Guide YVL B.4, Nuclear fuel and reactor

1 Introduction

This Guide presents criteria and detailed requirements to ensure and demonstrate the fulfilment of the requirements of the Radiation and Nuclear Safety Authority Regulation on the Safety of a Nuclear Power Plant (STUK Y/1/2018) during the design of the nuclear power plant, reactor core and nuclear fuel. Criticality safety requirements apply to all nuclear facilities where fissile material is used, stored or handled. The requirements for the reactor core and reactivity control systems are given in chapter 3 of this Guide, those for nuclear fuel and fuel design in chapter 4 and the requirements for the prevention of a criticality accident in chapter 5.

2 Scope of application

Guide YVL B.4 shall be applied to the design of the reactors, reactivity control systems and nuclear fuel as well as fuel handling and storage systems of nuclear facilities.

In addition to fuel design, control rod design shall comply with the requirements of chapters 4 and 5 of Guide YVL B.4 for applicable parts.

3 Justifications of the requirements

Requirement 202. By mentioning control rods separately, later text can be streamlined, not needing to specify in each case that the requirement also concerns control rods. Measuring instruments located inside fuel assemblies, for example, shall also be designed so that damage to them cannot threaten fuel integrity.

Requirement 303. Because of the development of BWR fuel, the isothermal temperature feedback of the reactor might be positive in the nuclear heating phase, especially towards the end of the operating cycle. This is acceptable with the following conditions:

- The reactivity feedback of the water temperature inside the fuel channel is negative. This limits the increase of power in fast transients where the water between the channels does not have time to warm up.
- The absolute value of the positive isothermal feedback remains sufficiently low, and the phenomenon has been prepared for in the plant's operating instructions and the training of personnel.

The initiating event causes a reactivity increase in, for example, a BWR pressure transient, a control rod fall/ejection and boron dilution. The loss of cooling takes place in LOCA. A break in the PWR steam pipe does not immediately cause either phenomenon, so in that case, the feedback may raise the power.

Requirement 306. The requirement is related to the accident type in a pressurised water reactor where, as a result of primary water vaporisation, a plug of water with a low boron concentration may be created. The requirement demands that a plug like this shall not get to the reactor; before that happens, it shall be sufficiently mixed with primary water with higher boron concentration. It is also required that control rods shall not selectively lose their efficiency as a result of a pipe break (for example, in pressure tube reactors, this is often the case).

Requirement 406. The following is a list of examples of phenomena and issues to take into account in fuel design:

- stresses and strains of the various parts of fuel
- fatigue damages caused by cycling loads during operation
- oxidation of various parts and hydriding of the rod cladding
- chemical and physical properties of the coolant
- densification and swelling of fuel pellets
- spring force of the spring inside the fuel rod to prevent fuel pellets from moving during the transport and handling of fresh fuel
- stresses caused by handling and transport, which can affect the behaviour of fuel and control rods during operation.

Requirement 407. During the licensing of nuclear fuel, its suitability to all phases of the planned life cycle shall be demonstrated. In terms of final disposal, the examination may be carried out so that fuel design is demonstrated to be within the limits set by the encapsulation and disposal facility. In this case, the safety analyses of the disposal facility do not need to be renewed for each type of fuel.

Requirement 409. The Guide does not directly determine how the burn-up limits to be applied to the fuel shall be presented. The formulation of the Guide leaves it for the licence applicant to decide with what kind of operational limits to ensure the compliance to the experimentally justified safe limits usually set for a rod or a pellet. In determining the operational limits, it shall be taken into account, on the one hand, that they shall ensure the adherence to the safe limits and, on the other hand, that it shall be possible to monitor the compliance with them with reasonable effort.

In terms of final disposal, the intention is to ensure that the operational limits of the reactor and fuel are set so that spent fuel is disposable according to the safety requirements. The characteristics of spent fuel (for example, residual heat, radiation level and reactivity) shall be in accordance with the design basis of planned or existing processing and disposal facilities. If the final disposal solution for a new plant project is not exactly known yet, the licensability of the fuel shall be assessed as part of the licensing of the intermediate storage and final disposal facilities.

