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Integral Pressurized Water Reactor Simulator Manual: Exercise Handbook

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INTEGRAL PRESSURIZED WATER REACTOR SIMULATOR MANUAL: EXERCISE HANDBOOK

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

TRAINING COURSE SERIES No. 65

INTEGRAL PRESSURIZED WATER REACTOR SIMULATOR MANUAL: EXERCISE HANDBOOK

INTERNATIONAL ATOMIC ENERGY AGENCY
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For further information on this publication, please contact:

Nuclear Power Technology Development Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

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FOREWORD

The IAEA has established a programme in nuclear reactor simulation computer programs to assist Member States in educating and training nuclear professionals in the operation and behaviour of nuclear power plants. The simulators enable hands-on training for nuclear professionals involved in teaching and training topics such as nuclear power plant design, safety, technology, simulation and operations. The simpler design of the simulators allows professionals to grasp the fundamentals without becoming lost in the details of a more complex full scope simulator. The objective is to provide, for various reactor types, insight and practice in reactor operational characteristics and their response to perturbations and accident situations.

Together with management and development, the IAEA regularly produces training material and provides training courses to assist professionals in Member States to understand the simulators and their associated technologies. This training is more cost effective and less time consuming than alternative methods and is highly suitable for Member States with limited resources.

This Exercise Handbook accompanies Training Course Series No. 65, Integral Pressurized Water Reactor Simulator Manual. It contains practical exercises as part of the educational and training material provided during IAEA training courses and workshops. The Manual provides an explanation of the theoretical concepts of integral pressurized water reactors and a description of the simulator's features. The Exercise Handbook complements this by providing detailed, step by step operating instructions together with the required explanations to run various normal operations and transients in the simulator. The publications can be used both independently and together, and they serve as educational and training material for IAEA training courses and workshops. This publication provides comprehensive reference material to support human capacity building in all Member States improving their expertise in education and training related activities for small modular reactor technology.

The IAEA gratefully acknowledges the contribution of I. Parrado (Spain) to the preparation of this publication. The IAEA officer responsible for this publication was C. Batra of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The International Atomic Energy Agency (IAEA) has a suite of nuclear reactor simulation computer programs to assist its Member States in education and training. The objective is to provide, for a variety of advanced reactor types, insight and practice in-reactor operational characteristics and their response to perturbations and accident situations. To achieve this, the IAEA arranges for the supply and development of a suite of basic principles nuclear power plant simulators which are available for free to Member States upon request and are intended for educational purposes. The IAEA also provides associated training material, sponsors training courses and workshops, and distributes the documentation and computer programs.

The use of basic principle simulators to aid in teaching complex system interactions can considerably improve students' comprehension and retention of engineering course materials. In addition, the use of simulators on nuclear fundamentals type training courses can greatly add to trainees' understanding of reactor operation and the role of various systems.

The IAEA's existing suite of basic principles simulators are currently based on a variety of large scale, water cooled nuclear reactor technologies. The basic principle simulator helps in demonstrating the essential physical processes as well as fundamental system engineering concepts. This type of simulator also serves training objectives such as providing an overview of plant behaviour or a basic understanding of the normal as well as abnormal operation modes.

Such simulators may consist of complete primary and secondary circuits, sometimes with a reduced number of loops or redundancies. The scope of simulation focusses on the main systems where auxiliary or supporting systems may be neglected. The control room or panels very often have a fundamentally different design in comparison with conventional control room design.

The IAEA's suite of simulators is used on personal computers to develop understanding of the various reactor designs as well as their operational characteristics. They are intended for nuclear professionals involved in teaching and training on topics related to nuclear power plant design, safety, technology, simulation and operations; and could also be used, in some cases, for a broad audience of both technical and non-technical personnel as introductory educational tool. The simulators are not expected to produce accurate results but do demonstrate realistic trends and transients in response to changes made by the user.

In recent years the IAEA has seen an increase in the participation of its Member States in its programme for the technology development of small modular reactors. Various designs are under development in several Member States. A large number of the designs that are in development are light water cooled and moderated small integral pressurized water reactors (iPWRs). Common features of iPWR designs include modularity, passive safety systems for core and containment cooling, and integrated design — where most or all primary components are located inside the reactor vessel.

1.2. OBJECTIVES

The objective of this exercise handbook is to provide a basic set of pratical exercises to understand various normal operations as well as possible transients in this type of reactor. It also serves as a step-by-step guidance document during the training courses. Full instructions on how to install the software and all of the background information is contained in the accompanying Intergral Pressurized Water Reactor Simulator Manual (Training Course Series No. 65).

1.3. SCOPE

This publication covers only a certain predefined list of standard operations and malfunction transients. The simulator in itself is capable of simulating more transients and therefore users can run various other transients depending upon his or her understanding level as well as the capability of simulator. Sever accidents are out of scope of this simulator and therefore cannot be simulated.

Most importantly, the responses manifested by the simulator, under accident situations, should not be used for safety analysis purposes, despite the fact that they are realistic for educational training.

1.4. STRUCTURE

The publication is divided into three sections. The first section provides the background information along with the objectives, scope and structure of the document. The second and third sections of this manual contain a set of exercises in normal and abnormal operation respectively in order to help the user understand the working of an iPWR-SMR power plant.

Each exercise is made in the form of a table and contains five columns:

(a) Number of step in the exercise;
(b) Procedure step that indicates the user what has to be done;
(c) The display where the action has to be done;
(d) What is the expected response;
(e) A column where the user could indicate if the step has been done/succesful.

2. SIMULATOR EXERCISES FOR STANDARD OPERATIONS

This section contains the exercises required to allow the user to understand how to operate an iPWR-SMR nuclear power plant under normal conditions.

In order to understand it, the following exercises are described:

1. Load maneuvering (10%) in turbine leading mode;
2. Load Maneuvering (10%) in reactor leading mode;
3. Reactor power decrease from 100% to 0% in turbine leading mode;
4. Reactor power rise from 0% to 100%;
5. Reactor trip and restart.

2.1. LOAD MANEUVERING (10%) IN TURBINE LEADING MODE

The load maneuvering in turbine leading mode operation exercise steps are listed in Table 1.

TABLE 1. LOAD MANEUVERING (10%) IN TURBINE LEADING MODE

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
1	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10) 287.5ºC; (11) 15.5 MPa; (12) 43%.	
2	Verify plant mode is in turbine leading mode.	Rod position control	— Selector in turbine leading mode.	

TABLE 1. LOAD MANEUVERING (10%) IN TURBINE LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
3	Start turbine load reduction to 90%: (1) Introduce turbine load demand (40.5 MW) and turbine load rate (2 MW/min); (2) Start turbine load change pushing GO; (3) Check turbine valves begin to close; (4) Check generator load begins to lower.	Turbine control	— Introduced values appear correctly; — Turbine valves begin to close; — Generator load (GENPT02_CE) begins to change.	
4	Borate RCS to compensate for the power defect, Xe concentration and rod position reactivity changes (optional): (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in ‘boration’; (3) Check boron concentration increases to the boron concentration setpoint; (4) Repeat 1. and 3. as desired; (5) Place selector in ‘OFF’.	Core	— Introduced values appear correctly; — Boron concentration (RCS_BC) begins to rise; — Neutron power (RCSNP01_TR) lowers.	
5	Check main steam flow begins to lower due to turbine load reduction.	FW control	— Steam line flows (MSSFT01_TR and MSSFT02_TR) lower; — Reference temperature begins to lower.	
6	Verify control rods move according to T_{avg} - T_{ref} deviation.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) lowers.	

TABLE 1. LOAD MANEUVERING (10%) IN TURBINE LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
7	Check the following: (1)PZR level begins to lower due to coolant contraction; (2)PZR level control recovers PZR level.	PZR level control	— PZR level (RCSLT02_TR) begins to lower.	
8	Thermal power (MW(th)) lowers according to generator load (MW(e)).	Overview	— Neutron power (RCSNP01_TR) and generator load change at similar rates.	
9	Once turbine load demand (40.5 MW) has been reached, verify there is no further change.	Overview	— Generator load (GENPT02_CE) settles at turbine load demand.	
10	Check that neutron power settles at correct value (90%) and verify using sur (dpm) there is no further change.	Core	— Neutron power (RCSNP01_TR) settles at correct value.	

TABLE 1. LOAD MANEUVERING (10%) IN TURBINE LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
11	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Turbine load(MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview	All variables stable at: (1) 90%; (2) 0 dpm; (3) 135 MW(th); (4) 40.5 MW(e); (5) ~74 steps; (6) 47.3 mmHg; (7) ~2.7 MPa; (8) 71 kg/s; (9) 172ºC; (10)283.6ºC; (11)15.5 MPa; (12)41%.	
12	Verify plant mode is in turbine leading mode.	Rod position control	— Selector in turbine leading mode.	
13	Raise turbine load to 100%: (1) Introduce turbine load demand (45 MW) and turbine load rate (2 MW/min); (2) Start turbine load change pushing GO; (3) Check turbine control valve begins to open; (4) Check generator load begins to rise.	Turbine control	— Introduced values appear correctly; — Turbine control valve begins to open; — Generator load (GENPT02_CE) begins to rise.	

TABLE 1. LOAD MANEUVERING (10%) IN TURBINE LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
14	Dilute RCS to compensate for the power defect, Xe concentration and rod position reactivity changes (optional): (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in 'dilution'; (3) Check boron concentration decreases to the boron concentration setpoint; (4) Repeat (1) and (3) as desired; (5) Place selector in 'OFF'.	Core	— Introduced values appear correctly; — Boron concentration (RCS_BC) begins to lower.	
15	Check main steam flow begins to rise due to an increase in turbine load.	FW control	— Main steam flow (MSSFT01_TR and MSSFT02_TR) rises; — Reference temperature begins to rise.	
16	If user is not diluting, verify control rods withdraw in order to match T_{avg} with T_{ref}.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) increases.	
17	Check the following: (1) PZR level begins to rise due to coolant expansion; (2) PZR level control recovers PZR level.	PZR Level control	— PZR level (RCSLT02_TR) begins to rise.	

TABLE 1. LOAD MANEUVERING (10%) IN TURBINE LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
18	Thermal power (MW(th)) rises according to Generator load (MW((e))	Overview	— Neutron power (RCSNP01_TR) and generator load (GENPT02_CE) changing at similar rates.	
19	Once turbine load setpoint (45 MW) has been reached, verify there is no further change.	Overview	— Generator load (GENPT02_CE) settles at turbine load setpoint.	
20	Check that neutron power settles at correct value (100%) and verify using SUR (dpm) there is no further change.	Core	— Neutron power (RCSNP01_TR) settles at correct value.	

2.2. LOAD MANEUVERING (10%) IN REACTOR LEADING MODE

The load maneuvering in reactor leading mode operation exercise steps are listed in Table 2.

TABLE 2. LOAD MANEUVERING (10%) IN REACTOR LEADING MODE

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 '100% BOL natural circulation' or IC #4 '100% BOL forced circulation'.			
1	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (°C); (10) T_{avg} (°C); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: 1. 100%; 2. 0 dpm; 3. 150 MW(th); 4. 45 MW(e); 5. 80 steps; 6. 47.3 mmHg; 7. 2.7 MPa; 8. 78 kg/s; 9. 173°C; 10. 287.5°C; 11. 15.5 MPa; 12. 43%.	
2	Ensure plant mode is in reactor leading mode.	Rod position control	— Selector in reactor leading mode.	

TABLE 2. LOAD MANEUVERING (10%) IN REACTOR LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
3	Start reactor power reduction to 90%: (1) Introduce desired reactor power demand (90%) and reactor power rate (2%/min); (2) Start reactor power change pushing GO; (3) Check control rods begin to insert.	Rod position control	— Introduced values appear correctly; — Control rod position changes.	
4	Borate RCS to compensate for the power defect, Xe concentration and rod position reactivity changes (optional): (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in 'boration'; (3) Check boron concentration increases to the boron concentration setpoint; (4) Repeat (1) and (3) as desired; (5) Place selector in 'OFF'.	Core	— Introduced values appear correctly; — Boron concentration (RCS_BC) begins to rise; — Neutron power (RCSNP01_TR) lowers.	
5	Check main steam operation: (1) Check flow in both main steam lines begins to lower; (2) Check turbine control valve begins to close.	FW control	— Main steam flow (MSSFT01_TR and MSSFT02_TR) lowers; — Turbine control valve closes.	

