Translation

OVER-PRESSURE PROTECTION AND PRESSURE CONTROL DURING DISTURBANCES IN THE PRIMARY CIRCUIT AND STEAM GENERATORS OF A PWR PLANT

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APPENDIX SITUATIONS IN WHICH THE PRIMARY OR SECONDARY PRESSURE OF A PRESSURIZED WATER REACTOR TENDS TO RISE

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1 INTRODUCTION

To ensure the safety of a nuclear power plant, it is essential that the heat transfer from the reactor to the primary coolant and further to the ultimate heat sink be maintained without interruptions. A continuous heat transfer can be best assured if the circuits taking part in the heat transfer chain maintain their integrity and if the pressure and temperature conditions in the circuits remain favourable. The over-pressure protection of the primary circuit and the steam generators is a central factor in maintaining the integrity of the heat transfer chain, and appropriate pressure control during disturbances makes it possible to keep up favourable pressure and temperature conditions.

The ductility of the materials used in the main components of a nuclear power plant depends on temperature, and therefore the requirements to be set for over-pressure protection are different under different operating conditions. Chapter 2 of this guide provides guidance on systems that can be used for over-pressure protection at normal operating temperature. The design bases of these systems are also discussed. Chapter 3 presents some acceptable ways of assuring over-pressure protection at low operating temperatures.

Chapter 4 deals with the requirements that certain disturbances set for the systems to be used for pressure control.

2 OVER-PRESSURE PROTECTION AT NORMAL OPERATING TEMPERATURE

2.1 Systems used in over-pressure protection

2.1.1 Safety valves

The primary circuit of the plant and each steam generator shall be provided with at least two safety valves.

To ensure the reliable opening and closing of the safety valves, one shall use a valve type of which there is sufficient operating experience or which has undergone sufficient tests in conditions corresponding to the real operating conditions.

The opening pressures, response curves (rise of stem as a function of pressure), and operating times of the safety valves shall be known or they shall be adjustable, as required by the analyses of over-pressure protection. Similarly it must be known how the function of the safety valves depends on their connection to the rest of the process (inlets and outlets of main and pilot valves).

The safety valves shall be provided with position indicators that are independent of control equipment.

There shall be an opportunity to test the safety valves periodically.

Redundant safety valves protecting the same object shall be adjusted to open at least in two stages so that there will be as few unnecessary openings of the safety valves as possible. In this way the risk of the valve being stuck open will be reduced, and the transient associated with the opening will be diminished.

As a rule, there should be no shut-off valve between the protected object and the safety valve, in the discharge line of the safety valve, or in the control line needed in the opening of the safety valve. If a deviation is made to this rule to facilitate testing or maintenance or to provide against a stuck open safety valve, there shall be a reliable way of preventing the shut-off valve from being closed unintentionally.

The safety valves shall be pilot-operated safety valves with properties corresponding with either sub-section a) or b) below:

a) Pilot-operated safety valves loaded with a limited closing force

The load closing the safety valve is created with a spring or with electric or pneumatic external energy, or with a combination of these. Part of the closing load can also be obtained from the energy of the protected object itself. The valve is opened when the pressure directed towards the valve disc causes an opening force in excess of the closing load.

To improve the leak-tightness of the safety valve, the load closing the valve is chosen so that it is greater than the opening force affecting the valve disc in the opening pressure. The planned opening is accomplished with a pilot device which operates in the opening pressure, either eliminating part of the closing load or causing an additional force which makes the valve open. The pilot device can use either the internal energy of the protected object or some external energy.

The load closing the safety valve is no more than 10 % higher than the opening force that is directed to the valve disc in the opening pressure.

The safety valve has one or more pilot devices.

b) Pilot-operated safety valves loaded with an unlimited closing force

The load closing the safety valve is created with the energy of the protected object itself, with a spring or with electric or pneumatic extrnal energy or with a combination of these. The pressure of the protected object affecting the valve disc can cause a force that is either opening or closing the valve.

The safety valve is opened when the pilot device eliminates at least part of the closing load (releasing) or causes a force opening the valve (loading). The pilot device can use either the energy contained in the object or some external energy. If the valve operates on loading and does not use the energy of the protected object, it has two sources of energy that are independent of each other.

The safety valve has at least two pilot devices indpendent of each other. In the case of malfunction of one device, the other will open the safety valve in a reliable way.

2.1.2 Protection system

In designing over-pressure protection, one can take into account the protection system that starts the shutdown of the reactor. The protection system shall meet the general safety principles presented in Chapter 5 of Guide YVL 1.0 and the more detailed requirements given in the standards mentioned in Guide YVL 5.5.

2.1.3 Other systems

The other systems that are used for over-pressure protection include relief valves and the systems decreasing pressure during normal pressure control, such as the pressurizer spray system.

