# WANO Services to support successful New Nuclear Reactor deployment

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**Abstract**

This paper is to introduce WANO services to support safe and successful deployment of new nuclear units of its member utilities. Since 2015, WANO and its members interacted to ensure safe and reliable deployment of about 60 various new nuclear power plants. Majority of new nuclear being large size, new technology reactors include the High Temperature Gas Cooled Reactor – Pebble Bed, the Floating reactors, and Fast Breeder Reactors. The review of WANO supports to SMRs found that the areas in need of support are similar to those for large nuclear power plant, even though, the scope and timing can be slightly different..

WANO, as a non-profit, member organisation of nuclear power plant operators in the world, is providing new units with customised supports according the technology, size, and experience of the new nuclear units. These services include multiple new unit assistance visits, operational readiness assistance, roadmap to operational readiness, and pre-startup peer reviews. Lessons learnt from new units started up in the last 10 years have proved that WANO services had been effective in supporting safe and reliable operations. The lessons learnt also highlighted that earlier engagement of new units with WANO activities is essential to build highest level of operational readiness.

## INTRODUCTION

For the last 10 years, WANO, as a non-profit, member organisation of nuclear power plant operators in the world, has been providing about 60 new units with customised support such as new unit assistance, operational readiness assistance, and pre-startup peer reviews. As a result, all of these new units started up nuclear operations safely and reliably.

This paper is to introduce WANO services to new nuclear units to ensure safe operation of new nuclear units including small size reactors.

## world association of nuclear operators (wano)

The World Association of Nuclear Operators (WANO) unites every company and country in the world that has an operating commercial nuclear power plant to achieve the highest possible standards of nuclear safety. More than 150,000 nuclear professionals work for about 130 members of WANO. Together, WANO members operate 450 reactors across the globe. As of 2024, WANO members are also constructing about 58 units around the world.

With an office in London, and regional centres in Atlanta, Paris, Moscow and Tokyo, WANO works to maximise the safety and reliability of nuclear power plants worldwide by working together to assess, benchmark and improve performance through mutual support, exchange of information and emulation of best practices.

WANO is rolling out a new integrated suite of services to its members, which will be available for all member plants and facilities worldwide.

The infographic below explains how WANO will interact with each member plant or facility over the four-year cycle between each peer review. It shows how peer review, enhanced Performance Monitoring (ePM) and other new services (such as performance-based assistance visits) will work together to support members in achieving high levels of sustainable performance.



Fig. 1 WANO Member Interaction Cycle

Under this model, WANO will assess each plant or facility’s ePM results in a Collegial Review Meeting (CRM) to ensure gaps have been correctly and clearly identified. This will ensure the plant benefits from the most appropriate engagement category - based solely on its performance. Afterwards, in the Executive Review Meeting, WANO’s experts will communicate the results to their counterparts in the plant.

Peer review will focus on delivering an evaluation and assessment, and ePM will track each plant’s progress and provide it with support as required. With regular monitoring, each member gains an accurate picture of the current performance and likely trajectory of every plant or facility.

WANO then provides a graded level of support to individual members, which will be based on each plant’s performance and specific needs.

WANO services will fully integrate with each other to continuously improve the industry standards of excellence as the industry evolves. By working closely with WANO, each member plant or facility will elevate and achieve sustainable high levels of performance.

## WANO Services to new nuclear deployment including SmRs

In order to ensure that new nuclear units operate safely and reliably, WANO offers a New Unit Assistance (NUA) service. This new service offers bespoke and focused support to members during the transition from project phase all the way through to the operating phase of a company, ready for safe and reliable operation.

WANO services to SMRs no different from its services to large nuclear power plants. The scope and timing of WANO new unit services for SMRs could be different. For example, WANO provided the following supports to High Temperature Gas-Cooled Reactor from 2016 to 2023.

* Nuclear Safety Culture
* Operational Decision Making
* Operational Readiness Assistance
* Crew Performance Observation
* Reactivity Management
* Shift Supervisor Leadership
* Section Head Leadership
* Human Performance Instructor Skills Improvement
* Operator Fundamentals
* Operating Experience
* Self-Assessment
* Benchmarking
* Significant Operating Experience Report (SOER) Self-Assessment

As can be seen, these topics are similar to WANO services to large nuclear power plants. However, it is noteworthy that more efforts were placed on operator proficiency considering that this is first of a kind reactor.

For floating power plant, WANO services on provided to support implementation of SOER recommendations and engineering support.