TABLE 2. LOAD MANEUVERING (10%) IN REACTOR LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
6	Check the following: (1) PZR level begins to lower due to coolant contraction; (2) PZR level control recovers PZR level.	PZR level control	— PZR level (RCSLT02_TR) begins to lower.	
7	Verify generator load (MW(e)) decreases according to thermal power (MW(th)).	Overview	— Thermal power (RCS_TP_MW) and generator load (GENPT02_CE) changing at similar rates.	
8	Once reactor power reaches reactor power demand (90%), verify there is no further change.	Core	— Neutron power (RCSNP01_TR) ~90%.	
9	Check that turbine load settles around 40 MW.	Overview	— Generator load (GENPT02_CE) ~ 40 MW.	

TABLE 2. LOAD MANEUVERING (10%) IN REACTOR LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
10	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Turbine load(MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview	All variables stable at: (1) 90%; (2) 0 dpm; (3) 135 MW(th); (4) 40.5 MW(e); (5) ~74 steps; (6) 47.3 mmHg; (7) ~2.7 MPa; (8) 71 kg/s; (9) 172ºC; (10) 283.6ºC; (11) 15.5 MPa; (12) 41%.	
11	Verify plant mode is in reactor leading mode.	Rod position control	— Selector in reactor leading mode.	
12	Start reactor power increase to 100%: (1) Introduce desired reactor power demand (100%) and reactor power rate (2%/min); (2) Start reactor power change pushing GO; (3) Verify control rods begin to withdraw.	Rod position control	— Introduced values appear correctly; — Control rod position changes.	

TABLE 2. LOAD MANEUVERING (10%) IN REACTOR LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
13	Dilute RCS to compensate for the power defect, Xe concentration and rod position reactivity changes: (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in 'dilution'; (3) Check boron concentration decreases to the boron concentration setpoint; (4) Repeat 1. and 3. as desired; (5) Place selector in 'OFF'.	Core	— Introduced values appear correctly; — Boron concentration (RCS_BC) begins to lower.	
14	Check main steam operation: (1) Check flow in both main steam lines begins to rise; (2) Check turbine control valve begins to open.	FW control	— Main steam flow (MSSFT01_TR and MSSFT02_TR) lowers; — Turbine control valve opens.	
15	Check PZR level begins to rise due to coolant expansion and how level control recovers PZR level.	PZR level control	— PZR level (RCSLT02_TR) begins to rise.	
16	Verify generator load (MW(e)) is increasing according to thermal power (MW(th)).	Overview	— Thermal power (RCS_TP_MW) and generator load (GENPT02_CE) changing at similar rates.	

TABLE 2. LOAD MANEUVERING (10%) IN REACTOR LEADING MODE (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
17	Once reactor power reaches reactor power demand (100%), verify there is no further change.	Core	— Neutron power (RCSNP01_TR) settles at 100%.	
18	Check that turbine load settles at correct value (45 MW).	Overview	— Generator load (GENPT02_CE) settles at 45 MW.	

2.3. REACTOR POWER DECREASE FROM 100% TO 0%

The reactor power decrease operation exercise steps are listed in Table 3.

TABLE 3. REACTOR POWER DECREASE FROM 100% TO 0%

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
1	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 3. REACTOR POWER DECREASE FROM 100% TO 0% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
2	Verify proper status of the main plant controls: (1) Verify plant mode is in turbine leading mode; (2) Control rods in auto; (3) MSB in T_{avg} mode; (4) FW system in auto; (5) Condenser and circulating water systems in service; (6) No active alarms.		— Plant mode selector in turbine leading mode; — MSB selector in T_{avg} mode; — FW control valves (FWSV13/FWSV14) in auto; — CWS in service (open or closed loop).	
3	Start turbine load reduction to 15%: (1) Introduce turbine load demand (6.75 MW) and turbine load rate (1 MW/min max); (2) Start turbine load change pushing GO; (3) Check turbine control valves begin to close; (4) Check generator load begins to lower.	Turbine control	— Introduced values appear correctly; — Turbine control valve begins to close; — Generator load (GENPT02_CE) begins to change.	

TABLE 3. REACTOR POWER DECREASE FROM 100% TO 0% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
4 Continuous action	Borate RCS to compensate for the power defect, Xe concentration and rod position reactivity changes: (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in 'boration'; (3) Check boron concentration increases to the boron concentration setpoint; (4) Repeat 1. and 3. as desired; (5) Place selector in 'OFF'.	Core	— Introduced values appear correctly; — Boron concentration (RCS_BC) begins to rise.	
NOTE	ΔI should be controlled as follows: (a) If ΔI is at the left side of the target band, rods are excessively inserted. This means that rods depress neutron flux in the upper half of the core and force a high flux to exist in the lower half. To make ΔI return to the target band, borate the RCS to make rods withdraw from the core; (b) If ΔI is at the right side of the target band, rods are excessively withdrawn. This means that a higher flux exists in the upper half of the core compared to the lower half. To make ΔI return to the target band, dilute the RCS to make rods insert into the core.			
5 Continuous action	Check that ΔI is maintained within the target band if reactor power is above 50%.	Core	— ΔI stays within the target band.	

TABLE 3. REACTOR POWER DECREASE FROM 100% TO 0% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
6	Check main steam flow begins to lower due to turbine load reduction.	Systems	— Main steam flow (MSSFT01_TR and MSSFT02_TR) lowers; — Reference temperature begins to lower.	
7	Verify control rods insert in order to match T_{avg} with the new lower T_{ref}.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) lowers.	
8	Check the following: (1) PZR level begins to lower due to coolant contraction; (2) PZR level control recovers PZR level.	PZR level control	— PZR level (RCSLT02_TR) begins to lower.	
9	Thermal power (MW(th)) lowers according to generator load (MW(e)).	Overview	— Neutron power (RCSNP01_TR) and generator load (GENPT02_CE) change at similar rates.	
10	Check the following: (1) FW pump speed lowering; (2) FW flow lowering.	FW Control	— Flow in both FW trains (FWSFT01_TR and FWSFT02_TR) lowering; — FW pump speed (FWSP01) lowering; — FW control valve (FWSV17) closing.	

TABLE 3. REACTOR POWER DECREASE FROM 100% TO 0% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
NOTE	Even if Control rods withdraw due to Xe concentration increasing before reaching a lower equilibrium concentration, control rod position and SUR should still be considered stable in step 11.			
11	Verify stable plant conditions: (1) Once turbine load demand (6.75 MW) has been reached, verify there is no further change; (2) Check that step 1 variables remain stable.	Overview	— Generator load (GENPT02_CE) settles at turbine load demand.	
12	Check that neutron power settles at correct value (around 22%).	Rod position control	— Neutron power (RCSNP01_TR) settles at correct value.	
13	Start turbine load reduction to 6%: (1) Introduce turbine load (3 MW) and turbine load rate (0.2 MW/min max) in turbine display; (2) Start turbine load change pushing GO; (3) Check turbine control valve begins to close; (4) Check generator load begins to lower.	Turbine control	— Introduced values appear correctly; — Turbine control valve begins to close; — Generator load (GENPT02_CE) begins to change.	
14	Check reactor power changes according to turbine load reduction.	Rod position control	— Control rod position changes.	

TABLE 3. REACTOR POWER DECREASE FROM 100% TO 0% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
15	When turbine load reaches 3 MW: (1) Manually trip the turbine; (2) Verify turbine trip; (3) Verify speed is lowering up to turning gear speed (5 rpm).	Systems	— Turbine isolation valve (MSSV07) closes; — Generator breaker opens; — Main steam flow to turbine (MSSFT04_TR) goes to zero.	
16	Check MSB is maintaining T_{avg} at no-load T_{ref}.	Systems	— Non-zero flow through turbine bypass (MSSFT05_TR). — Main steam pressure (MSSPT03_TR) stable.	
17	When reactor power is 3%, manually trip the reactor.	Rod position control	— All control and shutdown rods at bottom; — Neutron power (RCSNP01_TR) reduces to 0%; — Plant mode switches to reactor leading mode after reactor trip.	

TABLE 3. REACTOR POWER DECREASE FROM 100% TO 0% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
18	Check the variables from step 1 remain constant: (1) Thermal power (subcriticality); (2) Neutron power (subcriticality); (3) SUR (subcriticality); (4) Primary temperature (core cooling); (5) Primary pressure (integrity); (6) Primary level (inventory); (7) FW flow (heat sink).	Overview		

TABLE 3. REACTOR POWER DECREASE FROM 100% TO 0% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
19	Ensure the following: (1) Reactor power at 0%; (2) Turbine load at 0 MW; (3) Reactor thermal power exhausted to condenser via MSB valves; (4) Control rods totally inserted and in manual; (5) Plant Mode in reactor leading mode; (6) MSB is controlling secondary Steam pressure; (7) FW system in auto adjusting FW flow; (8) CW system and condenser systems in service; (9) Turbine speed (after 30 minutes approximately) at 5 rpm with the turning gear engaged.	Overview	— MSB control in switches to steam Pressure mode after reactor trip; — Place rod control selector in manual.	
20	Check the following alarm conditions exist: (1) Reactor trip; (2) Turbine trip; (3) Turning gear; (4) Generator breaker open; (5) Rods in manual.			

2.4. REACTOR POWER RISE FROM 0% TO 100%

The reactor power rise from 0% to 100% exercise steps are listed in Table 4.

TABLE 4. REACTOR POWER RISE FROM 0% TO 100%

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #7 '0% BOL, NC, before rod withdrawal' or IC #10 '0% BOL, FC, before rod withdrawal'.			
1	Check the following variables are stable: (1) Thermal power (subcriticality); (2) Neutron power (subcriticality); (3) SUR (subcriticality); (4) Primary temperature (core cooling); (5) Primary pressure (integrity); (6) Primary level (inventory); (7) FW flow (heat sink).	Overview	All variables stable at: (1) 1.59 MW(th); (2) 0%; (3) 0 dpm; (4) ~ 248ºC (tending to 250ºC = $T_{ref,0\text{-}load}$); (5) 15.5 MPa; (6) ~ 23%; (7) ~ 0.02 kg/s;	
2	Ensure proper status of the main plant controls: (1) Plant mode in reactor leading mode; (2) Rod control in manual; (3) MSB is controlling steam pressure; (4) FW system in auto; (5) CW and CNR systems in service; (6) FW control adjusting FW flow.		— Plant mode selector in reactor leading mode; — Rod control selector in manual mode; — Selector in steam pressure mode; — FW control valves (FWSV13/FWSV14) in auto; — CW system in service (opened or closed loop).	

TABLE 4. REACTOR POWER RISE FROM 0% TO 100% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
3	Check the following alarm conditions exist: (1) Reactor trip; (2) Turbine trip; (3) Turning gear (or turbine decelerating); (4) Generator breaker open.			
4	Reset reactor trip.	Trips	— Reactor trip alarm deactivates.	
5	Check boron concentration stable.	Core		
6	Withdraw shutdown bank while monitoring neutron flux: (1) Ensure bank A is selected; (2) Push OUT until bank A is fully withdrawn.	Rod position control	— Shutdown rod position changes.	
7	Withdraw control bank B while monitoring neutron flux: (1) Ensure bank B is selected; (2) Push OUT until bank B is fully withdrawn.	Rod position control	— Control rod position changes; — Source range power (RCSNP03_TR) begins to rise but stabilises or falls when rod movement stops.	

TABLE 4. REACTOR POWER RISE FROM 0% TO 100% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
8	Withdraw control bank C to the estimated critical condition while monitoring neutron flux for criticality: (1) Ensure bank C is selected; (2) Push OUT until bank C reaches 49 steps.	Rod position control	— Control rod position changes; — Source range power (RCSNP03_TR) begins to rise but stabilises or falls when rod movement stops.	
9	Dilute RCS for criticality: (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in 'dilution'; (3) Check boron concentration decreases to the boron concentration setpoint; (4) Repeat 1. and 3. until neutron flux slowly rises without control rod movement (criticality observed). Plot neutron power and SUR; (5) Place selector in 'OFF'.	Core	— Introduced values appear correctly; — Boron concertation (RCS_BC) begins to lower; — When critical, neutron power (RCSNP01_TR) rises slowly without control rod movement; — Point of adding heat occurs when intermediate range ~ 10E-8.	
NOTE	Above the point of adding heat, SUR should not exceed a sustained 0.5 dpm.			
10	Raise reactor power to 8% with rod control in manual.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) rises and stabilises at 8%.	

