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Interested committees:

Title: BS IEC 60911 Nuclear Power Plants - Instrumentation systems - Measurements for monitoring of adequate cooling within the core pressurized light waterreactors

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

PROJECT NUMBER:

IEC 60911 ED2

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2023-05-05

SUPERSEDES DOCUMENTS:

45A/1431/RR

IEC SC 45A : INSTRUMENTATION, CONTROL AND ELECTRICAL POWER SYSTEMS OF NUCLEAR FACILITIES

SECRETARIAT:

France

SECRETARY:

Mr Jean-Paul Bouard

OF INTEREST TO THE FOLLOWING COMMITTEES:

PROPOSED HORIZONTAL STANDARD:



Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.

FUNCTIONS CONCERNED:

☐ EMC☐ ENVIRONMENT☐ QUALITY ASSURANCE☒ SAFETY

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- any relevant patent rights of which they are aware and to provide supporting documentation,
- any local regulations or technical reasons that may exist and should be considered should this proposal proceed, recognizing that failure to address such requirements could result in the need for new or existing "in some countries" clauses. See AC/22/2007.

TITLE:

Nuclear Power Plants – Instrumentation systems – Measurements for monitoring adequate cooling within the core of pressurized light water reactors

NOTE FROM TC/SC OFFICERS:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**NUCLEAR POWER PLANTS – INSTRUMENTATION SYSTEMS –
MEASUREMENTS FOR MONITORING ADEQUATE COOLING WITHIN THE
CORE OF PRESSURIZED LIGHT WATER REACTORS**

FOREWORD

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International Standard IEC 60911 has been prepared by subcommittee 45A: Reactor instrumentation, of IEC technical committee 45: Nuclear instrumentation.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
45A/XX/FDIS	45A/XX/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The National Committees are requested to note that for this document the stability date is 2022.

THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

NUCLEAR POWER PLANTS – INSTRUMENTATION SYSTEMS – MEASUREMENTS FOR MONITORING ADEQUATE COOLING WITHIN THE CORE OF PRESSURIZED LIGHT WATER REACTORS

0 Introduction

Adequate core cooling can be achieved only by providing sufficient coolant flow to the core to remove the heat. Under normal power operation, cooling of the core is adequately monitored by the normal reactor protection measurement. Normally, the coolant is forced circulation to facilitate the heat transfer. However, during certain abnormal shutdown conditions, the coolant might circulate naturally or the coolant might even become stationary.

The coolant can be in one phase or two phases:

- a) one phase: either liquid, or steam, or a mixture of steam and gas.
- b) two phases: a mixture of liquid and steam/gas.

Sufficient measurements of the coolant inventory shall be provided, of which the level measurement is a part, to monitor that adequate cooling is being achieved under those abnormal conditions for which operator action may be needed or for which confirmation of coolant inventory status is of value.

Measurement of the subcooling and its time history shall also be provided to assist the operator in avoiding those abnormal conditions.

1 Scope and object

This International Standard applies to pressurized water reactors (PWRs) with configurations similar to those shown in Figure 1 through Figure 7 and presents requirements for the monitoring of adequate cooling within the core in all operations, including normal and abnormal operations. Requirements for core cooling monitoring during conditions beyond a DBA (DEC-A or DEC-B) are also covered in this standard.

The objective of this standard is to define requirements for instrumentation to measure coolant parameters, which are of interest when abnormal conditions arise with either one or two phases of coolant or with gas included in the reactor vessel.

PWR users can acquire this instrumentation to present information on coolant conditions, to assist the operator to decide on actions needed to maintain adequate core cooling.

Typical applications in operating power plants are also presented.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, 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. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050-395:2014, International Electrotechnical Vocabulary (IEV) – Part 395: Nuclear instrumentation – Physical phenomena, basic concepts, instruments, systems, equipment and detectors

IEC 60737:2010, In-core temperature or primary envelope temperature measurements in nuclear power reactors – Characteristics and test methods

IEC 62828-2:2017, Reference condition and procedures for testing industrial and process measurement transmitters – Part 2: Specific procedures for pressure transmitters

IEC/IEEE 60780-323:2016, Nuclear facilities – Electrical equipment important to safety – Qualification

IEC 60880:2006, Nuclear power plants – Instrumentation and control systems important to safety – Software aspects for computer-based systems performing category A functions.

