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Submittal of X Energy, LLC (X-energy), Xe-100 Licensing White Paper: Maintenance Staff Optimization

The purpose of this letter is to submit the subject white paper to the U.S. Nuclear Regulatory Commission (NRC) on behalf of X Energy, LLC ("X-energy"). This paper describes the approach developed by X-energy to optimize the maintenance staffing plan for the Xe-100 reactor design and associated multi-unit plants. It is provided for NRC staff review and feedback as indicated in the paper. X-energy has determined this paper is available for unrestricted release. X-energy will work with NRC project management to develop the detailed review schedule.

This letter contains no commitments. If you have any questions or require additional information, please contact Ingrid Nordby at inordby@x-energy.com.

Sincerely,

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Xe-100 Licensing

Maintenance Staff Optimization

White Paper

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EXECUTIVE SUMMARY

This white paper presents the approach to determining the Maintenance staffing plan at an Xe-100 site. It reviews regulatory and industry documents relevant to the topic of Maintenance in nuclear power plants. It summarizes the philosophy and strategy developed for the Maintenance of the Xe-100, incorporating best practices from the nuclear and non-nuclear industry, where possible, to achieve an optimal maintenance plan that supports safe and reliable operation of the Xe-100 plants. This white paper accomplishes the maintenance staffing goals of the Department of Energy's (DOE) Advanced Research Projects Agency-Energy (ARPA-E) funding.

This white paper performs a review of industry and regulatory documents to determine the requirements of a maintenance staff in a nuclear power plant and provide an analysis-based approach to optimize maintenance staffing for the Xe-100. Current United States Nuclear Regulatory Commission (NRC) regulations for licensing the Xe-100 under 10 CFR Part 50 do not specify the staffing compliment for maintenance personnel. This white paper presents the methodology developed by X-energy and the Electric Power Research Institute (EPRI) to first define what maintenance is needed on the components critical to the safe and reliable operation of an Xe-100 plant. Then, through the use of the EPRI Preventive Maintenance Basis Database, EPRI Member experience, and EPRI Subject Matter Experts, the time and personnel requirements for each task are assessed. These results are then used to calculate the number of staff needed to support the execution of a Maintenance schedule aligned with ~~the~~ best practices in component maintenance strategies in the nuclear and non-nuclear industry.

X-energy is submitting this white paper to the NRC to communicate the strategy and methodology being applied to optimize maintenance staff levels required for safe and reliable operation of the Xe-100.

Note that the enclosed information is preliminary, pre-decisional, and subject to change as the design progresses. It is provided for planning and familiarization purposes in support of pre-application discussions with NRC Staff.

CONFIGURATION CONTROL

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ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
AI	Artificial Intelligence
ARDP	Advanced Reactor Demonstration Project
ARPA-E	Advanced Research Projects Agency-Energy
BOP	Balance of Plant
CBM	Condition Based Maintenance
DOE	US Department of Energy
EOPs	Emergency Operating Procedures
EPRI	Electric Power Research Institute
ERO	Emergency Response Organization
FIN	Fix-it-now
FTE	Full Time Employee
GEMINA	Generating Electricity Managed by Intelligent Nuclear Assets
LCO	Limiting Condition for Operation
LTSAs	Long-Term Service Agreements
LWR	Light Water Reactor
MSA	Maintenance Strategy Analysis
MTW	Maintenance & Training Week
NRC	US Nuclear Regulatory Commission
NEI	Nuclear Energy Institute
OBM	Operator Based Maintenance
O&M	Operations and Maintenance
PFT	Production Field Technician
PMBD	Preventive Maintenance Basis Database
PSAR	Preliminary Safety Analysis Report
RAP	Reliability Assurance Program
RIM	Reliability and Integrity Management
RTM	Run-to-Maintenance
SSCs	Structures, Systems, and Components

Abbreviation or Acronym	Definition
TBM	Time Based Maintenance

1. INTRODUCTION

X-energy is developing the Xe-100 modular high-temperature gas-cooled reactor (HTGR).

The Xe-100 combines proven pebble-bed, high-temperature gas-cooled reactor (HTGR) technology with conventional steam energy conversion technology in a new way that offers:

- Inherent nuclear safety, relying solely on natural laws and passive systems and components, including a large negative reactivity coefficient,
- Higher efficiency electricity production and/or supply of high-temperature steam,
- Sequential deployment of units in increments, which allows short construction times and revenue generation from initial units while subsequent units are being added,
- Online refueling, which effectively decouples planned maintenance outages from the fuel cycle,
- The ability to serve sites proximate to population centers or industrial facilities and/or with restricted water availability.

In the development of the Xe-100, the emphasis has been placed upon the use of established and proven technology. The Xe-100 reactor concept is based upon pebble-bed reactor technology previously demonstrated in past operating reactors and is presently being commissioned at commercial-scale reactors in China. The remainder of the Xe-100 plant utilizes conventional steam energy transport and conversion technology.

The US deployment of the Xe-100 is funded, in part, through the Department of Energy's (DOE) Advanced Research Projects Agency-Energy (ARPA-E) and Advanced Reactor Demonstration Project (ARDP) via cooperative agreement.

The ARPA-E GEMINA (Generating Electricity Managed by Intelligent Nuclear Assets) [16] project is intended to use advanced analytical modelling, monitoring, prediction algorithms and artificial intelligence (AI), which is centered on the development of a Digital Twin technology platform for advanced nuclear reactors. For the Xe-100 plants, the Digital Twin is a virtual representation of the Xe-100 reactor plant, with all systems modelled, that will span the lifecycle of the Xe-100 plants, be updated from real-time data coming from Xe-100 plants, and be the foundation for determining more effective and flexible operating and maintenance processes and procedures. The end goal of Digital Twin integration is to automate complex engineering tasks so that the results are always at your fingertips to improve decision making [20]. Relevant goals of the ARPA-E project are:

- Design tools that introduce greater flexibility and increase autonomy in operations for the systems in the Nuclear and Commercial Islands, which include the Reactor and Balance of Plant (BOP) systems.
  - X-energy refers to the "Reactor" and other components in the primary system as the Nuclear Island (NI). X-energy refers to the BOP systems as the Conventional Island (CI).
- Create a 10x reduction in Operations and Maintenance (O&M) costs at advanced reactor power plants, improving their economic competitiveness.

- Apply diverse technologies that are driving efficiencies in other industries, such as AI, advanced control systems, predictive maintenance, and model-based fault detection through means such as advanced pattern recognition (APR) or remaining useful life (RUL) algorithms.

Innovations are needed in the nuclear industry:

- Nuclear plants are shutting down permanently due to cost pressure and O&M costs are approximately 80% of the reactor plant total generating cost. Innovations in both inherently safe plant designs and in the advanced use of data analytics may be able to optimize and substantially reduce the future costs of O&M.
- Integrating AI, advanced data analytics, distributed computing, powerful physics simulation tools, and other breakthroughs are needed to advance autonomous, efficient, and lower the cost of O&M

The ARDP [17 and 18], within the DOE's Office of Nuclear Energy, is designed to help domestic private industry demonstrate advanced nuclear reactors in the United States. Advanced nuclear energy systems hold enormous potential to lower emissions, create new jobs, and build a strong economy. Rapidly demonstrating advanced reactor designs is necessary to provide clean energy and expand market opportunities before access to key infrastructure and supply chain capabilities in the United States is lost. In 2020, the DOE selected X-energy to deliver a commercial TRISO fuel fabrication facility and a four-module version of its Xe-100 high temperature gas cooled reactor.

To meet the goals of the ARPA-E and ARDP projects and primarily designing, constructing, operating and maintaining safe and reliable Xe-100 power plants, X-energy has developed a Maintenance Philosophy and Strategy. The philosophy and strategy will be presented in this white paper, as well as the method to determine optimum staffing levels needed for performing Xe-100 maintenance tasks.

1.1. PURPOSE

This white paper describes the approach X-energy has taken in developing an optimized maintenance staffing plan, for Xe-100 power plants. Xe-100 plants will be designed, constructed, and maintained to operate with high reliability and to achieve an optimal O&M budget in line with the goals of the DOE ARPA-E GEMINA project, while meeting applicable US regulatory requirements, including 10 CFR 50.65 (Maintenance Rule).

1.2. SCOPE

This white paper explains the research and methodology results that are used to develop the staffing plan for the Xe-100 plant personnel responsible for maintenance activities. "Maintenance" is bounded and defined based on NRC Regulatory Guide (RG) 1.160, Monitoring the Effectiveness of Maintenance at Nuclear Power Plants [23] and Federal Register Vol. 53, No.56, March 23, 1988 [7], which provides the following definition:

> *Maintenance is defined as the aggregate of those functions required to preserve or restore safety, reliability, and availability of plant SSCs. Maintenance includes not only activities traditionally associated with identifying and correcting actual or potential degraded conditions (i.e., repair,*

> *surveillance, diagnostic examination, and preventive measures) but extends to all supporting functions for the conduct of these activities. The activities that form the basis of a maintenance program are also discussed in the* 53 FR 9430 *"Final Commission Policy Statement on Maintenance at Nuclear Power Plants."*

Discussion on the importance of and best practices in implementing the various supporting functions are provided in Section 4 Xe-100 Maintenance Philosophy [1] and Section 5 Xe-100 Maintenance Strategy [2].