TABLE 4. REACTOR POWER RISE FROM 0% TO 100% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
11	Raise Rractor power to 15% with rod control in auto (1) Verify plant mode is in reactor leading mode; (2) Insert 15% in reactor power demand and 5%/min in reactor power rate; (3) Press GO; (4) Place control rods in auto.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) rises and stabilises at 15%.	
12	Start-up the turbine: (1) Reset turbine trip; (2) Ensure turbine control valve (MSSV07) is in auto; (3) Push run-up; (4) Turbine control valve opens around 3%; (5) When 'ready to sync' light appears, push 'sync' button to close generator breaker; (6) Check turbine accepts a minimum load; (7) Check turbine control valve is in manual.	Turbine control	— Turbine trip alarm deactivates; — Turbine control valve opens around 3%; — Turbine speed increases (TURCN01_TR) from 5 rpm to 3600rpm; — Turning gear and generator breaker alarms clear.	
NOTE	Upon closing the generator breaker, turbine load should be raised to 3% to prevent motoring of the generator.			

TABLE 4. REACTOR POWER RISE FROM 0% TO 100% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
13	Raise turbine load manually to 3% (1) Manually open turbine control valve to 3%; (2) Check generator load begins to rise.	Turbine control	— Turbine control valve opens; — Generator load (GENPT02_CS) would be around 3.5 MW(e) when MSSV07 is 3% open; — Steam through MSB lowers.	
14	Place turbine control in auto: (1) Place turbine control valve in auto; (2) Check turbine control is controlling Steam pressure (plant mode in reactor leading).	System display		
NOTE	Switching to turbine leading mode with a big temperature error may lead to power oscillations and turbine trip (reactor power<4%).			
15	If temperature error is greater than 2.50ºC: (1) Place rod control in manual; (2) Reposition bank C to make temperature error less than 2.80ºC; (3) Change plant mode to turbine leading mode; (4) Check MSB mode to T_{avg} mode; (5) Go to Step 18.	Rod position control Turbine bypass control	— $T_{avg} - T_{ref}$ deviation correction (after moving bank C) will only last for a few seconds.	
16	Change plant mode to turbine leading mode when error is less than 2.5ºC.	Rod position control	— Place selector in turbine leading mode.	

TABLE 4. REACTOR POWER RISE FROM 0% TO 100% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
17	Check MSB mode to T_{avg} mode.	Turbine bypass control	— MSB selector in T_{avg} mode.	
18	Raise turbine load to full power conditions: (1) Introduce turbine load demand (20 MW) and turbine load rate (1 MW/min) in turbine display; (2) Press GO; (3) Check turbine control valve begins to open; (4) Check generator load begins to rise; (5) When turbine load reaches 20 MW, check step 1 variables are stable; (6) Raise turbine load to 45 MW at a turbine load rate of 1 MW/min repeating substeps 18.1, 18.2, 18.3 and 18.4.	Turbine control	— Introduced values appear correctly; — Turbine valves begin to open; — Generator load (GENPT02_CS) begins to rise.	

TABLE 4. REACTOR POWER RISE FROM 0% TO 100% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
19 Continuous action	Dilute RCS to compensate for the power defect, Xe concentration and rod position reactivity changes: (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in ‘dilution’; (3) Check boron concentration decreases to the boron concentration setpoint; (4) Repeat (1) and (3) as required; (5) Place selector in ‘OFF’.	Core	— Introduced values appear correctly; — Boron concentration (RCS_BC) begins to rise.	
20 Continuous action	When bank C reaches 80 steps (fully withdrawn): (1) Hold the turbine load by pressing on HOLD in the turbine control display; (2) Dilute the RCS to reposition bank C; (3) Continue increasing turbine load by clicking on GO in the turbine control display.	Rod position control Core Turbine control	— This step would not normally be performed.	
21	Check main steam flow begins to rise due to rise in load increase.	Turbine control	— Main steam flow (MSSFT01_TR and MSSFT02_TR) rises; — Reference temperature begins to rise.	

TABLE 4. REACTOR POWER RISE FROM 0% TO 100% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
22	Verify control rods withdraw in order to rise average temperature.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) increases.	
23	Check PZR level begins to rise due to coolant expansion and how level control recovers the level.	PZR level control	— PZR level (RCSLT02_TR) begins to rise; — Check charge/discharge flows.	
24	Verify thermal power (MW(th)) rises according to generator load (MW(e)).	Overview	— Neutron power (RCSNP01_TR) and generator load (GENPT02_CS) changing at similar rates.	
25	Once turbine load reaches turbine load demand (45 MW), verify there is no further change.	Overview	— Generator load settles at turbine load demand.	
NOTE	ΔI should be controlled as follows: (a) If ΔI is at the left side of the target band, rods are excessively inserted. This means that rods depress neutron flux in the upper half of the core and force a high flux to exist in the lower half. To make ΔI return to the target band, borate the RCS to make rods withdraw from the core; (b) If ΔI is at the right side of the target band, rods are excessively withdrawn. This means that a higher flux exist in the upper half of the core compared to the lower half. To make ΔI return to the target band, dilute the RCS to make rods insert into the core.			
26	Check ΔI is maintained within the target band.	Core	ΔI stays within the target band.	

TABLE 4. REACTOR POWER RISE FROM 0% TO 100% (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
27	Check that neutron power settles at correct value (100%) and verify using SUR (dpm) there is no further change.	Core	— Neutron power (RCSNP01_TR) settles at correct value.	
28	Check the following conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW; (3) Turbine leading mode selected; (4) Control rods in auto; (5) MSB in T_{avg} mode; (6) FW system in auto; (7) CW system and condensate systems in service; (8) No active alarms.			

2.5. REACTOR TRIP AND RESTART

The reactor trip and restart operation exercise steps are listed in Table 5.

TABLE 5. REACTOR TRIP AND RESTART

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 '100% BOL natural circulation' or IC #4 '100% BOL forced circulation'.			
1	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10) 287.5ºC; (11) 15.5 MPa; (12) 43%.	
2	Verify plant mode is in turbine leading mode.	Rod position control	— Selector in turbine leading mode.	
3	Trip the reactor.		— Both reactor and turbine trip.	

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
4	Verify reactor trip: (1) Verify all control and shutdown rods are fully inserted; (2) Check neutron flux is lowering and Start-up rate is negative.	Rod position control	— Control rod position at bottom; — Neutron power (RCSNP01_TR) lowers; — Start-up rate (RCS_SUR_TR) is less than zero.	
5	Verify turbine trip: (1) Verify turbine control valve MSSV07 has closed; (2) Verify MSB is taking main steam flow to CNR.	Turbine control	— MSS to TUR flow (MSSFT04_TR) goes to zero; — MSS to CNR flow (MSSFT05_TR) rises; — Turbine trip alarm activates.	
6	Verify main steam flow lowers (after the reactor trip).	Bypass control	— Main steam flow (MSSFT01_TR and MSSFT02_TR) lowers.	
7	Check PZR level begins to lower due to coolant contraction (after the reactor trip).	PZR level control	— PZR level (RCSLT02_TR) begins to lower.	
8	Verify thermal power (MW(th)) has lowered.	Overview		
9	Check boron concentration stable.	Core		
10	Check Xe reactivity becoming more negative.	Core	— Xenon reactivity (RCS_XE_PCM) becoming more negative.	

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
NOTE	It takes approximately 27 hours after the reactor trip from a full power condition to return to the Xe equilibrium value existing at 100% of power. It takes approximately 72 hours after the reactor trip from a full power condition to return to the new Xe equilibrium value. For time compression, the reactor would be promptly restarted. Reactivity changes introduced by Xe should be identified and compensated in a deliberate, carefully controlled manner during the criticality and power ascent.			
11	Check the following: (1) Plant mode is reactor leading mode and MSB is in steam pressure mode; (2) Step 1 variables remain stable.	Rod position control Turbine bypass control	— Plant mode automatically changed to reactor leading mode after the reactor trip; — MSB automatically changed to steam pressure mode when plant mode changed to reactor leading mode.	
12	Reset reactor trip.	Trips	— Reactor trip alarm deactivates.	
13	Place rod control in manual.	Rod position control	— Rods in manual alarm activates	
14	Withdraw shutdown bank while monitoring neutron flux: (1) Ensure bank A is selected; (2) Push OUT until bank A is fully withdrawn.	Rod position control	— Shutdown rod position changes.	

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
15	Withdraw control bank B while monitoring neutron flux: (1) Ensure bank B is selected; (2) Push OUT until bank B is fully withdrawn.	Rod position control	— Control rod position changes; — Source range power (RCSNP03_TR) begins to rise but stabilises or falls when rod movement stops.	
16	Withdraw control bank C to the estimated critical condition while monitoring neutron flux for criticality: (1) Ensure bank C is selected; (2) Push OUT until bank C reaches 49 steps.	Rod position control	— Control rod position changes; — Source range power (RCSNP03_TR) begins to rise but stabilises or falls when rod movement stops.	
17	Dilute RCS for criticality: (1) Place selector in ‘dilution’; (2) Lower the RCS boron concentration by 20 ppm; (3) Check RCS boron concentration decreases to the target value; (4) Repeat substeps 2. and 3. until neutron flux slowly rises without control rod movement (criticality observed). Plot neutron power and SUR; (5) Place selector in ‘OFF’.	Core	— Introduced values appear correctly; — Boron concentration (RCS_BC) begins to lower; — When critical, neutron power (RCSNP01_TR) rises slowly without control rod movement; — Point of adding heat occurs when intermediate range ~ 10E-8.	

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
NOTE	Above the point of adding heat, SUR should not exceed a sustained 0.5 dpm.			
18	Raise reactor power to 8% with rod control in manual.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) rises and stabilises at 8%.	
19	Raise reactor power to 15% with rod control in auto: (1) Verify plant mode is in reactor leading mode; (2) Insert 15% in reactor power demand and 5%/min in reactor power rate; (3) Press GO; (4) Place control rods in auto.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) rises and stabilises at 15%.	

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
20	Start-up the turbine: (1) Reset turbine trip; (2) Ensure turbine control valve (MSSV07) is in auto; (3) Push run-up; (4) Turbine control valve opens around 3%; (5) When ‘ready to sync’ light appears, push ‘sync’ button to close generator breaker; (6) Check turbine accepts a minimum load; (7) Check turbine control valve is in manual.	Turbine control	— Turbine trip alarm deactivates; — Turbine control valve opens around 3%; — Turbine speed increases (TURCN01_TR) from 5 rpm to 3600rpm; — Turning gear and generator breaker alarms clear.	
NOTE	Upon closing the generator breaker, turbine load should be raised to 3% to prevent motoring of the generator.			
21	Raise turbine load manually to 3% (1) Manually open turbine tontrol valve to 3%; (2) Check generator load begins to rise.	Turbine control	— Turbine control valve opens; — Generator load (GENPT02_CS) would be around 3.5 MW(e) when MSSV07 is 3% open; — Steam through MSB lowers.	
22	Place turbine control in auto: (1) Place turbine control valve in auto; (2) Check turbine control is controlling Steam pressure (plant mode in reactor leading).	System display		

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
NOTE	Switching to turbine leading mode with a big temperature error may lead to power oscillations and turbine trip.			
23	If temperature error is greater than 2.50ºC: (1) Place rod control in manual; (2) Reposition bank C to make temperature error less than 2.50ºC; (3) Change plant mode to turbine leading mode; (4) Change MSB mode to T_{avg} mode; (5) Go to step 26.	Rod position control Turbine bypass control	— $T_{avg} - T_{ref}$ deviation correction (after moving Bank C) will only last for a few seconds.	
24	Change plant mode to turbine leading mode.	Rod position control	— Place selector in turbine leading mode.	
25	Change MSB mode to T_{avg} mode.	Turbine bypass control	— MSB selector in T_{avg} mode.	

