ASSESSING COSTS AND EFFECTIVENESS OF SAFETY MEASURES FOR THE TRANSIT OF SMALL TYPE A PACKAGES THROUGH ROAD TUNNELS

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Abstract

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The Mont Blanc Tunnel is situated under the highest mountain in Europe. Being 12 km long, it is also one of the longest road tunnels in the world. Local authorities have to state whether the general regulations for the road transportation of radioactive materials, as defined by the IAEA, apply, or whether additive measures need to be taken. Whereas an activity limit – A_2 – applies only to the content of a Type A package containing dispersible materials, a derived limit applying to the whole cargo of a truck has been in use in the tunnel and can be redefined. The present paper deals with the question of the choice of a proper figure for such a limit that might regulate the transit for technetium generators (Elumatic III from Oris France). The first step of the study is a risk assessment, with the truck content as an explicit parameter. The yearly traffic is of 150 trucks, carrying, on the average, 26 Ci of technetium-99 m in Elumatic generators at the time of the crossing. On a yearly basis about 5×10^{-6} road accidents might be expected, while the expected radiological fatalities would amount to approximately 2×10^{-8} and the expected monetary loss would be US $10. The second step is the implementation of decision aiding techniques based on the previous estimates. As the mathematical expectations of such risk indices were not dependent on the shipped activity, a classical approach, the cost effectiveness curve, did not lead to an optimum. Other approaches and other criteria were investigated, such as the comparison with other hazardous materials, the likelihood of lethal or morbidity effects and ground contamination. Should the latter criterion be considered pertinent, it would lead to a limit of 130 Ci of technetium at the time the truck crosses the tunnel.

1. SCOPE OF THE STUDY

The transportation of small quantities of dispersible radioactive materials is allowed on European roads according to the IAEA standards [1] in the so called 'A package', up to a certain limit in activity for a single package (the 'A_2 limit', which depends on the radionuclide). Under specific traffic conditions, namely when crossing the 12 km long tunnel under Mont Blanc, more restrictive standards can prove necessary. A possibility is to prohibit the crossing when the content of a whole cargo is above a certain activity limit. This measure was applied, with a very restrictive limit, until recently. The question is then to determine the authorized activity in the tunnel, and the purpose of this paper is to show the analyses supporting a decision in this field.

2. TRANSPORTATION SYSTEM

Traffic of technetium generators

There are three transits weekly through the tunnel. The vehicle in use is generally a light truck. Its cargo content, expressed in actual activity, averages to 54 Ci,[1] ranging from half to twice this figure. It consists of various radioisotopes, but technetium generators account for 99% of this activity (28 Ci of molybdenum and 25.5 Ci of technetium).

This device shipped in a Type A package, contains molybdenum-99 (half-life 66 h), which is transformed gradually into technetium-99 m (half-life 6 h). Generators of this kind can provide technetium during a week for medical scanning purposes. Although its content in activity can vary, the generator itself, the Elumatic III from Oris, is always the same. It contains, within a parallelepiped plastic box of about 20 cm, a system to extract the required solution of technetium out of a small glass column in which both isotopes are contained and a biological shielding of 13 kg of lead (see Fig. 1).

Tunnel environment

The total length of the tunnel is 12 km and there is one lane in each direction. On average there are about 30 vehicles in the tunnel at a given time [2]. Should an accident occur that would shut one lane, about 90 people might be subjected to potential consequences, and possibly 10 vehicles might be trapped behind the truck. The important 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.

The emergency response system comprises fire extinguishers distributed in the tunnel; this has been used to extinguish 13 of the 14 fires which took place in the tunnel. At the portals there is an emergency vehicle equipped with more powerful extinguishers and breathing apparatus. With regard to radiation hazard there is

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[1] 1 Ci = 37 GBq.

