COMPETENT AUTHORITY APPROVED FISSILE EXCEPTIONS ONE REGULATOR'S VIEW

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ABSTRACT

The IAEA transport regulations contain criteria for excepting packages containing enriched uranium and/or plutonium from the requirements pertaining to fissile material. Many of these fissile exception criteria were designed to ensure a subcritical k_∞ so that criticality safety was ensured regardless of packaging and without the need to control accumulations of packages or material. Concerns were raised over the adequacy of some of these criteria, in particular over the continued adherence to a criterion under accident (or even normal) conditions of transport. Material might initially meet a criterion, however, following an impact or fire the disposition of the fissile isotopes could change leading to the criteria not being met and consequently it may no longer be possible to guarantee criticality safety. With the introduction of TS-R-1 in 1996 a limit on the total mass of fissile material in a consignment was imposed on top of some of the fissile exception criteria in order to address these concerns.

The fissile exception criteria have been under review for some time and one aim has been how to exempt materials containing fissile isotopes mixed with much larger quantities of non-fissile material and which do not pose a realistic criticality hazard.

One provision in the proposed new fissile exceptions is for a material to be approved by the Competent Authority as fissile excepted and therefore posing no criticality safety concern. Such an approval would be given only following the successful assessment of a safety case justifying that material would remain subcritical under normal and accident conditions.

This paper gives a view of the type of material that might be approved under this scheme, the criteria against which an application for approval may be assessed and the type of arguments that an applicant would be expected to present.

This paper is the personal view of the author and does not represent UK Competent Authority policy.

INTRODUCTION

Two of the fissile exceptions in the current IAEA transport regulations [1] permit an unlimited quantity of fissile material to be transported without the need to comply with those requirements pertaining to fissile material. Criticality safety is ensured by the nature of the material being

transported without the need to control either the amount of material per package or accumulations of packages containing it. These exceptions cover:

1. Uranium enriched to 1% or less provided that lattices cannot occur (which excludes pins and pellets).

2. Uranium enriched to 2% or less provided that it is in the form of uranyl nitrate solutions with a minimum N/U ratio of 2

In addition, natural uranium is excluded from the definition of fissile material which could also be considered a form of exception.

EXCEPTION FOR WASTE

Prior to the introduction of TS-R-1 the regulations [2] contained a third such exception based on there being no more than 5g of fissile nuclides in any 10 litre volume. This exception was introduced to cover waste materials where non-fissile material is contaminated by small amounts of fissile isotopes.

The safety inadequacy of this exception had long been noted [3] as volume reduction (eg crushing of the package following a drop or slumping following a fire) could easily take the material "out of spec" and destroy the basis of the exception. The safety of unlimited quantities of the material under accident (or even normal) conditions of transport cannot be guaranteed.

When TS-R-1 was introduced in 1996 a consignment limit of approximately half a critical mass was "bolted" onto this exception. The nature of the exception therefore changed from being one based only on material properties to one based primarily on accumulation control.

Excepting packages from the fissile requirements removes the mechanism for controlling accumulations, namely the Criticality Safety Index (CSI) but at the same time the exception requires that package numbers are controlled ! Consignment mass limits were also considered unsatisfactory as there is nothing to prevent multiple consignments being transported on the same conveyance. Evidence from the USA indicates that single shipments have been artificially divided into multiple "consignments" in order to circumvent the consignment limits. When the mass of fissile nuclides per consignment is very small this may not be too much of a problem but with each consignment potentially containing half a critical mass then criticality safety could be prejudiced.

The draft revised regulations [4] therefore no longer includes this exception.

COMPETANT AUTHORITY APPROVED FISSILE EXCEPTIONS

The draft revised regulations [4] include a scheme that has been developed [5] for excepting packages from many of the fissile material requirements but at the same time retaining the CSI to control accumulations of packages. This scheme, however, is aimed at limited quantities of fissile nuclides of an unspecified nature rather than unlimited quantities of very low reactivity material.