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
26	Raise turbine load to full power conditions: (1) Introduce turbine load demand (20 MW) and turbine load rate (1 MW/min) in turbine display; (2) Press GO; (3) Check turbine control valve begins to open; (4) Check generator load begins to rise; (5) When turbine load reaches 20 MW, check step 1 variables are stable; (6) Raise turbine load to 45 MW at a turbine load rate of 1 MW/min repeating substeps 26.1, 26.2, 26.3 and 26.4;	Turbine control	— Introduced values appear correctly; — Turbine valves begin to open; — Generator load (GENPT02_CS) begins to rise.	
27 Continuous action	Dilute RCS to compensate for the power defect, Xe concentration and rod position reactivity changes: (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in 'Dilution'; (3) Check boron concentration decreases to the boron concentration setpoint; (4) Repeat 1. and 3. as desired; (5) Place selector in 'OFF'.	Core	— Introduced values appear correctly; — Boron concentration (RCS_BC) begins to rise.	

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
28 Continuous action	When bank C reaches 80 steps (fully withdrawn): (1) Hold the turbine load by pressing on HOLD in the turbine control display; (2) Dilute the RCS to reposition bank C; (3) Continue increasing turbine load by clicking on GO in the turbine control display.	Rod position control Core Turbine control	— This step would not normally be performed.	
29	Check main steam flow begins to rise due to rise in load increase.	Turbine control	— Main steam flow (MSSFT01_TR and MSSFT02_TR) rises; — Reference temperature begins to rise.	
30	Verify control rods withdraw in order to rise average temperature.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) increases.	
31	Check PZR level begins to rise due to coolant expansion and how level control recovers the level.	PZR level control	— PZR level (RCSLT02_TR) begins to rise; — Check charge/discharge flows	
32	Verify thermal power (MW(th)) rises according to generator load (MW(e)).	Overview	— Neutron power (RCSNP01_TR) and generator load (GENPT02_CS) changing at similar rates.	

TABLE 5. REACTOR TRIP AND RESTART (cont.)

STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
33	Once turbine load reaches turbine load demand (45 MW), verify there is no further change.	Overview	— Generator load settles at turbine load demand.	
34	Check that neutron power settles at correct value (100%) and verify using SUR (dpm) there is no further change.	Core	— Neutron power (RCSNP01_TR) settles at correct value.	
35	Check the following conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW; (3) Turbine leading mode selected; (4) Control rods in auto; (5) MSB in T_{avg} Mode; (6) FW system in auto; (7) CW and condensate systems in service; (8) No active alarms.			

3. SIMULATOR EXERCISES FOR MALFUNCTION TRANSIENT EVENTS

This section contains the exercises required to allow the user to understand how to operate iPWR-SMR nuclear power plants under transient/accident conditions.

The following exercises are described:

(a) Turbine trip and recover;
(b) Loss of feedwater flow;
(c) Turbine runback;
(d) Large steam generator tube rupture (SGTR);
(e) Large main steam line break (MSLB);
(f) Station blackout (SBO);
(g) Steam line isolation;
(h) Reactor pressure vessel safety valve opening;
(i) Reactor coolant pump trip;
(j) All reactor coolant pumps trip.

3.1. SPURIOUS TURBINE TRIP AND RECOVERY

The spurious turbine trip and recovery operation steps are listed in Table 6.

TABLE 6. SPURIOUS TURBINE TRIP AND RECOVERY

MALFUNCTION:	SM-TUR-1	DESCRIPTION:	Spurious turbine trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) Tavg (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 6. SPURIOUS TURBINE TRIP AND RECOVERY (cont.)

MALFUNCTION:	SM-TUR-1	DESCRIPTION:	Spurious turbine trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW(e); (3) Control rods in auto; (4) FW system in auto; (5) CW and condensate systems in service; (6) No active alarms.	Overview		
2	Push turbine trip button or load 'turbine trip' malfunction (SM-TUR-1).		— Turbine trip, generator breaker and stepback alarms.	
3	Verify turbine trip: (1) MSSV07 closes; (2) MSB takes main steam flow to CNR.	System	— MSS to TUR flow (MSSFT04_TR) goes to zero; — MSS to CNR flow (MSSFT05_TR) rises.	
4	Verify reactor stepback: (1) Control rods insert into the core to the new power target; (2) Reactor power lowers to 60%.	Rod position	— Control rod position changes; — Neutron power (RCSNP01_TR) lowers to 60%; — Reactor stepback alarm becomes active.	
NOTE	A reactor stepback is expected to occur following a turbine load rejection that exceeds the capacity of the steam dump and rod Control (e.g. turbine trip). In other words, a reactor stepback assumes the load rejection that is beyond the steam dump and rod control design. With a 100% capacity steam dump, a reactor stepback would not be necessary. Even so a reactor stepback to 60% has been implemented for training purposes.			

TABLE 6. SPURIOUS TURBINE TRIP AND RECOVERY (cont.)

MALFUNCTION:	SM-TUR-1	DESCRIPTION:	Spurious turbine trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
5	Verify main steam flow lowers.	Turbine control	— Main steam flow (MSSFT01_TR and MSSFT02_TR) lowers.	
6	Ensure plant mode is in reactor leading mode and MSB in steam pressure mode.	Rod position control Steam dump control	— Plant mode selector should be placed in reactor leading mode; — MSB switches automatically to steam pressure mode with plam in reactor leading.	
7	Check PZR level begins to lower due to reactor coolant contraction.	PZR level control	— PZR level (RCSLT02_TR) begins to lower;	
8	Check variables from the initial condition are stable.		All variables from the initial condition are expected to be stable.	
9	Remove 'turbine trip' malfunction (SM-TUR-1) If user did not use the turbine trip button.			
NOTE	Wait until the turning gear has engaged before starting up the turbine.			

TABLE 6. SPURIOUS TURBINE TRIP AND RECOVERY (cont.)

MALFUNCTION:	SM-TUR-1 DESCRIPTION:	Spurious turbine trip		
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
10	Start-up the turbine: (1) Reset turbine trip; (2) Ensure MSSV07 in auto; (3) Roll turbine to synchronous speed (3600 rpm) by clicking on 'run-up'; (4) Once 'ready to sync' light has appeared, click on 'sync' to close breaker; (5) Check turbine accepts a minimum Load; (6) Check MSSV07 is in manual.	Turbine control	— Turbine trip alarm clears; — Turbine control valve MSSV07 opens around 3%; — Turbine speed increases (TURCN01_TR) from 5 rpm to 3600 rpm; — Generator breaker closes and generator breaker alarm clears; — Turning gear alarm clears.	
11	If rising turbine load in auto: (1) Ensure MSSV07 control is in auto; (2) Go to step 14.	Turbine control	— MSS to TUR flow (MSSFT04_TR) rises; — MSS to CNR flow (MSSFT05_TR) goes to zero.	
12	If rising turbine load in manual: (1) Manually open MSSV07 until steam header pressure equals the turbine control reference pressure; (2) Check generator load begins to rise; (3) Check MSSV09 starts closing.	Turbine control	— The turbine control reference pressure would be ~ 2.98 MPa (MSSV07 ~ 21%); — MSSV09 would be fully closed before the steam header pressure equals the turbine control reference pressure.	
13	Place MSSV07 in auto.	Systems		

TABLE 6. SPURIOUS TURBINE TRIP AND RECOVERY (cont.)

MALFUNCTION:	SM-TUR-1	DESCRIPTION:	Spurious turbine trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
14	Reset stepback.	Trips	— Stepback alarm clears.	
15	If reactor leading mode is still desired to increase reactor power to 100%: (1) Set reactor power demand to 100% and reactor power rate to 1%/min; (2) Press GO; (3) Verify control rod withdrawal to match reactor power with reactor power demand.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) increases	
16	If turbine leading mode is desired to increase turbine load to 45 MW (100%): (1) Change plant mode from reactor leading mode to turbine leading mode; (2) Check steam dump from steam pressure mode to Tavg mode; (3) Set turbine load demand to 45 MW and turbine load rate to 2%/min; (4) Verify MSSV07 starts opening; (5) Verify control rod withdrawal.	Rod position control Steam dump control	— Plant mode selector should be manually placed in turbine leading mode; — Generator load (GENPT02_TR) begins to rise.	
NOTE	Xenon concentration (neutron poison) will increase in the next few hours due to the reduction in core power. An RCS dilution will be necessary to compensate for Xe effects and recover the 100% condition.			

TABLE 6. SPURIOUS TURBINE TRIP AND RECOVERY (cont.)

MALFUNCTION:	SM-TUR-1	DESCRIPTION:	Spurious turbine trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
17	Dilute RCS: (1) Introduce the new boron concentration setpoint (max 20 ppm per badge); (2) Place selector in 'dilution'; (3) Check boron concentration decreases to the boron concentration setpoint; (4) Repeat (1) and (3) as desired; (5) Place selector in 'OFF'.	Core	— Boron concentration (RCS_BC) lowers.	
18	Check main steam flow begins to rise due to an increase in turbine load.	Turbine control	— Main steam flow (MSSFT01_TR and MSSFT02_TR) rises.	
19	Check PZR level begins to rise due to coolant expansion.	PZR level control	— PZR level (RCSLT02_TR) begins to rise.	
20	Verify thermal power (MW(th)) rises according to generator load (MW(e)).	Overview	— Neutron power (RCSNP01_TR) and generator load (GENPT02_CE) changing at similar rates.	
21	Once turbine load demand (45 MW(e)) has been reached, verify there is no further change.	Overview	— Generator load (GENPT02_CE) stabilizes at 45 MW.	
22	Check reactor power is stable at 100% and verify using SUR (dpm) there is no further change.	Core	— Neutron power (RCSNP01_TR) settles at correct value.	

TABLE 6. SPURIOUS TURBINE TRIP AND RECOVERY (cont.)

MALFUNCTION:	SM-TUR-1	DESCRIPTION:	Spurious turbine trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
23	Check the following final plant conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW; (3) Rod control in auto; (4) Steam dump in auto; (5) FW system in auto; (6) CW and condensate systems in service; (7) No active alarms.			
NOTE	ΔI should be controlled as follows: (a) If ΔI is at the left side of the target band, rods are excessively inserted. This means that rods depress neutron flux in the upper half of the core and force a high flux to exist in the lower half. To make ΔI return to the target band, borate the RCS to make rods withdraw from the core. (b) If ΔI is at the right side of the target band, rods are excessively withdrawn. This means that a higher flux exist in the upper half of the core compared to the lower half. To make ΔI return to the target band, dilute the RCS to make rods insert into the core.			

3.2. LOSS OF FEEDWATER FLOW

The loss of feedwater flow exercise steps are listed in Table 7.

TABLE 7. LOSS OF FEEDWATER FLOW

MALFUNCTION:	SM-FWS-3	DESCRIPTION:	Loss of normal feedwater flow (FW pumps trip)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 '100% BOL natural circulation' or IC #4 '100% BOL forced circulation'.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg). (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) Tavg (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 7. LOSS OF FEEDWATER FLOW (cont.)

MALFUNCTION:	SM-FWS-3	DESCRIPTION:	Loss of normal feedwater flow (FW pumps trip)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW; (3) Control rods in auto; (4) FW system in auto; (5) CW and condensate systems in service; (6) No active alarms;			
2	Load 'loss of FW flow' malfunction (SM-FWS-3).	Systems	— FW pumps trip.	
3	Verify malfunction: (1) Check FW header pressure lowers initially; (2) Check second FW pump fails to start; (3) Check FW control valve opens completely; (4) Check FW flow drops.	Systems	— FW pump discharge pressure (FWSPT01_TR) goes to 0; — 2^{nd} FW pump (FWSP02) fails to start; — FWSV17 opens; — FWSFT01/2 drops;	

TABLE 7. LOSS OF FEEDWATER FLOW (cont.)