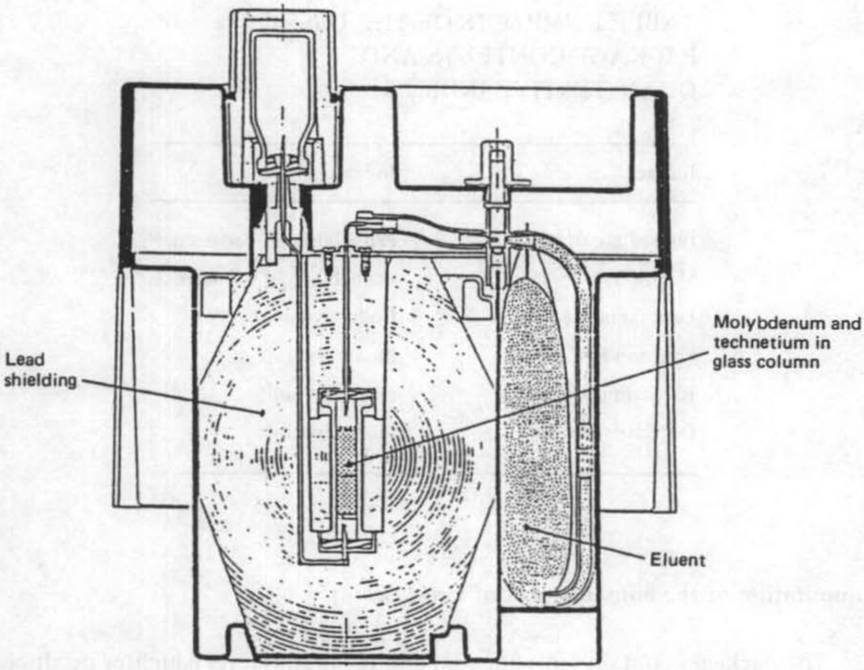

FIG. 1. The Oris technetium generator.

no monitoring device available at the tunnel site. The decontamination teams would have to come from Lyon, which is located 200 km from the tunnel [2, 3].

3. RISK ASSESSMENT

Possible consequences of an accident

There are two main categories for the possible consequences of an accident. First, the economic impacts; these can include the cost of monitoring, the cost of decontamination and the loss of earnings due to the shutting down of the tunnel. Second, the radiation health effects can be either short term effects or long term stochastic effects. Table I summarizes the main impacts of an accident and the way they will be quantified. They are not of the same importance. Some are very unlikely, others are almost certain. The risk assessment comprises two steps: computation of the consequences of an accident and probabilistic assessment.

TABLE I. IMPACTS OF THE LOSS OF PACKAGE CONTENTS AND QUANTITATIVE INDICES

Impact	Index
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

Computation of the consequences of a release

The packages contain molybdenum and technetium, its daughter product. For 1 Ci guaranteed to the customer (one can speak of 'nominal' activity), there is, at the time the truck reaches the tunnel, 2.1 Ci of technetium and 2.3 Ci of molybdenum. The radiological hazard can arise from external irradiation and inhalation. *External irradiation* results from a loss of shielding. Neglecting its contribution to the collective dose, a lethal area (10^{-3} m^2 per nominal Ci at the 5 Sv threshold) and a morbidity area (10^{-2} m^2 per nominal Ci at the 0.5 Sv threshold) correspond to the hypothesis that a bystander would stay half an hour. *Inhalation* occurs when the products are airborne. In this case a model must be implemented for atmospheric transport. Before it reaches the lining of the tunnel (about 15 s after the release) the initial puff can be assumed to be Gaussian and *immediate effects* may be observed. Lethal (25 Gy to the lung and 30 Gy to the intestine) and morbidity areas can be computed as previously, but they are five times larger. For distances larger than about 50 m a box model is applied. Only *delayed effects* are expected in this case and a collective dose (1.5×10^{-3} man·Sv per airborne nominal Ci) for an average location of the release and an average number of people in the tunnel accounts for them.

The *loss of toll fees* is directly linked to the duration of the closure of the tunnel. Any accident involving a truck would lock the tunnel for about one hour. An average figure of US $2000 can be assumed for the loss of earnings. Should there be any doubt about the integrity of the cargo, a radiological survey team would be called upon and *radiological monitoring expenses* would follow. The work of the team would be to check the cargo and the cars which were behind it. In addition, the roadway and walls would be monitored. These costs are almost insensitive to the amount of damage to the packages. The work would last about five hours, since three are needed for the team to get to the tunnel location. The total cost is estimated at US $17 000, and the loss of earnings remains the main component.