For fast breeder reactor plant, WANO provided the following supports.

* Leadership in Safety Culture
* Organising and conducting Walkdown
* Fire Safety
* Safety Culture Assessment
* Task Observation
* Safety Culture
* FME controls
* Configuration Management

Again the topics are applicable to all types and sizes of nuclear power plant.

Full and effective engagement of new units with the NUA programme can significantly reduce the risk of a delay to startup or a setback during the construction phase. The modules include Nuclear Safety Culture, Operator Fundamentals, Organisational Effectiveness and Oversight, Operator Decision-Making and Training, and others that match typical nuclear project milestones. Provision of the NUA modules can be tailored to members’ specific needs, and the delivery methods are varied to ensure the member receives the right information for them in the most effective way - via sharing of industry best practices, benchmarking, the use of operating experience, and the delivery of targeted support missions and training.

### The new unit assistance modules for new nuclear including SMR.

The NUA modules offered are intended to assist WANO members along the length of the NUA timeline. The modules include Nuclear Safety Culture, Operator Fundamentals, Organisational Effectiveness and Oversight, Operator Decision-Making and Training, and others that match typical nuclear project milestones.

Provision of the NUA modules can be tailored to members’ specific needs, and the delivery methods are varied to ensure the member receives the right information for them in the most effective way - via training materials, sharing of industry best practices, benchmarking, and use of operating experience, targeted support missions and training. Fig. 2 shows simplified timeline with possible delivery of WANO NUA modules. The following sections introduce some of the WANO NUA modules.



Fig. 2 Simplified NUA Timeline

3.1.1 Nuclear Safety Culture

The contents of nuclear safety culture topic include individual commitment to safety, for example, establishing a nuclear safety culture (NSC), what is the difference between safety and safety culture?, what makes nuclear special? Also, the topic includes management commitment to nuclear safety, leader’s roles in NS, Management systems, safety culture team exercises / case studies.

This NSC module can be delivered in the earlier phase of project and repeated during operation organisation staffing and evolution.

Also, the audience can be wide, senior leadership team and extended leadership team, operations and maintenance managers, independent nuclear safety oversight experts, training personnel for NSC training for the workforce and construction managers.

3.1.2 Operator Fundamentals, Crew Performance and Teamwork

This module is to discuss the operating margins, reactivity management, operator fundamentals, operator knowledge and skills, system knowledge and purpose of systems turnovers, procedure use and adherence, operating crew team building.

This can be effectively delivered multiple times during initial operator training, simulator training, and crew performance observations before first fuel load. This is also useful for operations training personnel developing training programmes including simulator training scenarios. Normally, it is expected and good practice that 2 to 3 hour training scenarios covering normal, abnormal, and emergency operating conditions.

3.1.3 Organisational Effectiveness, Oversight and Leadership Fundamental

This module is to provide learnings about operating model, standards and expectations, owning the plant, material condition and equipment status (leaders responsibility in technical conscience, leadership, delegation, accountability, promoting nuclear safety, human performance fundamentals for leaders.

This module also provides fundamentals of risk management, managing for excellent performance, team building, team work, coaching techniques.

This module can be delivered as soon as senior leadership team are onsite and then repeatedly as the operating organisation builds up.

 3.1.4 Operational Decision Making

 This module provides training and exercise opportunities regarding the operational decision making principles of recognising and reporting degrading conditions & safety margins, clearly defining roles and responsibilities, assessing short & long term risks and potential combined effects of different options, developing an implementation plan, compensatory measures & back-up plan, and periodically reviewing the decisions & the ODM process.

3.1.5 Training

The training module is to provide senior managers and training staff with practical learnings regarding the training programme principles, such as, what is the key training timeline, awareness of importance of training in new units, how to build training policy, what a typical training organisation is like, and key idea of Systematic Approach to Training model.

3.1.6 Significant Operating Experience Report

This module is to discuss lessons learned from the industry’s significant operating experience and to discuss how to implement the recommendations of each SOER. It is important to have some of the recommendation reviewed and implemented even during bid evaluation and negotiation stages so that the contract requirements and plant design are included. As of 2024, there are 17 WANO SOERs published with about 236 recommendations. The 17 SOERs are:

 3.1.6.1 Safety System Status Control (1998-1) 3.1.6.2 Loss of Grid (1999-1) 3.1.6.3 Unplanned Radiation Exposure (2001-1)

