



CRITICALITY SAFETY IN THE TRANSPORTATION OF FISSILE MATERIALS

Special requirements must be met when transporting fissile materials. These are aimed at ensuring that the conditions leading to a critical or supercritical state are never encountered under any circumstances. These requirements have been adopted in international regulations that serve as a basis for national regulations.



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Drop test on a nuclear material container and its transport cask from a height of 9 m at a 30° angle. Among other things, this test serves to demonstrate that subcriticality is guaranteed under all circumstances.

Ph. Lesage/COGEMA



Spent fuel containers being transported by truck to the Cogema plant at La Hague.

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J.-M. Taillat/COGEMA

IAEA regulations

When transported outside nuclear facilities, **fissile** materials are governed by a set of rules aimed at preventing criticality risks (see *The risk of criticality and its prevention in nuclear plants and laboratories and during transportation*). These rules, which take account of the specific nature of the situations encountered during transportation, are based on the transport regulations applying to **radioactive** materials issued by the International Atomic Energy Agency (IAEA), which has its headquarters in Vienna, Austria. The need for consistency in the safety analyses performed in different countries concerning radioactive material transport led the IAEA, at a very early stage, to issue technical recommendations setting out safety standards capable of limiting to an acceptable degree the radiological, thermal and criticality hazards to which people, equipment and the environment were exposed as a result of the transportation of these materials. IAEA regulations provide a reference for national regulations applying to different means of transportation (sea, air and land).

The safety regulations are specific to a unit referred to as a **package**, consisting of a shipping container and a clearly defined content of radioactive material.

Safety regulations applying to transportation are not the same as those concerning nuclear facilities as they must take into account specific requirements imposed by IAEA transport regulations regarding the conditions to be met for package approval. These conditions

include passing a series of tests such as being dropped from a variable height onto an unyielding target, stamping tests, hydrocarbon fire tests, immersion in water, thus defining the state of the package under “normal” (package undamaged) and “accident” (package damaged) transportation conditions.

Fissile materials (such as uranium hexafluoride UF_6 , fresh and spent fuel **assemblies**, waste, etc.) must be transported in such a way as to maintain subcriticality under normal and accident transportation conditions. A number of different eventualities must be considered to achieve this: water infiltration into or leakage out of the packages, failure or degraded performance of the built-in **neutron** absorbers or **moderators**, redistribution of the content inside the package or, following loss of content, reduced spaces between or inside packages, packages immersed in water or buried in snow, temperature variations.

Lastly, the IAEA transport regulations impose three configurations used to assess the criticality safety of the packages and define the **maximum number** N of packages that can be transported at the same time (the criticality safety index is $CSI = 50/N$): packages considered separately, several packages considered together, under *normal* and *accident* transportation conditions.

Packages considered separately

It is assumed that water can penetrate all the empty spaces in the packages,

except for those possessing special sealing properties (e.g. multiple **barriers**) designed to prevent any water ingress. The package is surrounded by 20 cm of water (the water acting as a neutron reflector) and is considered in the state resulting from the tests (damaged or undamaged) that leads to the maximum neutron multiplication (maximum **reactivity**).

Several packages considered together/normal transportation conditions

A stack of $5 \times N$ packages (N to be determined) must be **subcritical** under the following conditions: it is surrounded on every side by 20 cm of water and arranged so as to obtain maximum reactivity (as compact as possible). There is nothing between the packages (no moderator or reflector) and the state of the packages is defined in accordance with the results of the regulation tests defined for *normal* transportation conditions.

Several packages considered together/accident transportation conditions

A stack of $2 \times N$ packages (N to be determined) must be subcritical under the following conditions: it is surrounded on every side by 20 cm of water and arranged so as to obtain maximum reactivity (as compact as possible). A hydrogenated material can be placed between the packages to act as a moderator. The



Loading a MOX fuel container ship before it sets sail for Japan.



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state of the packages is defined in accordance with the results of the regulation tests defined for *accident* transportation conditions.

There are a number of “exceptions” allowing packages to be exempted from the rules applicable to fissile materials. The main exception allows any package containing less than 15 g of fissile material to be classified as an “exempted package”.

Criticality assessment methods

The computing methods used to assess the criticality of packages containing fissile materials (in accordance with regulatory instructions) are based for the most part on the **Monte Carlo method** which is particularly effective in calculating highly complex configurations of separate or stacked packages containing a wide variety of fissile media.

The subcriticality criteria adopted (based on the k_{eff}) take into consideration the degree of confidence attributed to the computing methods (existence of any calculation biases seen in representative **benchmarks**) and the conserva-

tism of calculation models and hypotheses. At this point, it is useful to stress the importance of qualifying the calculation scheme selected (the 1996 edition of the IAEA regulations applicable in 2001 reinforces requirements in this area). For example, it is usual international practice to take a 0.05 safety margin ($k_{\text{eff max}} = 0.95$) when evaluating isolated packages, though this value is nevertheless subject to expert appraisal.

Package approval

The competent authority issues a document called a “certificate of approval” for each type of package, authorizing and defining the transportation. This document includes a description of the package, a detailed description of the fissile material(s) authorized for transportation and any special requirements to be met, a reference to the safety report concerning the package type and, more specifically, to criticality safety justifications and, lastly, the *criticality safety index* (CSI) of each authorized content.

In France, transportation approvals for packages of radioactive materials are issued by the Directorate for Nuclear Facility Safety (DSIN), under the joint authority of the Ministry for Regional Development and the Environment and the Secretary of State's Office for Industry, for civil materials, and the high commissioner for atomic energy for defense-related materials. The Institute for Protection and Nuclear Safety (IPSN) is responsible for dealing with the technical aspects of safety files on behalf of the competent authorities.

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