Safety and Security in Transportation of Radioactive Material- the Perception of Risk.

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1. Introduction

Since the event of September 11, 2001, the way most people look at transportation risk has changed. There is now a lot more focusing on the security concerns related to the transportation of radioactive material. Most people are now more concerned about the risk of terrorist actions or sabotage than of accidents. This is probably due to the fact that the safety record for transportation of radioactive material has so far been very good and that most people experience terrorism and sabotage more scaring and less controllable than general accidents. This paper will compare the safety and the security regulations and discuss synergies and contradictions between the sets of regulations.

1.1 Transport Safety - purpose and goal

The IAEA transport safety regulation is focusing on "establishing standards of safety which provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment that are associated with the transport of radioactive material".
The philosophy of the regulations is that all packages as far as possible should be dealt with the same way as other hazardous goods, and that the safety depends primarily on the package and not on operational control.
Furthermore the consignor should be responsible for ensuring safety during transport. This includes characterization of contents, proper packaging, adequate operational actions and communication. Communication includes documentation such as shipping information, advance notification etc..
The transport safety regulations states that routing or physical protection imposed by governmental agencies for other purposes than radiological safety must not detract from the standards of safety for which the Regulations have been developed.
For material under safeguards the practices valid for the originating facility will come into force. For these materials safeguard requirements and/or physical protection actions will interfere with the transport system. It is stated in the transport safety regulations that no such actions can degrade the safety of the shipment.
The IAEA transport safety regulations do not address intentional acts like sabotage or theft, i.e they only address safety but not security.

1.2 Transport Security– purpose and goal

Transport security requirements are meant to:
-prevent intentional radiation of the public and the environment. Intentional radiation of the public may occur in the situation of sabotage to a transport containing radioactive material.
-prevent social disruption which means that the security requirements must include means to avoid threats to any transport while on route.
-in accordance with the safeguard requirements prevent theft of nuclear material. This requirement is in accordance with the non-proliferation of nuclear weapons treaty (NPT).
- prevent theft of radioactive material. This material can be used to make "dirty bombs", non-proliferation and /or poisoning etc.
-prevent threat situation. This is valid for all types of material.

The security requirements that are applicable to transportation include mainly three areas; safeguards, non-proliferation and physical protection.
The safeguard part is addressed in the safeguard agreement between the IAEA and the Member State and in the facility attachment for the originating facility. The requirements related to safeguards include operations such as accurate shipping documents, advance notification, shipping permits etc. They also include supervised loading of transport containers, proper seals of the containers, safeguard monitoring and accountancy procedures.
Physical protection of material should minimize the possibilities for unauthorized removal of material and/or sabotage and to provide means for rapid and comprehensive measures to locate and recover missing material and to minimize radiological consequences of sabotage or theft.

Infcirc.225 provides a set of recommendation of requirements for a physical protection system for fissile material. The nonproliferation includes means, like export control, to prevent from selling or transferring material in a way that is in conflict with the non-proliferation treaty (NPT).
The security requirements do not address safety.

