

Nuclear reactor instrumentation — Boiling water reactors (BWR) — Stability monitoring

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the CEI IEC title page, pages ii to iv, pages 1 to 27 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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**Instrumentation des réacteurs nucléaires –
Réacteurs à eau bouillante (BWR) –
Surveillance de la stabilité**

**Nuclear reactor instrumentation –
Boiling water reactors (BWR) –
Stability monitoring**



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Introduction

Thermal hydraulic instability is a known phenomenon in conventional steam generators. Two phase flow oscillations in steam generators can result in local channel overheating. This phenomenon and its impact on the design of steam generators is well documented. Under certain conditions boiling water reactors are also susceptible to such thermal hydraulic instabilities. The design of the reactor recirculation system has a large impact on the stability of the reactor system. Four different BWR recirculation systems are used in modern BWRs:

- a) Internal pumps (Figure 1a)
- b) Jet pumps (Figure 1b)
- c) External pumps (Figure 1c)
- d) Natural recirculation (Figure 1d)

Another critical factor in BWR stability is the neutronic feedback to the local fuel channel thermal-hydraulic perturbation. The two feedback mechanisms, thermal-hydraulic and neutronic, are coupled in a BWR core and can, under certain conditions, generate oscillations in both core flow and thermal power. In addition, reactor instabilities can occur even when neither feedback mechanism alone is sufficient to generate instability. The physics of such BWR-instabilities are explained with some detail in clause 5.

In order to identify flux oscillations characteristic of a thermal-hydraulic instability, a system that monitors neutron flux (APRM and LPRM signals) can be used. This system generates an output signal which can be used for automatic suppression functions. A short description of automatic detection and suppression is included in Annex A.

A short account of examples of BWR instability incidents which have occurred during the last several years is given in Annex B. These events illustrate the importance and the need for a standard on stability monitoring of BWR.

A significant amount of information is now available relative to BWR stability from experience at operating BWRs. Special tests have been performed at numerous plants under controlled conditions to provide information on individual plant response during an instability and the portion of the operating domain most susceptible to oscillations for the operating conditions present at the time of the test. Examples of such special tests are given in Annex C.

An instability prevention concept is described by the power flow diagram given in Annex D, which is used in Japan and Germany.

In Annex E an account of operating experience with stability monitoring in different countries is given.

Annex F gives an estimation of neutron noise characteristic functions, while the estimation of phase difference is described in Annex G.

Annex H is a bibliography.

1 Scope and object

This International Standard applies to boiling water reactors (BWR) designed to ensure that thermal-hydraulic oscillations are either not possible, or can be reliably and readily detected and suppressed. Compliance with the criteria can be demonstrated by:

- a) preventing power oscillations;
- b) detecting and automatically suppressing power oscillations.

Monitoring of the reactor stability state, which is the object of this standard, can support a) and b) by providing information on plant stability characteristics. Monitoring will detect the approach to, and occurrence of, oscillations.

The purpose of this standard is to

- describe appropriate plant parameters for use in stability monitoring;
- define analysis methods for relating time-varying plant information to reactor stability figures of merit, such as the decay ratio;
- provide technical guidelines regarding stability monitoring functional and performance requirements.

The following items are not covered by this standard:

- a) control system instability;
- b) recommendations for implementing a particular solution or a combination of solutions;
- c) requirements for analytical methods associated with each method;
- d) requirements for manual operator and automatic actions necessary to suppress power oscillations or reduce decay ratios;
- e) general safety significance of reactor instability.

This standard also does not cover predictor type stability monitors (e.g. frequency domain models which may be used on line to calculate decay ratio for current reactor conditions).

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(393):1996, *International Electrotechnical Vocabulary (IEV) —*

Chapter 393: Nuclear instrumentation: Physical phenomena and basic concepts.

IEC 60557:1982, *IEC terminology in the nuclear reactor field.*

IEC 60780:1998, *Nuclear power plants — Electrical equipment of the safety system — Qualification.*

IEC 60880:1986, *Software for computers in the safety systems of nuclear power stations.*

IEC 60964:1989, *Design for control rooms of nuclear power plants.*

IEC 60980:1989, *Recommended practices for seismic qualification of electrical equipment of the safety system for nuclear generating stations.*

IEC 60987:1989, *Programmed digital computers important to safety for nuclear power stations.*

IEC 61000-4, — *Electromagnetic compatibility (EMC) — Part 4: Testing and measurement techniques.*

IEC 61226:1993, *Nuclear power plants — Instrumentation and control systems important for safety — Classification.*

IEC 61343:1996, *Nuclear reactor instrumentation — Boiling light water reactors (BWR) — Measurements in the reactor vessel for monitoring adequate cooling within the core.*

IAEA Safety Guide 50-SG-D8:1984, *Safety-related instrumentation and control systems for nuclear power plants.*

3 Terms and definitions

For the purposes of this International Standard, the following definitions are applicable. For terms defined elsewhere, the source is given in parentheses.

