Design bases and general design criteria for nuclear fuel

This Guide is in force as of 1 May 2000 until further notice. It replaces Guide YVL 6.2 published on 15 February1983.

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Authorisation

By virtue of the below acts and regulations, the Radiation and Nuclear Safety Authority (STUK) issues detailed regulations that apply to the safe use of nuclear energy and to physical protection, emergency preparedness and safeguards:

- Section 55, paragraph 2, point 3 of the Nuclear Energy Act (990/1987)
- Section 29 of the Council of State Decision (395/1991) on the Safety of Nuclear Power Plants
- Section 13 of the Council of State Decision (396/1991) on the Physical Protection of Nuclear Power Plants
- Section 11 of the Council of State Decision (397/1991) on the Emergency Preparedness of Nuclear Power Plants
- Section 8 of the Council of State Decision (398/1991) on the Safety of a Disposal Facility for Reactor Waste
- Section 30 of the Council of State Decision (478/1999) on the Safety of Disposal of Spent Nuclear Fuel.

Rules for application

The publication of a YVL guide does not, as such, alter any decisions made by STUK before the publication of the guide. It is only after it has heard those concerned that STUK makes a separate decision on how a new or revised YVL guide is applied to operating nuclear power plants, or to those under construction, and to the licence-holders' activities. The guides apply as such to new nuclear facilities.

When it considers how new safety requirements presented in the YVL guides apply to operating nuclear power plants, or to those under construction, STUK takes into account the principle prescribed in section 27 of the Council of State Decision (395/1991), according to which *for further safety enhancement, actions shall be taken which can be regarded as justified considering operating experience and the results of safety research as well as the advancement of science and technology.*

If deviations are made from the requirements of the YVL guides, STUK shall be presented with some other acceptable procedure or solution by which the safety level set forth in the YVL guides is attained.

Translation. Original text in Finnish.

1 General

The general requirements for the safety of nuclear power plants are presented in the Council of State Decision (395/1991). The requirements, the purpose of which is to assure the integrity of nuclear fuel, are presented in section 15 of the Decision. According to paragraphs 1 and 2 of section 15:

The probability of significant degradation of fuel cooling or of a fuel failure due to other reasons shall be low during normal operational conditions and anticipated operational transients.

During postulated accidents, the rate of fuel failures shall remain low and fuel coolability shall not be endangered.

A fuel damage means a situation, in which a fuel rod loses its integrity and fission gases are released from the fuel rods into the coolant, or in which the permissible design basis deformations are exceeded. The loss of fuel coolability means such damage in the fuel that the fuel consequently loses its coolable geometry.

To prevent fuel damage and to ensure fuel coolability, limits for fuel design have been determined, in which adequate safety margins are included. In determining these limits, attention is paid to the fact that the normal function of control rods may not be prevented because of fuel damage. The limits are based on experimental results concerning the fuel and the type of control rod in question.

The design of fuel and reactor and the systems connected to them is based on the fuel design limits. Some of these limits may be connected to the design of all the objects mentioned above or to the design of only one object. Guide YVL 1.0 presents, how these limits are taken into consideration in the design of the nuclear power plant. Guide YVL 6.3 describes, how these design limits and criteria are taken into consideration in fuel design and in analyses concerning fuel.

As applicable, fuel design limits are presented in the safety analysis report of the plant unit, in topical reports and in the pre-inspection documents of the fuel.

2 General design criteria

To prevent damage and to maintain coolability, attention shall be paid to the following criteria in the design of fuel and control rods :

According to the Guide YVL 1.0 *The structure of the fuel and reactor internals shall be designed compatible so that when the reactor is assembled, each component fits reliably in the right place and position. After reactor loading, it must be possible to check that the fuel and reactor internals have been correctly positioned.*

The fuel structure shall be designed in such a way that it is not damaged during operation. The fuel boxes and bundles as well as their components must maintain position in all operational conditions and in postulated accidents. They have to endure the respective loading so that the reactor shutdown and cooling are not endangered.

The changes affecting fuel properties, resulting from the radiation exposure, shall be taken into account in determining the limits of safe fuel usage. The criteria presented in this Guide can be applied for fuel, the maximum bundle burnup of which does not exceed the value 40 MWd/kgU. With burnup values higher than this, the acceptable limits of fuel shall be separately justified by experiments.

The control rods must endure wear and other stresses induced by operation so that their normal function is not endangered. The control rods shall retain their ability to absorb neutrons during operation to an adequate degree.

Stresses caused by handling and transport shall be taken into account in the design of fuel and control rods.

3 Design criteria for normal operational conditions

In order to prevent damage of fuel and control rods and to ensure coolability in normal operational conditions, attention shall be paid to the following criteria:

No melting may occur in the fuel pellets, and the cladding temperature may not substantially exceed the coolant temperature.

The cladding of the fuel rod may not collapse during the design operating life of the fuel rod bundle.

The release of fission gases into the fuel rod shall remain low. The internal pressure in the rod caused by the release of fission gases and pre-pressurisation must remain so low that the internal pressure of the rod will not exceed the normal pressure of the coolant.

Limits shall be defined for the deformations of fuel and control rod components, e.g. for bowing, distortion and growth of fuel rods, bundles, boxes and control rods, so that
- no significant increase in power in the fuel rods and possible fuel damage resulting from it occur
- cooling of fuel is not endangered
- a reactor scram with the help of control rods is not endangered
- the handling of fuel rods is not endangered.

