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EFFICIENT LICENSING OF PACKAGE DESIGNS FOR FISSILE MATERIAL

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ABSTRACT

International regulations for transport of fissile materials require multilateral approval of each package design. In addition, approvals by states which may become involved may be requested. Alternative routes are needed. Approval from the authority of the nationality of a ship is required. The lengthy licensing procedures in most states may require applications long before an actual shipment is prepared.

The industry requests more realism and more realistic interpretations of requirements. Many proposals have been made by Sweden and other states in recent years to allow more realism in the regulations. Some progress may have been achieved, but it is very slow. Many states seem to avoid changes, even when the current requirements are clearly incorrect or unrealistic. In some cases, authorities and applicants show a similar reluctance to correct faulty and incomplete safety assessments.

Realism is a prediction of the future. It must be compatible with observed reality, which is the current situation, while taking past experience into account. A separate paper on technical criticality safety issues related to realism and reality will be presented at ICNC 2007 in St. Petersburg, Russia. Examples specific to transport licensing during the last years will be presented at PATRAM 2007. The sources of information or details of the designs will not be revealed. Exchange of experience is required to allow increased realism, to improve safety reports and for licensing efficiency.

During the last years, there are signs of improved cooperation at a technical level between authorities. However, unilateral approval will not be a wise option for many years. The quality of applications and authority reviews is unfortunately not indicating a reduced need for independent review. There is no single authority that with credibility can claim such quality in criticality safety licensing that no additional review is needed. On the other hand, a large number of authority approvals are no safety indication either.

Increased cooperation between authorities will lead to improved consistency in interpretation of the requirements, shorter overall licensing delays and, most likely, higher overall quality of the safety review. For the industry, these are all advantages but there are also other benefits.

INTRODUCTION

Shipment of fissile material covers a range of materials with varying properties related to economic value, nuclear criticality hazard, radiation hazard, other safety hazards and to nuclear weapons development. This paper focuses on nuclear criticality safety, with the understanding that all issues need to be considered.

An issue in improving the efficiency of licensing relates to the credibility of Regulations, of authorities and of the nuclear industry. Compared with the abstract written in early 2007, the paper adds conclusions in connection with the 2007 IAEA process to investigate the need to revise the Regulations [1]. The scope is the same; to support improved efficiency in the transport of fissile material, benefiting authorities, industry and safety.

IMPROVEMENT OF THE TRANSPORT REGULATIONS

Fissile material as opposed to radioactive material

Consideration of a potential criticality accident in transport is limited to fissionable (contains one or more nuclides with significant potential for fission when hit by a free neutron) materials that, alone or together with other fissionable materials, are likely to be present in sufficient quantity and concentration to be a criticality safety concern.

The current IAEA Transport Regulations [1] limit the range of fissionable nuclides to ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu. A common property of these nuclides is that they are all fissile (significant potential for fission when hit by a free thermal energy neutron). In practice this means that presence of water needs to be considered and that compression of the materials does not necessarily give optimum conditions for criticality.

Radioactive material is defined in the Regulations as a function of radionuclide concentration and of total activity per consignment.

There is no link between the definitions of radioactive material and of fissionable material. A material can be radioactive without being fissionable. More interesting is that the material can be fissionable without being radioactive. The Regulations refer to "Safe Transport of Radioactive Material". The scope of the Regulations clearly specifies that criticality safety is covered.

Fissionable materials are assumed to be a sub-section of radioactive materials in the Regulations. This means that the definition of radioactive materials in the Regulations is not complete and thus is not correct. The definition of radioactive material must cover materials that *could* cause a criticality hazard during shipment or during transit storage.

The only fissionable nuclide that could cause a criticality hazard without being covered by the definition of radioactive material is ^{235}U. The concentration limit was reduced by a factor seven in the 1996 Edition of the Regulations. It now appears unlikely that a non-radioactive but fissile material could cause a criticality hazard during shipment or transit storage.