When the fuel burn-up increases, the oxide layer and crud of the cladding might change the heat transfer characteristics of the cladding. This might affect the occurrence of a heat transfer crisis. The issue has been brought up in the NEA report NEA/CSNI/R(99)25 (section 3.1).

Requirement 412. The internal pressure of a fuel rod is affected by the release of fission gases and the pre-pressurisation of the rod. It can be considered that there is now sufficiently experimental information to allow the system pressure to be exceeded and the lift off limits to be justified experimentally. The limiting of the internal pressure of the fuel rod has also created extra certainty for the retaining of coolability in LOCA situations, which shall be taken into account in the inspection of LOCA analyses.

Requirement 415. Heat transfer crisis here refers to two phenomena, DNB occurring at low steam concentrations and dryout occurring at high steam concentrations. The first of these is typically a limiting phenomenon in a pressurised water reactor and the latter in a boiling water reactor.

Requirement 416. A short-term heat transfer crisis does not necessarily cause fuel damage, but it is a clear criterion that can be assessed with reasonable reliability. If a short-term heat transfer crisis was allowed, the creation of fuel damages would have to be assessed with analyses involving considerable uncertainties. The oxidation of the cladding during an accident remains low if its temperature does not exceed 700 °C. In terms of the rupture risk, the test material is largely valid up to a temperature of 650 °C at low pressure. At temperatures higher than this, the normal system pressure and the short-term nature of the situation minimise the rupture risk.

Requirements 420, 424. In Finland (originally, in VVER reactors), the value 140 cal/g (586 J/kg) has generally been used as the RIA fuel failure limit and the value 230 cal/g (963 J/kg) as the fragmentation limit.

Requirement 422. In analyses, it must be taken into account that the cladding may be oxidised both internally and externally during an accident. Loads caused by accidents include, for example, stresses due to thermoshock during quenching at the late phase of a loss of coolant accident.

Requirement 424. The formulation does not prohibit local melting in the middle of a fuel pellet in RIA situations, as long as the fragmentation enthalpy is not exceeded.

Requirement 501. The criticality safety of the final disposal canister shall be demonstrated for new fuel types. If the final disposal solution for a new plant project is not exactly known yet, the licensability of the fuel shall be assessed as part of the licensing of the intermediate storage and final disposal facilities.

Requirement 502. During the licensing of nuclear fuel, its suitability to all phases of the planned life cycle shall be demonstrated. In terms of the criticality safety of final disposal, the demonstration may be done by, for example, using a reference assembly whose criticality safety has been demonstrated to fulfil the requirements. In this case, in the licensing of a single fuel assembly design, it is sufficient to demonstrate that its reactivity in circumstances corresponding to the final disposal situation is below the reactivity curve depending on the burn-up of the reference assembly in question.

Requirement 506. For structures utilising burn-up credit, the smallest allowed fuel burn-up shall be presented.

Requirement 507. If necessary, the criticality safety of a rack may be improved by preventing the use of certain positions in a permanent manner. Administrative methods are not sufficient.

4 International provisions concerning the scope of the Guide

- IAEA Safety Guide NS-G-1.12: Design of the Reactor Core for Nuclear Power Plants
- IAEA Safety Guide NS-G-1.4: Design of Fuel Handling and Storage Systems in Nuclear Power Plants.
- IAEA Safety Guide SSG-2: Deterministic Safety Analysis for Nuclear Power Plants

5 Impacts of the Tepco Fukushima Dai-ichi accident

No impact on the Guide.

6 Needs for changes taken into account in the update

The needs for changes due to changes made to international and national laws/regulations and the change proposals made in connection with the preparation of the YVL Guide implementation decisions (SYLVI) together with others recorded in STUK's change proposal database have been considered when updating the requirements. In addition, the possibilities to reduce the so-called administrative burden have been considered.

The content and requirement level of the Guide have remained unchanged. A few requirements have been clarified (106, 203, 409), and one new description has been added (104a). The references have been reviewed and updated. The Guide does not contain any possibilities for administrative burden reduction.