The damage caused by the mechanical interaction between fuel pellet and cladding shall be prevented. Because of that, operating limits concerning changes in power and the rate of the changes shall be determined for the fuel types used. The stress corrosion of the cladding, among other things, shall be taken into account in determining the limits.

The damage of fuel and control rods has to be prevented during operation, handling and transport. To ensure this, at least the following phenomena and facts shall be taken into account:
- stresses and strains of the various parts of fuel and control rods
- fatigue damages caused by cycling loads during operation
- oxidation of various parts and hydriding of the 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.

As applicable, safety limits shall be determined for the loads caused by these phenomena and for the changes of fuel properties.

The fuel design shall be such that, after normal usage, it endures long-term storage and handling connected to disposal.

4 Design criteria for operational transients

In anticipated operational transients, in which the initial event frequency is higher than 10^{-2}/year, the following criteria shall be taken into consideration in order to prevent fuel damage and to ensure coolability:
- Melting may not occur in the fuel pellets.
- The adequate cooling of the cladding shall be ensured. It will be reached, if there is a 95% probability, at the 95% confidence level that the hottest fuel rod does not reach the heat transfer crisis or transition boiling condition. The number of rods reaching the heat transfer crisis shall not exceed 0.1% of the total number of fuel rods in the reactor.

- The probability of fuel damage caused by the mechanical interaction between fuel and cladding shall be extremely low.

5 Design criteria for postulated accidents

In this Guide, postulated accidents have been divided into two classes according to their probability. In Class 1 the initiating event frequency of postulated accidents is $10^{-2}\ldots10^{-3}$/year. Events with lower probability are classified as Class 2 postulated accidents.

Class 1 postulated accidents

The number of fuel rods reaching the heat transfer crisis shall remain small in Class 1 accidents. The consequences of an accident may not cause significant changes to the original fuel geometry. To ensure this, the following criteria shall be taken into account:

- The number of rods reaching the heat transfer crisis may not exceed 1% of the total number of fuel rods in the reactor.
- The maximum temperature of the fuel cladding may not exceed 650 °C.
- It has to be shown that the probability of fuel damage caused by the mechanical interaction between fuel and cladding remains extremely low.

Class 2 postulated accidents

The higher the initial event frequency of a Class 2 postulated accident, the smaller the number of damaged fuel rods shall be. The number of damaged fuel rods may not exceed 10 % of the total number of fuel rods in the reactor. The consequences of the postulated accident may not endanger the coolability of the fuel, either.

In determining the total number of rods damaged owing to the temperature rise of the cladding, the changes in cladding temperature, chemical reactions, deformations, ballooning and collapse of the cladding and the damaging of cladding caused by the increase of the fuel enthalpy shall be taken into account.

The bursting and collapse limits for the cladding material have to be experimentally determined. As applicable, in determining these limits at least the following facts have to be taken into account:

- the internal pressure in the fuel rod caused by the release of fission gases
- aggressive fission products in relation to the cladding corrosion, for example iodine, cumulating in the gas gap of the cladding
- azimuthal variations in the thickness of the cladding material; maximum tolerances specified in the production specifications can be used
- cracks and scores caused by the mechanical interaction between fuel and cladding or developed during the fuel production
- oxidation and hydriding of the cladding during normal operation
- the effect of fuel irradiation on the properties of the cladding material and fuel pellet.

A fuel damage is assumed to happen, when the average radial enthalpy of fuel exceeds the value 586 J/gUO_2 (140 cal/g).

An excessive embrittlement of the cladding shall be prevented. To ensure this, it shall be shown that

- the cladding is not oxidised during an accident to the degree that it cannot withstand the loads caused by the accident, for example stresses due to thermoshock during quenching at the late phase of a loss of coolant accident. In estimating the total thickness of the required ductile part of the cladding, attention has to be paid to the external and possible internal oxidation of the cladding during the accident and to the preceding oxidation during normal operation. Additionally, the chemical interactions between uranium dioxide and cladding material in connection with cladding collapse have to be taken into consideration. Also the loads caused by the handling, removal transport

and storage of the fuel rod bundle after the accident have to be included in this assessment
- the oxygen adsorbed during normal operation and during an accident does not excessively embrittle the cladding. The effect of the adsorbed oxygen on the cladding shall be experimentally determined.
- the temperature rise of the cladding has been limited to the level, where the oxidation of the cladding as a consequence of metal-water reaction is still controllable. Because of this, the highest temperature of the cladding may not exceed 1200 °C in case of an accident.

The fragmentation and melting of the fuel rod shall be prevented. The fuel enthalpy of any fuel rod may not exceed the value of radial average enthalpy, i.e. 963 J/g UO_2 (230 cal/g).

The interactions of the various parts of the fuel rod bundle may not lead to the melting of fuel cladding. Such interactions are for example eutectic reactions between parts of different material. In case of these reactions, the fuel cladding may melt at lower temperatures than the melting temperature of the cladding material.

The amount of hydrogen caused by the chemical interaction between coolant and cladding shall not exceed 1% of the amount, which could be developed, if the whole active cladding surrounding fuel pellets would react with the coolant.

Fuel flow channels may not be blocked so that the coolability of the fuel is endangered due to ballooning or breaking down of the cladding, or due to deformation of other parts of fuel or reactor internals, or due to possible debris in the reactor resulting from an accident.

No melting may occur in the control rods. The structural deformations in fuel, control rods and reactor internals may not prevent the movement of control rods in the reactor.