Relief valves are automatically operating valves, which can also be opened from the control room and which can be used for controlled pressure regulation and pressure reduction. A relief valve can be one component or, for instance, a combination of a control valve and a fast-opening valve of the safety valve type.

The "other systems" referred to in this section shall be designed in such a way that an uncontrolled pressure reduction caused by a single component failure (e.g. a stuck open relief valve) can be stopped with control actions taken in the control room.

2.2 Transients and accidents to be used as design basis for over-pressure protection

In designing over-pressure protection, one shall analyse the transients and accidents which involve

1. An increase in reactor power

2. A reduction in heat transfer from the primary circuit to the normal heat sink

3. An uncontrolled increase in primary or secondary coolant.

Examples of these pressure-increasing situations are given in the appendix of this guide.

The situations to be analysed shall be divided into anticipated transients and postulated accidents. The division is based on the estimated frequency of the event, the dividing line being one occurrence during the planned operating life of the plant. The operating experiences gained of comparable power plants and components and probabilistic assessment methods are utilized in the division.

As concerns the over-pressure protection of the secondary circuit, one shall also examine a case in which primary coolant is leaking to the secondary side and which is to be defined as a postulated accident. The volume of the leak is determined so as to correspond with the largest rupture that can be regarded as possible on the basis of the steam generator structure and the construction materials used.

Anticipated transients shall be examined at three different levels:

1. All systems of the power plant operate as designed and in conformity with the nominal parameters before and during the disturbance, with the exception of the initiating fault and its direct consequences.

2. The operating conditions of the power plant are assumed to be as unfavourable to the over-pressure protection as possible, and it is assumed that the

disturbance is aggravated by additional faults, as listed in section 2.3 of this guide.

3. The protection system starting a reactor trip is inoperable and the control rods do not move inwards, but otherwise the automatic systems of the power plant operate as designed.

Postulated accidents need only be examined at level 2.

If it can be shown on obvious grounds that a certain transient has less severe consequences with respect to over-pressure protection than another transient of the corresponding type, the first-mentioned need not undergo a detailed quantitative analysis.

In addition to the analyses concerning the sufficiency of the over-pressure protection, one shall also examine the possibility that a correctly opened safety valve is stuck in the open position. The faulty position may result in an excessive leak of the reactor coolant or in too rapid cooling of the primary circuit.

If the discharge outlets of the steam generator safety valves are outside the containment, the consequences of a single safety valve being stuck open in connection with a primary-to-secondary leak shall also be analysed with respect to the sufficency of the primary coolant and the radiological effects.

2.3 Assumptions to be used in analyses of over-pressure protection and acceptance criteria of the analyses

Analyses of the first level are only carried out for anticipated transients. With the exception of the initiating fault and its direct consequences, it is assumed that all plant systems are operating as designed and in accordance with the nominal parameters. The acceptance criterion of the first-level analyses is that no safety valve is opened in the primary circuit during the transient, but the event can be handled by means of the reactor protection system and the other systems that are used for over-pressure protection.

Analyses of the second level are carried out for anticipated transients and for postulated accidents. It is assumed that

- the reactor operates at power that is the nominal power plus the uncertainty relating to the power control

- the reactor and the associated systems are operated in conditions that are as unfavourable as possible, taking into accout inaccuracies in measurements and the limits allowed by the Technical Specifications

- the reactivity coefficients are as unfavourable as possible in regard to the situation, taking into account the whole operating life of the reactor

- the reactor trip follows the second signal given by the reactor protection system in the case of an anticipated operating disturbance, and the first signal in the case of a postulated accident

- the relief valves fail, with the exception of those valves which meet the requirements laid down for safety valves in section 2.1.1

- the other systems referred to in section 2.1.3 fail

- safety valves (and relief valves that are equivalent to them) will fail in the closed position (i.e. do not open) as follows:

total number of safety valves	failed
2 - 3	1
4 - 8	2
9 or more	one fourth of the number rounded off to the next integer

- the discharge flow capacity of the safety valve equals to the nominal capacity determined on the basis of an applicable standard and the opening pressure equals to the nominal setting pressure
- safety valves with different discharge flow capacities fail in the order of size (starting from the largest) as follows: first, fourth, ninth, thirteenth, etc, always at intevals of four
- safety valves which have the same discharge flow capacity but have been set to open at different pressures fail in the order of the opening pressures (starting from the lowest pressure) as follows: first, fourth, ninth, thirteenth, etc, always at intervals of four
- if a safety valve has more than one pilot device and these devices have been set at different pressures, the opening pressure is the lower setting pressure.

The acceptance criterion for the analyses of the second level is that the pressure keeps lower than 1.1 times the design pressure of the protected object.

