RADIOACTIVE WASTE AND FISSILE EXCEPTIONS

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ABSTRACT
The paper presents the use of exception for fissile material in the field of radioactive waste shipments. It gives an historical view of the changes introduced in the regulations for fissile exception, and gives an overview of the safety and operational issues generated by the current exceptions.

Examples from the industry are developed to illustrate:

- the need for shipment of radioactive wastes containing fissile material;
- the quantities of wastes concerned by fissile material;
- the importance the criteria for definition of fissile-excepted material, and their durability in time, may have on the design and global cost of a complete process for radioactive waste conditioning, shipment and storage.

The work done, with the full participation of WNTI, to completely review the exception criteria and requirements for fissile-excepted material to increase together safety and fitness for the needs of industry, is described.

The new criteria and requirements for fissile exceptions as proposed to be introduced in the forthcoming new edition of IAEA regulations for the transport of radioactive material are presented in this paper, and illustrated by examples of waste shipments.

Gain in safety margins as well as in transport capacities as a result of these new exceptions for fissile material are illustrated by some examples from the industry.

The difficulties which can arise from the implementation of some of these new criteria are listed and discussed.

INTRODUCTION
Fissile materials are essentially used in the nuclear fuel industry. All the stages of the nuclear fuel cycle industry from enrichment to recycling and waste disposal are concerned by fissile material. All plants, where the fissile materials are handled and/or transformed, generate radioactive wastes which, inevitably, may contain small amounts of fissile materials. In most cases, due to national policies regarding radioactive waste disposal, these wastes are required to be treated, conditioned and finally, stored in dedicated disposal centres for radioactive wastes.

From its inception, the Regulations for the Safe Transport of Radioactive Material as issued by the IAEA - implemented through international and national modal regulations - have contained fissile exceptions for low quantities and/or low concentrations of fissile material. Some of the most frequently used exceptions were introduced very early in the IAEA Regulations, and did not change

significantly for tens of years. This stability allowed industry to accommodate its practices and processes to be in a position to beneficiate as much as possible of the existing fissile exceptions. Industry finds two major advantages by using fissile exceptions in case of radioactive wastes:

- communication about safety of these wastes – it is easier to convince the public that a final disposal is safe when these wastes are carried as non-fissile than when they are transported as fissile; and
- cost – cost of design, manufacture and operation for industrial packages (IP) containing non-fissile or fissile-excepted material is much lower than for packages containing fissile material.

By this time, it appeared that fissile exceptions needed to be reviewed in order to increase safety and practicality. It was then decided, at international level, that the regulatory authorities would reconsider the principles on which the sub-criticality and safety of fissile exceptions are based, taking into account the latest knowledge and practices about sub-criticality demonstration, and taking into account the needs of the nuclear industry.

The World Nuclear Transport Institute (WNTI) has participated in the international review of these fissile exception principles and criteria; and contributed to adopt the best solutions that reconciled as far as possible safety objectives with industry needs.

The adopted changes concerning fissile exceptions this paper refers to are those included in the Draft Safety Requirement DS437 submitted by the IAEA Secretariat on 15th of July 2010 for 120-day comments.

FISSILE EXCEPTIONS IN RADIOACTIVE WASTES - HISTORY

The current exceptions for fissile material are those specified in the IAEA Regulations for the Safe Transport of Radioactive Material (TS-R-1), 2005 Edition (it is this Edition of the Regulations which is currently in force through the modal regulations). Among these current fissile exceptions, the most frequently used for radioactive wastes are:

- natural or depleted uranium, unirradiated or irradiated in thermal reactors only;
- uranium enriched in uranium-235 to a maximum of 1% by mass;
- 15 g of fissile nuclides per package, or 5 g of fissile nuclides in any 10 litre volume of material, with consignment limits as stated in Table 12 of TS-R-1, 2005 Edition;

These exceptions have existed for decades in the IAEA Regulations. Except the 5 g / 10 L exception, introduced in 1973, they were already present in the 1967 Edition of these Regulations. Several changes were made to these exceptions over the years. These mainly resulted in additional conditions and restrictions to avoid occurrence of unsafe situations:

- The minimal external dimension of 10 cm for packages containing 15 g or less of fissile nuclides was introduced in 1973;
- Limits applicable to plutonium and uranium-233 in case of uranium enriched in uranium-235 up to 1% by mass, were introduced in 1973;
- Mass limits per consignment (table 12) and restriction on beryllium and deuterium quantities were introduced in 1996.