The lack of interest by authorities and by industry to correct the definition and to justify the exemption limits for radioactive materials, in order to assure criticality safety, reduces the credibility of the Regulations and of its users. Safety is coincidental rather than intentional. The definition of LSA-I (Low-Specific Activity) material options (iii) and (iv) in the Regulations demonstrates that criticality safety can be covered together with activity concerns.

A first step in improving the efficiency in transport of fissionable materials is to establish a reliable overall structure of the Regulations and to demonstrate understanding of criticality safety foundations. The radioactive material definition issue shows that we are not there yet. When large quantities of material classified as non-radioactive are transit stored in someone's backyard, worries about potential criticality are not completely out of order – nobody checked.

<u>Exception criteria for materials, packages and consignments from criticality safety control</u>

The previous sub-section deals with total exemption of materials and consignments from coverage by the Regulations. The next level relates to materials and consignments that are inherently subcritical due to material properties and to other circumstances of credible transport conditions. As always with criticality safety evaluation, credible incidents and human error must be considered when the associated exception criteria are determined.

The fissile exception options in the Regulations have sometimes been questioned by criticality safety specialists. What is the minimum safety level expected from application of the exceptions, including consideration of incidents and human error? There appears to be two significantly different minimum criticality safety levels. The options related to para. 672(b) and (c) are related to an essentially negligible criticality hazard. Many indications show that this is the expected minimum safety level. One such indicator is the LSA-I definition, using the fissile exceptions as a justification for assured low specific activity. Another indication is Table 8 in the Regulations, showing examples of the UN numbers. Non-fissile and fissile-excepted material packages are separated from fissile material packages. It has been pointed out to the author that documents related to international liability refer to the fissile exceptions in the Regulations.

The options related to para. 672(a) allow a lower criticality safety level than for authority approved package designs and shipments. The safety of a single consignment depends on correct determination of the fissile nuclide quantities and correct understanding of the exception requirements. It is not the package that is excepted; it is the consignment. A package containing 1 g of ^{235}U may not be excepted if the consignment already is "full". This means that a package that is excepted for one shipment may not be excepted in another shipment. The observed (even in several locations of the Regulations) difficulties in separating the meaning of "package" and "packaging" is an additional source of error. If the packaging is assumed to be the exception basis, it could result in loading of uranium with higher enrichment ^{235}U than originally intended.

The additional complication of separating consignments in time (from the same consignor) and in space (6 meters) reduces the safety level related to para. 672(a) further. Option (i), based on a maximum of 15 g of fissile nuclides per package, is used to discuss the safety level. A consignment based on para. 672(a) should be seen as equivalent to a consignment of fissile material packages with a total CSI of 50. In addition, the neutron moderation and interaction properties should be expected to be strong both for normal and accident condition packages in a para. 672(a) consignment. There appears to be no restriction on multiple consignments on a single vehicle, e.g. in a sea vessel hold. Consignments of packages supported by authority approved package designs would be strictly limited based on the total CSI. Multiple consignments of packages based on para. 672(a) result in a lower safety level.

A second step in improving the efficiency in transport of fissionable materials is to separate the exception options related to paras 672(a)-(d) even clearer. The best solution may be to move subpara. 672(a) and (d) to a new para. The safety of this new para. could rely on some packaging, loading and consignment controls but should not rely on criticality safety evaluation, testing, quality assurance and other requirements related to authority approved package designs for fissile materials. This solution would make it easier to introduce new fissionable exception options in a way that is consistent with expected minimum safety levels.

Any package with less than 1 kg of plutonium (<200 g fissile) is fissile-excepted

This issue was added after the deadline for the paper. A few weeks ago, the U.S. proposed changes to para. 672 of the Regulations. One of many changes was a correction to para. 672(d). The need for a correction is now obvious. Two days before PATRAM 2007, I had a look at this paragraph in the Regulations. It is so remarkable that it is quoted in total below:

“Packages containing, individually, a total plutonium mass not more than 1 kg, of which not more than 20 % by mass may consist of plutonium-239, plutonium-241 or any combination of those radionuclides”.

