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On-site Transport of Spent Fuel Casks : the Belgian Approach

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ABSTRACT

In Belgium, spent fuel is currently stored at the nuclear sites in dedicated interim spent fuel storage installations. The spent fuel assemblies are transferred between the fuel buildings and those facilities by means of robust spent fuel casks (transfer shuttle or dual purpose cask, designed with reference to the IAEA rules).
Public transport of spent fuel is well regulated by the IAEA Safety Guides and Safety Requirements, which define criteria and test conditions for routine, normal and accidental conditions, covering the risks during public transport. Nonetheless, on-site transport occurs in well-known conditions and in a supervised environment, so spent fuel casks users could decide to carry out the on-site transport with some differences compared to the configuration for public transport.(e.g. without the impact limiters). Such site-specific transport configurations are currently part of the discussions in the framework of IAEA's GeTec working group (Approach to define generic test conditions for dual purpose casks 2016 - 2019).
Based on a Hazard Identification (HAZID) study conducted at each site, a Fuel Transfer Reference Document has been developed for the Belgian NPP sites of Tihange and Doel, defining, for the specific on-site transport, the administrative and practical requirements to be met as well as the additional safety evaluations needed for the used on-site transport configuration to satisfy the conclusions of the site Hazard Identification study.
This paper will share the approach developed by Engie to establish its Fuel Transfer Reference Document.

INTRODUCTION

Most of the electric energy distributed on the Belgian grid is generated by seven nuclear pressurized water reactors distributed on two sites: Doel and Tihange.
As the available storage capacity of the unit's deactivation pools is limited, the nuclear spent fuel assemblies are transferred to interim storage facilities (dry or wet storage). The on-site transport to interim storage facilities is implemented using heavy metallic spent fuel casks on each site.

The interim storage facility on the Doel site is currently composed of a first dry storage building commissioned in 1995 and will be complemented with a second dry storage building (construction license should be granted around 2020 and operation license 3years later). The interim storage facility on the Tihange site is currently composed of a centralized storage pool, commissioned in 1997, and will be complemented as well with a dry storage building (construction license should be granted around end 2020 and operation license 3 years later).
Figure 1 shows an overview of the current Belgian strategy for the management of the back end of the fuel cycle (Note: The conditioning plant location is not defined at this point).

