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AGEING MANAGEMENT OF DPC

- SOME ASPECTS OF BOLTED SYSTEMS AT PACKAGES -

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ABSTRACT

Dual Purpose Casks (DPCs) are currently loaded and stored for decades in dedicated facilities. Stored, but ready to be transported at any time: some facilities have to maintain a valid agreement for transport for all stored casks.

The new edition of IAEA Transport Regulations (SSR-6 Rev 1) introduces the obligation of taking into account ageing mechanisms in the design phase of the package. In the same time, some preparations of DPCs for transport after storage have been performed. This article focusses on the issues raised by the assessments of the package design safety report (PDSR) of DPCs and by the preparations of DPCs for transport concerning bolted package component systems.

Bolts are usually very important components for the safety of a package e.g. for lids or trunnions. Replacement of bolts before transport is not easy and can be impossible, e.g. bolts of thermal dissipaters. Depending on the design, replacement of threaded holes may be impossible. Moreover, replacement of components may lead to high doses to the operators and should be limited in a radioprotection point of view. Even verification of the tightening torque may be difficult.

The main expected ageing mechanisms of the bolted connection deal with the tightening torque. Many parameters can influence the tightening torque: of course, the torque applied after loading, with uncertainties from the tool; but also the grease applied on the bolts, the emplacement of the grease; temperature of the bolt; creep during storage etc. This article discusses some aspects of ageing management of the bolted systems related with data traceability such as initial torque, grease used and practical application on real preparation for transport.

INTRODUCTION

DPCs are currently used in numerous countries for the dry storage of irradiated fuel or high activity waste.

After irradiation, irradiated fuel is usually cooled in pool for some years. After this cooling phase, it may be charged in a dual purpose cask (DPC) cask and transported in a storage facility. In some cases, the fuel is transported in a transport cask, and placed in a DPC in the storage facility.

The same process occurs for high activity waste. After cooling in pool, irradiated fuel may be treated in a reprocessing facility. Fission products and minor actinides extracted from the irradiated fuel are vitrified and placed in stainless steel canisters. The canisters may be charged in a dual purpose cask (DPC) cask and transported in a storage facility.

This article does not deal with the safety of the storage facility, but with the safety of the transport after storage of the DPCs. One of the key components for the safety of the transport after storage is the screws. Screws are very commonly used in DPCs, mainly to fix the lid(s), but they may also be used to fix the trunnions and/or internal components such as thermal dissipaters. The screws, the associated torque and the traceability of their characteristics may be subject to ageing.

This article is based on the feedback of the assessment of PDSR and highlights some parameters to be controlled or recorded to facilitate the transport after storage.

OVERVIEW OF THE DESIGN OF A DUAL PURPOSE CASK

The design of the most commonly used DPCs includes, in its transport configuration:

- the body of the cask, mainly composed of ductile cast iron or steel. In some designs, thermal conductors in different material such as copper are bolted to the body;
- two lids (primary lid and secondary lid) made of steel, bolted to the body;
- four to six trunnions made of stainless steel, welded or bolted to the body;
- two impact limiters, designed as wood, foam or honeycomb filled steel sheeted constructions, bolted to the body.

Transport configuration and storage configuration are mostly different from each other. For instance, the impact limiters are usually used only for transport and not for storage. They are added to the cask during the preparation for transport. The secondary lid for transport and the secondary lid for storage may be different. In this case, the secondary lid for transport is also added to the cask during the preparation for transport.

This article concerns only the parts of the cask subject to ageing in storage: the body of the cask, with thermal conductors and trunnions, and the primary lid. The secondary lid and the impact limiters are considered added just before transport after storage and not concerned by ageing mechanisms during storage.

REGULATION FOR TRANSPORT AFTER STORAGE

New paras of the current edition of SSR-6 [Ref. 1] directly address the ageing management, in para 613A “the design of the package shall take into account ageing mechanisms”, and para

809 mentions that “An application for approval shall include […], for packages which are to be used for shipment after storage, a gap analysis programme describing a systematic procedure for a periodic evaluation of changes of regulations, changes in technical knowledge and changes of the state of the package design during storage.”

The related advisory material SSG-26, is currently under revision to include guidance on what should be considered as ageing mechanisms and what is expected in a gap analysis programme.