This fissile exception includes all packages containing only uranium (any quantity) or uranium plus up to 1 kg of plutonium (up to 200 g of fissile plutonium). There is no consignment limit for the number of packages or for the total quantity of uranium or plutonium. Fresh LWR fuel assemblies and research reactor fuel can be shipped as fissile-excepted packages. Solutions of high-enriched uranium can be shipped without limitation. This is not an editorial error. The text has been developed and approved by IAEA/TRANSSC and by the IAEA member states. It was really multilaterally approved. There are many issues with this text and the U.S. proposal pointed out the most important one. It is also not clear what the 20 % refers to (20 % of 1 kg which means 200 g ^{239}Pu and ^{241}Pu or 20 % of the actual plutonium mass). The U.S. proposal needs more work but is needed for safety and credibility. The derivation of this limit is tied to the heat generation of ^{238}Pu and this needs to be covered in the exception. If there is any plutonium with that much ^{240}Pu and ^{242}Pu, the safety will not be obvious.

Package designs for fissionable material requiring multilateral approval

The criticality safety requirements for package designs are based on general criticality safety principles and on expected conditions at quite extreme but credible accidents involving a single package. The accident conditions are based on statistics, evaluations of real accident and of tests, theoretical evaluations, etc. The general criticality safety requirements take human error into account to a higher degree than other types of safety requirements normally do. This is based on experience in handling of fissile materials during more than sixty years.

One of the weaknesses in current and past Regulations is the focus on water as a neutron reflector. It is reasonable that water needs to be considered since it can surround the package and enter the package to provide better reflection. However, there are better neutron reflectors in many packages. In addition, better reflection can be obtained by using an overpack or by adding shielding objects to reduce external radiation levels. Surrounding packages, even without fissile material, can provide better neutron reflection than water. This issue does not motivate any significant change of the Regulations, only increased awareness. An existing requirement that features added to a package at the time of transport shall be considered needs to be complemented by a similar requirement for the consignment (e.g. use of overpacks).

The requirements for criticality safety of arrays of packages are not as consistent and as realistic as those for single packages. The concept that 2N large packages with large N's are simultaneously damaged to optimum criticality hazard conditions and then arranged in a compact array is not credible. However, for small packages this potential may be credible. Older editions of the Regulations had a maximum of 250 accident condition packages but this limit was removed in the 1996 Edition. One reason was that large arrays had been observed on sea vessels.

Using the same criteria for arrays of large packages as for arrays of small packages reduces efficiency considerably, without improving safety.

Other requirements for arrays of packages are not providing adequate safety. The Criticality Safety Index (CSI) may provide some information but it is certainly not an index of criticality safety. The method of allowing different packages to be mixed in a configuration based on evaluations of arrays of identical packages is not credible. It is a fairy-tale. Two different packages, each with a CSI of 0, could be critical under routine conditions of transport. There is now some awareness of this among criticality safety specialists. However, the reluctance in changing the Regulations makes them less credible.

Another problem with requirements for criticality safety of arrays is that there is too much focus on water between packages. In many cases, probably most, water between packages will absorb neutrons and the criticality hazard will be reduced. Other materials between the packages (or between the containments in different packages) could increase the criticality hazard. Examples are steel, aluminium and charred wood. The requirement to consider any feature that is added to the package at the time of transport covers some of this concern. Again, that requirement should be expanded to cover consignment features (e.g. overpacks). The requirement for normal condition packages states that there shall not be anything between the packages in the evaluation and was introduced in the 1996 edition of the Regulations. It is a misleading requirement.

If the general problem caused by the lack of credible safety control of arrays of packages (they are all different even when they comply with the same approved package design) can be solved, there are significant opportunities for making transport of fissile materials more efficient. Without a solution to that problem, it may be too risky to allow consideration of more credible array configurations (e.g. lower than 10 meter high stacks of optimally damaged packages).

A third step in making the transport of fissile material more efficient is to look at reality and forget the fairy-tales that are currently used to control criticality safety of a configuration of packages. The overall effect of balancing increased awareness of mixed array problems with more credible configurations will be a significant increase in efficiency while improving safety.