In the beginning of next year, the 2009 Edition of the IAEA Regulations will come into force through the international and national modal regulations. The only change to these fissile exceptions concerns limits on beryllium: beryllium in concentrations of 1 g or less in 1000 g of material will not need to be considered anymore.

As it can be seen, the modifications that occurred in the last forty years were largely additional precautions introduced to avoid unsafe situations. They did not fundamentally change the most important figures which are: enrichment in uranium-235, mass of fissile nuclides per package, mass of fissile nuclides per volume unit of material, mass limit per consignment.

The changes which are going to occur with the next revision of the IAEA Regulations for the Safe Transport of Radioactive Material will be of a larger magnitude than those that occurred in the past.

SAFETY AND OPERATIONAL ISSUES GENERATED BY THE CURRENT EXCEPTIONS

With the development of further knowledge and techniques in the domain of criticality safety assessment, it has become easier to explore a much higher number of situations than in the past. Further exploration demonstrated that some situations do not provide for safety. These possible situations required a more and more restrictive set of criteria and conditions.

The most frequent remarks made to the existing system for fissile exceptions are the following:

- minimal critical masses on which certain exceptions are based do not comply with the latest knowledge and practices;
- assumptions made to demonstrate sub-criticality of these exceptions in any situation (routine, normal and accident condition of transport) are questionable compared to the principles adopted to demonstrate sub-criticality in case of fissile material;
- because accumulation control is managed by different methods for fissile excepted material (mass of fissile nuclide per consignment) compared to fissile material (CSI), it is not possible to mix packages containing these two materials in the same consignment.

Based on these statements; and on proposals of change linked with these statements, the IAEA asked criticality specialists to consult each other in order to review and discuss the principles and figures on which exceptions for fissile material can be based, from the criticality-safety point of view.

Large exchanges took place from 2004 to 2009 between criticality-safety experts from concerned competent authorities and from the industry, to propose new principles and figures for fissile exceptions. The results of these exchanges, and of the discussion which took place during the last review and revision cycle of TS-R-1, are the requirements for exceptions concerning fissile material stated in the Draft Safety Requirement DS437, as submitted by the IAEA Secretariat on 15th of July 2010 for 120-day comment to Member States.

During these exchanges, industry had the chance to expose its needs and to make or to amend proposals of change to allow the largest quantity of waste to be transported as fissile excepted material while enhancing criticality-safety.

THE NEED FOR SHIPMENT OF RADIOACTIVE WASTES CONTAINING FISSILE MATERIAL

Chemical or mechanical activities of factories produce more or less technological and process wastes. It is the same with nuclear fuel facilities where fissile material is handled. Wastes can be treated on the spot and stored at the production site. However, in most of the situations the ultimate wastes have to be moved from the production site to a repository site for final disposal. All the wastes coming from workshops where fissile materials are handled are suspected to contain fissile materials in small amounts. Except plutonium-241, fissile nuclides are long life radio-nuclides (half-life above 24000 years), therefore there is no possibility to wait for the decrease of their activity. That is why, even if during its active stage a factory can retain these wastes on site, at the end, in most cases, they have to be moved when the factory is going to be dismantled. It is then a fact that shipments of wastes containing fissile material are a necessity, and that this will continue as long as the nuclear fuel industry will exist.

ACCEPTANCE CRITERIA FOR RADIOACTIVE WASTES DISPOSAL AND FISSILE EXCEPTIONS FOR TRANSPORT

Generally wastes are grouped in categories that take into account the activity concentration and the life duration of this activity.

For high level radioactive wastes and long-life radioactive wastes, principles developed for their safety are such that the waste, as specifically conditioned, shall be safe by itself in the disposal site, even for very long term storage. In this case, safety of fissile material can be considered, as it is the case for transport, taking into account their specific conditioning.

