the additional shielding. But this can be decided by the carrier of these products and it does not pertain to the authority to state whether or not some money should be spent on this matter.

The question is thus to find the other criteria on which it will be possible to ground the decision about the limit in the tunnel. A probabilistic approach appears difficult because the expected number of deaths and loss of money is very low. However, if one postulates that the present A2/3 limit is acceptable, it should be the same for A2 or even 2A2 because the order of magnitude of the health risk does not change.

A different criterion arises from the comparison with the other materials whose transportation is allowed under the tunnel. For example, in the authorized 3 kg of hydrogen chloride and of phosphorus trichloride, there are respectively 0.2 and 1.3×10^6 times the amount of a lethal inhaled dose. With 1,000 Ci of nominal activity, there are only 6,000 times the lethal dose. The worst case accident is therefore about 1,000 times less harmful with Technetium generators.

Considering the consequences of the major event, in this case a large fire, two figures can be quoted. For approximately 1,000 Ci, the likelihood of inducing a lethal effect increases. The same was computed for 100 Ci looking at morbidity effects. Both these impacts can be considered as possible criteria for the acceptability.

Lastly, an interesting figure corresponds to the amount above which, still in the worst case accident, it would be necessary to decontaminate a whole 300-m section of the tunnel. This quantity is around 60 Ci of nominal activity. This criterion is significant because such work would have a considerable impact on public opinion. However, this figure implies the acceptance of the levels adopted in this study for deciding whether decontamination is necessary.

CONCLUSION

This study has a clear result. It shows the low level of the risk associated with the transportation of medical sources under the tunnel, both from a probabilistic and worst case approach. It unfortunately did not provide a straightforward answer to the issue of setting the authorized limit of activity. The health risk is constant when the limit increases and the economic impacts are decreasing together with the transportation costs so that there are only advantages, when dealing with the mathematical expectation of the cost and benefits, in releasing the limits. Because of this difficulty with that objective criterion, other criteria of a more subjective nature have been examined. Within the possible range of activity (0 to 100 Ci) and, in fact, well beyond this figure, the risk of an accident and even of the worst case accident is very low when compared to the risk of death from the road accident itself, or when compared to the risk associated with other allowed hazardous materials. Of course, it can be postulated that the particular nature of nuclear activities invalidates such comparison, but even so, there is no gap between allowances of 100 and 33 Ci. If one is acceptable, the other should also be acceptable. One criterion was also found to be of interest—the limit above which important decontamination work would have to be undertaken after a very serious accident. Because of the economic impact and especially of the potential impact on the public opinion of a long shutdown of the tunnel attributable to a radioactive material incident, this should be taken into account. It would lead to choosing a value of about 60 Ci of nominal activity. Nevertheless, it clearly appears that such a figure relies on a subjective judgment, and the final decision should carefully weigh these subjective factors.

Besides providing the preceding figures, one of the main interests of this study was to illustrate the problems linked to emergency action after an incident involving radioactive materials. For incidents with very little consequences, the difficulty of adapting the response to the actual situations has been exemplified in many circumstances. The lack of precise criteria and the subjective nature of the problem resulted in difficulties when assessing the possible remedial actions under Mont Blanc. There is a need for clarification in this field. Also, it is hoped that the descriptions of incidents cited in this study would avoid the misunderstandings that happen too often when a radioactive incident occurs on a public road and thus will help to mitigate the health, economic, and psychological consequences of such an event.

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