"Simplified Arrangement" rather than "Special Arrangement"

The principle of "Special Arrangement" is very attractive in theory. However, experience shows that this concept gets a very negative perception by many authorities and by the public. This is particularly unfortunate with shipment of fissile material since the criticality hazard is not linear to the quantity or concentration of fissile nuclides. This is unlike activity which increases more linearly with the quantity and concentration of radionuclides. Containment is essential for activity control but not necessarily for criticality safety. General testing and quality assurance may not be very useful tools to avoid criticality.

The enormous gap between the simplicity of the fissile exceptions and the often complicated and (eventually) multilaterally approved package designs is a threat to efficiency and probably also to criticality safety during transport.

Shipments of large quantities of fissile solutions, powders or pellets should be made under strict administrative control of loading, using strong packagings and with consideration of human error. The competent authorities should be well aware of such shipments. The source and the destination of the material should be checked. Cross-checking with other types of controls (e.g. security, safeguards, safety at the site receiving the material, etc.) should be simplified.

The process to prepare an application for a package design allowing large quantities of fissile liquids and to get the design multilaterally approved often takes years and there is no guarantee that the application will be approved. The process of packing the material as excepted consignments takes hours or at most a few days. Air shipment is no problem for fissile-excepted consignments. The notion that it is the package that is excepted and not the consignment increases the hazard.

As mentioned earlier, the exception options in para. 672(a) are still too generous to fit in a category of essentially negligible criticality risk. However, before those options are moved into another category, the remaining exception options in 672 need to be complemented to cover many of the inherently safe shipments that are carried out under para. 672(a).

The fourth step in improving the efficiency of fissile material transport is to fill the gap between fissile exception and multilaterally approved package designs. "Special Arrangement" could have filled this gap but has been incorrectly viewed as less safe. Some authorities even refuse "Special Arrangement". The problem could be solved by an introduction of a new category, based on a few specific requirements and on competent authority approval, but without all the general requirements (criticality safety evaluation, tests, quality assurance) associated with package designs for fissile material. The existing fissile exception options need to be expanded to cover industry needs, without introducing additional criticality hazards.

SELECTED CREDIBILITY ISSUES - REGULATIONS, AUTHORITIES, INDUSTRY

Overview

Even with improvements of the Regulations, it is also important that the industry and the competent authorities continue to increase the quality in safety evaluations and reviews. A few examples of issues that continue to cause delays and sometimes confusion are mentioned below. Further discussion between all parties involved and further cooperation between competent authorities will reduce the issues.

Regulations: Criticality Safety Index

As mentioned earlier, the CSI is not an index of criticality safety. A few routine condition packages with a total CSI of zero could be critical without violation of any requirements. Another configuration of accident condition packages with a total CSI of several hundred may be subcritical under all credible circumstances. The CSI control is not a reliable safety method.

Regulations: The confinement system

A primary function of the confinement system is sometimes to maintain the separation of components in the package. An example is a package containing two fresh fuel assemblies. Besides having a misleading name, the definition is incorrect. The worst mistake is the suggestion that the confinement system is intended to "preserve" safety. The original intention for the system was to "be subcritical" and not to "preserve safety". Experience has shown that the applications often lack definitions of this system and that many authorities don't ask for it. One of the strongest supporters of introducing this system in the 1996 Edition of the Regulation was the U.S. Later adaptation of the 1996 edition of the Regulations in the U.S. resulted in ignoring the confinement system. It is a concept often used for other purposes. Currently it has no value and should be scrapped also in the Regulations.

Regulations: Packaging, Package, Package Design, Consignment

It is sometimes difficult to separate the concepts of "package", "packaging" and "package design" in a conversation. When used in the Regulations, it is important that they are used correctly. Some incorrect uses will eventually be changed, e.g. "before first shipment of any package …". Fissile material can never escape a package since it is by definition the most important part of the package. Correct application of para. 672(a) does not allow a package to be classified as fissile-excepted since the specifications apply to a specific consignment. This makes the general specification of an "excepted package" in para. 515 consignment-dependent. Packages are not approved by authorities, except in shipment approvals and special arrangement.