3.1

alarms

signals given by annunciators or other display systems to alert the operator to plant and equipment faults and out-of tolerance changes in plant conditions requiring action by the operator [IEC 60964]

3.2

boiling water reactor (BWR)

a nuclear steam supply system in which process steam is generated in the reactor vessel [IEC 61343]

3.3

coolant

water and/or steam for heat removal from the core [IEC 61343]

3.4

decay ratio

decay ratio (*DR*) of an oscillating system is defined as the ratio between two consecutive maximal of the system impulse response and gives information about the system stability. An oscillation which decreases in size has a $DR < 1,0$, while a growing oscillation has a $DR > 1,0$. Decay ratios greater than 1,0 are often referred to as growth rates

3.5

man/machine interface

interface between operating staff and I&C systems and computer systems linked with plant. The interface includes displays, controls, and the Operator Support System Interface [IEC 60964]

3.6

monitoring

means provided to indicate continuously the state or condition of a system, subsystem, equipment or assembly [IEV 393-08-48]

3.7

power oscillations

periodic time varying changes in global or regional core power which are excited by disturbances to the core state parameters that can be random in nature or caused by oscillating control systems. The power oscillations can decay in time, maintain a stable limit cycle behaviour, or grow, depending on the stability of the reactor system

3.8**protection system**

system which encompasses all those electrical and mechanical devices and circuitry, from sensors to the input terminals of the Safety Actuation Systems and the Safety System Support Features, involved in generating the signals associated with the Protective Tasks [IAEA 50-SG-D8]

3.9**reactor instability**

condition where power oscillations are either growing or have reached limit cycle oscillations or have amplitudes beyond inherent neutron noise amplitude

3.10**redundancy**

provision of alternative (identical or diverse) elements so that any one can perform the required function regardless of the state of operation or failure of any other [IAEA 50-SG-D8]

3.11**redundancy group**

group that duplicates the essential function of other groups to the extent that it can perform the required function independently of the state of the other groups of the same function [IEV 393-08-45]

3.12**response time**

amount of time required for a component to achieve a specified output state from the time that it receives a signal requiring it to assume that output state [IAEA 50-SG-D8]

3.13**single failure criterion**

criterion applied to a system such that it is capable of performing its safety task in the presence of any single failure [IEV 393-08-29]

3.14**stability margin**

the stability margin indicates the distance of the operating conditions of the system to the state space where the system becomes unstable

different measures may be used for expressing the stability margin, for example

- decay ratio (ratio of amplitude of two subsequent maxima or minima of neutron flux or channel flow);
- the amount of change in a reactor parameter (core power, core flow rate or core inlet subcooling) necessary to reach instability if all other boundary conditions are held constant.

3.15**stable limit cycles**

a stable limit cycle is an oscillation of the system with a constant frequency and a constant amplitude, such that the oscillation is time invariant

3.16**sub-cooled water**

water at a temperature lower than the saturation temperature corresponding to the existing pressure [IEC 61343]

3.17**superheated steam**

steam at a temperature higher than the saturation temperature corresponding to the existing pressure [IEC 61343]

4 Abbreviations

APSD	Auto Power Spectral Density
APRM	Average Power Range Monitor
AR	Autoregression
ASF	Automatic Safety Function
ATWS	Anticipated Transient Without Scram
CPR	Critical Power Ratio
DR	Decay Ratio
DROL	Decay Ratio Operating Limit
EMI	Electromagnetic Interference
FFT	Fast Fourier Transform
HW	Hardware
LPRM	Local Power Range Monitor
MCPR	Minimum Critical Power Ratio
M/M	Man-Machine
PC	Personal Computer
PD	Phase Difference
RFI	Radio Frequency Interference
RT	Real Time
STPM	Simulated Thermal Power Monitor
SLMCPR	Safety Limit Minimum Critical Power Ratio
SW	Software
WS	Work Station
VDU	Visual Display Unit