For low level radioactive wastes and short live radioactive wastes the principles adopted are quite different. It is generally admitted that after a relatively short period of time (300 years), the activity will so decrease that the impact of the radioactive wastes can be considered to be the same as that of natural radioactivity. It is then accepted that after this period of decrease no specific precaution will be needed to maintain safety. Taking into account that, up to a certain concentration, wastes containing uranium 235 are considered as low level wastes (LLW): it means that, taking account the fact that uranium 235 is a long life radionuclide, no criticality risk has been foreseen for these wastes in the long term when they meet the acceptance criteria of the disposal, whatever the way they could be conditioned. Big differences between criteria for fissile exceptions in transport and acceptance criteria for fissile materials in LLW disposals could be very confusing: how to explain that a substance in the same concentration and condition can be considered safe when stored out of supervision and be considered unsafe when transported?

However, this kind of situation already occurred in the past. For example, a few years ago, an approval was necessary for 210-litre drums transporting homogenous cemented wastes with less than 21 g of uranium 235 per drum, and up to 280 g of beryllium contained in copper-beryllium alloys. This led to unnecessary assessments in comparison to the actual risk (criticality analysis made for an unlimited quantity of that material gave a $k\infty$ close to zero, whatever the quantity of water), and to excessive cost, while these drums were intended to be disposed of in surface facility, out of supervision after a period of 300 years!

This example shows that it is in the interest of both the industry and the Competent Authorities to find solutions to harmonize criteria for transport and for storage in such a way that nobody could argue that disposal or transport of these low level wastes is not safe.

The work done by WNTI during this last revision cycle concerning fissile exceptions for transport involved proposing solutions to have exceptions for fissile material in the transport regulations as close as possible to the acceptance criteria of the low level and short life radioactive wastes disposal facilities.

RELAXATION OF BERYLLIUM RESTRICTION PUT ON CERTAIN FISSILE EXCEPTIONS

Beryllium can be found in metal alloys, and mainly in copper alloys, where it can represent up to 4% in mass of the alloy. Beryllium copper alloys have exceptional strength, thermal and electrical conductivity and outstanding wear resistance. These copper-beryllium alloys are commonly used for small mechanical pieces like springs, electric contactors, computer components, metallic gaskets, but also for bigger components, like packing rings, chains, etc., and are also used in equipments for nuclear industry, in particular in the uranium enrichment industry.

For example, the Georges-Besse enrichment plant in Pierrelatte – French owned by AREVA – is equipped with more than 1400 compressors, each of them containing up to 15 kg of copper-beryllium, which represents about 300 g of beryllium per compressor. Because of the presence of that beryllium in excess of the current criteria prescribed for fissile exceptions in the transport regulations, it would be required to dismantle the compressor completely and to remove any of the pieces made of copper-beryllium prior to transport the compressors to the LLW disposal centre. An alternative would be to transport the compressors as fissile material in packages approved for fissile material, while the mass of uranium per compressor is in the order of a few grams per compressor. Both of these solutions lead to unnecessary dismantling and to high expenses.

Taking into account that elements of alloys are well distributed throughout the alloy and are inseparable from each other, it was possible to demonstrate, taking account of the copper, that beryllium up to 4% in mass in copper-beryllium alloys is not more reflective or reactive than carbon steel.

Calculation cases were constituted by:

- A homogeneous sphere of 400 g of uranium-235 mixed with water;
- The reflection around the fissile matter was made of 500 g of beryllium + x cm of additional reflector + 20 cm of water;
- Additional reflectors were copper, beryllium-copper alloy, zirconium, beryllium-zirconium alloy, steel, beryllium-steel alloy.
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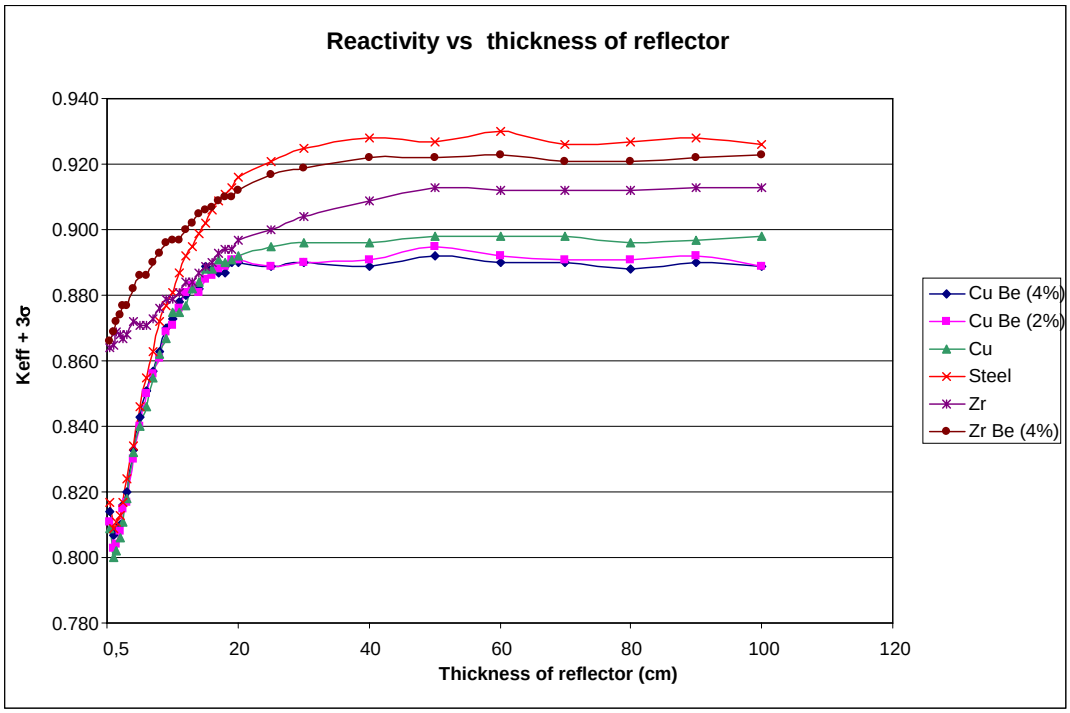
The calculations showed that adding copper-beryllium as reflector, whatever its thickness does not have a significant impact on the reactivity in comparison with other metallic reflector (steel). The resulting change proposed in the IAEA Regulations corresponding to this demonstration is in paragraph 672 of the draft Regulations: “Beryllium incorporated in copper alloys up to 4% in weight of the alloy does not need to be considered”.

In the example given here above, the change will allow carrying the compressors with the benefit of fissile exception, without the need for dismantling and without the need for an approved package design. It will also significantly reduce the total cost of the shipment of these components.

Configuration of the mediums and results are given in the graph below:



NEW FISSILE EXCEPTIONS AND RADIOACTIVE WASTES

The new principles to demonstrate that exceptions for fissile material are safe are as close as possible to the principles adopted for fissile material:

- When accumulation of packages containing fissile excepted material could lead to critical situations, a CSI is assigned to the packages containing that fissile excepted material, and accumulation is limited through the same principles as for fissile material. These packages are exempted from package design and approval requirements applicable to package containing fissile material. As a consequence, these packages will be declared and shipped as fissile material (UN number, proper shipping name and labelling). These exceptions are set in paragraph 672 of the draft of the new edition of the Regulations.
- When fissile excepted material is safe in whatever the quantity, UN number, proper shipping name and labelling are those used for non-fissile material, as it is the case for the current exceptions. These exceptions are set in paragraph 417 of the draft of the new edition of the Regulations, called “fissile-excepted” in this paper.

Some of the existing exceptions have been kept as they were before:

- natural or depleted uranium, unirradiated or irradiated in thermal reactors only (see paragraph 222 of the draft Regulations) ;

- uranium enriched in uranium-235 to a maximum of 1% by mass (see paragraph 417 (a) of the draft Regulations).