MALFUNCTION:	SM-FWS-3	DESCRIPTION:	Loss of normal feedwater flow (FW pumps trip)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
4	Verify Reactor trip: (1) Verify all control and shutdown rods are have fully inserted; (2) Check neutron flux is lowering and Start-up rate is negative.	Rod position control	— Reactor trip due to FW pumps trip; — Control rod position at bottom; — Neutron power (RCSNP01_TR) lowers; — Start-up rate (RCS_SUR_TR) is less than zero; — Reactor trip alarm.	
5	Verify turbine trip: (1) Verify turbine control valve MSSV07 has closed.	Systems	— MSS to TUR flow (MSSFT04_TR) goes to zero; — MSS to CNR flow (MSSFT05_TR) is greater than zero; — Turbine trip and breaker open alarms.	
6	Check DHR actuation: (1) Verify DHR inlet and outlet isolation valves have opened and there is flow through both legs; (2) Check FWS isolation.	Systems	— DHR inlet and outlet isolation valves (DHRV02/04/01/03) have opened and there is flow through both legs (DHRFT01/2_TR); — Both main FW isolation valves (FWSV15/16) have closed; — PDHR actuation alarm.	

TABLE 7. LOSS OF FEEDWATER FLOW (cont.)

MALFUNCTION:	SM-FWS-3	DESCRIPTION:	Loss of normal feedwater flow (FW pumps trip)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
7	Check DHR operation: (1) RCS temperature is stable or lowering; (2) RCS pressure is lowering; (3) CB DHR pools temperature is rising.	Systems	— RCS temperature (RCSTE01_TR) is stable or lowering; — CB DHR pool temperatures (CBSTE01/2_TR) are rising.	
NOTE	DHR cooling depressurizes RCS. Users should block ADS before RCS pressure drops below 9.0 MPa to avoid an unnecessary ADS actuation.			
8	Block ADS actuation: (1) Press BLOCK on trips display; (2) Verify ADS block status light is on.	Trips	— ADS block actuated to avoid ADS actuation.	
9	Check reactor is stable: (1) Neutron flux is not rising and SUR is not positive; (2) RCS flow is positive; (3) RCS temperature is stable or lowering.	Systems	— Neutron power (RCSNP01_TR) is not rising; — RCS coolant flow (RCSFT01_TR) is non-zero; — Start-up rate (RCS_SUR_TR) is less than zero; — RCS temperature (RCSTE01_TR) is stable or lowering.	

3.3. TURBINE RUNBACK

The turbine runback exercise steps are listed in Table 8.

TABLE 8. TURBINE RUNBACK

MALFUNCTION:	SM-TUR-2	DESCRIPTION:	Spurious turbine runback	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 8. TURBINE RUNBACK (cont.)

MALFUNCTION:	SM-TUR-2	DESCRIPTION:	Spurious turbine runback	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Reactor at 100%; (2) Turbine load at 45 MW; (3) Control rods in auto; (4) FW system in auto; (5) CW system and condensate systems in service; (6) No active alarms;			
2	Push runback button or load 'major turbine runback' malfunction (SM-TUR-2).	Trips	— Runback alarm.	
3	Verify steam dump operation in response to the turbine runback.	Steam dump control	— MSS to CNR flow (MSSFT05_TR) rises.	
4	Verify rod control operation: (1) Verify control rods have inserted to match T_{avg} with the new lower T_{ref}; (2) Check neutron power lowers.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) lowers.	
5	Check PZR level has lowered due to coolant contraction.	PZR level control	— PZR level (RCSLT02_TR) lowers.	
6	Check main steam flow has lowered due to turbine load reduction.	Systems	— Main steam flow (MSSFT01_TR and MSSFT02_TR) lowers.	

TABLE 8. TURBINE RUNBACK (cont.)

MALFUNCTION:	SM-TUR-2	DESCRIPTION:	Spurious turbine runback	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
7	Check main FW flow has lowered due to turbine load reduction.	Systems	— Main FW flow (FWSFT01_TR and FWSFT02_TR) lowers; — Valve FWSV17 closes and FW pump speed lowers (during the runback).	
8	Check variables from the initial conditions have stabilized.			
NOTE	ΔI should be controlled as follows: (a) If ΔI is at the left side of the target band, rods are excessively inserted. This means that rods depress neutron flux in the upper half of the core and force a high flux to exist in the lower half. To make ΔI return to the target band, borate the RCS to make rods withdraw from the core; (b) If ΔI is at the right side of the target band, rods are excessively withdrawn. This means that a higher flux exist in the upper half of the core compared to the lower half. To make ΔI return to the target band, dilute the RCS to make rods insert into the core.			

3.4. LARGE STEAM GENERATOR TUBE RUPTURE (SGTR)

The large steam generator tube rupture exercise steps are listed in Table 9.

TABLE 9. LARGE STEAM GENERATOR TUBE RUPTURE

MALFUNCTION:	SM-MSS-2	DESCRIPTION:	Steam generator 1 tube rupture	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 9. LARGE STEAM GENERATOR TUBE RUPTURE (cont.)

MALFUNCTION:	SM-MSS-2	DESCRIPTION:	Steam generator 1 tube rupture	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Both reactor and turbine at 100% of power; (2) Control rods in auto; (3) FW system in auto; (4) CW system and condensate systems in service; (5) No active alarms.			
2	Load 'Steam generator tube rupture1' malfunction (SM-MSS-2, Severity = 100.0%).	Systems		
3	Verify malfunction: (1) Check for high radiation level in Main Steam line 1 (N-16); (2) Check RCS pressure begins to drop; (3) Check PZR level begins to drop; (4) FW flow lowers; (5) Subcooling margin lowers.	Systems	— High radiation alarm in main steam line 1; — RCS pressure (RCSPT01_TR) drops; — PZR level (RCSLT02_TR) drops; — Charging flow (RCSFT02_TR) rises;	

TABLE 9. LARGE STEAM GENERATOR TUBE RUPTURE (cont.)

MALFUNCTION:	SM-MSS-2	DESCRIPTION:	Steam generator 1 tube rupture	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
4	Verify reactor trip: (1) Verify all control and shutdown rods are fully inserted; (2) Check neutron flux is lowering and Start-up rate is negative.	Rod position control	— Reactor trip on low PZR level; — Control rod position changes; — Neutron power (RCSNP02_TR) lowers; — Start-up rate (RCS_SUR_TR) is less than zero; — Reactor trip alarm.	
5	Verify turbine trip: (1) Verify turbine control valve MSSV07 has closed; (2) Verify MSB is taking main steam flow to CNR.	Systems	— MSS to TUR flow (MSSFT04_TR) goes to zero; — MSS to CNR flow (MSSFT05_TR) rises; — Turbine trip and breaker open alarms.	
6	When Upper plenum pressure < 9 MPa (Low-Low) OR Vessel level < 90% (Low-Low), verify ADS actuation: (1) ADS valves open sequentially with flow through each valve; (2) RCPs trip (if previously running).	Trips	— RCS pressure (RCSPT02_TR) below 9 MPa is expected to occur first; — ADS valves open sequentially with 5 min time delays; — Flow rising through all three ADS valves (ADS_W1/2/3); — ADS actuation alarm.	

TABLE 9. LARGE STEAM GENERATOR TUBE RUPTURE (cont.)

MALFUNCTION:	SM-MSS-2	DESCRIPTION:	Steam generator 1 tube rupture	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
7	If ADS actuation occurs, check ADS operation: (1) RCS pressure lowers; (2) CB suppression pool temperature rises. PZR heaters are disconnected automatically.	Systems PZR pressure control	— RCS pressure (RCSPT02_TR) lowers; — CB suppression pool temperature (CBSTE03_TR) rises.	
8	Actuate PDHR to isolate FW lines.	Trips		
9	Check DHR actuation: (1) Verify DHR inlet and outlet isolation valves have opened and there is flow through both legs; (2) Check FWS isolation; (3) Check MSS isolation when MSS pressure line <2.5Mpa with DHR signal.	Systems	— DHR inlet and outlet isolation valves (DHRV02/04/01/03) have opened and there is flow through both legs (DHRFT01/2_TR); — Both main FW isolation valves (FWSV15/16) have closed; — PDHR actuation alarm.	
10	Check DHR operation: (1) RCS temperature stable or lowering; (2) CB DHR pools temperatures rising.	Systems	— RCS temperature (RCSTE01_TR) is stable or lowering; — CB DHR pool temperatures (CBSTE01/2_TR) are rising.	

TABLE 9. LARGE STEAM GENERATOR TUBE RUPTURE (cont.)

MALFUNCTION:	SM-MSS-2	DESCRIPTION:	Steam generator 1 tube rupture	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
11	Check core status: (1) Neutron flux is not rising and SUR is not positive; (2) Natural circulation is maintaining coolant flow.	Systems	— Neutron power (RCSNP01_TR) is not rising; — Start-up rate (RCS_SUR_TR) is less than zero; — Coolant flow (RCSFT01_TR) is not zero.	
12	When RCS pressure is less than 5.0 MPa, verify PIS actuation: (1) PIS flow rising in both trains; (2) PIS tanks level lowering.	Systems	— PIS flow into RCS (PISFT01/2_TR) rises; — PIS tanks (PISTL01/2_TR) level lowers.	
13	When RCS pressure is less than 0.5 MPa, verify GIS actuation: (1) GIS flow rising in both trains; (2) GIS tanks level lowering.	Systems	— GIS flow into RCS (GISFT01/2_TR) rising; — GIS tanks (GISTL01/2_TR) level lowering.	

TABLE 9. LARGE STEAM GENERATOR TUBE RUPTURE (cont.)

MALFUNCTION:	SM-MSS-2	DESCRIPTION:	Steam generator 1 tube rupture	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
14	Check reactor stable: (1) Neutron flux is not rising and SUR is not positive; (2) Boron concentration is rising; (3) Natural circulation is maintaining Reactor coolant flow; (4) RCS subcooling is positive; (5) RCS temperature is stable or lowering.	Systems	— Neutron power (RCSNP01_TR) is lowering; — RCS boron concentration (RCS_BC) is rising; — RCS flow rate (RCSFT01_TR) is non-zero; — Start-up rate (RCS_SUR_TR) is less than zero; — RCS temperature (RCSTE01_TR) is stable or lowering.	

3.5. LARGE STEAM LINE BREAK (MSLB)

The lastge steam line break (MSLB) exercise steps are listed in Table 10.

TABLE 10. LARGE STEAM LINE BREAK

MALFUNCTION:	SM-MSS-4 DESCRIPTION:	Major steam system piping failure within containment		
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 10. LARGE STEAM LINE BREAK (cont.)

MALFUNCTION:	SM-MSS-4	DESCRIPTION:	Major steam system piping failure within containment	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Both reactor and turbine at 100% of power; (2) Control rods in auto; (3) FW system in auto; (4) CW system and condensate systems in service; (5) No active alarms.			
2	Load 'Main steam line break inside containment' malfunction (SM-MSS-4, Severity=100%).			
3	Verify malfunction: (1) Check main steam header and steam lines pressures drop; (2) Check containment pressure begins to rise; (3) Check PZR pressure drops; (4) Check containment sump level rises.	Systems	— Main steam header pressure (MSSPT03_TR) drops; — Main steam line pressures (MSSPT01_TR/MSSPT02_TR) drop (steam line 2 pressure recovers after MSS isolation); — Containment pressure (CBSPT01_TR) rises; — PZR pressure RCSPT02_TR drops; — Containment sump level CBSLT04_TR rises.	

TABLE 10. LARGE STEAM LINE BREAK (cont.)

MALFUNCTION:	SM-MSS-4	DESCRIPTION:	Major steam system piping failure within containment	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
4	Check the following alarm conditions exist: (1) High CBS pressure; (2) Low steam pressure.		— High CBS pressure alarm when CBS pressure > 0.012 MPa.	
5	Verify reactor trip: (1) Verify all control and shutdown rods are have fully inserted; (2) Check neutron flux is lowering and Start-up rate is negative.	Rod position display	— Control rod position at bottom; — Neutron power (RCSNP01_TR) lowers; — Start-up rate (RCS_SUR_TR) is less than zero; — Reactor trip alarm.	
6	Verify turbine trip: (1) Verify turbine control valve MSSV07 has closed.	Systems	— MSS to TUR flow (MSSFT04_TR) goes to zero; — MSS dumping steam to atmosphere through MSSV01/2 relief valves; — Turbine trip and generator breaker open alarms.	

TABLE 10. LARGE STEAM LINE BREAK (cont.)