Authorities: Inconsistent interpretation of the Regulations – Structural materials

Steel, charred wood and other materials can reduce neutron leakage from the fissile material in each package and from an array of packages. The material can be a constituent of the contents, an additional packaging component or components of the consignment (e.g. overpacks).

Authorities: Different criteria for safety

It is reasonable to use different limits of k_{eff} for routine, normal and accident conditions of transport. It is also reasonable to have different limits for extremely large (geometry, not number of packages) arrays of packages than for small arrays of packages. Other parameters that can motivate different k_{eff} limits are moderation (e.g. fissile liquids under routine conditions), low ^{235}U enrichment, etc. The key is to assure an extremely low probability of criticality.

Even if the accident conditions result in a higher value of k_{eff} it doesn't mean that they are limiting. The limit is often lower, e.g. 0.95 for normal conditions than for accident condition, e.g. 0.97 or 0.98. This is easy to support for individual packages. For arrays, the different factors in front of "N" (five and two) give both array types very low criticality probabilities. If the competent authorities can agree on a consistent set of criteria, multilateral approval will become easier. A limit of 0.95 for all evaluations is safe but very conservative and not efficient.

Industry: Selected specifications should be safe – Gadolinium rods

The use of burnable absorber rods containing gadolinium in BWR fuel continues to be a complication in criticality safety evaluations. The specifications for the number of rods, their positions and their compositions are determined by the applicant. The reviewing authority sometimes finds that the selected specifications are not sufficiently supporting the safety evaluation. In that case either the specifications or the safety evaluation need to be revised.

Industry: The safety evaluation needs to be made before the application to the authority

The authority should specify its interpretation of the Regulations and justify any decision made to reject assumptions and conclusions by the applicant. However, when the applicant has difficulties in solving a problem, the competent authority must be careful in suggesting a solution. The independent review expected from the authority could be compromised if the authority has also contributed to the application. It may be difficult to see the line, but sometimes the applicant clearly asks for advice and even solutions that the authority should not provide.

COMPETENT AUTHORITY COOPERATION

Competent authority safety reviews

Multilateral approval is required for package designs with fissile material. The most elaborate review is expected from the authority in the country of origin of the design. However, also other authorities will review the safety evaluation with varying ambition levels.

Some authorities (e.g. NRC in the U.S.) publish the review reports on their web pages. This is valuable to other authorities and to the applicant. If all authorities could agree to release safety review reports to other authorities and to the applicants, the efficiency in transport of fissile material would improve significantly. It is often impractical to have significantly different approval conditions from different states if the package design and the shipment circumstances are identical. Better communication between authorities is easily achievable. The best solution is if the certificate of origin can support all the particular requests from involved authorities.

The applicant can support this development by including authority safety reviews and a summary of the licensing process in other states. Solved problems and remaining issues should be covered.

Peer review of competent authority safety reviews

A competent authority has the power to delay or refuse approval of applications. The authority can also be under pressure, just as the applicant, and the resulting review may not be adequate. Human error is involved also in the licensing process. Recent experience has demonstrated the value of peer reviews of authority safety reviews. In addition to supporting a complete and fair review, the peer review process makes the safety reviewer aware of some of the difficulties that the applicant meets. A peer review process can be organized inside a competent authority but may also involve specialists outside that organization, including in other competent authorities.

CONCLUSIONS

The efficiency in licensing and transport of fissile materials can be improved significantly in a short time. A number of revisions and clarifications are needed in the Regulations to support a more realistic approach to some of the issues causing delays in shipments and to some of the concerns about safety. An important improvement is to introduce a new category between excepted fissile materials and package designs requiring multilateral approval. Better communication on experience from the licensing process in different states is important. The general understanding of criticality safety is improving but the Regulations in themselves and many applications of package design approval demonstrate that the performance is not always impressive. More sharing of safety review reports is a good way to increase cooperation. Peer reviews of authority safety reviews improve the quality and the "fairness" of the review process.

ACKNOWLEDGMENTS

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REFERENCES

[1] IAEA Safety Requirements No. TS-R-1, *Regulations for the Safe Transport of Radioactive material*, 2005 Edition, IAEA 2005.