The previous calculations performed with the box model allow one to compute the *ground contamination*. It requires the definition of an acceptable level: 50 $mCi \cdot m^{-2}$ of molybdenum should be acceptable for a location that is not a working place. The tunnel is divided into 40 sections of 300 m, corresponding to the ventilation system. The probability of having one of these sections contaminated is dependent on the released activity. It vanishes when the release is below a 'nominal' 60 Ci. If the contamination is very slight (little release, or simple loss of biological shielding) it can be assumed that the control team might handle the problem within one hour. This implies one hour more of tunnel shutdown. When a whole 300 m section is to be decontaminated, one other team is necessary, and the operation would take about eight hours.

Various impacts have been computed (see Table II) that can or cannot be observed according to the type of the accident. In every case but the last one (the probability of one whole action to decontaminate depends on the activity), the economic impacts are not dependent on the activity carried. On the other hand, the health impacts are proportional to this parameter.

Probabilistic assessment

The aim of the probabilistic part of the assessment is to establish the accident scenarios that can result in the 'consequence scenarios' stated above, and to compute their probabilities.

Although some statistics are available on Type A package accidents [4, 5], they are not specific to technetium generators. A crush and fire experiment has been performed in the Amersham Centre with a light truck containing a mixed cargo of Type A and B packages [6]. An interesting feature was the very short time which was necessary for a fire to encompass the whole vehicle. However, the results of the regulatory tests, the analyses of a train accident, and the destructive fire test performed in June 1985 are specific to the French Elumatic technetium generator.

A review of these data and of the tunnel accident records has allowed us to focus on four accident scenarios, with the following consequences:

- light crash: no loss of shielding,
- frontal collision (i.e. about 120 $km \cdot h^{-1}$): loss of shielding, 1% airborne material,
- short fire: no effect,
- strong fire (i.e. destroyed vehicle): 75% airborne material.

The probability of light crashes is 3.5×10^{-6} at each crossing of the tunnel, half of them requiring monitoring. This probability is 4×10^{-7} for a collision,

TABLE II. MAGNITUDE OF THE IMPACTS FOR VARIOUS ACCIDENT SCENARIOS

	Cost of traffic interrupt (US \$)	Cost of control (US \$)	Cost of decontamination (US \$)	Probability of morbidity	Probability of mortality	Collective dose (man·Sv)
Trivial accident	2 000	–	–	–	–	–
Suspected loss of content	10 000	7000	–	–	–	–
Loss of biological shielding	12 000	6000	1 000	–	–	–
Actual airborne release	12 000	6000	1 000	$2.5 \times 10^{-3} \times$ A.f	$2.5 \times 10^{-4} \times$ A.f	$1.5 \times 10^{-3} \times$ A.f
Actual airborne release and decontamination of a tunnel section	28 000	7000	14 000	$2.5 \times 10^{-3} \times$ A.f	$2.5 \times 10^{-4} \times$ A.f	$1.5 \times 10^{-3} \times$ A.f

A.f: Released fraction expressed in 'nominal' curies (1 'nominal' Ci = 2.3 Ci of molybdenum).

8×10^{-7} for a light fire and 5×10^{-8} for a severe fire. On the basis of the actual traffic of 150 passages with 12 Ci of nominal activity (25.2 Ci of $^{99}Tc^{m}$ and 27.5 Ci of ^{99}Mo) the risk is as follows:

– accident probability	7.1×10^{-4}
– expected monetary loss	US $6.5
– expected collective dose	1.11×10^{-7} man·Sv
– probability of a lethal effect	1.85×10^{-8}
– probability of reversible effect	1.85×10^{-7}

The level of risk appears to be low, and this not only due to the small amount of traffic. For instance, the number of health effects is one thousand times lower than the expected number of deaths due to the traffic accidents themselves.