1.3. APPROACH TO MAINTENANCE OF AN XE-100 PLANT

The goal of an optimized maintenance strategy for the Xe-100 is to enhance the safety and reliability of the plant by developing a highly effective maintenance program, to attain the Xe-100 target of 95% availability [15] and to reduce the nuclear plant O&M cost (one of the goals of the ARPA-E GEMINA project). One of the most significant costs of Maintenance is the cost of permanent on-site personnel, so the optimized maintenance strategy approach is designed to identify ways of multiplying the effectiveness of on-site maintenance staffing and leveraging their capabilities in the maintenance program.

The Xe-100 Maintenance Philosophy [1] and Xe-100 Maintenance Strategy [2] documents were developed for Xe-100 by the EPRI Nuclear Maintenance Application Center, based on the most up-to-date experiences with industry-wide advanced maintenance methods, and are summarized in Sections 4 and 5 of this white paper. These documents contain the results of the research intended to provide methodologies and process/program guidance to achieve an optimized maintenance strategy for the Xe-100.

As discussed in the Xe-100 Technology Description Technical Report, the Xe-100 is a unique reactor with many benefits regarding safety, automation, and reliability. Although best practices from the nuclear industry are being applied, the approach to the Xe-100 maintenance staffing planning includes a review and analysis of innovative staffing and maintenance strategies applied in non-nuclear power plants that are able to achieve O&M rates of < $10/MWhr, while including practices not commonly seen in nuclear power that can bring other savings or efficiencies.

Since one of the initiatives of the DOE ARPA-E GEMINA project is to use advanced analytical technologies like a Digital Twin to enhance the effectiveness of the maintenance program, X-energy is evaluating experiences in several industries where the latest Digital Twin developments are being applied. Based on this evaluation, efficiencies are expected to be developed that benefit the Maintenance Staffing. Examples of possible applications of the Digital Twin when paired with Augmented (AR) or Mixed Reality (XR) applications, such as portable tablet computers for production field technicians, are:

- Visible notifications of components in the field with parameters out of normal
- Accessing Xe-100 component and system drawings and documents, creating notifications of deficiencies during inspections
- Ready means of audio, video and AR communicating with Xe-100 remote SMEs.
- Assistance in Correct Component Verification process

- Through integration with the Safe Work Clearance boundary and 3D models of the Xe-100, system boundaries can be highlighted for verification of condition before starting work.
- Utilization of AR or XR guided procedures for infrequent or critical maintenance tasks and inspections.
- Effective dress-rehearsal of maintenance activities to promote efficient execution of process steps while keeping radiation exposure as low as reasonably achievable

1.4. DOCUMENT LAYOUT

The document will be presented in five sections:

- **Section 2 – Xe-100 DESIGN:** This section will provide a brief overview of the Xe-100 in regard to safety and other relevant information needed to establish the early basis for a non-traditional staffing plan compared to a typical US commercial nuclear power plant. This information is provided with the assumption that readers of this white paper are familiar with the content discussed within this section. Reviewers are advised to reference the "Xe-100 Technology Description Technical Report" [Braudt 2021], ADAMS Accession Number ML21120A330 [3] for details on the Xe-100 design and unit and plant operations.
- **Section 3 – OVERVIEW OF US REGULATORY REQUIREMENTS:** This section will perform a review of US regulatory requirements relevant to Maintenance staffing, organization, training, and other relevant sub-topics at nuclear plants.

- **Section 4 – Xe-100 MAINTENANCE PHILOSOPHY:** This section provides a summary of the maintenance philosophy of the Xe-100 high temperature gas reactor power plant. This document was created to influence the Xe-100 plant design and construction to support a reduced O&M cost for an Xe-100 plant but is very applicable to the staffing of maintenance personnel at an Xe-100.

- **Section 5 – Xe-100 MAINTENANCE STRATEGY:** This section discusses the Maintenance Strategy Analysis (MSA) methodology to be used to develop the Xe-100 Maintenance Program and defines the processes that will be required to support an optimal maintenance strategy. The method of analysis of the Xe-100 plant Structures, Systems, and Components (SSCs) supports the initial plan for the maintenance strategy, schedule, staff, and implementation plan for the Xe-100. Development of the Xe-100 MSA may result in changes to the baseline Xe-100 staffing plan as initially proposed. Results of the MSA will be used to help determine the need for possible changes to the plant design, the use of contractors and technologies, the training curriculum, and other considerations to develop the Xe-100 optimal Maintenance Program.

- **Section 6 – Xe-100 MAINTENANCE STAFFING ANALYSIS METHODOLOGY:** This section will describe the Maintenance Staffing Analysis Process and provide an example of how the amount of maintenance task performing personnel that are needed for a Xe-100 plant can be determined.

2. XE-100 DESIGN

The overview of the Xe-100 plant design and key safety features has been provided to the NRC staff in the Xe-100 Technology Description Technical Report [Braudt 2021] [3]. With the expectation of fewer safety related systems and components, in addition to other factors, smaller footprint, standard designs, and appropriate design for maintainability, for example, the burden on maintenance task performing personnel is expected to be much less than the existing Light Water Reactor (LWR) nuclear fleet in the US. Ultimately, the Maintenance Staffing Analysis process (see Section 6) will determine the required maintenance staff needed based on the tasks required to maintain the Xe-100 components in accordance with the Xe-100 Equipment Reliability Program.

3. OVERVIEW OF US REGULATORY REQUIREMENTS

This section reviews US NRC regulatory requirements for insight and applicability to Xe-100 high temperature gas reactor nuclear power plant maintenance staffing levels and organizational alignment.

Current US NRC regulatory requirements were developed for commercial LWRs commonly used in the United States. The Xe-100 licensing approach will follow 10 CFR Part 50 for the preparation for a construction permit and operating license application for the Xe-100 plant planned for ARDP. This section discusses 10 CFR 50 requirements relevant to the Xe-100 maintenance strategy.

3.1. 10 CFR 50, DOMESTIC LICENSING OF PRODUCTION AND UTILIZATION FACILITIES

3.1.1. Appendix B Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants

10 CFR 50, Appendix B Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants (Appendix B To Part 50—Quality Assurance Criteria For Nuclear Power Plants And Fuel Reprocessing Plants | NRC.gov) [4] provides requirements for a quality assurance program. These requirements are applicable to the maintenance program and impact the development of administrative controls such as instructions, procedures, parts and component control, control and qualification for special process such as welding and non-destructive testing, inspection, test control, control of measuring and test equipment, handling, shipping, storing, cleaning, measures to indicate the status of inspections and tests performed and to prevent inadvertent operation, installing, testing, operating, maintaining, repairing, modifying SSCs, records, and corrective action. Staffing of personnel performing maintenance activities supporting these activities must be sufficient to support and perform these tasks.

3.1.2. 10 CFR 50.55a, Codes and standards

10 CFR 50.55a [5] provides requirements for the use of nuclear industry codes and standards the NRC has incorporated by reference (§ 50.55a Codes And Standards. | NRC.gov). Requirements for activities such as examination and testing of components are provided that may be applicable to Xe-100 plants. Maintenance staffing and organizational alignment of Xe-100 plants will be implemented to meet these requirements if they are deemed applicable.

3.1.3. 10 CFR 50.65, Requirements for monitoring the effectiveness of maintenance at nuclear power plants

10 CFR 50.65 [6], referred to as the “Maintenance Rule” provides four rules to monitor the structures, systems, and components (SSCs) against licensee-established goals, in a manner sufficient to provide reasonable assurance that these SSCs are capable of fulfilling their intended functions. The following SSCs are included in the scope of the Maintenance Rule:

- Safety-related
- Non-safety related
    - Relied upon to mitigate accidents or transients or are used in plant emergency operating procedures (EOPs)
    - Whose failure could prevent safety-related structures, systems, and components from fulfilling their safety-related function
    - Whose failure could cause a reactor scram or actuation of a safety-related system

Maintenance Rule does not specify a staffing size or recommend an approach to maintenance staffing but does define the requirements for SSCs to keep them capable of fulfilling their intended functions as described in the plant's licensing basis. Sufficient staffing is required to implement the Maintenance Rule as well as other conditions-based monitoring.

In accordance with RG 1.233 (Guidance for a Technology-Inclusive, Risk-Informed and Performance-Based Methodology to Inform the Licensing Bases and Content for Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors), and industry in NEI 18-04 and in the Technology Inclusive Content of Application Project (TICAP) and Advanced Reactor Content of Application Project (ARCAP) guidance under development, the Xe-100 will designate SSCs as safety-related, non-safety related with special treatment, and non-safety-related with no special treatment. X-energy anticipates its approach will be consistent with the guidance for Advanced Nuclear Reactors published by NRC and industry in 10 CFR 53 Subpart F (Licensing and Regulation of Advanced Nuclear Reactors (DRAFT).

Because the Xe-100 refuels online and essentially continuously, the Xe-100 Maintenance Rule Program will need to define a risk-informed frequency for establishing performance and condition monitoring activities and associated goals and preventive maintenance activities.