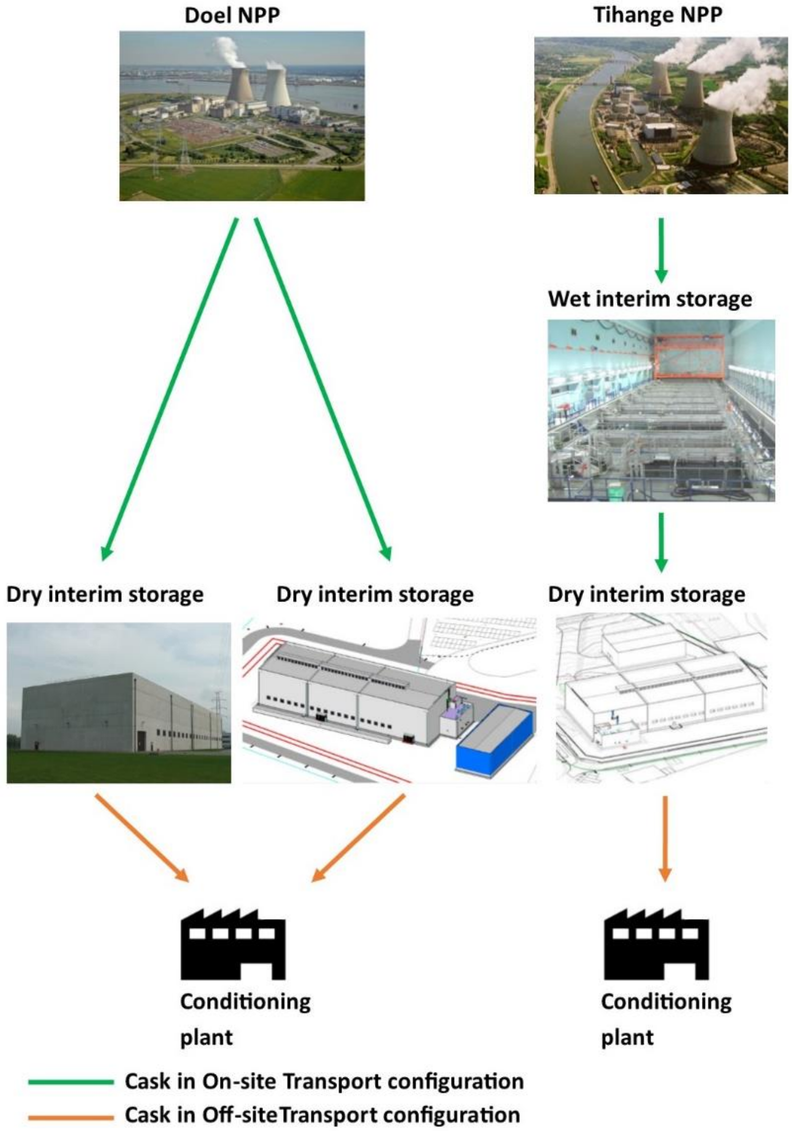

Figure 1. Back end management of the nuclear spent fuel of Doel and Tihange

Arrows in orange represent off-site transport on public roads. Such transports must be carried out in accordance with the IAEA SSR-6 regulations. Therefore the cask systems need to be set in transport configuration, i.e. equipped with their transport auxiliary equipment (shock absorbers and other impact limiters, thermal barriers, etc.).

Arrows in green represent the on-site transport. Because of operational constraints and risks, ALARA considerations as well as plant interface constraints, the on-site transport of nuclear spent fuel casks in the Doel and Tihange sites has been historically performed in a configuration that differs from the transport configuration needed to comply with SSR-6 requirements.

Figure 2. On-site transport between unit and the interim storage facility in Doel (left – Dual Purpose Cask for Transport & Storage) and Tihange (right – Shuttle cask)

As on-site transport of spent fuel assemblies is not covered by the IAEA SSR-6 regulations and no other established regulations exist, the Belgian authorities requested the Utility to define the rules to be applied to safely perform the on-site transport activities of spent fuel.
At the present time, a draft IAEA TECDOC is under preparation where specific conditions of the on-site transport configuration and related requirements and countermeasures are addressed (namely the GeTeC project).
In Belgium, following the request of the safety authorities, a Fuel Transfer Reference Document has been established to define a framework for the spent fuel cask on-site transport in Doel and Tihange. This reference document specifies requirements and safety measures which must be fulfilled to guarantee a safe on-site transport, and hence the protection of the personnel, the public and the environment from the effects of radiation.

This paper will describe the methodology followed to establish the Fuel Transfer Reference Document and give some details about the identified hazards and specific safety measures for the spent fuel on-site transport on the sites of Doel and Tihange.
The scope of the spent fuel cask on-site transport is limited to the movement of the conveyance from the exit of the departure building to the entrance of the destination building.

METHODOLOGY

The assessment has been based on a risk analysis performed for the on-site transport of nuclear spent fuel between two buildings (door-to-door) for the nuclear power plants in Doel and Tihange.

The steps of the risk analysis are:
1. A walkdown along the paths foreseen for the on-site transport on each site
2. A HAZID evaluation as described in the figure below.
3. Ranking of the residual risks