1.3 Possible synergies and contradictions.

The two concepts, safety and security have a common goal. The overall goal is to protect the general public from any exposure of radiation from radioactive and nuclear material. There are to some degree different approaches to achieve this goal but there are also similarities.
The different approaches originate mostly from the fact that the risk of exposure of general public originates from two different causes. For safety the risk is looked at from an accident point of view while in the security case it is looked at from an intentional exposure caused by some act of terrorism or sabotage. The means to meet the goal of protecting the public therefore needs to be different. From a safety point of view it is necessary to put a great deal of effort into the construction of packages and transportation safety in general. When it comes to security, a package that can withstand such forces that it might be exposed to in a transport accident is valid but is far from enough. In the case of sabotage it is intended to expose the package to forces as far beyond the test criteria as possible to achieve the largest consequence possible. A strong package, however, makes it more difficult to achieve this goal. In the security case the focus must therefore be put on minimizing the accessibility to the package and the transport itself. Minimizing the accessibility is something that is also desirable for safety reasons as there is to a certain degree radiation and possible exposure of low doses also from packages not involved in any accidents.
Routing of transports is used both for safety and security reasons. The reason for routing might though be different. From a safety perspective the reason for routing is to find the safest way in terms of low accident rates while from a security point of view it might be to find a route where the transport is easily supervised and controlled.
Especially when it comes to strategic material and other radioactive material that can be looked at as attractive for terrorist purposes the differences in approach can be even bigger. From a security point of view this material is best transported by air where it is easiest to have control over the transport. From a safety point of view on the other hand there has been a lot of reluctance from different groups to transport this type of material by air.
Another area where contradictions may appear is the area of information about the transport. For safety reasons there is a no need of being restrictive with information about the transport quite the opposite in fact, but for security reasons there should be as little information as possible as the knowledge about the transport route and timing may come in the wrong hands.
Even when it comes to stops and inspections during transport there is a contradiction between safety and security. It has to be remembered though that safety is also a concern in the security perspective. There is however situations where there might be a conflict, and there are also situations, probably most cases, where security concerns only require additional actions to protect the material from outside interference. It is important, never the less, that there is a unified approach to this issue to make sure that certain requirements on one part not actually make the total risk higher by interfering with requirements of the other part.
An additional consideration for security that is not covered in the safety requirements is the non-proliferation part. All countries that have ratified the NPT have agreed not to sell, buy or transfer material in a way that contradicts this agreement. The export/import control in Member States has the responsibility for this control.

2. THE CONCEPT OF RISK ASSESSMENT

2.1 Considerations in Risk Assessment – as used in transport safety

Most risk assessments of transportation of radioactive material made so far, excludes sabotage, theft and terrorism. There are, however, recommendations in for example the USDOE's Resource Handbook on Transportation Risk Assessment that the focus should be put on the largest foreseeable release of radioactive material (the bolding case) that could result from a traffic accident or an act of terrorism or sabotage.
During the last couple of years the concern for terrorist acts and sabotage have grown and therefore also the necessity of including such intentional acts when determining the risk from transportation of radioactive material.
The probabilistic risk assessment used in the transport safety area involves consideration on of certain parameters over the transport routes as well as the statistical nature of transport incidents and accidents. There are two components to be quantified: the expected frequency of occurrence of an initial event leading to a consequence and the severity of the potentially adverse consequence resulting from transportation accidents. Incident-free is the

consequence of low level exposure from a package during shipment, where thee probability of the exposure is unity.
The risk is considered to be an estimate of the expected dose calculated as the probability of an accident times the consequence of such an accident usually expressed in the terms of population dose (in units of person-Sv)
Looking on the probability of an accident of a certain severity there are generally two parts to be considered. First the probability of the initial event, i.e the probability of a car- , train-, boat- or airplane accident has to be determined. Given the initial event the severity of the accident has to be considered. The severity is used to distinguish the variation in the distribution of package damage during an accident. Less severe accidents results in less damage to a package, while very severe accidents may result in the total release of the package content.
The severity categorization is focusing on the package response and is related to the limits set up in the requirements for different packages. The package requirements for type B packages are intended to cover 95% of all non-intentional transport accidents.
In the case of non-intentional accidents, the frequency of a severe accident is usually much lower than the frequency of less severe accidents.
For an intentional act such as sabotage the goal would be to get a severe as possible accidents i.e get as much as possible material released from the package. This leads to that given a sabotage the probability for a very high release of material has to be set to one.
In the case of theft the problem is different. In this case there is no immediate release of material and the possibility of a future release has to be taken into account. There is also a possibility in this case that no release will actually occur. The material might only be used to provide a threat to society.
The accident analysis can be used to identify and quantify specific hazard features such as how a selected transport route or transport mode may challenge the safety of a package. This use of the transportation risk assessment is one part that might be used when including also intentional acts.