A large amount of regulatory guidance related to maintenance exists for current LWRs has been created or evolved due to their specific design and operational requirements and experience. These other regulatory references may provide requirements that should be considered in the development of maintenance staffing depending on the requirements included in Regulatory Guide 1.233 and NEI 18-04. NEI 18-04 provides guidance on required maintenance for safety related SSCs, non-safety related SSCs with special treatment, and non-safety related SSCs This includes Reliability Assurance Program (RAP), Maintenance Rule, and Reliability and Integrity Management (RIM) programs as detailed in Table 4-1 of NEI 18-04. Additional regulations and guidance that will be considered include:

- Regulatory Guide 1.160, Monitoring the Effectiveness of Maintenance at Nuclear Power Plants
    - https://www.nrc.gov/docs/ML1136/ML113610098.pdf
- 10 CFR 50 Appendix B Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants
    - https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appb.html
- 10 CFR 50.120: Training and qualification of nuclear power plant personnel
    - https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0120.html
- 10 CFR 50, Appendix E: Emergency Planning and Preparedness for Production and Utilization Facilities
    - https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appe.html

- 10 CFR 26, Fitness for Duty Program
  - https://www.nrc.gov/reading-rm/doc-collections/cfr/part026/index.html
- NRC Generic Letter 83-14, Definition of "Key Maintenance Personnel," (Clarification of Generic Letter 82-12)
  - https://www.nrc.gov/reading-rm/doc-collections/gen-comm/gen-letters/1983/gl83014.html
- 10 CFR PART 53, Licensing and Regulation of Advanced Nuclear Reactors (DRAFT)
  - https://www.nrc.gov/reactors/new-reactors/advanced/rulemaking-and-guidance/part-53.html
  - Subpart A - General Provisions
    - https://www.nrc.gov/docs/ML2111/ML21112A195.pdf

3.1.4. **10 CFR 50.34, Contents of applications; technical information.**

10 CFR 50.34 [23] provides the requirements for the technical information that is to be submitted with a Preliminary Safety Analysis Report (PSAR). Regarding maintenance, section b.6.iv states, "*Plans for conduct of normal operations, including maintenance, surveillance, and periodic testing of structures, systems, and components.*"

Information generated through the maintenance strategy effort relevant to the above will be included in the submittal for the PSAR, as applicable.

3.2. 10 CFR PART 53 LICENSING AND REGULATION OF ADVANCED NUCLEAR REACTORS

10 CFR Part 53 is a new set of regulations currently being developed for advance non-LWRs. The novel design of these type reactors requires a new and unique rule structure. The development of the rule is currently progressing, and the two applicable sections below represent the latest information from the draft.

3.2.1. **Draft 10 CFR 53 Subpart F - Requirements for Operations**

Draft 10 CFR 53 Subpart F was reviewed with a focus on Xe-100 Maintenance Staffing. The document generally requires a staffing plan that considers, at minimum, resources for training, qualification and ERO, but is not specific on the quantity or explicit roles of personnel in this staffing plan.

The following subsections of Subpart F are provided as acknowledgement of the applicable rules and regulations. The guidance within will be used to develop the detailed maintenance staffing plan that includes the resources as necessary for training, qualification and ERO duties.

- **10 CFR 53 53.750 – 53.799** addresses areas related to staffing, training, qualifications, and human factors. This is mostly directed to the Operations and Training staffing and does not directly address Maintenance staff. However, as discussed in the Xe-100 Maintenance Staffing Analysis in Section 6, personnel performing tasks traditionally assigned to Operations, building operators for example, will also perform maintenance tasks as an Operations and Maintenance cross-trained technician.

- **10 CFR 53.753 (f)(2)** includes the need for the staffing plans to contain the numbers, positions, and responsibilities of personnel providing support in areas such as Maintenance and the Emergency Response Organization (ERO).

It is important to note that Subsection F is in the DRAFT phase and further development and guidance may be incorporated. X-energy's Licensing and Maintenance personnel are monitoring the development of Subpart F for further requirements applicable to the Maintenance Staff.

4. XE-100 MAINTENANCE PHILOSOPHY SUMMARY

Research organizations, like the EPRI, have been researching methods to improve maintenance, reliability, and reduce costs in new nuclear SMR fleets for several years. X-energy contracted with the EPRI to consolidate this research and create the Maintenance Philosophy for the Xe-100 plant. The EPRI Nuclear Maintenance Application Center (NMAC) leads the initiative and collaborated with many of the sectors within EPRI to collect the best practices in maintaining generating stations, from its existing and ongoing research and membership. EPRI also extended the search for best practices in the areas of maintenance and technology beyond the electric power / energy industry, contacting personnel and reviewing literature from military, refinery, manufacturing, airline, automotive, and other industries.

The Xe-100 Maintenance Philosophy Report [1] consolidates the collected best practices, and technologies and applies it to the Xe-100, X-energy HTGR SMR (Xe-100). A listing of the major core concepts relevant to Maintenance Staff optimization from the Xe-100 Philosophy Report are provided below.

1. Prioritizing Reliability and Maintainability in the Design and Construction phases
2. Standardizing the Xe-100 SSCs to gain the benefits of standardization in areas like design, operation, maintenance, inventory management, training, monitoring and diagnostics, and contract costs.
3. Understanding inputs into minimum staffing requirements at Nuclear Power Plants and refining them based on best practices (e.g., Delivering the Nuclear Promise documents) including:
    - Utilizing cross-training of on-site personnel to perform the function of both operations and maintenance personnel.
    - Centralizing departments and functions that can support all Xe-100 plants remotely and reduce redundant site staffing.
        - For example: Work Planning, Engineering, Training, Supply Chain, Outage and Major Maintenance Planning, etc.
    - Replacing activities historically performed by personnel with automation.
    - Utilization of robotics, sensors, and cameras for monitoring and maintenance/operator rounds data acquisition.
    - Emphasizing the importance of connectivity for on-site and Central personnel support and communications.
    - Using advance technologies like Augmented Reality for communication, training, and in field support.
    - Training Program optimization considerations.
    - Supply Chain staff optimization consideration.
    - Use of off-site-based traveling support teams going from plant to plant (X-energy-based or contractor-based) as resource teams to perform specialty periodic maintenance services between outages (e.g., calibration checks).
    - Utilizing Long-Term Service Agreements to outsource frequently and/or infrequently performed specialty skill and labor-intensive tasks to Original Equipment Manufacturers (OEMs) and Equipment Vendors.

5. XE-100 MAINTENANCE STRATEGY [2]

A Maintenance Strategy is the cyclical process that exists in an organization to maintain the overall facility at the desired level of reliability. The development of a maintenance strategy is essential to achieve a higher level of plant reliability in any form of plant, electric power generating or other. There are several organizations, functions, and processes that must be in place for the optimal Maintenance strategy to be developed, implemented, and improved over time. The Maintenance Strategy is presented initially in Figure 1 below.

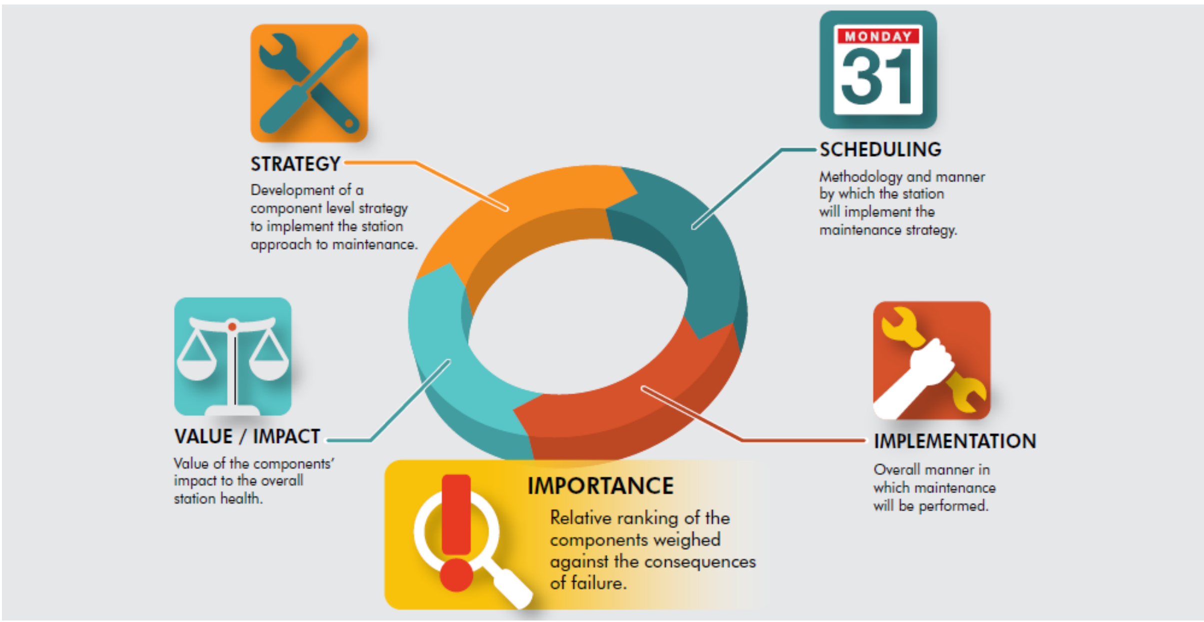

Figure 1: Xe-100 Maintenance Strategy Evaluation Process

Summarizing the process, the analysis begins with the design of the plant, its modes of operation, and the selection of SSCs. This enables an evaluation to be performed that determines the **IMPORTANCE, VALUE** and **IMPACT** the SSC has on the Xe-100 plant's safety, operational and business goals. This evaluation is essentially the ***Equipment Reliability*** process described in INPO's AP-913 [24], Equipment Reliability Process Description document. The Strategy is then created to maintain the SSC in a manner that aligns with its previously defined Importance, Value, and Impact. The **STRATEGY,** or Maintenance Strategy, is the method of identifying the SSC's failure modes and selecting the appropriate methods (i.e., component monitoring, time-based tasks, repair-vs-replace, etc.) for each SSC to ensure it operates reliably in accordance with the needs of the plant. Once the strategy is developed, the activities are tracking and executed in accordance with the **SCHEDULES** for the online or outage maintenance periods and the strategy is **IMPLEMENTED** by the maintenance activities of the staff through a condition-based or time-based maintenance approach.