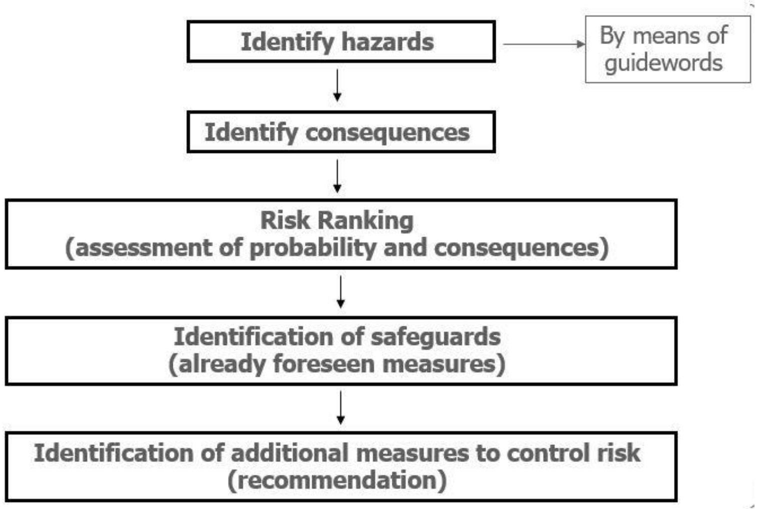

Figure 3. Description of the steps of the HAZID

Scope

The scope of the risk analysis presented in this paper is limited to the on-site transport of nuclear spent fuel with spent fuel casks from one facility to another facility on the same nuclear power plant site. The concerned departure and arrival facilities are the fuel buildings from different nuclear islands and the on-site interim storage fuel buildings (wet or dry). The loading of the cask as well as the preparation steps to get the cask in on-site transport configuration are out of scope and are addressed by other plant documentation. Similarly the operations subsequent to the arrival of the cask at its destination facility are out of scope and addressed in the facility documentation.. The analysis is performed strictly from door-to-door between the facilities.

Walkdown and hazard identification

A walkdown has been performed to identify all the visible and permanent hazards along the paths of the on-site transport such as fire sources, interfering road configurations, obstacles, road degradation, etc. The outcome has been used as a basis for the HAZID evaluation.

HAZID (**HAZ**ard **ID**entification) is a technique for early identification of potential hazards and threats.
The HAZID was implemented through a meeting gathering a highly experienced multi-disciplinary team. The format of the meeting is a structured brainstorming. The procedure uses a set of guidewords which are carefully chosen to promote creative thoughts about all possible hazards (impact of the environment on the safety functions of the cask). The table 1 shows examples of guidewords defined in the framework of the on-site transport of nuclear spent fuel cask between two buildings of the Doel/Tihange nuclear power plant site.

Table 1. Examples of guide words

Typical events	Guide words
Natural hazards	Wind (high wind, hurricane), Fog, Flooding, Earthquake, Ice, Snow
External effects	Activities of third parties (adjacent industrial facilities, third parties on site), Vehicle traffic
Danger from the site installations and the route	Leak, losses, Ignition Sources, Fire, Explosion, Road condition
Inspection/maintenance issue	Requirements related to heavy weights/loads equipment

Initial Risk ranking

The risk ranking is based on a classification of the likelihood and of the severity of the hazards identified in the HAZID. In the context of the on-site transport of nuclear spent fuel cask on a Belgian nuclear power plant site the risk matrix defined in the IAEA SRS-77 has been used as basis. The likelihood ranking defines various probability levels (from P1 to P4). A P0 level is added and reflects such low likelihood that the event does not have to be taken into account. The probability includes the annual likelihood of the event, the annual duration of potential exposure to the event considered (number of on-site transports per year and standard duration of an on-site transport) and a factor reflecting the elimination by site design of the considered event.

Likelihood	Description
P4	**Anticipated** $10^{-1} – 10^{-2}$ per year typically
P3	**Unlikely** $10^{-2} – 10^{-4}$ per year typically
P2	**Extremely unlikely** $10^{-4} – 10^{-6}$ per year typically
P1	**Beyond extremely unlikely**: $10^{-6} – 10^{-8}$ per year typically
P0	**Event not considered**

The severity ranking defines various levels (from S1 to S4) based on radioprotection/activity release consequences, localized or extended. A S0 level is added to take into account the event whose consequences do not impact the safety.

Severity	Description
S4	**Off-site consequences** Containment or criticality issues
S3	**On-site consequences** Cask cooling issues
S2	**On-site consequences, localized** Cask shielding material degradation
S1	**On-site consequences, work area** Localized radioprotection issues
S0	**No impact**

The risk level of a hazard is the combination of its likelihood and severity:

$$R = P \times S$$

The ranking of the risk levels is described in table 2 and the corresponding risk matrix is shown figure 4.