4. ELEMENTS FOR THE DECISION MAKING PROCESS

Cost benefit analyses

The question is whether there is an optimum in a possible allowed nominal activity for the technetium generators. One must therefore look at the costs and the benefits of an increase in this level. The benefit arises from the reduction in the number of shipments. 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. It has already been stressed that most of the costs of the accident are not dependent on the activity carried while the health effects are linearly connected with it. Increasing the allowed limit means decreasing the number of shipments and therefore the accident probability. The conclusion (see Fig. 2) is that the expected number of health effects remains constant, while the monetary cost of the accidents decreases.

This is a situation in which cost benefit analysis does not lead to an optimal level. Thus a limit must be searched for among the constraints that might apply to this kind of transportation. The analysis was however of some interest. It illustrated the orders of magnitude of the impacts and it showed that increasing the limit is sound.

Other criteria

A regulatory constraint, the Transportation Index, makes it difficult to reach figures higher than 100 Ci, but it is technically feasible. Another criterion arises from the comparison with other hazardous materials. It would lead to allowed amounts well beyond plausible figures. Looking at the consequences of the major

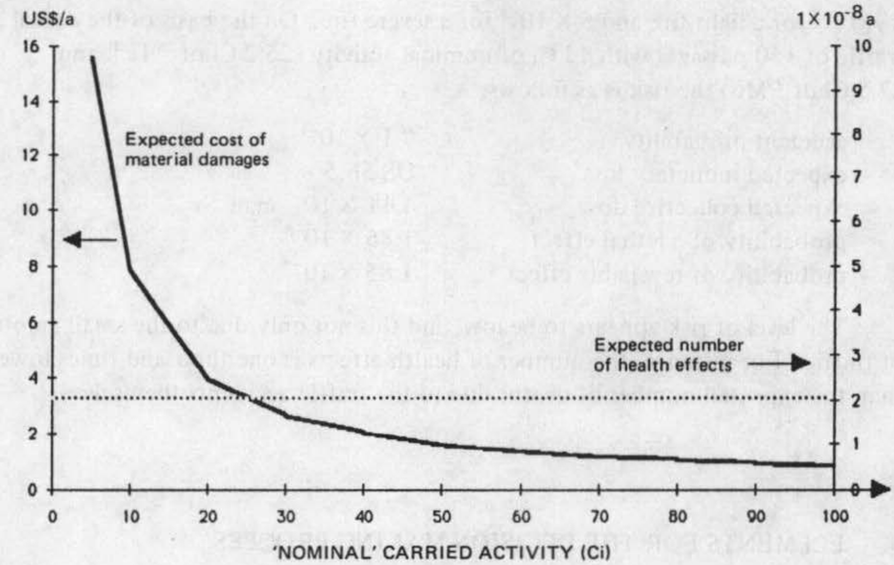

FIG. 2. Annual expectation of the economic and health impacts as a function of the shipped activity.

event, here a large fire, two other criteria appear. For about 1000 Ci, the likelihood of inducing a lethal effect becomes of some magnitude. The same was computed for 100 Ci looking at morbidity effects. Finally, an interesting figure corresponds to the amount above which, still in the worst case accident, it would be likely to have to decontaminate a whole 300 m section of the tunnel. This quantity is around 60 Ci of 'nominal' activity. This criterion is worthwhile considering since such work would have a considerable impact on public opinion.

5. CONCLUSION

This study has a clear result. It demonstrates the low level of risk associated with the transportation of medical sources under the tunnel, both from a probabilistic and a worst case viewpoint. However, the use of a traditional cost benefit approach is not possible because there are only advantages, when dealing with the mathematical expectation of the cost and benefits, in raising the limits. Owing to the difficulty with that objective criterion, other criteria of a more subjective nature have been examined.

The limit above which important decontamination work would have to be undertaken after a very serious accident was found to be a criterion of interest. This is due to the economic impact, but especially to the potential effect on public opinion of a long shutdown of the tunnel attributable to a radioactive material incident. It would lead to a value of about 130 Ci of technetium at the time the truck passes through the tunnel (60 Ci of 'nominal' activity). Although it clearly appears that the last figure relies on a subjective judgement and that the final decision should carefully weigh these subjective factors, this study has illustrated how a quantitative assessment and a formal approach prove useful when dealing with decision related problems of this kind.

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