2.2 Accident severity Categorization

For non-intentional accidents the severity categorization is based on impact force and fire duration, leading to a number of categories with different frequency of occurrence attached to them.

Impact Category	**Impact Speed Range (km/h)**				
	No mechanical impact	4,9 ms^{-1} (17,6 km/h) ~ 1,2 m drop	13,3 ms^{-1} (47,9 km/h) ~ 9 m drop	27 ms^{-1} (97,2 km/h) ~ 37 m drop	40 ms^{-1} (144 km/h) ~ 85 m drop
Mechanical, No fire	**M0/F0**	**M1/F0**	**M2/F0**	**M3/F0**	**M4/F0**
< 30 minute 800°C fire	**M0/F1**	**M1/F1**	**M2/F1**	**M3/F1**	**M4/F1**
> 30 minute 800°C fire	**M0/F2**	**M1/F2**	**M2/F2**	**M3/F2**	**M4/F2**

Figure 1. Generic Accident Severity Categorisation Scheme (adopted from Heywood et al. 1999 ref.3)

Fig 1. provides an example of a categorization scheme for rail transport.
The categorization scheme defines a fixed number of impact categories and a fixed number of thermal load categories. The number of categories can be defined on a case by case base and is usually different for different transport modes. The speed limits and fire duration is selected to correspond to the IAEA testing requirements for different package types.
The frequency of occurrence of each severity category is determined from accident statistics available for a specific mode. Note that these statistics only includes accidents and not intentional acts.

For each severity category an estimation of the package response has to be made for each type of package. Intentional acts such as sabotage will strive to have the highest impact force and fire duration possible to disperse a much material as possible, which means being as close as possible in the lower right corner of the scheme.
For accidents the tendency is that the more to the lower right corner the less is the frequency, while for intentional acts the tendency is the opposite.
Theft and associated terror actions with the intent of psychological threat and/or delayed effects have to be dealt with differently. The probability of theft is almost impossible to determine and there are strong efforts in the security to avoid this to happen. There is, however, one aspect of the probabilistic risk assessment that can be used in the case of theft and that is use of risk assessment for routing purposes and/or the selection of transport mode. This part of the risk assessment approach can as a matter of fact be used for all intentional acts to a certain degree. For security purpose the material should be transported in such a way that the accessibility to the material is kept to a minimum.
There might be cases when the risk for sabotage and theft gets higher if a transport mode or route giving the lowest safety risk is chosen. There need to be an overall approach given to this question to avoid any sub-optimization of the transportation system.

2.3 Consequences

Definition of consequence for accidents is a calculation of dose due to release of material or loss of shielding. The dose is determined from estimation of the release fraction corresponding to a certain accident severity and a certain package. Given a damaged package it is assumed that some part of the content will be available for air entrainment. The inhalation and ingestion doses are the calculated using the ICRP 60 factors. The consequence is presented both as highest individual doses and population doses. This approach can also be used in the case of sabotage with an immediate release of the material.
For intentional acts, such as theft, it should also include the consequences of a theft and the resulting potential threat that might be the result.
There is also a need to be able to compare different types of consequences, radiological, chemical and psychological.
Synergies and contradictions in the threat/risk assessment for safety and security have to be thoroughly discussed.