 3.1.6.4 Severe Weather Rev. 1 (2002-1) 3.1.6.5 Emergency Power Reliability (2002-2) 3.1.6.6 Reactor Pressure Vessel Head Degradation at Davis-Besse Rev. 1 (2003-2) 3.1.6.7 Managing Core Design Changes (2004-1) 3.1.6.8 Reactivity Management Rev. 1 (2007-1) 3.1.6.9 Intake Cooling Water Blockage (2007-2) 3.1.6.10 Rigging, Lifting and Material Handling (2008-1) 3.1.6.11 Shutdown safety (2010-1) 3.1.6.12 Large Power Transformer Reliability Rev. 1 (2011-1) 3.1.6.13 Station Spent Fuel Pool/Pond Loss of Cooling and Makeup Rev. 1 (2011-3 ) 3.1.6.14 Operator Fundamentals Weaknesses (2013-1) 3.1.6.15 Rev. 1 Post Fukushima Nuclear Accident Lessons Learned (2013-2) 3.1.6.16 Rev. 1 Safety Challenges from Open Phase Events (2015-1) 3.1.6.17 Risk Management Challenges (2015-2)

#### WANO New Unit Representatives and their interactions with new units

WANO Representatives (WANO Rep) will be assigned for each new unit. The WANO Reps would normally have necessary expertise and experience related to construction, commissioning, and startup testing of new units. Together with new nuclear leadership team, WANO Rep will develop customised support plans through periodic interviews, observations, and discussions during various phases of the new nuclear project. The roles and responsibilities of this WANO Representative would typically include leading WANO effort to engage new entrants in WANO activities, developing long-term and yearly interaction plan for new units in the region​, delivering NUA missions as per the interaction plan​, visiting new unit sites to identify supports needed​, and monitoring and developing new unit performance dashboard up to first core load and update interaction plans to provide effective support in achieving industry goals.

* 1. Operational Readiness Assistance (ORA)

The goal of WANO ORA visit is to help new nuclear power plant personnel prepare for a successful transition from the construction and component and system testing phase to fuel load, and plant start up. As a team, WANO ORA team will provide recommendations and insights to the new power plant leadership team that will help ensure operational readiness; i.e., ORA review will determine whether programs, processes, and other activities are adequate and being effectively implemented to support a smooth transition from construction to start up. The ORA team will also focus on station leadership and organizational effectiveness behaviours that support operational readiness.

While on site, the ORA team members will review plant documents and relevant on-going activities necessary to support the eventual successful transition to commercial operation. Interviews with station and possibly contract personnel will also be conducted as necessary. The team’s primary focus will be on operational readiness and any associated programs, processes, and procedures. If the team determines that improvements are needed based on industry standards and the team’s experience, recommendations will be provided to station leadership team.

The visit will include interviews with personnel on expectations associated with operational readiness. Associated program and process documents will be reviewed. In addition, team observations of work, walk downs, meetings, training, and other important activities related to operational readiness will be conducted, when possible.

An ORA visit plan with specific focus areas will be developed by the ORA team prior to arriving on site, based on the information provided in the advanced information package (AIP), the team’s experience and their review of station documents, programs and processes.

The ORA team is expected to review and discuss the following areas in accordance with the Pre-Start up PO&C (PO&C 2013-2 Rev. 1) and to give assistance recommendations to close any relevant gaps. These areas can be adjusted according to the plant needs and WANO team composition:

* + 1. Management, leadership, nuclear safety culture, field observations and independent oversight (OR)
		2. Management oversight of station activities to ensure CAP effectiveness, including timely and effective resolution of adverse trends, issues and implementation of operating experience, contractors (OE)
		3. Station oversight of vendor/commissioning organization Quality Assurance (QA) programs (OR)
		4. QA auditing, surveillance, and self-assessment activities (OR)
		5. CAP thresholds for initiation and action (OE)
		6. Transition from construction to operation, interface with the operating unit(s) (if applicable) (OR/OP/EQ/PS)
		7. Plans, timelines, and sequence for turning over systems and components (OP)
		8. Commissioning activities (EQ)
		9. Preparation for and involvement of operators, maintenance personnel, and system/ component/program engineers in system and equipment transition/handover activities (OR)
		10. Plans for maintaining and handover of configuration control (OP/PS)
		11. Plans for hiring, staffing as well as training programs for staff needed to support station operation (operator and technical training programs are reviewed separately) (OP/TR)
		12. Construction scheduling and planned sequence of activities in preparation of operations (OR)
		13. Materials management, foreign material exclusion (FME) (EQ/PS)
		14. Activities for ensuring parts quality/receipt inspections (EQ/PS)
		15. Work control and work activity risk assessment (nuclear safety, industrial safety, schedule) (OR)
		16. Oversight to ensure adherence to procedures, work documents, and processes and adequate documentation review and closure (OR)
		17. Development of appropriate chemistry process, programs, and procedures (CY)
		18. Identification of radiation control areas, high radiation areas, alpha monitoring programs, and hot particle programs (RP)
		19. Station and corporate oversight of operational readiness (OA)
		20. Readiness of:
			1. Programs, processes, procedures (if they are under development then it is important to see if the plant has a functional project to deliver procedures in time to support key activities such as licensed operator training)
			2. Simulator
	1. Pre-Startup Peer Review (PSUR)