IEC 60964:2018, Nuclear power plants – Control rooms – Design

IEC/IEEE 60980-344:2020, Nuclear facilities – Electrical equipment important to safety – Seismic Qualification

IEC 60987:2021, Nuclear power plants – Instrumentation and control important to safety – Hardware requirements

IEC 61225:2019, Nuclear power plants – Instrumentation, control and electrical power systems – Requirements for static uninterruptible DC and AC power supply systems

IEC 61226:2020, Nuclear power plants – Instrumentation, control and electrical power systems important to safety – Categorization of functions and classifications of systems

IEC 61227:2008, Nuclear power plants – Control rooms – Operator Controls

3 Definitions and abbreviations

For the purposes of this standard, the following definitions and abbreviations apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

IEC Electropedia: available at <http://www.electropedia.org/ISO> Online browsing platform: available at <http://www.iso.org/obp>

3.1

ALARA

as low as reasonably achievable

3.2

coolant

water and/or steam for heat removal from the core

3.3

anticipated operational occurrences

expected to occur over the operating lifetime of the plant

3.4

DBA

design basis accident

3.5

DEC-A

design extension condition without significant fuel degradation

3.6

DEC-B

design extension condition with core melting

3.7

diversity

existence of two or more different ways or means of achieving a specified objective. Diversity is specifically provided as a defence against common cause failure. It may be achieved by providing systems that are physically different from each other or by functional diversity, where similar systems achieve the specified objective in different ways[IEV 395-07-115]

3.8

monitoring

the continuous determination of the state or condition of a system or subsystem[IEV 395-07-99]

3.9

pressurized water reactor (PWR)

nuclear steam supply system in which the pressurized coolant is heated by the reactor core, and process steam is generated in the steam generator by heat transfer from the coolant

3.10

RCS

reactor coolant system

3.11

reactor containment

structure enclosing the reactor coolant system and parts of associated systems, including pressure containment structures that enclose individual components in some nuclear power plant designs

3.12

reduced inventory condition

intentional condition that exists during specific maintenance operations whenever water level in the RPV is lower than the top of the RPV outlet piping nozzle elevation, plus an allowance for water level measurement uncertainty

3.13

redundancy

provision of alternative (identical or diverse) elements so that anyone can perform the required function regardless of the state of operation of any other[IEV 395-07-116]

3.14

RHRS: residual heat removal system

auxiliary system in a PWR for removing heat from the reactor core during shutdown operations

3.15

PRHRS: passive residual heat removal system

passive auxiliary system in a PWR for removing heat from the reactor core during abnormal operations

3.16

RSIS: reactor safety injection system

auxiliary system in a PWR for injecting coolant to the reactor core during abnormal operations

3.17

CIS: cavity injection and cooling System

auxiliary system in a PWR for injecting coolant to the reactor cavity during severe accident

3.18

RPV

reactor pressure vessel

3.19

single failure criterion

criterion (or requirement) applied to a system such that it must be capable of performing its task in the presence of any single failure[IEV 395-07-90]

3.20

subcooled water

water at a temperature lower than the saturation temperature corresponding to the existing pressure

3.21

superheated steam

steam at a temperature higher than the saturation temperature corresponding to the existing pressure

3.22

subcooling

the difference by which the saturation temperature corresponding to the pressure existing in the liquid exceeds the liquid temperature at that point

3.23

superheating

the difference by which the saturation temperature corresponding to the pressure existing in the steam is below the steam temperature at that point

3.24

void

the volume occupied by steam or gas. This definition applies both to bubbles dispersed within a liquid phase or to large homogeneous volumes

3.25

void fraction

the ratio of void to total volume

3.26

liquid level

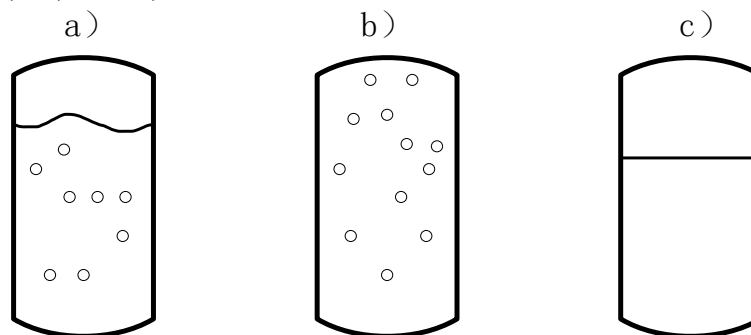
the level of the horizontal surface dividing liquid from steam or gas

3.27

equivalent liquid level

the level that would result in the reactor vessel if the steam and water phases of the coolant were completely separated, and which is also described as the collapsed water level

different void distributions may have the same equivalent liquid level as shown in the following sketches a), b) and c):



sketch c) illustrates the equivalent level for the same volume of liquid as sketches a) and b)

4 Operational conditions

4.1 General

This clause should be considered with the safety analysis for the plant in normal and abnormal conditions. It explains the conditions for which this instrumentation is used for measurement and display of coolant parameters. The thermodynamics analysis of coolant refers to Annex A.

Adequate core cooling can be confirmed by a measurement indicating that coolant is being circulated through the RPV at an appropriate temperature, pressure and flow to remove heat from the core. The requirement for adequate cooling exists for all operating modes. Annex B lists plant operating states (POS) as defined for the analysis performed to evaluate the potential of severe accidents during all operations. The analysis also includes an estimate of the duration of the plant operation states examined. Some POSs can last several months.