With the withdrawal of the 5g in 10 litre exception there remains the need for a way to exclude from the fissile requirements packages containing materials which could not conceivably go critical but nevertheless contain significant quantities of fissile nuclides. Such exception(s) would be particularly intended to cover waste products but would not be specifically limited to them.

The option for Competent Authority (CA) approved fissile exceptions has been included in the draft revised regulations [4] which has been sent out to member states for 120 day review (ends 16 November 2010).

The rational for CA approved fissile exceptions are:

- Each country is likely to have specific waste streams that are unique to their industry. Overloading TS-R-1 with a large number of exceptions of interest to a limited number of countries would not be desirable.

- The revision process highlighted the difficulties in obtaining international agreement on the extent to which an exception needs to be specified (more later).

- Different countries have different acceptance standards (eg subcritical margins) for criticality safety assessments.

- CA approved exceptions are intended mainly to facilitate waste transport. As waste is not normally transported internationally the problems regarding different country's requirements will not arise frequently. It should ne noted that as a CA approved fissile exception involves a criticality safety analysis multilateral approval will be required.

An operator will apply to their CA to have a material approved as being fissile excepted. Following a detailed assessment the CA will issue a certificate approving the material and specifying what requirements need to be met. Once approval has been given then this material may be transported in any package subject only to its suitability for radiological purposes.

CRITICALITY SAFETY CASE ASSUMPTIONS

In transport criticality safety assessments, unless the disposition of the fissile nuclides is specified precisely (eg by reference to a drawing) and there is no doubt that the intended disposition would be maintained in an accident, the worst case is usually assumed. For waste materials this approach usually leads to modelling an optimally moderated and reflected sphere of pure fissile material.

Such pessimism is appropriate if a package design is being approved to transport general waste where there are no constraints at all on the disposition of the fissile nuclides. There is unlikely to be a detailed specification for a candidate for fissile exception (let alone a drawing). If the prevailing approach is rigidly adhered to any known disposition of the fissile material cannot be claimed and the criticality safety assessment returns once again the familiar optimum sphere. The ability to claim credit for the known, but not necessarily 110% guaranteed disposition of the fissile nuclides lies at the heart of CA approved fissile exceptions.

CA assessors must be prepared to be pragmatic and not expect to receive technical justifications based on precise tests on as would be expected for fissile package designs. It should be stressed that CA approved fissile exceptions are for materials that are clearly safe even allowing for uncertain specifications and behaviour in an accident. If there is any concern that an unsafe situation could arise, except by deliberate action a fissile exception would not be given.

It is in accepting a criticality safety case based on a less deterministic model whilst at the same time giving due consideration to the requirements of the regulations where the big intellectual change to the current approach to criticality in transport lies. It could be the case that this alone will be sufficient for waste transport without the need to obtain fissile exceptions. Operators will have to decide between applying for:

- A fissile exception which will apply to any package and need only be performed once. Shipments of this material will be non-fissile.

- A fissile design where mass limits and/or package accumulation control can be applied. This could be easier to obtain, however, would have to be carried out for each package design and shipments would be carried out under a fissile UN number.

Because accepting arguments concerning the disposition of fissile material that are not as precise as has traditionally been expected consideration must be given to sensitivity analysis. There must be no cliff edges where a small departure from the specified disposition will lead to an unsafe situation.

APPLICATIONS FOR CA APPROVAL

Paragraph 605bis of the draft revised regulations [4] lists the requirements for a material to be fissile excepted. These requirements are quite general and point to the existing requirements for fissile package designs in that safety must be demonstrated under normal and accident conditions.

Draft guidance material [6] has been prepared giving further details of what should be considered in an assessment for CA approval. The following points should be noted by an operator considering making a fissile exception application:

- The need to demonstrate the safety of an unlimited quantity of material would indicate that the criticality safety assessment should demonstrate that $k_\infty<1$. However, it could be the case that $k_\infty>1$ but the amount of material required for criticality is far in excess of anything that might conceivably be transported.

- Moderation of the material by water from an external source must be considered as part of normal and accident conditions. If it proves necessary to claim undermoderation to demonstrate criticality safety then fissile exception is not appropriate as a package design must be specified to exclude water. The only likely exception would be if the material itself could be demonstrated to remain as a solid block, totally impermeable to water.