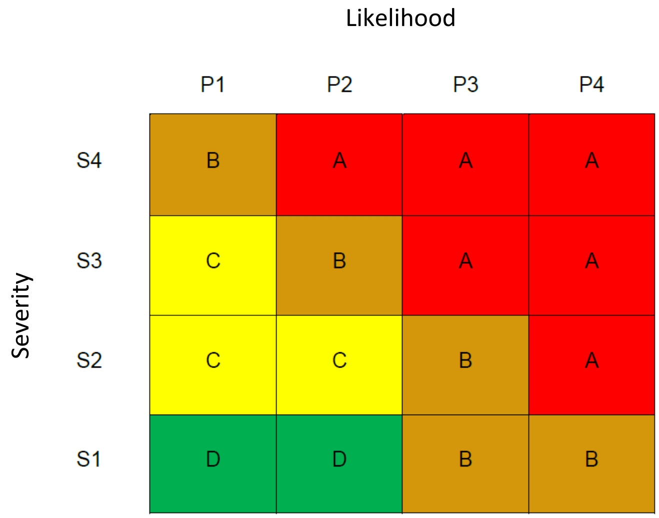

Figure 4. Risk matrix

Table 2. Risk ranking

Risk Rank	**Description**
A	High consequence / high likelihood - unacceptable risk - safety assessment/measures required
B	Intermediate consequence/ intermediate likelihood - unacceptable risk - safety assessment/measures required
C	Low consequence / low likelihood - low risk - define and implement simple measures to lower the risk
D	Acceptable risk – No specific action required

Mitigation measures and residual risk ranking

When the initial risk ranking for an event is categorized in A, B, C levels, mitigation measures are defined so that after implementation the residual risk is D.
Mitigation measures may reduce the likelihood or the severity (or both) and may include specific safety demonstrations, administrative measures, hardware modifications, etc…

IMPLEMENTATION ON THE BELGIAN NUCLEAR SITES

Risks identification and initial ranking

Tables 3 and 5 show examples of identified events of risk level A and B after the application of the HAZID evaluation in the framework of the on-site transport of nuclear spent fuel casks within the Doel/Tihange site.

Table 3: Examples of identified events of risk ranking A before the implementation safety measures

Event type	Event	Likelihood	Severity	Risk ranking	Consequence
Natural hazards	Fog	P3	S4	A	Mechanical impact on cask
Danger of the installation and the road	Snow & ice	P3	S4	A	Mechanical impact on cask
Danger of the installation and the road	On-site traffic	P4	S4	A	Mechanical impact on cask

Events from table 3 can be prevented by forbidding the on-site transport operation in case of unfavorable weather and by forbidding on-site traffic during the on-site transport.
After taking these administrative measures, no event leads to a credible accident scenario which would impact the safety of the on-site transport. The residual likelihood of the events after the implementation of the administrative measures are shown in table 4.

Table 4: Residual risk ranking of identified events of initial risk ranking A after the implementation of safety measures

Event type	Event	Likelihood	Severity	Risk ranking	Consequence
Natural hazards	Fog	P0	S4	D	None
Danger of the installation and the road	Snow & ice	P0	S4	D	None
Danger of the installation and the road	On-site traffic	P0	S4	D	None

Table 5:Examples of identified events of risk level B with the highest severity level before the implementation of specific safety measures

Event type	Event	Likelihood	Severity	Risk ranking	Consequence
Natural hazards	Earthquake	P1	S4	B	Mechanical impact on cask
Danger of the installation and the road	Severe degradation of the road structure (sink hole,…)	P1	S4	B	Mechanical impact on cask
Danger of the installation and the road	Fire on the road	P1	S4	B	Degradation of the cask

For the earthquake event, a safety demonstration evaluating the convoy behavior under a seismic excitation representative of the site SSE spectra has been performed. The evaluation shows that the stability of the convoy is not compromised. Besides the transport frames integrity has been assessed and modifications/replacements are ongoing.
To mitigate the risk level related to the degradation of the road structure, a visual inspection of the road must be performed just before each on-site transport and a maintenance program must be defined and implemented. In addition the on-site transport speed is limited to 5 km/h.
The risk of a fire damaging the cask is mitigated by identifying and removing, if possible, the fire source along the path before the on-site transport. The on-site fire brigade is also notified about the on-site transport and put on standby to intervene within a few minutes to stop the fire and cool down the cask in case of a fire.
Considering the safety demonstration and the specific safety measures abovementioned, the residual risk ranking comes to an acceptable level (see table 6).

Table 6: Residual risk ranking of identified events of initial risk ranking B after the implementation of safety measures

Event type	Event	Likelihood	Severity	Risk ranking	Consequence
Natural hazards	Earthquake	P1	S0	D	None
Danger of the installation and the road	Severe degradation of the road structure (sink hole,…)	P0	S4	D	None
Danger of the installation and the road	Fire on the road	P1	S1	D	None

The evaluation was performed for all events identified during the HAZID and the overall analysis shows that after mitigation by the appropriate specific safety measures, the residual risk level becomes low enough so that no additional measures are necessary.