The other exceptions currently used for wastes containing fissile material have been completely reviewed. The new exceptions covering the current exception using 15 g of fissile nuclides per package or 5 g of fissile nuclides per 10 litres of volume, are those in 672 (a), (b) and (c), and as last possibility, 417 (f) in the draft Regulations. Unfortunately, no consensus could be reached about proposals of exceptions based on mass-ratio criteria (1g in 200 g, 1 g in 2000 g and 1 g in 10000 g), which could have the advantage to be close to criteria already adopted for LLW disposals.

Paragraph 672 uses formulas to determine the CSI of packages containing fissile material (excepted from package design and approval requirements). These formulas may be written as follows:

$CSI = 50 \times 5 \times \left[\frac{m_1}{Z} + \frac{m_2}{Y} \right]$: used for 672 (a) ; $CSI = 50 \times 2 \times \left[\frac{m_1}{Z} + \frac{m_2}{Y} \right]$: used for 672 (b) and (c)

where m_1 is the mass of U-235, m_2 is the mass of other fissile nuclides, Z and Y are the values taken from the table M.

Table M

Fissile nuclide	*Uranium enrichment in U-235*	*Fissile nuclide* mass (g) limited use	*Fissile nuclide* mass (g) general use
U-235 (taking into account of the maximum enrichment) **Z**	≤1.5%	2400	2000
	≤ 5%	1000	770
	≤ 10%	810	550
	≤ 20%	700	470
	≤ 100%	540	360
Other fissile nuclides : **Y**		350	230

Adaptations made to the proposed new exceptions to take into account the industry needs, and especially in the field of radioactive wastes are the following:

- Definition of fissile nuclides/fissile material: material in packages containing up to 0.25 g of fissile nuclides is non-fissile material (see paragraph 222 of the draft Regulations)
- Consignment containing up to 45 g of U-235 considered as fissile-excepted, packaged or unpackaged (see paragraph 417 (c) and (e) of the draft Regulations)
- Other fissile nuclides in quantity up to 0.5 g per package and 15 g per consignment, considered as fissile-excepted (see paragraph 417 (d) of the draft Regulations)

Adaptation of the accumulation-based exceptions:

- Smallest dimension increased up to 30 cm (standardized drums above 30 litres of inner volume comply with this minimal dimension), which allows higher numbers of packages to be accepted in a consignment, due to the increase of the pitch between packages when in array (see paragraph 672 (b) of the draft Regulations)

- Taking account of the dilution of fissile nuclides in non fissile uranium for various enrichment values: taking account of the dilution of the fissile nuclides permits to increase the acceptable limits to higher values than before (see paragraphs 672 (a), (b), (c) and table M of the draft Regulations)
- New UN number and proper shipping name to allow the use of 672 exceptions for LSA-I materials as LSA-I, FISSILE (see table 1 of the draft Regulations)

The following table gives the maximum quantities of fissile nuclides per package and per consignment for "limited use" as specified in the draft Regulations and using 672 (a) or (b) exceptions. It shows that:

- quantities of fissile nuclides allowed per package will generally be greater than 15 g;
- quantities of fissile nuclides allowed per consignment increase for uranium at low enrichment and decrease for other cases (however, those quantities may be increased by a factor of two when under "exclusive use shipment" and when the shipment is approved).

Maximum quantities per package and consignment for "limited use"

Fissile nuclide		U235 mass / package (g)		U235 mass / consignment (g)	
		672 a) CSI=10	672 b) CSI=10	672 a) CSI=50	672 b) CSI=50
U235 Enrichment	1.5%	96	240	480	1200
	5%	40	100	200	500
	10%	32.4	81	162	405
	20%	28	70	140	350
	100%	21.6	54	108	270
Other fissile nuclides		14	35	70	175

Coloured cells indicate lower quantities than previously

CONCLUSION

Despite the efforts made by WNTI, no solution could be drafted and a consensus could not be reached to replace the 5 g in 10 litres current exception. However, the exception 417 (f) in the draft Regulations offers the possibility to issue specific exceptions on a country per country basis in order to recover the possibility to ship such materials as fissile-excepted; especially when, for example, the materials comply with acceptance criteria for the final disposal of radioactive wastes.

The way these exceptions have been reviewed, with the full consideration of the implication of the industry through WNTI, illustrates that combining industrial objectives and safety objectives is possible and can converge to suitable rules.