It is important to note that the Maintenance Strategy Analysis process is a cyclical process, meaning this process is expected to be reviewed and changed to improve strategies applied to SSCs to increase SSC reliability over the life of the Xe-100 plant.

The figure below introduces the Foundational Elements. To efficiently navigate through the Maintenance Strategy Evaluation process, an organization should possess the Foundational Elements (i.e., tools, programs, and processes) in the areas of Design Basis, Configuration Control, Enterprise Asset Management and Risk. The foundational elements allow an organization to utilize plant information effectively during the development, implementation, and improvement of an optimal maintenance strategy throughout the life of the plant.

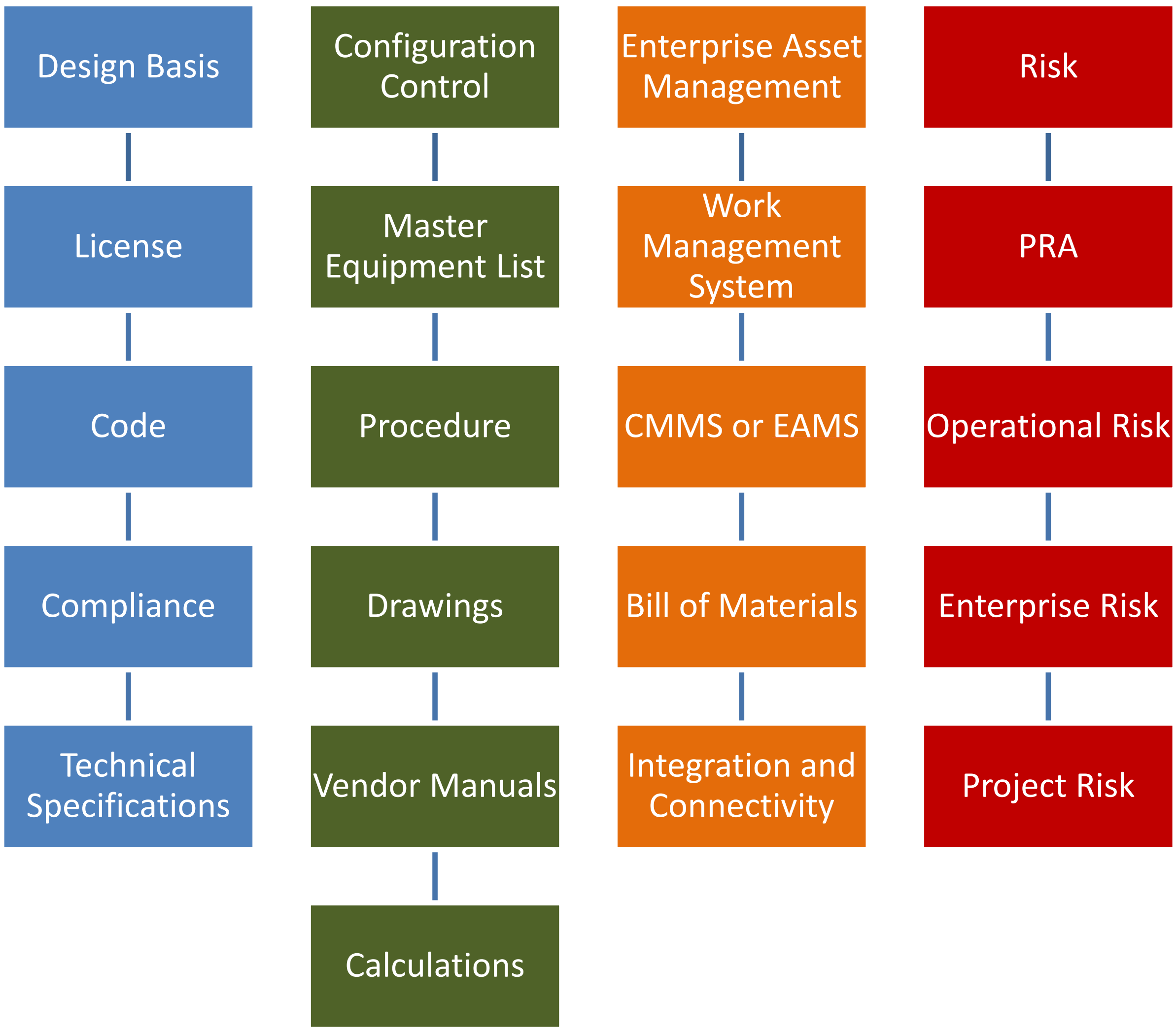

Figure 2: Foundational Elements of an Effective Maintenance Strategy

These foundational elements are common tools in the industry, and as such, will not be discussed further in this white paper. EPRI document 3002009068, Maintenance Strategy Reference Guide Overview [19], explains the fundamental elements. This is a publicly available document available for download at www.epri.com.

5.1. XE-100 MAINTENANCE STRATEGY EVALUATION PROCESS EXPLAINED

The following sections will describe the activities being performed by X-energy to develop the Maintenance Strategy for the SSCs in the Xe-100 design. This process is explained because the selected Maintenance Strategy ultimately determines what maintenance tasks must be performed to maintain the SSCs as required by the Xe-100 Equipment Reliability Process, discussed in the following Section 5.1.1. These tasks form the baseload of the Maintenance Schedule for Xe-100 and directly affect the staffing needed to maintain the Xe-100.

5.1.1. Xe-100 Equipment Reliability Process: Determining the SSC's Importance, Value, and Impact

Through the Xe-100 Equipment Reliability Process, currently under development, the Importance, Value, and Impact of the SSCs in the Xe-100 plant will be defined and classified using a Criticality Scale applicable to the Xe-100 design and licensing bases as well as business case bases. This process will determine the strategies to be used for each SSC and the priorities for available staffing. This process will also incorporate best practices and guidance from the current US nuclear fleet from various industry guidance documents [11, 12, & 13].

The resulting classification of the Xe-100 SSCs will become one of the essential inputs into the Strategy portion of the Maintenance Strategy Evaluation Process to identify the level at which the SSCs must be maintained by Maintenance tasks.

5.1.2. Developing the Maintenance Strategy for the Xe-100 SSCs

The process of developing the Strategy for a given SSC can be described in the steps presented for a component case in Table 1.

It is important to restate that the Maintenance Strategy Analysis process is a cyclical process, meaning this process is expected to be reviewed and changed to improve strategies applied to SSCs to increase SSC reliability over the life of the Xe-100 plant.

Table 1: Maintenance Strategy Analysis Process

1. Classify the component into a logical group by component type	8. Determine the most effective Maintenance Tasks that address the failure modes a. This step considers replacement in lieu of in-situ repair or refurbishment if time and cost savings can be realized
2. Define the boundary of component	9. Assign task effectiveness against the failure modes
3. Collect references	10. Evaluate Sensors and Predictive Monitoring as an alternative to performing PM Tasks
4. Define Criticality	11. If allowed by the Xe-100 Equipment Reliability Process, determine if the task can be performed as

	required following a "Run to Maintenance" strategy
5. Define Duty Cycle	12. Determine the necessary frequency for the Time-based Maintenance tasks, given the expected time to failure of the failure modes addressed by the task
6. Define Service conditions	13. Determine if Condition-Based Maintenance can be performed in lieu of Time-Based Maintenance
7. Perform Failure Modes and Effects Analysis (FMEA)	14. Finalize the Maintenance Strategy in a living PM Basis Document

X-energy is intentionally utilizing many off-the shelf components in the Xe-100 power plant design as part of the standardization and cost reduction effort. However, there is a need for first-of-a-kind (FOAK) components and FOAK environmental conditions in the Xe-100 reactor and reactor support systems (e.g., the cartridge valves in the Fuel Handling System and the fuel sphere unloader at the base of the reactor vessel). It is important to note that the **Table 1** process is applicable to both existing designs and FOAK components.

This **Table 1** process has been developed and refined over 30 years by EPRI as the core process of the Preventive Maintenance Basis Database (PMBD) Component Maintenance Templates. The PMBD has become a standard in the in electric power industry for determining the optimal maintenance strategy for components in power plants. New components can be added to the PMBD by members and EPRI SMEs.

More information on the PMBD is available in the following publicly available EPRI products:

- 3002007394, Preventive Maintenance Basis Database (PMBD): Quick Reference Guide
  - https://www.epri.com/research/products/000000003002007394
- 3002007555, Preventive Maintenance Basis Database (PMBD) Familiarization Video
  - https://www.epri.com/research/products/000000003002007555

5.1.3. **Developing the Implementation Method for the selected Maintenance Strategy for the Xe-100 SSCs**

The maintenance implementation method for each SSC is determined in the Maintenance Strategy evaluation process. The most successful blend of implementation strategies for the Xe-100 have been evaluated and determined to be:

- Condition Monitoring with Time-Based Maintenance (TBM) and Feedback Process
  - This strategy is the most effective maintenance strategy to apply to components that have a proven time-based failure mode(s) propagation but can benefit from the application of condition monitoring to identify unexpected degradation and prevent

failures that challenge plant goals. The feedback process allows for task frequency adjustments based on as-found information during maintenance activities.

- Condition Monitoring with Condition Based Maintenance (CBM)
  - This stage incorporates the use of predictive and condition monitoring techniques as the primary input to performing maintenance. This stage minimizes cost and maximizes reliability by performing maintenance when maintenance is needed. The site monitors failure modes and the work management system are flexible so needed maintenance can be performed prior to component failure.