- As an unlimited amount of material is involved there is no need to look separately at the material under normal conditions as these will be bounded by the accident conditions. In the terminology of the fissile requirements "N" is infinite for both normal and accident conditions. However, it might be beneficial to look at routine conditions where the material is "in-spec" in order to gauge the safety margins prior to looking at accident conditions.

FISSILE / NON-FISSILE DISTRIBUTION

The first hurdle in making an application for fissile approval is likely to be agreeing with the CA how the material would be specified. The most likely candidates for CA fissile approval would be waste materials consisting of small amounts of fissile nuclides either mixed with much larger quantities of non-fissile material or where the fissile material is a contaminant (analogous to LSA and SCO). The fissile exception specification in this case will consist of a fissile / non-fissile ratio plus a description of the extent to which they are mixed. If the specification is too tight then it might be impossible to demonstrate compliance; too loose and the use of the exception may not be adequately controlled with potential safety problems.

Ideally for an exception based on a fissile/non-fissile ratio the fissile isotopes would be uniformly distributed among the non-fissile material. Any sample of the material, howsoever small, would contain no more than the permitted mass of fissile nuclides. Such an ideal situation is unlikely to be achievable in practice. In particular for waste products the fissile nuclides are likely to be distributed among the non fissile material in a random manner. An exception requiring the fissile and non-fissile material to be "homogeneous" is only likely to be of limited use.

At one extreme will be waste which has been deliberately treated to immobilise the radioactive material, for example by vitrification or encapsulation. A midway type of material might be sludge where there has been no deliberate attempt to mix the fissile and non-fissile material but they are clearly intermingled. At the other extreme would be "general" waste which is known to be contaminated with fissile material "somewhere" but with the exact disposition being unknown.

The better a material is characterised the more "generous" the requirements are likely to be in terms of a lower fissile/non-fissile ratio and the sub-critical margins used in the criticality safety assessment.

ACCIDENT BAHAVIOR

In order to provide the same level of safety as the IAEA regulations criticality safety must not be compromised in an accident. Therefore the extent to which the required fissile to non-fissile ratio is preserved under accident conditions needs to be considered. The ideal situation would be one where the arrangement of fissile nuclides and non-fissile material remains unchanged. However, in view of the severity of the IAEA tests, in particular the fire test, it is unlikely that a material would be totally unaffected by them. Therefore any regulatory wording requiring that the ratio be maintained in an accident could make the exception unusable.

Consideration of the material behaviour under accident conditions must assume that any package containing this material is subjected to the IAEA accident condition tests, however, as the fissile

exception must be package independent claims on the ability of the packaging to protect the material would not normally be made. In assessing a package design the regulations are clear: a representative package must be subjected to the tests. For a material, however, this is not so straightforward as the question arises as to what must be subjected to any tests. A large quantity of material would have significant thermal inertia to be "self protecting" so it might be argued that the bulk of the material would be unaffected. Such an argument is unlikely to impress a CA and consideration should be given to what might happen to a small sample.

Although consideration of an accident should be based on the IAEA accident condition tests alternative influences (eg vibration) could be a more effective way of separating fissile from non fissile material than an impact and/or fire. It is easy to imagine loose fissile material (eg powders) being shaken loose and accumulating at the bottom of a package. A fissile exception should be worded to exclude such situations, perhaps by requiring that the fissile material may only be present as fixed contamination, however, this might make compliance hard to demonstrate. Grouting of a container might mitigate the presence of loose material.

US WASTE EXCEPTION – THE 1ST CA APPROVED EXCEPTION ?

The US regulations [7] includes an exception based on there being at least 2000g of non fissile material for every gram of fissile nuclides. This type of exception could cover a wide range of waste products and might be a candidate for the first CA approved exception. Whether the criticality safety analysis [8] supporting the exception is acceptable would be up to individual countries to decide as would the need for further analysis or to impose any further requirements.