DEFENSE IN DEPTH

Based on the risk analysis, it was concluded that the on-site transports, as carried out with their specific safety measures, meet the safety requirements to protect the personnel, the public and the environment.
However to build more confidence and reinforce the case of spent fuel on-site transport without transport auxiliaries installed on the cask, complementary safety demonstrations have been defined as a defense-in-depth. They are based on potential dynamic and fire hazards identified during the risk analysis.

The complementary safety demonstrations address hypothetical incidental and accidental scenarios. This categorization follows the graded approach philosophy of the SSR6 . The scenarios defined are:
For Normal On-site transport Conditions:

- Dynamic incident :
    - Collision of the convoy travelling at its maximum speed (5 km/h) with a fixed obstacle or,

- Impact of a light vehicle travelling at the maximum authorized speed on the site (30 km/h).

For Accidental On-site transport Conditions:

- Dynamic accident: Lateral impact on the static convoy of a heavy transport vehicle travelling at the maximum authorized speed on the site (30 km/h). Followed by:
- Thermal accident: A fire engulfing the convoy, generating an ambient temperature of 800°C during 15 minutes, followed by a natural or forced cooling. The fire duration considered takes into account the proximity of the fire brigade.

Dynamic incidents

The approach followed for the evaluation of the dynamic incidents described above consists in assessing drop scenarios for which potential energy is equivalent to the kinetic energy of the incident considered. For reasons of conservatism and simplification, no energy dissipation by deformation of the obstacle or the incoming vehicle is taken into account and the kinetic energy is totally converted into potential energy. The dynamic incidents are evaluated by finite element analysis.

The drop conditions to be considered for this study are:

- Unyielding target compliant with the requirement in SSR-6;
- Drop height defined to envelope both dynamic incidents and the different casks;
- Drop initial positions: horizontal and vertical on the lid side;
- Cask loaded with its maximal thermal power;
- Maximum ambient temperature as defined in SSR-6 paragraph 656 (38°C);
- Minimum ambient temperature of the sites (-20°C).

The demonstration provides proof of the compliance to the following criteria:

- The confinement criterion as defined in SSR-6 paragraph 659 (a) ($\leq 10^{-6}$ A_2 /h);
- The dose rate level after incident does not increase compared to the value before the incident.

Dynamic accident and fire

The approach followed for the evaluation of the dynamic accident consists in applying on the convoy the loading curve from a numerical simulation corresponding to the impact of a heavy vehicle on a rigid wall. The load curve has been computed by finite element analysis and calibrated on experimental data.

This loading is then either applied directly on the convoy model or is used to define an impactor calibrated to deliver the same loading.

To add conservatism, no dissipation of energy in convoy tilting/slipping is considered. In addition the impact is directly applied on the cask in its critical area, depending on the cask design.

The conditions to be considered for this study are:

- Maximum authorized speed for the heavy vehicle on site (30 km/h);
- Lateral impact directly on the cask;
- Cask loaded with its maximal thermal power;

- Maximum ambient temperature as defined in SSR-6 paragraph 656 (38°C);
- Minimum ambient temperature of the sites (-20°C).

A fire accident is considered following the above mentioned impact with a heavy vehicle. The conditions to be considered for this study are:

- Cask loaded with its maximal thermal power;
- Engulfing fire of 800°C during 15 min.

After the cumulated accidental events described in this section, the demonstration provides proof of the compliance to the following criteria (as defined in SSR-6 paragraph 659 (b)).

- The cumulated release of the radioactive content over one week does not exceed 10 A_2 for ^{85}Kr and A_2 for all the other radionuclides;
- The dose rate at 1m from the external surface of the cask does not exceed 10 mSv/h.

STATUS AND CONCLUSION

The Fuel Transfer Reference Document has been approved by the Belgian Authority end of 2018. The specific safety measures are being processed (for those not yet completely implemented). The complementary defense in depth safety demonstrations are under study by the different cask designers.

The drafting of this referential is the results of several years of collaboration and discussion between the involved parties (Utility, Owner Engineer, Owner and Authorities). While the selected approach may be generic in nature so that it could be used at the international level, the results and implementation are site dependent and conveyance dependent.

ACKNOWLEDGEMENT

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