- Run-to-Maintenance (RTM)
  - This strategy is for the least critical and least important components. This can also be applied to components where the cost of performing condition monitoring, time-based maintenance or Condition-based maintenance is cost prohibitive to the cost of a failure and the resulting emergent maintenance costs. This strategy does not apply Condition monitoring or time-based activities but repairs the component when it has failed. The repair would not need to be pre-planned on a time-based frequency, but rather planned after the component fails and scheduled according to the plant risk.

One of the above implementation methods will be applied to the selected maintenance tasks for each Xe-100 component analyzed by the Maintenance Strategy Analysis process.

An example of this is presented below in Table 2 for a critical Horizontal - Single Stage - Single Suction Pump:

Table 2: Example Maintenance Strategy for a Critical Horizontal - Single Stage - Single Suction Pump

TASK	Implementation Method	Frequency if applicable
Refurbishment/Replacement	CBM	As Required
Acoustic Monitoring	CBM	3 Months
Functional Testing	TBM	2 Years
Oil Analysis	TBM	6 months
Operator Rounds	TBM	Once per shift
Packing or Seal Replacement	CBM	As Required
Performance Trending	TBM	2 years
Technical Walkdown	TBM	3 months
Vibration Analysis	TBM	1 month

NOTE: A run to maintenance (RTM) method is not applied because failure of this component is not acceptable.

Various aspects of the Work Management systems have been converted to electronic and in some instances automated to reduce staff requirements, improve efficiencies in work planning and execution, to reduce costs associated with Operations and Maintenance budgets. Examples of advanced work management process enabled through software applications and process enhancements in use in commercial nuclear plants today are provided below.

- Providing software applications to accelerate creation of initiating a work request based on a deficient condition on a component.
- Use of auto-assisted work planning tools developed to streamline processes and reduce workload involved with processes of screening, planning, and compiling work packages.
- Use of resource awareness tool to optimize scheduling through bundling similar work opportunities, displaying worker profiles, determining the need for walkdowns, and tracking task progress.
- Use of advanced dashboards to validate worker skills and qualifications.
- Application and removal of holds based on criteria affecting work process flows.
- Automated archival of work packages upon completion of work.

Advanced Work Management tools like those listed above optimize the work management processes required to identify, prepare, schedule, execute, and process for record retention. These advancements have allowed for optimization in Maintenance planning and Scheduling staffs.

For additional information, including financial analyses are available in EPRI document 3002020884, “Nuclear Plant Modernization Business Case: Business Process Automation for Online Work Management” [21].

5.1.4. **Developing the Schedule of the selected Maintenance Strategy and Implementation Methods for the Xe-100 SSCs**

The Schedule is the tool by which the plants’ risk is minimized, goals are met, while allowing the required maintenance tasks to be performed at the frequency needed, by the appropriate personnel. Tracking and planning for the execution of the selected Maintenance Strategy time-based, condition-based, or emergently required (i.e., RTM) maintenance tasks are performed through use of a Maintenance Schedule.

Foundational Elements (e.g., tools, programs, and processes) like Risk, Design, Enterprise Asset Management Systems are inputs into the Work Management Process, which includes the scheduling tool. The Xe-100 Maintenance Strategy [2] describes considerations when developing and maintaining the schedule in the discussions provided on the Foundational Elements.

6. MAINTENANCE STAFFING ANALYSIS

The X-energy Xe-100 Maintenance Staffing Analysis methodology has been developed with the support of EPRI in the Xe-100 Maintenance Strategy document [2].

The outcome of the process explained in Section 5, Maintenance Strategy, will create a population of tasks. Each task will require qualified personnel, appropriate level of work instructions, time, and materials to be allocated in the schedule to execute the task in accordance with the Maintenance Strategy. These tasks will be reviewed by the Xe-100 Training Program to understand the knowledge and skills necessary to qualify the personnel performing the tasks. The personnel at the Xe-100 plant are expected to be permanent Xe-100 site staff, specialty Xe-100 Maintenance SMEs (Fuel Handling components, for example), and contracted Vendors and Original Equipment Manufacturers.

The above approach is very similar to the common practices in a US Nuclear plant today; however, due to the robust nature of the inherent and passive safety features anticipated in the Xe-100 design (see Section 2), the Xe-100 has the potential to take advantage of traditionally non-nuclear Maintenance staffing plans and apply technologies that are effective in staff reduction in industries outside of nuclear power.

The training programs for the positions described below are in development and will be completed as required to support the ARDP project schedule.

The following sections will explain Maintenance Staffing Strategy for the Xe-100 plant and how it will be developed as the Maintenance Strategy Analysis continues. First, in Section 6.1 the personnel that will perform Maintenance activities will be described. In Section 6.2, the Maintenance Staffing Analysis Process will be presented, and an explanation will be provided for how the required staffing numbers are determined.

6.1. IDENTIFYING PERSONNEL THAT WILL PERFORM MAINTENANCE ACTIVITIES AT XE-100 PLANTS

The following sections will describe the Xe-100 organizations and staff that perform maintenance activities.

6.1.1. Centralized Production Support Center

A critical aspect of the staffing plan for an Xe-100 is understanding the concept in the non-nuclear power plant industry referred to as “Production.” A Production Organization is a combination of the Maintenance and Operations departments that are typically separated in the US Nuclear utilities, but often combined in the non-nuclear industry. Production organizations often rely on centralized organization that contains the functional departments like Engineering, Work Control, Inventory Management, Training, and Outage and Major Project Management, for example.

X-energy is applying this approach in the form of the Production Support Center, or PSC, to provide the necessary functions required for the operation and maintenance at all of the Xe-100 plants, as well as the support of the personnel stationed at the site.

The working DRAFT of the Maintenance Division in the Xe-100 PSC is provided below in Figure 3 for reference.

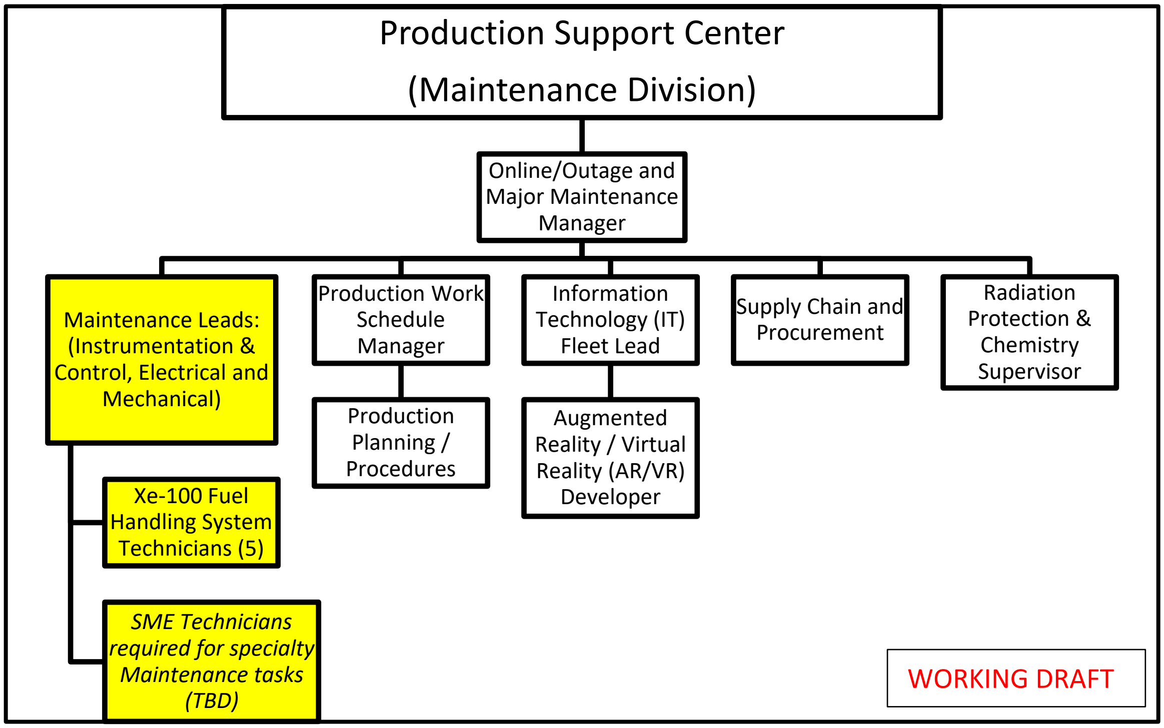

Figure 3: WORKING DRAFT Maintenance Division – Xe-100 Production Support Center

Personnel that perform maintenance have been highlighted yellow in **Figure 3** and will be explained in subsection 6.1.1.1 that follows.

The personnel in this organization will support several functions, like but not limited to:

- Developing the necessary work orders and procedures.
- Managing the Maintenance schedules for the Xe-100 plants.
- Managing inventory based on normal stock levels and future maintenance activities.
- Providing onsite subject matter expertise and oversight for online, outage and major project maintenance periods.
- Providing subject matter expertise remotely to personnel on site, through traditional means and Augmented or Mixed Reality functions.
- Managing the contracts for supplemental personnel and long-term service agreements (LTSA) at the Xe-100 required to supplement the station staff during online, outage and major project maintenance periods.

The final configuration and staffing of this organization will be evaluated further, with the final numbers, and justifications for the numbers determined through job-tasks analysis, Xe-100 plant coverage requirements, and Human Factors Engineering (HFE) evaluations.

A plant staffing and functionality plan has been developed in an Xe-100 plant staffing analysis and report.. XE01-P-X-Z-D_000077_Xe-100 Plant Staffing Report [8].