MALFUNCTION:	SM-MSS-4	DESCRIPTION:	Major steam system piping failure within containment	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
7	When Upper plenum pressure < 9 MPa (Low-Low) OR CBS pressure > 0.019 MPa (High-High), verify ADS actuation: (1) ADS valves open sequentially with flow through each valve; (2) RCPs trip (if previously running).	Trips	— Low pressure upper plenum (RCSPT02_TR) lower than 9.0 MPa is expected to occur first; — ADS valves open sequentially with 5 min time delays; — Flow rising through all three ADS valves (ADS_W1/2/3); — ADS actuation alarm.	
8	If ADS actuation occurs, check ADS operation: (1) RCS pressure lowers; (2) CB suppression pool temperature rises. and disconnect PZR heaters.	Systems PZR pressure control	— RCS pressure (RCSPT02_TR) lowers; — CB suppression pool temperature (CBSTE03_TR) rises.	
9	When containment pressure is greater than 0.019 MPa, check: (1) Containment spray pumps start; (2) Containment spray system injects.	Systems	— CCSP01/02 start; — Flow rising through both spray containment legs (CCSFT01/02_TR); — Containment pressure (CBSPT01_TR) drops when containment spray system is in service.	

TABLE 10. LARGE STEAM LINE BREAK (cont.)

MALFUNCTION:	SM-MSS-4	DESCRIPTION:	Major steam system piping failure within containment	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
10	Verify main steam isolation: (1) MSSV05 and MSSV06 closed.	Systems		
11	Verify feedwater isolation: (1) FW isolation valves closed.	Systems	— FWSV15/16 closed.	
12	Verify DHR actuation: (1) DHR inlet and outlet isolation valves (DHRV02/04/01/03) open; (2) Positive flow through both DHR legs.	Systems	— DHR flows (DHRFT01/2_TR) greater than 0.	
13	Check DHR operation: (1) RCS temperature is stable or lowering; (2) CB DHR pools temperatures rise.	Systems	— RCS temperature (RCSTE01_TR) is stable or lowering; — CB DHR pools temperatures (CBSTE01/2_TR) are rising.	
14	Check core status: (1) Neutron flux is not rising and SUR is not positive; (2) Natural circulation is maintaining coolant flow.	Systems	— Neutron power (RCSNP01_TR) is not rising; — Start-up rate (RCS_SUR_TR) is less than zero; — Coolant flow rate (RCSFT01_TR) is not zero.	

TABLE 10. LARGE STEAM LINE BREAK (cont.)

MALFUNCTION:	SM-MSS-4	DESCRIPTION:	Major steam system piping failure within containment	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
15	When RCS pressure is less than 5.0 MPa, verify PIS actuation: (1) PIS flow rising in both trains; (2) PIS tanks level lowering.	Systems	— PIS flow into RCS (PISFT01/2_TR) rises; — PIS tanks (PISTL01/2_TR) level lowers.	
16	When RCS pressure is less than 0.5 MPa, verify GIS actuation: (1) GIS flow is rising in both trains; (2) GIS tanks level lowering.	Systems	— RCS pressure (RCSPT01_TR) is less than 0.5 MPa; — GIS flow into RCS (GISFT01/2_TR) rising; — GIS tanks (GISTL01/2_TR) level lowering.	
17	Check reactor is stable: (1) Neutron flux is not rising and SUR is not positive; (2) Boron concentration is rising; (3) RCS subcooling positive; (4) RCS temperature is stable or lowering.	Systems	— Neutron power (RCSNP01_TR) is not rising; — RCS boron concentration (RCS_BC) is rising; — Start-up rate (RCS_SUR_TR) is less than zero; — RCS temperature (RCSTE01_TR) is stable or lowering.	

3.6. STATION BLACKOUT (SBO)

The station black out (SBO) exercise steps are listed in Table 11.

TABLE 11. STATION BLACKOUT

MALFUNCTION:	SM-GEN-1	DESCRIPTION:	Station blackout (total loss of AC power)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 11. STATION BLACKOUT (cont.)

MALFUNCTION:	SM-GEN-1	DESCRIPTION:	Station blackout (total loss of AC power)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW; (3) Control rods in auto; (4) FW system in auto; (5) CW and condensate systems in service; (6) No active alarms.			
2	Load 'Station blackout' malfunction (SM-GEN-1).			
3	Verify malfunction: (1) All four RCPs trip (if previously running); (2) FW pumps trip; (3) CW pumps trip.	Systems	— All four RCPs (RCSP01/2/3/4) trip (if previously running); — FW pumps (FWSP01/02) trip; — CW pumps trip (CWSP01/2); — FWS isolation.	
4	Verify reactor trip: (1) Verify all control and shutdown rods are have fully inserted; (2) Check neutron flux is lowering and Start-up rate is negative.	Rod position control	— Shutdown and control banks at bottom; — Neutron power (RCSNP01_TR) lowers; — Start-up rate (RCS_SUR_TR) is less than zero; — Reactor trip on FWS pumps trip.	

TABLE 11. STATION BLACKOUT (cont.)

MALFUNCTION:	SM-GEN-1	DESCRIPTION:	Station blackout (total loss of AC power)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
5	Verify turbine trip: (1) Verify there is no steam flow going to the turbine.	Systems	— MSS to TUR flow (MSSFT04_TR) goes to zero (MSSV08 is a ‘fail close’ valve); — MSS to CNR flow (MSSFT05_TR) is zero (MSSV09 is a ‘fail close’ valve); — Turbine trip and generator breaker open alarms.	
6	Verify power supply: (1) Offsite power light is off; (2) Emergency diesel light is off; (3) Battery light is on.			
7	Verify main steam safety valves are dumping steam to atmosphere.	Systems	— MSSV03/4 open; — Safety valve relief setpoint is 5.70 MPa.	
NOTE	ADS valves are fail close valves. On a station blackout event, ADS valves close to avoid an unnecessary breach on the reactor coolant pressure boundary. These valves should be powered from its associated batteries before they are fully discharged.			

TABLE 11. STATION BLACKOUT (cont.)

MALFUNCTION:	SM-GEN-1	DESCRIPTION:	Station blackout (total loss of AC power)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
8	Check DHR actuation: (1) Verify there is flow through both DHR legs; (2) Check there is no flow through both MS lines; (3) Check in case there is small feedwater flow is being dumped through safety valves.	Systems	— DHR inlet and outlet isolation valves (DHRV02/04/01/03) are ‘fail open’ valves; — MS isolation valves (MSSV05/06) are ‘fail close’ valves; — FW isolation valves (FWSV15/16) are ‘fail close’ valves; — PDHR actuation alarm.	
9	Check DHR operation: (1) RCS temperature is stable or lowering; (2) CB DHR pools temperatures are rising.	Systems	— RCS temperature (RCSTE01_TR) is stable or lowering; — CB DHR pool temperatures (CBSTE01/2_TR) are rising.	
10	When RCS pressure is less than 5.0 MPa, verify PIS actuation: (1) PIS flow rising in both trains; (2) PIS tanks level lowering.	Systems	— PIS flow into RCS (PISFT01/2_TR) rises; — PIS tanks (PISTL01/2_TR) level lowers.	

TABLE 11. STATION BLACKOUT (cont.)

MALFUNCTION:	SM-GEN-1	DESCRIPTION:	Station blackout (total loss of AC power)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
11	Check core status: (1) Neutron flux is not rising and SUR is not positive; (2) Natural circulation is maintaining coolant flow.	Systems	— Neutron power (RCSNP01_TR) is not rising; — Start-up rate (RCS_SUR_TR) is less than zero; — Coolant flow (RCSFT01_TR) is not zero.	
12	Check reactor is stable: (1) Boron concentration is rising; (2) RCS subcooling is positive; (3) RCS temperature is stable or lowering.	Systems	— RCS boron concentration (RCS_BC) is rising; — Start-up rate (RCS_SUR_TR) is less than zero; — RCS temperature (RCSTE01_TR) is stable or lowering.	

3.7. STEAM LINE ISOLATION

The steam line isolation exercise steps are listed in Table 12.

TABLE 12. STEAM LINE ISOLATION

MALFUNCTION:	CM-VLV-MOT-8	DESCRIPTION: Inadvertent main steam line isolation		
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 12. STEAM LINE ISOLATION (cont.)

MALFUNCTION:	CM-VLV-MOT-8	DESCRIPTION:	Inadvertent main steam line isolation	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Reactor is at 100%; (2) Turbine load is at 45 MW; (3) Control rods in auto; (4) FW system in auto; (5) CW system and condensate systems in service; (6) No active alarms.			
2	Load: Config → Generic malfunction → VLV → MSS → MSSV05/MSSV06 → Close (both of them)			
3	Verify malfunction: (1) Verify both MSS isolation valves close; (2) Check both MSS line pressures are rising; (3) Check MSS header pressure drops.	Systems	— Both MSS isolation valves (MSSV05/6) close; — MSS line pressures (MSSPT01/2_TR) rise; — MSS header pressure (MSSPT03_TR) drops below 1.0 MPa, causing FWS pumps trip.	

TABLE 12. STEAM LINE ISOLATION (cont.)

MALFUNCTION:	CM-VLV-MOT-8	DESCRIPTION:	Inadvertent main steam line isolation	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
4	Verify reactor trip: (1) Verify all control and shutdown rods are fully inserted; (2) Check neutron flux is lowering and Start-up rate is negative.	Rod position control	— Reactor trips on FWS pumps trip; — Control rod position at bottom; — Neutron power (RCSNP01_TR) lowers; — Start-up rate (RCS_SUR_TR) is less than zero; — Reactor trip alarm.	
5	Verify turbine trip: (1) Verify turbine control valve MSSV07 has closed.	Systems	— MSS to TUR flow (MSSFT04_TR) goes to zero; — Both main steam isolation valves (MSSV05/6) have closed; — MSS flow through main relief valves (MSSV01/2); — Turbine trip and generator breaker open alarms.	
6	Check DHR actuation: (1) Verify DHR inlet and outlet isolation valves have opened and there is flow through both legs; (2) Check FWS isolation.	Systems	— DHR inlet and outlet isolation valves (DHRV02/04/01/03) have opened and there is flow through both (DHRFT01/2_TR); — Both main FW isolation valves (FWSV15/16) have closed; — PDHR actuation alarm.	

TABLE 12. STEAM LINE ISOLATION (cont.)

MALFUNCTION:	CM-VLV-MOT-8	DESCRIPTION:	Inadvertent main steam line isolation	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
7	Check DHR operation: (1) RCS temperature is stable or lowering; (2) CB DHR pools temperatures are rising.	Systems	— RCS temperature (RCSTE01_TR) is stable or lowering; — CB DHR pool temperatures (CBSTE01/2_TR) are rising.	
8	Block ADS actuation: (1) Press BLOCK on trips display; (2) Verify ADS block status light is on.	Trips	— ADS block actuated to avoid ADS actuation.	
9	Check reactor is stable: (1) Neutron flux is not rising and SUR is not positive; (2) RCS flow > 0; (3) RCS temperature is stable or lowering.	Systems	— Neutron power (RCSNP01_TR) is not rising; — RCS coolant flow rate (RCSFT01_TR) is non-zero; — Start-up rate (RCS_SUR_TR) is less than zero; — RCS temperature (RCSTE01_TR) is stable or lowering.	

3.8. PRESSURIZER SAFETY VALVE OPENING

The reactor coolant trip exercise steps are listes in Table 13.

TABLE 13. REACTOR COOLANT TRIP

MALFUNCTION:	CM-VLV-SEG-2	DESCRIPTION:	Inadvertent opening of pressurizer safety valve (LOCA)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #1 ‘100% BOL natural circulation’ or IC #4 ‘100% BOL forced circulation’.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 13. REACTOR COOLANT TRIP (cont.)

MALFUNCTION:	CM-VLV-SEG-2	DESCRIPTION:	Inadvertent opening of pressurizer safety valve (LOCA)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW; (3) Control rods in auto; (4) FW system in auto; (5) CW and condensate systems in service; (6) No active alarms.			
2	Load: Config → Generic malfunction → VLV → RCS → RCSV01 → Leakage			
3	Verify malfunction: (1) Check RCSV01 opens; (2) Check RCS pressure begins to drop; (3) CB suppression pool temperature begins to rise; (4) Subcooling loss.	Systems	— RCS pressure (RCSPT01_TR) drops; — CB suppression pool temperature (CBSTE03_TR) rises.	
4	Verify reactor trip: (1) Verify all control and shutdown rods are fully inserted; (2) Check neutron flux is lowering and Start-up rate is negative.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) lowers; — Start-up rate (RCS_SUR_TR) is less than zero; — Reactor trip alarm.	