The status of a typical nuclear power plants can be divided as follows:

Operation States		Accident conditions		
Normal operation	Anticipated operational occurrences	Design basis accident	Design extension conditions	
			Without significant fuel degradation	With core melting

Among them, the normal operating conditions of nuclear power plants include power operation, hot standby, reactor criticality, hot shutdown, biphasic intermediate shutdown with steam generator operate, biphasic intermediate shutdown with RHRS, monophasic intermediate shutdown, normal cold shutdown, maintenance cold shutdown, refuelling cold shutdown, etc.

For core cooling, nuclear power plants can be divided into steam generator cooling and residual heat removal system cooling states under normal operating conditions.

If an anticipated operating event or accident occurs, the cooling state of the reactor core can be covered by the division of sections 4.2~4.5.

This standard covers instrumentation considerations for monitoring core cooling at PWRs with configurations similar to those shown in Figure 1 to Figure 7. Although PWR configurations shown in Figure 1 to Figure 5 use vertical U-tube steam generators, there is no impact on core cooling monitoring if change them into superheat steam generators.

4.2 Cooling state with steam generator

When the reactor is in the cooled state of the steam generator, the primary loop is closed, and the flow of reactor coolant may be forced or natural. Core heat is transferred to the coolant and exported through the steam generator.

As in Annex A coolant thermodynamic analysis, the reactor coolant may be in three thermal states, subcooled, saturated and superheated.

The PWR configuration is shown in Figure 1.

4.2.1 Coolant subcooled state

Once the reactor coolant is subcooled, it indicates that the pressure vessel is filled with water at this time, which can be characterized by measuring the pressurizer level. As a special case, especially in the event of an accident, where the pressurizer level may be lost, the water load of the reactor pressure vessel can be directly monitored by measuring the RPV water level. Adequate core cooling can be confirmed by a measurement indicating that coolant is being circulated at an appropriate RPV outlet pipe flow to remove heat from the core.

In addition, adequate core cooling can also be confirmed by monitoring the subcooling of the coolant. For that the reactor coolant pressure, reactor coolant temperatures(core exit, RPV outlet pipe, RPV inlet pipe) are required.

4.2.2 Coolant saturated state

Under anticipated operational occurrences and accident conditions, the coolant in the RPV may be saturated, leaving the coolant in a two-phase state. At this time, the core exit temperature detector measures the temperature of saturated water or steam, so it cannot fully represent the cooling degree of the core, nor the trend information, and needs to rely on other parameters.

When the coolant is in the two-phase condition, it is important to know the equivalent liquid level or the void fraction. The equivalent liquid level is important because it indicates the extent to which the core could be uncovered if the phases are completely separated. Normally, there is a greater cooling capacity than what is indicated by the equivalent liquid level.

Once a saturated coolant condition exists, voids may form in the coolant system. The significance of void formation relative to adequate core cooling is dependent on the two coolant circulation modes as follows:

In natural circulation or stagnant conditions, void formation will result in the development of an equivalent liquid level in the reactor vessel. Adequate cooling under this condition exists if the core remains covered with water.

In forced circulation, reactor coolant pumps will continue to circulate the coolant as a homogeneous mixture of liquid and steam/gas. Adequate core cooling under this condition is ensured even with a relatively high void fraction.

Considering the above analysis, the RPV water level, RPV outlet pipe temperature, RPV inlet pipe temperature, RPV outlet pipe flow and core exit temperature need to be monitored.

4.2.3 Coolant superheated state

Superheating of the coolant often corresponds to a significant loss of core coolant charge, a high void fraction or an excessively lower equivalent liquid level than the top of the core active zone.

To monitor the severity of the superheated condition, instrumentation needs to be provided to indicate the core exit temperature and the amount of superheat. The reactor coolant pressure and the core exit temperature are required. The same instrument used to measure subcooling can be used to measure the amount of superheat. From this information it is possible to derive the amount of superheat, i.e., the difference between steam temperature and saturation temperature.

4.3 Cooling state with RHRS

Normally, RHRS is put into operation to remove the core residual heat from biphasic intermediate shutdown condition to cold shutdown condition.

It is important that plant operators have reliable information to confirm that the temperature and flow of coolant circulated through the RPV are adequate to remove heat from the core. Unreliable information can result in an interruption of core cooling, a condition that has occurred at several PWRs. Annex C, which describes some of these events, identifies conditions which should be considered in the design of core cooling monitoring instrumentation.

In general, the RHRS draws water from the hot leg of the main system, cools it by the heat exchanger, and injects it back into the cold leg of the main system. Therefore, in addition to the existing coolant-related monitoring parameters (RPV water level and RPV outlet pipe temperature, etc.), the flow rate and inlet temperature of the RHRS may also effectively represent the adequate cooling of the core.

In order to maintain the normal operation of the RHRS, the water inventory of hot leg section must remain submerged to avoid cavitation of the RHRS pump. Therefore, it is also necessary to monitor the RPV outlet pipe water level.

The PWR configuration is shown in Figure 2, Figure 3, and Figure 4.

4.3.1 General situation under RHRS operation