There was a proposal [9] to incorporate this exception directly into TS-R-1. This proposed the same fissile to non-fissile mass ratio but significantly altered the wording to try and define the mixing of the fissile and non-fissile materials and how this might survive an accident.

"Homogeneity Requirement"

The US exception uses the word "comingled" to describe how the fissile nuclides must be distributed among the non-fissile material together with the numerical acceptance criteria that any 360 kg of material must contain no more than 180g of fissile nuclides. This, however, is a very course requirement which leaves open the possibility of concentrations of fissile nuclides consisting of a significant fraction of a critical mass.

The wording in [9] required that the fissile nuclides be "essentially uniformly distributed" among a non-fissile "solid compact binding agent". This is quite open to interpretation as different operators and/or CAs could hold differing views as to what would and would not be acceptable.

"Survivability Requirement"

The US exception only requires that the non-fissile material be in solid form and imposes no other requirements on the extent to which the ratio must be maintained during transport. In the proposal [9] there is the requirement that the fissile nuclides are "relatively inseparable" from the non-fissile material by "leaching, burning or mechanical impact".

Because of the difficulties in obtaining international agreement to how the "homogeneity" and "survivability" criteria should be specified the incorporation into TS-R-1 of an explicit exception based on that in use in the USA was abandoned.

FURTHER POSSIBLE EXCEPTIONS

The USA exception assumes highly enriched material and does not specify what the non fissile material might be. Other CA exceptions could take credit for:

- The presence of particular non-fissile materials so that credit may be claimed for the neutron absorption.
- An upper bound on the uranium enrichment (ie claiming credit for absorption by U238)
- A better knowledge of how the fissile isotopes are distributed.
- A higher level of confidence that the fissile/non-fissile ration will not increase
- Some basic packaging standards based on that which will be needed for radiological purposes.
- A limit on the mass of fissile nuclides per individual package. Such a "hybrid" exception is in use in the USA [7] whereby the fissile/non-fissile mass ratio is increased by a factor of 10 if the mass of fissile nuclides per package is limited to 15g.

Credit for known material properties might be taken via a higher fissile/non-fissile ratio or a less stringent comingling or survivability requirements.

EXISTING EXCEPTIONS REVISITED

If the existing fissile exceptions referred to in the introduction were to considered as possible candidates for CA approval the following might be considered:

- The 1% enrichment exception is often used for powders, however, a powder is only a collection of small grains so the "no lattice" requirement is not strictly met. Should the regulations (rather than just the guidance) specify a minimum grain size to ensure that heterogeneous effects do not invalidate the safety basis of the exception ?
- The uranyl nitrate in the 2% exception could undergo a chemical change in a fire that would invalidate the basis of the exception. This seems unlikely but can it be totally ruled out ? Have tests been carried out on (suitable) samples to demonstrate this will not happen ? This exception could therefore be argued to be insufficiently robust in an accident compared with the standards required for a fissile package design.

Even the existing (and so far unchallenged) fissile exceptions could be considered to be inadequate if a totally deterministic approach is taken.

COMPLIANCE ISSUES

Any operator using a CA approved exception must ensure he could demonstrate compliance in the (likely) event of a CA audit.

CA approved fissile materials are likely to be transported in non-CA approved package types (Excepted, IP) and will be shipped using a non fissile/fissile excepted UN number. The revised requirements [4] require that if appropriate the reference number of any CA approved fissile exception must be quoted on the consignment documents. This link with the fissile exception approval certificate is important, especially for international shipments where the requirement for multilateral validation of the fissile exception must be clear.

CONCLUSIONS

Being able to claim credit for the known disposition of fissile nuclides in waste materials has the potential to ease the regulatory burden for transport. However, CAs must be prepared to accept a less than precise knowledge of the exact composition and behaviour of a material without demanding a worst case assumption that takes no account at all of what is actually present.

Attempts to incorporate into the IAEA regulations a fissile exception based on that currently in use in the USA has illustrated the difficulty in obtaining agreement as to the extent that one retreats from the absolute determinism usually employed in transport criticality safety cases. Permitting CAs to approve materials for use in their countries will resolve this problem and also permit waste materials unique to an individual country to be excepted.

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