Ageing mechanisms and gap analysis programme may address numerous parts of a package: fuel elements, basket, waste, shielding…, and may vary with the duration of the storage. This article concentrates only on bolts and takes into account a storage duration of up to 40 years.

Regulation for the storage facility is fully independent of the regulation for transport after storage.

BOLTS AND TORQUE

In a DPC, most of the bolts are very important for the package safety during transport operations. The bolts of the lid systems shall maintain the cask closed and leak-tight by appropriate loads on the gaskets, the bolts of the thermal dissipaters contribute to evacuate the residual thermal power, the bolts of the trunnions are essential for the safety of stowage and handling (as long as the cask is handled and stowed through the trunnions).

To ensure its functions, each bolt is required to have specific mechanical characteristics, e.g. yield strength and ultimate tensile strength, but also to apply a specified load to ensure a correct leaktightness of the lid system even in the case of an accident.

To apply a load, the bolts are usually tightened to a specified torque. Indeed, the effort applied by the bolt is deducted from the torque with formula (1) [REF 2]:

$$(1)\ F = \frac{C}{\frac{p}{2\cdot\pi}+\mu_{th}\cdot 0{,}577\cdot d_2+\mu_b\cdot\frac{d_o+d_h}{4}}$$

where F is the load in the bolt, C is the torque, μ_{th} is the friction coefficient on the thread of the bolt, μ_b is the friction coefficient under the head of the bolt, p, d_0, d_2, d_h are geometrical parameters of the bolt.

Consequently, the torque really applied, but also the friction coefficients on the thread of the bolts as well as under the head of the bolt directly influence the load in the bolt.

During recent decades, progress have been made in determination of the precision of the torque applied, due to improvement of the tightening procedure as well as the precision of the tools used. The range of torque to be considered some years ago (± 20 %) may have been reduced to ± 4 % in the most favorable cases. Therefore, the range of the load obtained varied in the same order of magnitude. **This point shall be taken into account in the gap analysis.**

For the future loadings, the torque really applied on the bolts shall be recorded as well as the precision of the tightening. For the stored casks, if such record is not available, estimation of the torque really applied on the bolts and its precision should be considered in the gap analysis. The friction coefficients on the thread of the bolts as well as under the head of the bolt are directly influenced by the lubrication applied on each part (see Fig. 2).

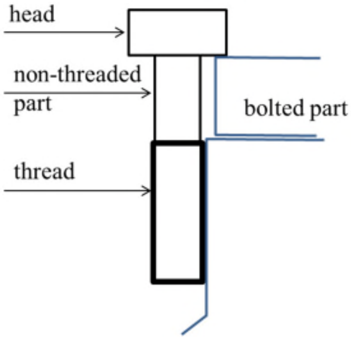

Fig. 1: schematic simplified representation of a bolt

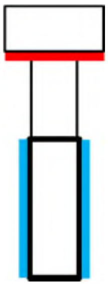

Fig. 2: schematic representation of the lubricant on thread (in blue) and under head (in red)

Many studies have been performed during recent decades, leading to a better characterization of the friction coefficient of the lubricants used in DPCs. **As well as the range of uncertainties on the tightening torque, the range of uncertainties on the friction coefficient of the lubricant applied on the bolt shall be taken into account (recorded for the future loadings, considered in the gap analysis for the stored casks).**

Bolts may be lubricated only on threads. But events recorded in France show that when lubricant is required only on thread (and even when lubrication is forbidden under head), it may be applied involuntarily under head. Different configurations may lead to involuntary lubrication under head. For instance, when the non-threaded part of the bolt is short, it is very difficult for the operator to apply the lubricant only on thread and not under head (see Fig. 3). Lubricant may also be transferred from the thread to the bolted part during introduction of the bolt in the hole (see Fig. 4). If the volume of the lubricant applied on the thread is higher than the volume between the bolt and the bolted part, lubricant may also spill over the bolted part and arrive under head (Fig. 5).