Analyses of the third level are carried out only for anticipated transients. In the third-level analyses it is assumed that the plant systems operate as planned and in accordance with the nominal parameters, with the exception of the following faults:

- the initiating fault and its direct consequences
- loss of the reactor trip signals and loss of the functions dependent on these signals
- the control rods remain in the positions that they had before the disturbance.

The reactivity coefficient of the coolant temperature that is used in the third-level analyses shall be the least negative of the values that prevail for 99 % of the operating time of the reactor at 100 % power.

The acceptance of the third-level analyses requires that nowhere in the primary circuit, except for the heat transfer tubes of the steam generator, does the calculated maximum strain exceed the value corresponding to the operating conditions of level C defined in Guide YVL 3.5. Furthermore, the deformations of the reactor primary circuit shall be so limited that the reactor can be safely shut down. For the heat transfer tubes of the steam generator, the limit can be a conservatively estimated pressure that is based on test results and that the tubes should be able to withstand.

In the analyses concerning a stuck open safety valve, it can be assumed that the operator takes actions to diminish or stop the safety valve leak in 30 minutes after the valve has been stuck. The automatic operations that relate to the reduction or stopping of the leak can be taken into account if their control has been reliably ensured. The acceptance of the analyses requires a demonstration that the components of the primary circuit and the steam generators are able to withstand the cooling transients in question. In connection with a primary-to-secondary leak, it shall be additionally demonstrated that a stuck safety valve will not deplete the reactor emergency cooling water or will not cause a situation in which the radiation dose limits concerning accident conditions would be exceeded.

3 OVER-PRESSURE PROTECTION AT LOW OPERATING TEMPERATURES

At low operating temperatures, the ductility of the construction materials used in the main components of a nuclear power plant can be essentially lower than at the normal operating temperature. Using pressure and temperature limits, one shall define the conditions in which the components can be safely used also at low temperatures. Deviations from the operating range determined by these limits shall be prevented by means of reliable protective arrangements.

The over-pressure protection at low temperatures can be based on

- safety valves whose opening pressure can be chosen according to the operating temperature,
- safety valves that have been reliably disconnected in warm operating states, or
- protection systems which make it possible to directly affect the functions that may cause over-pressure. These protection systems shall meet the general safety principles presented in Chapter 5 of Guide YVL 1.0, and the more detailed requirements that are given

in the standards referred to in Guide YVL 5.5. The function of the protection systems may be, for instance, to stop pumps with a high shut-off head or to open outlet lines. If the over-pressure protection is based on protection systems and not on safety valves, the protected circuits shall include a pressurizer tank that is operable also in the cold state and contains a gas or steam cushion levelling down fast pressure changes.

The sufficient over-pressure protection at the low operating temperature shall be demonstrated by analyses. In these analyses each mechanism capable of raising the pressure shall be considered separately.

In designing over-pressure protection at low operating temperatures, one shall also consider disturbances and accidents in which the temperature can drop as a direct consequence of the disturbance or in which the primary circuit must be cooled down in an abnormal way. The systems needed in these situations (e.g. emergency cooling systems) shall be so designed that they cannot raise the pressure over the set limit.

4 PRESSURE CONTROL DURING DISTURBANCES

The maintenance of the primary circuit pressure shall be ensured also in situations where the external supply of electricity has been lost.

The primary circuit shall be provided with devices that are suitable for the continuous controlled reduction of pressure and that can be controlled from the control room in all operating conditions. They shall be in continuous readiness for operation and independent of the external supply of electricity and the operation of the primary coolant pumps.

The steam generators shall be provided with devices that are suitable for the reduction of pressure and that can be controlled from the control room in all operating conditions. They shall be in continuous readiness for operation and independent of the external supply of electricity and the possible isolation of the steam lines.

The heaters that are used for increasing the pressure in the primary circuit shall be provided with a protection system interrupting the heating, if incorrect heating during some disturbance could jeopardize the integrity of the primary circuit.

In the event of any differences in interpretation of this guide, the Finnish version shall take precedence over this translation.

APPENDIX

SITUATIONS IN WHICH THE PRIMARY OR SECONDARY PRESSURE OF A PRESSURIZED WATER REACTOR TENDS TO RISE

1. Loss of external load (however, external electricity is in use)

2. Turbine trip as a consequence of a fault signal

3. Loss of condenser vacuum

4. Malfunction of the secondary pressure control making the turbine control valve move towards the closed position

5. Inadvertent closure of the isolation valve in one steam line

6. Inadvertent closure of the isolation valves simultaneously in all steam lines

7. Complete loss of external electricity

8. Simultaneous stopping of all feed water pumps

9. Stopping of a primary coolant pump

10. Simultaneous stopping of all primary coolant pumps

11. Uncontrolled withdrawal of a control rod or a group of rods

12. Dilution of the boron concentration in the reactor coolant due to a malfunction of the boron control

13. Increase in the volume of reactor coolant due to an inadvertent starting of the make-up water system or the emergency core cooling system.