One of the Post Fukushima Commission Recommendations for WANO members is to host Pre-Startup Peer Review (PSUR) for each new unit. As such all the new units started up hosted WANO PSUR. Even though the main objective is to support new units operational readiness, the purpose of PSUR is to:

* + 1. Assess the readiness of a new unit to start safely and reliably.
		2. Assess the initial performance of previously started new units during subsequent unit PSURs, if not reviewed by an operating peer review, in particular in areas where startup related AFIs had been identified in earlier pre-startup reviews.
		3. Reassess the readiness of a new unit in the case the unit has not achieved first criticality for more than one year after the original PSUR exit meeting. It is recognised that there is a timeliness factor involved with the effectiveness of a PSUR. If a significant period of time (typically one year) elapses between the performance of the PSUR exit meeting and the unit begins nuclear operation, an additional PSUR to assure a safe start up should be performed. This review may have a modified scope and duration, based on the results of the initial PSUR and, if appropriate, the causes/consequences/duration of the interruption. Modification in scope of such a review requires the approval of the RC director. The reasons for and approval of a reduction in scope will be documented and included in the PSUR report.
		4. Verify in all the above cases that the operating organisation and, in particular, the operators have made the transition from a construction mind-set to one that makes operational nuclear safety the overriding priority.

WANO Pre-Startup Performance Objectives & Criteria (PSUR PO&Cs) document contains performance objectives and criteria intended for use by the World Association of Nuclear Operators (WANO) in its pre-startup peer review (PSUR) visits to near-term operating license nuclear power plants, including small modular reactors. WANO Performance Objectives & Criteria (PO&Cs) was developed with an intention to be technology neutral - so that it can be applied to every new nuclear unit regardless of size and technology. Accordingly, since 2013, WANO PSUR PO&Cs have been used for reviewing operational readiness of water-cooled reactors, both in land and marine installations, and non-water-cooled reactors, such as small modular high temperature gas cooled reactors and fast breeder reactors. Nuclear utilities are encouraged to use this document in self-assessments of their own operational readiness.

WANO Pre-Startup Performance Objectives & Criteria (PSUR PO&Cs) have been developed to ensure PSUR will assess the overall station for operational activities and is ready to operate new plants in a safe and reliable manner. This also applies to reviewing the initial performance of the previously started units not covered by operating peer reviews during subsequent-unit PSURs.

WANO teams apply these PSUR PO&Cs based on observed performance and data reviews, including plans, programmes, schedules, and interviews – with emphasis on operational readiness regarding future safe and reliable plant operations. The PSURs of new plants preparing for commercial operation are scheduled at a time when a suitable number of plant systems are turned over to the plant staff and in operation, typically several weeks before first fuel load. Although some programmes and processes that support many of the PO&Cs may not be fully met at the time of the PSUR, plans shall be sufficiently defined and implemented such that operational readiness can be determined in support of major milestones, including fuel load, startup, and eventual full-power operation. Therefore, these PSU PO&Cs will be applied during PSURs in the context of a plant preparing to become operational rather than a plant that has been operating for some time.

The performance objectives are intended to be broad in scope. Each objective generally covers a single area and the supporting criteria describe a specific activity that contributes to the achievement of the performance objective; therefore, several criteria are typically listed under each performance objective. Therefore, WANO PSUR PO&Cs have been successfully used for all types of new units since 2013 including small size reactors, new technology reactors, and conventional large size reactors.