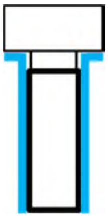

Fig. 3: involuntarily lubrication under head due to a short non-threaded part

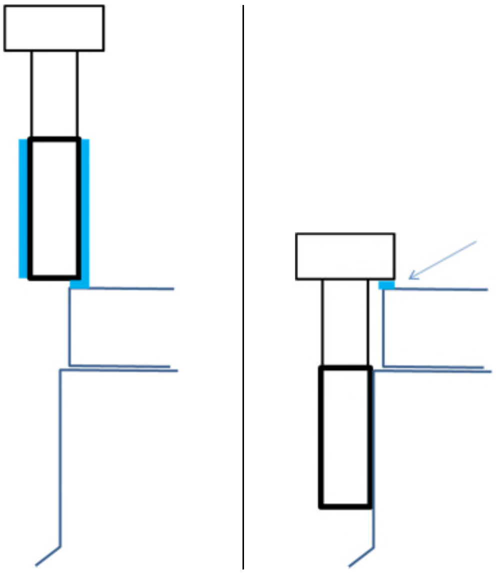

Fig. 4: transfer of lubricant from the thread to under head through the hole

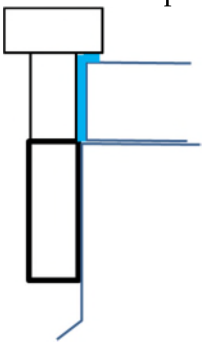

Fig. 5: lubricant spilling over

Lubrication under head of a bolt will dramatically decrease the friction coefficient μ_b in formula (1), and consequently increase the effort of the bolt for the same torque applied. To give an order of magnitude, this phenomenon may increase the effort in the bolt of up to 50 %. **Of course such an increase could have consequences (overstress of the bolts…) that should be analyzed. For future loadings, precautions should be taken to avoid any involuntary lubrication under head of the bolts (design of the bolted system, lubrication of the whole bolt or no lubrication at all etc.). For stored casks, possibility of involuntary lubrication under head should be considered in the gap analysis.**

TEMPERATURE OF THE BOLT, DURING TRANSPORT AND DURING STORAGE

The yield value of the material of the bolts as well as of the bolted part decrease with temperature. To give an order of magnitude, the yield of a steel commonly used for the bolts of the primary lid of DPCs may be 725 MPa at 20°C and 650 MPa at 150°C, i. e. a decrease of about 10 %. The yield of a steel commonly used for the primary lid of DPCs may be 270 MPa at 20°C and 210 MPa at 150°C, i. e. a decrease of about 20 %.

By tightening a bolt, the stress induced in the bolt may reach 90 % of the yield strength of the bolt (see [REF 2]). By increasing the temperature during transport or storage, the stress is quite stable but the yield strength decreases and may decrease below the stress induced by the tightening, leading to overstress the bolt.

The same applies on the pressure of the bolted part under head of the bolt.

In some cases, the bolt and the bolted part are made of materials with different thermal dilatation coefficient (copper thermal dissipaters bolted with steel bolts, for example). The differential thermal dilatation of the bolted part may induce an elongation of the bolt, leading to an overstress of the bolt if the elongation is excessive. It may also lead to an overstress of the bolted part, if the pressure under head increases over the yield strength of the bolted part.

In all those situations, if the bolt or the bolted part is stressed over yield, permanent deformation will occur. After decrease of the temperature, the torque value or even more the state of the bolt may not be guaranteed any more.

Given these elements, in the case of a long-term storage, the temperature conditions during the storage period should be considered carefully. For future loadings, sensibility of the bolted system to the temperature should be analyzed and temperature of the sensible bolted systems should be limited or recorded. For stored casks, analysis of the sensibility of the bolted systems to the temperature should be considered in the gap analysis**.**

CONCLUSION

The feedback from assessment of PDSR highlights safety issues related to the transport after *long duration* storage in terms of: traceability, uncertainties, temperatures, torques, overstress…

In the same time, even more storage in DPCs are made in different countries.

The transport regulation has been strengthened to reflect lessons learnt from this experience feedback and to address issues related to ageing mechanisms of the package. In particular, ageing management based on gap analysis programme has to be conducted during storage.

This article analyses some ageing phenomena of the bolts and gives first indications on what could be expected in such a gap analysis.

REFERENCES

[REF 1] IAEA SSR-6, Regulations for the Safe Transport of Radioactive Material, Rev.1, 2018 Edition.

[REF 2] Standard NF EN 25-030 Part 1 and 2 “Threaded connections with ISO metric thread – Part 1: Simplified procedure/ Part 2: Complete procedure” (2014 Edition).

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