6.1.1.1. PSC Personnel that perform maintenance activities

The personnel in the PSC that will support or execute the maintenance tasks developed in the maintenance strategy analysis process are as follows:

- Maintenance Leads: (Instrumentation & Control, Electrical and Mechanical)
    - The Maintenance Leads are Maintenance personnel in the PSC that possess the technical skills and expertise necessary to support and oversee the more complex maintenance activities at the Xe-100 plants.
    - Their roles and responsibilities include:
        - Function as the primary point of contact for technicians at the Xe-100 for technical support during performance of maintenance tasks.
        - Provide support in addition to what is provided from Engineering, vendors, and other sources, to the Station Production Field Technicians as needed in complex maintenance activities (preferably with Augmented or Mixed Reality in lieu of travel when possible).
        - Travel to the stations and provide onsite support and oversight for the Outage and Major Maintenance activities in their respective disciplines.
        - Interface with Maintenance Service Providers to develop the Long-Term Service Agreements (LTSAs) or short-term contracts necessary for the support of maintenance activities in their assigned coverage areas in the Online, Outage and Major Project Schedules.
        - Serve as the Single Point of Contact for their scope during Online, Outage and Major Maintenance activities to resolve issues encountered during execution.
- Xe-100 Fuel Handling System Technicians
    - The Xe-100 Fuel Handling System Technicians Maintenance personnel in the PSC that possess the technical skills and expertise in the FOAK components in the Reactor and Fuel Handling systems in the Xe-100 plants.
    - Their roles and responsibilities include:
        - Function as the primary point of contact for technicians at the Xe-100 for technical support during performance of maintenance tasks.
        - Travel to the stations as required to perform maintenance tasks, provide onsite support, or oversight for the Online, Outage and Major Maintenance activities on the Xe-100 Fuel Handling SSCs.
        - Provide support in addition to what is provided from Engineering, vendors, and other sources, to the Station Production Field Technicians as needed in maintenance activities on the Fuel Handling System SSCs (preferably with Augmented or Mixed Reality in lieu of travel when possible).
        - Interface with Maintenance Service Providers to develop the Long-Term Service Agreements (LTSAs) or short-term contracts necessary for the support of maintenance activities related to the FOAK Fuel Handling System SSCs.
        - Serve as the Single Point of Contact for the Fuel Handling system related scope during Online, Outage and Major Maintenance activities to resolve issues encountered during execution.

As a placeholder, the "SME Technicians required for specialty Maintenance tasks" has been provided for tasks that may require a more specialized skill set of the personnel located at the Xe-100 sites. Personnel in this area may be Turbine/Generator, Steam Generator or other complex component Maintenance SMEs that can be dispatched to stations to lead or perform maintenance tasks in their area of expertise.

6.1.2. **Standard Xe-100 Site Staffing Plan (baseline)**

The Xe-100 site baseline Production Staff is provided in the form of a baseline organizational chart as a reference in **Figure 4** below. The number of personnel in each role is provided below in a parenthetical but will be adjusted in response to the outcome of the Maintenance Strategy Analysis, Job-Task analyses, and human factors engineering (HFE).

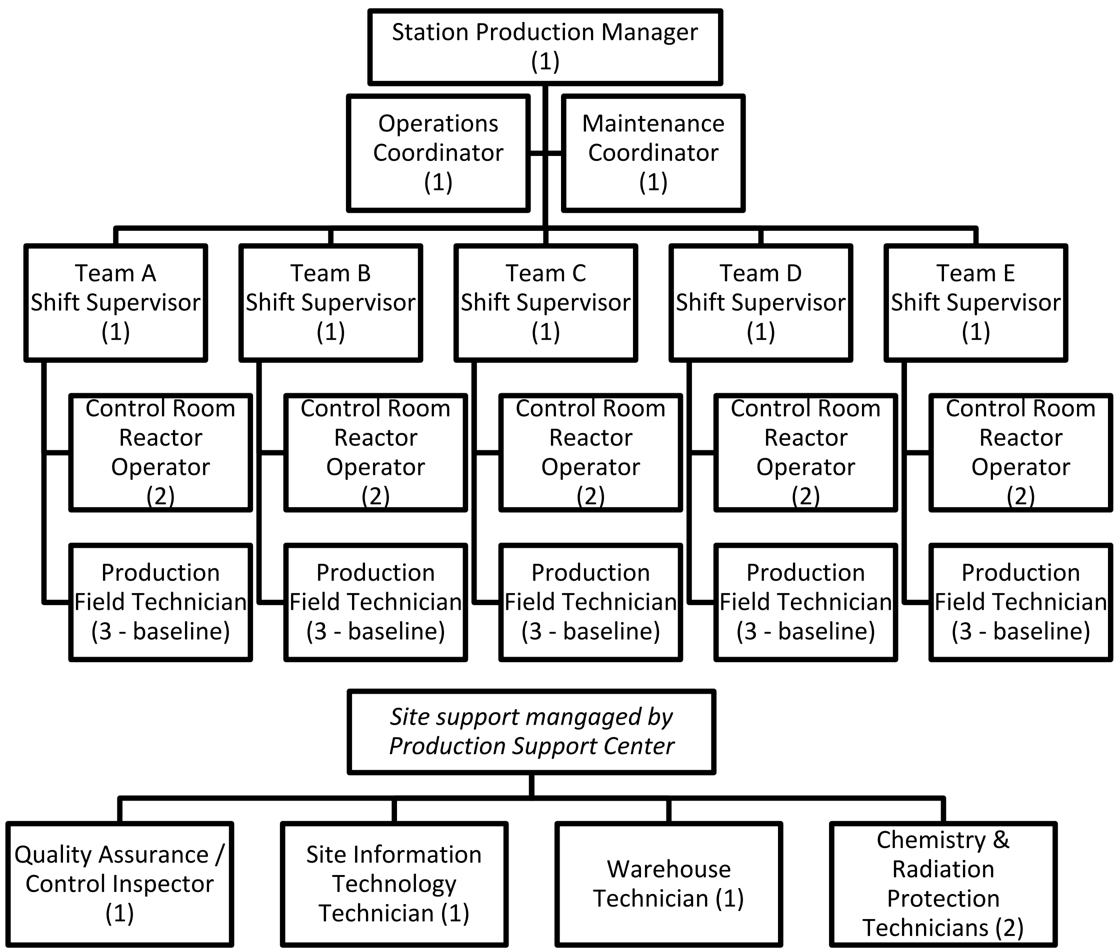

Figure 4: WORKING DRAFT – Standard 4 x Xe-100 Site Production Staff

It is important to note at this time that the 5 Team approach will utilize a 5-shift rotation to allow time for necessary training and for the performance of maintenance activities that cannot be performed when on-shift. **Table 3** below provides an example of the rotating schedule being considered for the Production Teams.

Weekday	Team A	Team B	Team C	Team D	Team E
Mon	TRNG	OFF	NIGHT	OFF	DAY
Tue	TRNG	OFF	NIGHT	OFF	DAY
Wed	TRNG	NIGHT	OFF	DAY	OFF
Thu	MTW	NIGHT	OFF	DAY	OFF
Fri	MTW	OFF	NIGHT	OFF	DAY
Sat	OFF	OFF	NIGHT	OFF	DAY
Sun	OFF	OFF	NIGHT	OFF	DAY
Mon	DAY	TRNG	OFF	NIGHT	OFF
Tue	DAY	TRNG	OFF	NIGHT	OFF
Wed	OFF	TRNG	NIGHT	OFF	DAY
Thu	OFF	MTW	NIGHT	OFF	DAY
Fri	DAY	MTW	OFF	NIGHT	OFF
Sat	DAY	OFF	OFF	NIGHT	OFF
Sun	DAY	OFF	OFF	NIGHT	OFF
Mon	OFF	DAY	TRNG	OFF	NIGHT
Tue	OFF	DAY	TRNG	OFF	NIGHT
Wed	DAY	OFF	TRNG	NIGHT	OFF
Thu	DAY	OFF	MTW	NIGHT	OFF
Fri	OFF	DAY	MTW	OFF	NIGHT
Sat	OFF	DAY	OFF	OFF	NIGHT
Sun	OFF	DAY	OFF	OFF	NIGHT
Mon	NIGHT	OFF	DAY	TRNG	OFF
Tue	NIGHT	OFF	DAY	TRNG	OFF
Wed	OFF	DAY	OFF	TRNG	NIGHT
Thu	OFF	DAY	OFF	MTW	NIGHT
Fri	NIGHT	OFF	DAY	MTW	OFF
Sat	NIGHT	OFF	DAY	OFF	OFF
Sun	NIGHT	OFF	DAY	OFF	OFF
Mon	OFF	NIGHT	OFF	DAY	TRNG
Tue	OFF	NIGHT	OFF	DAY	TRNG
Wed	NIGHT	OFF	DAY	OFF	TRNG
Thu	NIGHT	OFF	DAY	OFF	MTW
Fri	OFF	NIGHT	OFF	DAY	MTW
Sat	OFF	NIGHT	OFF	DAY	OFF
Sun	OFF	NIGHT	OFF	DAY	OFF
Mon	MTW	OFF	NIGHT	OFF	DAY
Tue	MTW	OFF	NIGHT	OFF	DAY
Wed	MTW	NIGHT	OFF	DAY	OFF
Thu	MTW	NIGHT	OFF	DAY	OFF
Fri	MTW	OFF	NIGHT	OFF	DAY

Table 3: Example of 5 Production Team Rotation with a Dedicated Maintenance/Training Month
*NOTE: "TRNG" is required Training and "MTW" represents the Maintenance/Training Week rotation. Each are discussed in Section 6.1.4

The Production Field Technicians will be discussed in detail in the following section as they will perform a significant portion of maintenance at the Xe-100 plants. Additional information on the roles and responsibilities of the other personnel in the above organizational chart were analyzed and documented in the Xe-100 Staffing Report [8].