TABLE 13. REACTOR COOLANT TRIP (cont.)

MALFUNCTION:	CM-VLV-SEG-2	DESCRIPTION:	Inadvertent opening of pressurizer safety valve (LOCA)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
5	Verify turbine trip: (1) Verify turbine control valve MSSV07 has closed; (2) Verify MSB is taking main steam flow to CNR.	Systems	— MSS to TUR flow (MSSFT04_TR) goes to zero; — MSS to CNR flow (MSSFT05_TR) rises; — Turbine trip and generator breaker open alarms.	
6	When upper plenum pressure < 9 MPa (Low-Low), verify ADS actuation: (1) ADS valves open sequentially with flow through each valve; (2) RCPs trip (if previously running).	Trips	— Low pressure upper plenum (RCSPT02_TR) < 9.0 MPa is expected to occur first; — ADS valves open sequentially with 5 min time delays; — Flow rising through all three ADS valves (ADS_W1/2/3); — ADS actuation alarm.	
7	If ADS actuation has occurred, check ADS operation: (1) RCS pressure lowers; (2) CB suppression pool temperature rises, and disconnect PZR heaters.	Systems PZR pressure control	— RCS pressure (RCSPT02_TR) lowers; — CB suppression pool temperature (CBSTE03_TR) rises.	

TABLE 13. REACTOR COOLANT TRIP (cont.)

MALFUNCTION:	CM-VLV-SEG-2	DESCRIPTION:	Inadvertent opening of pressurizer safety valve (LOCA)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
8	RCS temperature is stable or lowering.	Systems	— RCS temperature (RCSTE01_TR) is stable or lowering.	
9	Check core status: (1) Neutron flux is not rising and SUR is not positive; (2) Natural circulation is maintaining coolant flow.	Systems	— Neutron power (RCSNP01_TR) is not positive; — Start-up rate (RCS_SUR_TR) is less than zero; — Coolant flow (RCSFT01_TR) is positive.	
10	When RCS pressure is less than 5.0 MPa, verify PIS actuation: (1) PIS flow rising in both trains; (2) PIS tanks level lowering.	Systems	— PIS flow into RCS (PISFT01/2_TR) rises; — PIS tanks (PISTL01/2_TR) level lowers.	
11	When main steam header pressure reaches 1.0 MPa, verify: (1) FW pumps trip; (2) PDHR actuates.	Systems	— RCS temperature (RCSTE01_TR) is stable or lowering; — CB DHR pool temperatures (CBSTE01/2_TR) are rising; — MSS/FWS isolation and DHR actuation alarm.	

TABLE 13. REACTOR COOLANT TRIP (cont.)

MALFUNCTION:	CM-VLV-SEG-2	DESCRIPTION:	Inadvertent opening of pressurizer safety valve (LOCA)	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
12	When RCS pressure is less than 0.5 MPa, verify GIS actuation: (1) GIS flow is rising in both trains; (2) GIS tanks level lowering.	Systems	— GIS flow into RCS (GISFT01/2_TR) rising; — GIS tanks (GISTL01/2_TR) level lowering.	
13	Check reactor is stable: (1) Neutron flux is not rising and SUR is not positive; (2) Boron concentration is rising; (3) Natural circulation is maintaining reactor coolant flow; (4) RCS subcooling > 0; (5) RCS temperature is stable or lowering.	Systems	— Neutron power (RCSNP01_TR) is not positive; — RCS boron concentration (RCS_BC) is rising; — RCS flow rate (RCSFT01_TR) is non-zero; — Start-up rate (RCS_SUR_TR) is less than zero; — RCS temperature (RCSTE01_TR) is stable or lowering.	

3.9. REACTOR COOLANT PUMP TRIP

The reactor coolant trip exercise steps are listed in Table 14.

TABLE 14. REACTOR COOLANT TRIP (cont.)

MALFUNCTION:	CM-BOM-BOM-6	DESCRIPTION:	Reactor coolant pump trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset the simulator to IC #4 '100% BOL forced circulation'.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 14. REACTOR COOLANT TRIP (cont.)

MALFUNCTION:	CM-BOM-BOM-6	DESCRIPTION:	Reactor coolant pump trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW; (3) Control rods in auto; (4) FW system in auto; (5) CW and condensate systems in service; (6) No active alarms.			
2	Load: Config → Generic malfunction → BOM → RCS → RCSP01 → Electrical failure			
3	Verify malfunction: (1) 1 RCP trips; (2) RCS flow lowers.	Systems	— 1 RCP trips (coloured in red); — RCS flow (RCSFT01_TR) lowers.	
4	Verify reactor stepback: (1) Verify control rods insert into the core; (2) Verify reactor lowers to 50%; (3) Verify plant mode in reactor leading; (4) Verify MSB in steam pressure mode.	Rod position control	— Control rod position changes; — Neutron power (RCSNP01_TR) lowers to 50%; — Reactor stepback alarm.	

TABLE 14. REACTOR COOLANT TRIP (cont.)

MALFUNCTION:	CM-BOM-BOM-6	DESCRIPTION:	Reactor coolant pump trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
5	Verify turbine response to reactor stepback: (1) Verify turbine control valve begins to close; (2) Check turbine load begins to reduce to 50% approx.	Systems	— MSS to TUR flow (MSSFT04_TR) lowers.	
6	If plant mode was initially in turbine leading mode: (1) Verify plant mode has changed to reactor leading mode; (2) Verify MSB has changed from T_{avg} to steam pressure mode.	Rod position control	— Selector in reactor leading mode (Stepback); — Selector in steam pressure (plant mode in reactor leading).	
7	Check main steam flow begins to lower.	Systems	— Main steam flow (MSSFT01_TR and MSSFT02_TR) lowers.	
8	Check PZR level begins to lower due to coolant contraction.	PZR level control	— PZR level (RCSLT02_TR) begins to lower.	
9	Check variables from the initial conditions are stable.	Systems	— All variables stable at 50% of reactor power.	

TABLE 14. REACTOR COOLANT TRIP (cont.)

MALFUNCTION:	CM-BOM-BOM-6	DESCRIPTION:	Reactor coolant pump trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
10	Final state: (1) Both reactor and turbine at 50% of power; (2) Control rods in auto; (3) FW system in auto; (4) CW and condenser systems in service; (5) 1 RCP tripped.	Systems	— Stepback alarm activated.	
NOTE	ΔI should be controlled as follows: (a) If ΔI is at the left side of the target band, rods are excessively inserted. This means that rods depress neutron flux in the upper half of the core and force a high flux to exist in the lower half. To make ΔI return to the target band, borate the RCS to make rods withdraw from the core; (b) If ΔI is at the right side of the target band, rods are excessively withdrawn. This means that a higher flux exist in the upper half of the core compared to the lower half. To make ΔI return to the target band, dilute the RCS to make rods insert into the core.			

3.10. FOUR REACTOR COOLANT PUMPS TRIP

The reactor coolant pums trip (all four) exercise steps are listed in Table 15.

TABLE 15. FOUR REACTOR COOLANT PUMPS TRIP

MALFUNCTION:	CM-BOM-BOM-6	DESCRIPTION:	Four reactor coolant pumps trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
Setup	Reset simulator to IC #4 ‘100% BOL forced circulation’.			
Initial Conditions	Check the following variables are stable: (1) Neutron power (%); (2) Start-up rate (SUR) (dpm); (3) Thermal power (MW(th)); (4) Generator load (MW(e)); (5) Control rod position (steps); (6) Condenser pressure (mmHg); (7) Steam pressure (MPa); (8) FW flow (kg/s); (9) FW temperature (ºC); (10) T_{avg} (ºC); (11) Pressurizer pressure (MPa); (12) Pressurizer level (%).	Overview Rod position control	All variables stable at: (1) 100%; (2) 0 dpm; (3) 150 MW(th); (4) 45 MW(e); (5) 80 steps; (6) 47.3 mmHg; (7) 2.7 MPa; (8) 78 kg/s; (9) 173ºC; (10)287.5ºC; (11)15.5 MPa; (12)43%.	

TABLE 15. FOUR REACTOR COOLANT PUMPS TRIP (cont.)

MALFUNCTION:	CM-BOM-BOM-6	DESCRIPTION:	Four reactor coolant pumps trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
1	Check the following conditions: (1) Reactor power at 100%; (2) Turbine load at 45 MW; (3) Control rods in auto; (4) FW system in auto; (5) CW and condensate systems in service; (6) No active alarms.			
2	Load '4 RCP trip' malfunction (electrical failure) or SM-RCS-7			
3	Verify malfunction: (1) All RCPs trip; (2) RCS flow lowers;	System Display	— All RCPs trip (red); — RCS flow (RCSFT01_TR) lowers.	
4	Verify reactor stepback: (1) Verify control rods insert into the core; (2) Verify reactor lowers to 30%;	Control rods display	— Control rod position changes; — Neutron power (RCSNP01_TR) lowers to 30%; — Reactor stepback alarm.	

TABLE 15. FOUR REACTOR COOLANT PUMPS TRIP (cont.)

MALFUNCTION:	CM-BOM-BOM-6 DESCRIPTION:	Four reactor coolant pumps trip		
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
5	Verify turbine response to reactor stepback: (1) Verify turbine control valve begins to close.	System display	— MSS to TUR flow (MSSFT04_TR) lowers.	
6	If plant mode is in turbine leading mode: (1) Verify plant mode has changed to reactor leading mode; (2) Verify MSB has change from T_{avg} to steam pressure mode.	Control rods display	— Selector in reactor leading mode (stepback); — Selector in steam pressure (plant mode in reactor leading).	
7	Check main steam flow begins to lower.	System display	— Main steam flow (MSSFT01_TR and MSSFT02_TR) lowers.	
8	Check PZR level begins to lower due to coolant contraction.	PZR level control	— PZR level (RCSLT02_TR) begins to lower.	
9	Check variables from the initial conditions are stable.	System display	— All variables stable at 30% of power.	

TABLE 15. FOUR REACTOR COOLANT PUMPS TRIP (cont.)

MALFUNCTION:	CM-BOM-BOM-6	DESCRIPTION:	Four reactor coolant pumps trip	
STEP ID.	PROCEDURE STEPS	GUI SHEET	EXPECTED RESPONSE	STATE
10	Check reactor is stable: (1) Neutron flux is not rising and SUR is not positive; (2) Natural circulation is maintaining Reactor coolant flow; (3) RCS subcooling; (4) RCS temperature is reducing or stable.	System display	— Rod position will not be stable as rod control will be compensating the negative reactivity introduced by Xe.	
NOTE	ΔI should be controlled as follows: (a) If ΔI is at the left side of the target band, rods are excessively inserted. This means that rods depress neutron flux in the upper half of the core and force a high flux to exist in the lower half. To make ΔI return to the target band, borate the RCS to make rods withdraw from the core; (b) If ΔI is at the right side of the target band, rods are excessively withdrawn. This means that a higher flux exist in the upper half of the core compared to the lower half. To make ΔI return to the target band, dilute the RCS to make rods insert into the core.			

APPENDIX

A.1. SUMMARY OF THERMAL HYDRAULIC VARIABLES

The thermal hydraulic variables are listed in Table 16.

TABLE 16. THERMAL HYDRAULIC VARIABLES

Thermal hydraulic variable	Value	Units
Reactor neutron power	100.0	%
Thermal power	150.0	MW
Generator power	45.0	MW(e)
Primary pressure	15.5	MPa
Pressurizer level	43.0	%
Core level	100.0	%
Core flow	422.0	Kg/s
Inlet core temperature	255.51	ºC
Outlet core temperature	320.36	ºC
Average core temperature	288.0	ºC
Steam header pressure	2.72	MPa
Steam reheating	29.0	ºC
Steam flow	77.0	Kg/s
Feedwater flow	77.0	Kg/s
Feedwater temperature	173.0	ºC
Turbine speed	3600.0	rpm
Condenser vacuum	47.81	mmHg
Lake temperature	20.0	ºC
Containment pressure	0.011	MPa
Containment temperature	33.4	ºC

A.2. THERMAL HYDRAULIC VARIABLES AT DIFFERENT POWERS

In order to understand the reactor conditions at different power levels, the thermal hydraulic variables at differen powers are listed in Table 17-Table 22.