3. MINIMIZING TOTAL RISK

3.1 Risk determination

To determine the total risk from transportation of radioactive material is not an easy task. Even only looking at the safety side is connected to a lot of uncertainties. There is, fortunately, very little statistics available on accident involving radioactive material and therefore accident statistics valid for transportation systems in general has to be used. There are also big uncertainties of the actual behavior of a package in an accident situation, the release fraction and not at least the exposure and consequences of an accident to general public.
Nevertheless, probabilistic risk assessment has been a good tool to at least compare different types of risk, i.e transport modes, different routes etc. It is also the best tool available to at least get a ballpark figure of the expected risk.
To predict the risk from intentional acts might, at first thought, be even more difficult. How to determine the probability for such a situation in the first place? There are, however, situations where probabilistic risk assessment can be used. Given sabotage for example the technique can be used to determine the consequences. It has to be remembered that for this particular case it has to be expected that all material contained in the package will be released.
There is a need for a discussion on how theft should be dealt with in the total risk perspective. Theft might either lead to an actual detonation of a nuclear devise or a dirty bomb, spreading of radioactive material or threatening to do so. The consequence estimation from such scenarios has to include estimation of the damage caused from actually using the material and an estimation of the social consequences of a threat to do so.
To be able to determine the likelihood for a transport to be attractive for terrorist purposes there should be efforts made to rank the different radioactive and nuclear material. This ranking of material should take into account factors like usefulness for threats, usefulness for making nuclear or dirty bombs, effects of immediate sabotage etc. In the attractiveness ranking not only factors of the use of material should be considered but also how easy or difficult it is for a terrorist to handle the material.

3.2 Differences in risk determination for safety and security reasons

It is essential that safety and security is not separated when determining the risk involved in transportation of radioactive materials. There is a need for coordinating the efforts to make transportation of radioactive materials as safe and secure as possible.
The use of A or D values has been discussed (CS-10). Although it would be preferable to have a common way to deal with this, there are still ways to take care of these different approaches when trying to make a total risk optimization. In this case the most important thing is to be aware of the differences to be able to take them into account when estimating the total risk.
There are ways to overcome most if not all the differences in the in the risk estimations for the two areas and it is the efforts should be put in, at least in the beginning, rather than arguing over small details.
It has to be kept in mind that harmonizing the risk concept is the only way to minimize the risk and there is where the effort should be.

3.3 How to converge towards a minimum total risk

All aspects, on both safety and security, has to come together to find the minimum risk, for example a minimum risk in one aspect might lead to higher risk in another. Therefore, it is highly important that safety and security are not separated but looked at in total perspective. The risk analysis should as much as possible include both safety and security issues.
To be able to look at both safety and security risk at the same time it has to be realized that it is a three dimensional problem. The safety in transport is one of the dimensions. The second dimension is the security. In this case the attractiveness of the material has to be looked at. The third dimension is the change with time. The probability and methods for terrorist acts and sabotage will change in accordance with the change of the regulations. Also, when making the security very high on some material it will put other materials in focus for terrorist acts. Therefore, it is a need to look at all the three dimensions at the same time to be able to develop a method to minimize the total risk.

5. CONCLUSIONS

It is essential that safety and security are looked at from a broad perspective, and not separately, to make sure that no sub-optimization occurs. Especially after the terrorist attack in September 2001 and the increasing threat of terrorism security of the transportation system has come into focus. The safety record of transportation of radioactive material is very good and the safety regulations have so far proved to be adequate.
The aspect of looking at both safety and security becomes very important when it comes to air transport of spent fuel, high level waste and plutonium. There have been accidents, involving aircrafts, where the impact forces have exceeded the test criteria even for type C packages. In such an accident there will be no guarantee that the package will not fail. The probability for such an accident is, however, very low. The air mode is, on the other hand, the mode where the accessibility to the material from outside can be kept very low and from a security point of view this has to be considered of great importance.
When determining the minimum risk concerning transport of spent fuel, high level waste and plutonium both the safety and the security risk have to be considered as such material have to be considered attractive for terrorist purposes.
Therefore, when determining the risk from transportation of these materials a risk analysis has to consider both safety and security.
In the ongoing coordinated research program on airplane crashes only the safety aspects has been considered. Therefore, this study is not complete especially when it comes to transport of type C packages. There are security concerns that need to be looked at to get a complete picture of how to minimize the risk involved in these types of transports. Even if there are accidents, with very low probability of occurrence, in which the type C package might fail, the advantage with air transport of these materials will from a security point of view give a total risk that is much lower than would be the case if another transport mode is used.

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