The performance objectives are based on both functional and cross-functional areas. The functional areas generally coincide with the management, operation, maintenance and support activities needed to safely and reliably operate a nuclear-powered electric generating plant. These areas generally correspond to nuclear station organisational departments or groups that are responsible for the functional areas described. These functional areas are as follows:

• Operations

• Maintenance

• Engineering

• Radiological Protection

• Chemistry

• Training

The cross-functional performance objectives apply to multiple areas of an organisation and represent areas that include additional work processes and controls. Cross-functional performance objectives reviewed on a pre-startup peer review include the following:

• Nuclear Safety Culture

• Organisation & Administration

• Risk Management

• Plant Status and Configuration Control

• Work Management

• Equipment Performance and Condition

• Operating Experience

• Fire Protection

• Emergency Preparedness

In addition to normal scope of review, PSUR also reviews the following two important areas.

* + 1. Crew Performance Observations (CPO)

PSUR requires observations of operating crew performance in the full-scope simulator. These observations shall be performed prior to the first core loading and early enough to give the station time to correct possible weaknesses before the first criticality. Depending on the plant schedule, crew performance observations (CPO) may be carried out either during the PSUR or in advance at a date as close as possible to the PSUR. The results of these CPOs will be included in the PSUR report.

A CPO is being conducted for each new unit. Significant issues identified during a CPO will be described in the executive summary of the PSUR report.

* + 1. Review of WANO Significant Operating Experience Report (SOER) recommendations:
			1. Each PSUR team will review the implementation status of WANO SOER recommendations, issued six months after the SOER has been posted on the WANO member website.
			2. A summary of the results of the SOER recommendation implementation review will be included in the PSUR report.

## Lessons learnt

The performance of new units that have started up since 2013 shows that WANO support for new units has been effective. The performance of most of the new units was assessed as strong with some new units’ performance as exemplary.

However, there are also some lessons learnt that indicate that continued effort is required to achieve excellence in safety and reliability of new units including SMRs. The areas needing continuous improvement are:

4.1 Operator Fundamentals

 At some new units, operating crews lack proficiency in dealing with challenging operational conditions during simulated scenarios. Most common weakness exist with teamwork of operating crew that require targeted and repeated team exercises in the full scope simulator. More recent experience shows that this weakness is less common as WANO and its member have been placing more focus on building stronger operator fundamentals during earlier stages of project.

4.2 Quality construction and delivery of equipment

At many new units, the quality of construction of structures, delivery and installation of safety related equipment challenges safe and reliable operation. This is largely because the standards and expectations required for nuclear construction have not been well communicated with construction entities and overseen by operating organisation during construction. Operating organisations of new build project need to ensure quality products are delivered for commissioning and operation.

4.3 Protection of safety related equipment during construction and commissioning

At many new units, installed safety related equipment are not fully protected by adjacent construction and commissioning activities. Safety related structures, systems, and components need to be protected by welding, scaffolds, installation, and temporary transient tools and boxes as well as long-term exposure to harmful environment.

4.4 Prevention of foreign material intrusion (FMI)

At many new units, foreign material intrusion caused damages to safety related equipment and in some cases, unfortunately, earlier failure of fuel assemblies. Robust implementation of higher foreign material exclusion (FME) standards is need to prevent FMI.

4.5 Early availability of fire detection and protection systems

At many new units, fire detection and protection systems are available even after fuel assemblies are on-site. Also, compensatory measures are not in place nor effective in detecting and fighting fires even after fuel loading. Construction plan needs to be reviewed to ensure fire detection, protection, and suppression systems will be available well before first core load.

These lessons learnt are also applicable to new technology reactors or small size reactors highlighting the importance of highest level of operational readiness in the plan, people, and processes, programmes, and procedures. Also, earlier engagement in WANO activities will provide more focussed supports and interactions with other new members constructing new units, benefiting from benchmarking.

## Conclusion

While the scope of services can be optimised for new technology reactors including small size reactors, customised WANO services have been proved to be effective in supporting safe and successful startup and operation of new units. The performance of most of the 60 new units started operation in the last 10 years have been assessed as strong, even some of them as ‘exemplary’.

The lessons learned from these services highlight that continued efforts and supports are necessary in the areas of:

5.1 Operator Fundamentals

5.2 Quality construction and delivery of equipment

5.3 Protection of safety related equipment during construction and commissioning

5.4 Prevention of foreign material intrusion

5.5 Early availability of fire detection and protection systems

These lessons learnt areas are equally applicable to new units of both large and small nuclear power plants. The experience is that the earlier new units interact with other WANO members, the more the benefit for safe and reliable startup of new units. WANO new nuclear delivery team, consists of a representative from all regional centres are working to develop strategic approaches to ensure all new units startup and operate with highest level of safety and reliability.