6.1.3. **Production Field Technicians - Cross-Trained Operations and Maintenance Staff [1 and 2]**

As mentioned above, it is common in the non-nuclear power plants and other industries to have cross-trained personnel performing traditional Operations and Maintenance functions. This approach is referred to as "Operator Based Maintenance" (OBM), [9] which involves operators performing minor routine and recurring maintenance tasks to maintain the assets working efficiently for their intended purposes.

For the Xe-100, the Production Field Technician (PFT) will function as the combination of a traditional nuclear Building Operator and a Fix-it-Now (FIN) technician. The PFT approach requires the Production staff to consistently use their operations and maintenance skills together, developing proficiency and ownership. The PFT is part of the On-Shift team, reporting to the Shift Supervisor and working with the Control Room Reactor Operators as shown in **Figure 4**. When on-shift, a PFT will be responsible for tasks like but not limited to the following:

1. Traditional Operator tasks including:
    - Outside of Control Room operation actions, like:
        - Operator rounds as required
        - Safety clearance planning, hanging and removal
        - Manual valve adjustments
        - Starting and stopping equipment with local control
2. Maintenance tasks that are:
    - Minor and Routine Maintenance tasks that can be completed in less than 3 hours
    - Maintenance tasks that meet the following criteria from EPRI guide 3002007020, Maintenance Work Package Planning Guidance [10] provided below:
        - Tool Pouch Tasks:
            - Tasks that do not require work documents to be initiated. A set of criteria for the evaluation of tool pouch maintenance is developed.
        - Minor Maintenance Tasks – Level 3
            - Tasks that are minor in scope and do not require formal work order planning and that do not affect nuclear safety functions or increase the risk of a plant transient.
        - Simple Work Package – Level 2
            - A Simple Work Package task could be appropriate for non-routine tasks that are fairly complex and performed infrequently when detailed instructions are already available in existing maintenance instructions or procedures. This work presents low risk to loss of generation, entry into a Limiting Condition for Operation (LCO), or trip of the unit/generator.

The PFTs will be supervised by their respective Shift Manager and are supported by the Maintenance Coordinator.

The Maintenance Coordinator does not perform maintenance tasks, but provides the following support for the preparation and execution of maintenance tasks:

- Responsible for the Maintenance schedule at their Xe-100 station which requires interfacing with the PSC Production Work Schedule group.
- Responsible for performing Emergent Planning with the support of the PSC Production Planning / Procedures group.
- Work Week preparation and readiness reviews (parts, tools, electronic work packages (eWPs), etc.).
- Coordinates with Warehouse Storekeeper and PSC Inventory personnel to ensure materials needed for upcoming tasks are onsite and delivered to the appropriate staging/laydown areas in plant.
- Develops and provides oversite to contracts for site needs, as required.

The following section will discuss the function of the PFT when in the Maintenance/Training Week (MTW) Rotation.

6.1.4. **Maintenance Training Week Rotation**

The previous section described the role of a PFT when On-shift in the schedule rotation. As shown in **Table 3**, the Production Teams will rotate through a 5-Team rotating schedule. This rotation will include a 5-days x 8-hour (40-hour total) dayshift work week to allow for necessary training for the off-shift Team. This is referred to as the Maintenance Training Week, or MTW, rotation. During the MTW rotation, the MTW rotation personnel will not have any responsibilities tied to operation of the Xe-100s onsite and will be off shift rotation on a 5x8 work week (40 hours). The MTW rotation allows time for the PFTs to complete their estimated 24 hours of quarterly training. The remaining time in the weeks with training, or the full 40 hours in weeks without required training, will be used to perform more time or labor-intensive tasks that are beyond the scope of the tasks that can be performed by the on-shift PFTs described in Section 6.1.3.

At this time, training for the PFT personnel is expected to be 24 hours (3 days) per quarter, which allows for approximately twelve (12) 8-hour days for the performance of maintenance tasks the on-shift PFTs perform. The PFT personnel in a MTW rotation will be responsible for tasks like but not limited to the following:

- Maintenance tasks that require more than 3 hours to complete
- Maintenance tasks that meet the same criteria as those performed by the PFTs, plus Level 1 tasks, per EPRI guide 3002007020, Maintenance Work Package Planning Guidance [10] described below:
    - Detailed Work Package – Level 1
        - A Detailed Work Package is required for non-routine tasks that are fairly complex and performed infrequently. Because of the complexity of the work, detailed instructions are needed, and are not already available in existing maintenance instructions or procedures. As such, the details must be developed and communicated to the craft in the work package. Work that presents high

risk to loss of generation, entry into an LCO, or trip of the unit/generator would typically warrant detailed instructions as a means to preclude these events from occurring. In addition, work that presents high risk to industrial or radiological safety work would require a detailed work package.

6.1.5. **Long Term Service Agreement (LTSA) Contracted Staff**

Long-Term Service Agreements (LTSAs) are being evaluated as an option to reduce the size of the Xe-100 full-time Production staff during online and outage periods.

EPRI Guide 1019753, "Maintenance and Insurance Options for Managing Technical Risks in Combustion Turbine Projects" [13], describes the typical LTSA in use in non-nuclear power plants. It provides the following general LTSA Contract scope:

- Planned Maintenance
- Unplanned Maintenance
- Extra Work (as mutually agreed)
- Technical Field Assistance
- Assigned Technical Advisor
- Contract Performance Manager
- Monitoring and Diagnostics
- Performance Monitoring
- Spare Parts
- Outage Planning
- Craft Labor
- Parts Repair (replace if necessary)
- Plant O&M (full O&M less common)

Some Examples of SSCs maintained and tasks performed by LTSA vendors at an Xe-100 are provided:

- Chemical Injection Skids
  - Injection rate adjusted by station
- O&M of Demineralized Water Facility
- Flow Accelerated Corrosion (FAC) piping inspections
- Heat Exchangers maintenance and NDE inspections
- Main Turbine/Generator maintenance and inspections
- Major outage contract work in Outages
  - Plant staff operates other units and performs oversight of contracted labor
- Station Air compressors
- Switchyard and Transformer Maintenance
- Cooling Towers
- Welding
- Scaffolding
- Radiography

6.1.6. **Robotic options being evaluated for the performance of maintenance tasks**

Advances in technology in the areas of robots are being evaluated by X-energy for their potential to perform tasks typically assigned to maintenance personnel. Market available robots and aerial drones show promise in performing data acquisition tasks typically performed by nuclear station personnel in operations, maintenance, and radiation protection department. These same devices can also be remotely controlled by personnel to support inspections in hazardous areas. Custom built remote operated robots are also being considered for use in high radiation fields for maintenance tasks on FOAK Xe-100 Fuel Handling system components (ball sphere unloader, for example).

Further analysis will review the applications in which the technology can be used in lieu of a human staff member as well as costs associated with training personnel on their use and maintaining the devices.

6.2. XE-100 MAINTENANCE STAFFING ANALYSIS PROCESS:

The following section will describe the Maintenance Staffing Analysis Process. This section will explain how the required Production staffing numbers for personnel performing maintenance activities are determined for a Xe-100 plant.

For the purpose of this white paper, a single example with the results from the Maintenance Strategy Evaluation Process described in Section 5 is presented below. The majority of the references used, and information developed form this process are proprietary and will not be shared in public facing documents.

6.2.1. **Example of Xe-100 Maintenance Staffing Analysis Process**

In this example, the staffing required to maintain the Circulating Pump A of the A-Train of the Nuclear Island Cooling Water (NICW) system (NICA), hereby referred to as the NICA-PA, is provided. This pump is a Horizontal - Single Stage - Single Suction Pump that is used to circulate water in the NICA system to the various heat loads and heat-removal heat exchanger [14]. For the sake of this example, the NICW-PA has been classified as Critical (from INPO AP-913 [26] and EPRI's Preventive Maintenance Basis Database classification [2]), which means it is essential to plant operations due to its impact on safety, business, regulatory, or other criteria defined in the Xe-100 Equipment Reliability Process classification.

The following are results of the Maintenance Strategy Evaluation Process.

Table 4: Example Maintenance Strategy for the Xe-100 Nuclear Island Cooling Water (NICW) System, Circulating Pump A

Task Name	Crew	Number of Technicians	Labor hours / technician	Frequency
Acoustic Monitoring	COLM	N/A	N/A	continuous
Functional Testing	COLM	N/A	N/A	continuous
Oil Analysis	PFT	1	1	6M
Operator Rounds	PFT	1	0.01	1S
Packing or Seal Replacement	MTW	2	8	AR
Performance Trending	COLM	N/A	N/A	continuous
Refurbishment/Replacement	LTSA	4	30	AR
Vibration Analysis	COLM	N/A	N/A	continuous
Crew Legend: PFT: Production Field Technician, COLM: Continuous Online Monitoring, MTW: Maintenance/Training Week Team, & LTSA: Long-term Service Agreement				
Frequency Legend: AR: As Required, 1S: 1 Shift, 6M: 6 Months				

In this example, the decision was made to instrument the pump and NICA system with the necessary sensors for COLM to monitor the failure modes addressed by the Functional Test, Performance Trending, and Vibration Analysis tasks. Although the EPRI PMBD does not require Performance Trending or Functional Testing to be performed, this option was selected to provide operational information to the Xe-100 Digital Twin. The data is also monitored via the X-energy Monitoring and Diagnostic personnel (off-site) with the use of advanced pattern recognition, or other monitoring and diagnostic software models.