TABLE 17. 100% REACTOR POWER

Thermal hydraulic variable	Value	Units
Reactor neutron power	100.0	%
Thermal power	150.0	MW
Generator power	45.0	MW(e)
Primary pressure	15.5	MPa
Pressurizer level	43.0	%
Steam header pressure	2.72	MPa
Steam flow	77.0	Kg/s

TABLE 18. 75% REACTOR POWER

Thermal hydraulic variable	Value	Units
Reactor neutron power	75.0	%
Thermal power	113.0	MW
Generator power	33.75	MW(e)
Primary pressure	15.5	MPa
Pressurizer level	39.0	%
Steam header pressure	2.9	MPa
Steam flow	59.0	Kg/s

TABLE 19. 54% REACTOR POWER

Thermal hydraulic variable	Value	Units
Reactor neutron power	54.0	%
Thermal power	82.0	MW
Generator power	22.5	MW(e)
Primary pressure	15.5	MPa
Pressurizer level	34.0	%
Steam header pressure	3.15	MPa
Steam flow	42.0	Kg/s

TABLE 20. 30% REACTOR POWER

Thermal hydraulic variable	Value	Units
Reactor neutron power	30.0	%
Thermal power	47.0	MW
Generator power	11.25	MW(e)
Primary pressure	15.5	MPa
Pressurizer level	28.0	%
Steam header pressure	3.55	MPa
Steam flow	23.0	Kg/s

TABLE 21. 20% REACTOR POWER

Thermal hydraulic variable	Value	Units
Reactor neutron power	20.0	%
Thermal power	31.0	MW
Generator power	6.75	MW(e)
Primary pressure	15.5	MPa
Pressurizer level	26.0	%
Steam header pressure	3.65	MPa
Steam flow	16.0	Kg/s

TABLE 22. 12% REACTOR POWER

Thermal hydraulic variable	Value	Units
Reactor neutron power	12.0	%
Thermal power	18.0	MW
Generator power	3.6	MW(e)
Primary pressure	15.5	MPa
Pressurizer level	25.0	%
Steam header pressure	3.7	MPa
Steam flow	10.0	Kg/s

A.3. LIST OF MALFUNCTIONS

The specific malfunctions already present in the simulator are listed in Table 23.

TABLE 23. LIST OF MALFUNCTIONS

Number	System	Specific Malfunction
1	ADS	Inadvertent initiation of ADS
2	CBS	Loss of containment vacuum
3	CNR	Loss of condenser vacuum
4	CWS	Condenser coolant pumps trip
5	DHR	Inadvertent initiation of decay heat removal system
6	FWS	Reduction in feedwater temperature (loss of FW heating)
7		Abnormal increase in FW flow
8		Loss of normal feedwater flow (FW pumps trip)
9		Feedwater system pipe break
10	GEN	Station blackout (loss of AC power)
11	MSS	Steam header break
12		Steam generator tube failure 1
13		Steam generator tube failure 2
14		Major steam system piping failure within containment
15	RCS	Reactor setback fail
16		One bank of shutdown control rods drop into the core
17		Charging (feed) valve fails open
18		Inadvertent operation of pressurizer heaters
19		Uncontrolled control rod assembly withdrawal at power
20		Fail of PZR control system
21		Failure of main coolant pumps
22		Reactor stepback fail
23		Seismic event
24	TUR	Turbine spurious trip
25		Turbine spurious run-back
26		Turbine trip with bypass valves failed closed

A.4. VARIABLES TO PLOT

The variables than can be plotted by the simulator are listed in Table 24.

TABLE 24. VARIABLES TO PLOT

System	Variable
ADS	ADS total flow
	ADS1 valve flow
	ADS2 valve flow
	ADS3 valve flow
CBS	DHR1 pool level
	DHR2 pool level
	Suppression pool level
	Sump level
	Containment pressure
	DHR1 pool temperature
	DHR2 pool temperature
	Suppression pool temperature
	Containment temperature
CCS	Containment coolant spray flow rate of train 1
	Containment coolant spray flow rate of train 2
CNR	Condenser level
	Condenser pressure vacuum
CWS	Coolant pump 1 power
	Coolant pump 2 power
	Condenser coolant flow
	Coolant temperature at condenser inlet
	Coolant temperature at condenser outlet
DHR	Flow train 1
	Flow train 2
FWS	Feedwater total flow
	Pump-1 speed
	Pump-2 speed
	Flow to steam generator 1
	Flow to steam generator 2
	Flow through heater 3
	Flow through heater 2
	Flow through heater 1
	Water storage tank level
	Header feedwater pressure
	Feedwater line-1 pressure
	Feedwater line-2 pressure
	Pressure inlet heat exchanger-1
	Inlet temperature to SG1
	Inlet temperature to SG2
	Heater -3 outlet temperature
	Heater -2 outlet temperature

TABLE 24. VARIABLES TO PLOT (cont.)

System	Variable
	Heater -1 outlet temperature
GEN	Generator load
GIS	Water injection flow from gravity driven injection system-1
	Water injection flow from gravity driven injection system-2
	Gravity driven injection tank1 level
	Gravity driven injection tank2 level
MSS	% turbine valve opening
	% bypass valve opening
	Steam flow rate line-1
	Steam flow rate line-2
	Total flow through pressure header
	Steam flow to turbine
	Steam flow to condenser
	Steam pressure line 1
	Steam pressure line 2
	Pressure header
	Steam temperature header
	Saturation temperature
PIS	Water injection flow from pressure injection system-1
	Water injection flow from pressure injection system-2
	Pressure injection system tank1 level
	Pressure injection system tank2 level
RCS	Boron concentration
	Boron reactivity %dk/k
	Boron reactivity pcm
	Rod reactivity %dk/k
	Rod reactivity pcm
	Core reactivity %dk/k
	Core reactivity pcm
	Fuel reactivity (Doppler) %dk/k
	Fuel reactivity (Doppler) pcm
	Moderator temperature reactivity %dk/k
	Moderator temperature reactivity pcm
	Xe reactivity %dk/k
	Xe reactivity pcm
	Start-up rate (SUR)
	Clad surface temperature average
	Clad surface temperature max
	Average fuel temperature
	Peak fuel temperature
	Reactor thermal power (%)
	Reactor thermal power (MW)
	Relief valve flow
	Coolant flow rate
	Flow charge

TABLE 24. VARIABLES TO PLOT (cont.)

System	Variable
	Flow discharge
	Spray flow
	RPV water level
	PZR level
	Setpoint PZR level
	Nuclear power
	Power intermediate range
	Power source range
	RPV pressure
	PZR Pressure
	Coolant average temperature
	Coolant temperature at core inlet
	Coolant temperature at core outlet
	Delta temperature
	Subcooling margin
TUR	Turbine speed
	Pressure first stage

A.5. LIST OF SETPOINTS

The setpoints for all the systems are listed in Table 25.

TABLE 25. LIST OF SETPOINTS

System	Setpoint	Value
RCS	Heaters	P <15.5 MPA
	Spray	P >15.5 MPA
	Relief RCS valve	P>16.7 MPA
	Safety RCS valve	P>17.05MPA
	Alarm low RCS pressure	P<12.5MPA
PCS-Trips	Low pressure upper plenum	P <11. MPA
	Low level PZR	L<5%
	Low flow downcomer	W<347Kg/s
	High core outlet temperature	T>340ºC
	High reactor neutron core flux	Flux>120%
	High log rate	SUR>2dpm
	High pressure upper plenum	P>16.4
PCS-Setbacks	High PZR level	L>67%
	High steam header pressure	P>4.9 MPA
PCS-Stepbacks	High zone flux	Flux>115%
ADS	Low-low pressure upper plenum	P <9 MPA
	Low low level vessel	L<90%
	High-high pressure upper plenum	P>17.2MPA
	High-high pressure CBS	P>0.019MPA
CBS	Alarm high CBS pressure	P>0.012MPA
CCS	CCS starts at CBS pressure	P>0.019MPA
PIS	Pressure setpoint	P<5MPA
GIS	Pressure setpoint	P<0.5MPA
CNR	Alarm low CNR vacuum	P>100mmHg
	Loss of CNR vacuum	P>254mmHg
MSS	Relief RCS valve	P>5.3 MPA
	Safety RCS valve	P>5.7 MPA

A.6. VALVE FAILURE

The state of the failure of various valves is listed in Table 26.

TABLE 26. VALVE FAILURE

System	Valve	Failure
ADS	ADSV01	Close
	ADSV02	Close
	ADSV03	Close
PIS	PISV02	Open
	PISV04	Open
GIS	GISV02	Open
	GISV04	Open
MSS	MSSV01	Close
	MSSV02	Close
	MSSV05	Close
	MSSV06	Close
	MSSV08	Close
	MSSV09	Close
DHR	DHRV01	Open
	DHRV02	Open
	DHRV03	Open
	DHRV04	Open
RCS	RCSV07	Close
	RCSV08	Close
	RCSV09	Close
FWS	FWSV15	Close
	FWSV16	Close

ABBREVIATIONS

ADS	AUTOMATIC DEPRESSURIZATION SYSTEM.
AI	ANALOGICAL INPUT
BOL	BEGINNING OF LIFE
BOP	BALANCE OF PLANT
BWR	BOILING WATER REACTOR
CBS	CONTAINMENT BUILDING SYSTEM.
CCS	CONTAINMENT COOLING SYSTEM.
CNR	CONDENSER SYSTEM.
CWS	CIRCULATING WATER SYSTEM.
DNBR	DEPARTURE FROM NUCLEAR BOILING RATIO
EOL	END OF LIFE
FWS	FEEDWATER SYSTEM
FC	FORCE CIRCULATION
GEN	GENERATOR SYSTEM
GIS	GRAVITY INJECTION SYSTEM
GUI	GRAPHIC USER INTERFACE
HFE	HUMAN FACTORS ENGINEERING
HX	HEAT EXCHANGER
IAEA	INTERNATIONAL ATOMIC ENERGY AGENCY
IC	INITIAL CONDITION
iPWR	INTEGRAL PRESSURISED WATER COOLED REACTOR
LWR	LIGTH WATER REACTOR
LOCA	LOSS OF COOLANT ACCIDENT
MOL	MEDIUM OF LIFE

MSS	MAIN STEAM SYSTEM
NC	NATURAL CIRCULATION
NPP	NUCLEAR POWER PLANT
PCS	PROTECTION AND CONTROL SYSTEM.
PDHR	PASSIVE DECAY HEAT REMOVAL SYSTEM.
PID	PROCESS AND INSTRUMENTATION DIAGRAM
PIS	PRESSURE INJECTION SYSTEM
POAH	POINT OF ADDING HEAT
PWR	PRESSURISED WATER REACTOR
PZR	PRESSURIZER
RCP	REACTOR COOLANT PUMP
RCS	REACTOR COOLANT SYSTEM.
RPV	REACTOR PRESSURE VESSEL
SBO	STATION BLACKOUT
SCS	SHUTDOWN COOLING SYSTEM
SG	STEAM GENERATOR
SMR	SMALL MODULAR REACTOR
SUR	START UP RATE
TUR	TURBINE SYSTEM

CONTRIBUTORS TO DRAFTING AND REVIEW

Abarca, D.	TECNATOM, Spain
Batra, C.	International Atomic Energy Agency
De la Torre, R.	TECNATOM, Spain
Fernandez, D.	TECNATOM, Spain
Fuentes, A.	TECNATOM, Spain
Lenhardt, G.	TECNATOM, Spain
López, J.	TECNATOM, Spain
Maroto, E.	TECNATOM, Spain
Painter, C.	International Atomic Energy Agency
Parrado, I.	TECNATOM, Spain
Ruiz, J.A.	TECNATOM, Spain
Sancho, A.	TECNATOM, Spain
Subki, M.H.	International Atomic Energy Agency
Villalba, S.	TECNATOM, Spain

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