As a reminder, the tasks labelled “AR” are only performed if conditions exist that dictate the need for this task. “AR” tasks are added to the schedule based on station priorities, risk profiles, and personnel availability as emergent or corrective maintenance tasks.

The personnel selected to perform the tasks from the discussion in Section 6.1 are:

- PFT: Product Field Technicians On shift
- MTW: PFT personnel in the Maintenance/Training Week Rotation
- LTSA: Contracted personnel (Long-Term Service Agreement or Short-Term – scope dependent)

The Maintenance Strategy for the NICA-PA has created the following burdens on the designated personnel, or crews:

Table 5: Example Crew Burden based on Example Maintenance Strategy for the Xe-100 Nuclear Island Cooling Water (NICW) system, Circulating Pump A

Crew	1S	3M	6M	2Y	AR
PFT	1 x 0.01	0 x 0	1 x 1	0 x 0	0 x 0
MTW	0 x 0	0 x 0	0 x 0	0 x 0	2 x 8
LTSA	0 x 0	0 x 0	0 x 0	0 x 0	4 x 30
Note: Burden is shown as "Technicians x Hours"					

In this example, only the PFT position is assigned tasks at set frequencies and durations in the "Operator Rounds" and "Oil Analysis" tasks. The burdens will be added into the Crew designated as PFT in the Xe-100 Scheduling tool and tracked as the assignments from the other maintenance tasks developed in the Maintenance Strategy Evaluation Process.

The "Packing or Seal Replacement" task is performed by the Maintenance Training Week (MTW) rotation if a leak or other fault is detected by the "Operator Rounds," "Vibration Analysis," or "Acoustic Monitoring," requiring action. An LTSA contractor will be scheduled to replace the pump if the various monitoring tasks indicate it is necessary. In either case, the tasks would be added to the station's schedule and performed as a corrective maintenance task.

If the above exercise was applied to the entire NICA system, the figures below represent the burden on the PFT and MTW with the assumption that all components in NICA are Critical.

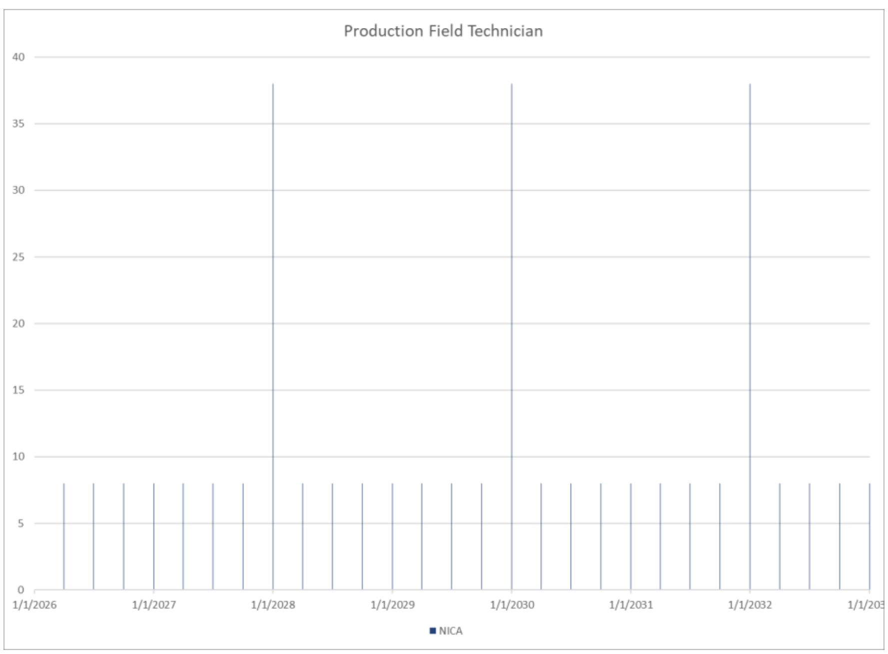

Figure 5: PFT NICA Maintenance task hours over 6-year period (all components assumed Critical)

Note: Tasks will be distributed into the available personnel's shift schedule in X-energy's selected scheduling tool.

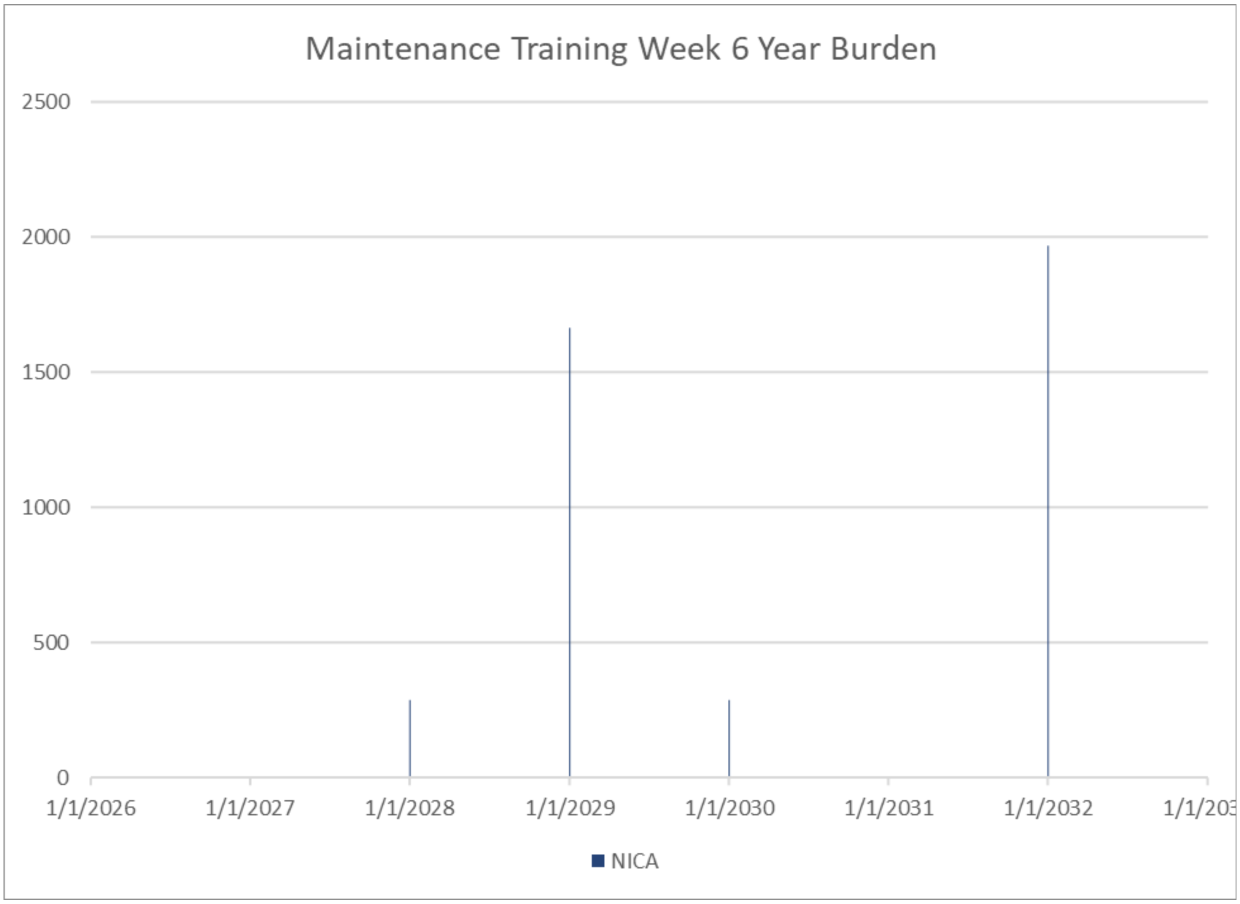

Figure 6: MTW NICA Maintenance task hours over 6-year period (all components assumed Critical)

Note: Tasks will be distributed into the available personnel's shift schedule in X-energy's selected scheduling tool.

6.2.2. **Current Baseline hours available per year for maintenance tasks**

Based on the current baseline staffing plan for a 4-unit Xe-100, including the effects of the training schedule and 5 team shift rotation, 19,551 total hours of maintenance tasks can be performed by the PFT and MTW crews per year.

Table 6: Calculating PFT and MTW hours available for maintenance per Year

Position	Production Field Technician	Maintenance/Training Week Rotation Technicians
Maintenance Staff (Technicians)	3	3
Hours Technician is onsite perf shift (Hour/Shift)	12	8
Shifts Technician Role is onsite per day (Shift/Day)	2	1
Days Technician Role is onsite per week (Day/Week)	7	5
Days Technicians on site per year (Day/Year)	365	201
Hours per shift for Turnover and Dedicated Operator Rounds (Hours/Shift)	4	0
Breaktime in hours per Technician (Hours/Shift)	1	1
Single Technician Maintenance Hours On-Shift (Hours/Shift)	7	7
Total Maintenance hours per Shift (Hours/Shift)	21	21
Total Maintenance time per day (Hours/Day)	42	21
Total Maintenance time per Week (Hours/Week)	294	(varies based on training schedule)
Total Maintenance time per Year (Hours/Year)	15330	4221
Total Maintenance Hours per year (Hours/Year) *	**19551**	

* **Production Field Technician and Maintenance/Training Week Rotation Technicians**

7. CONCLUSIONS

Developing a Maintenance Strategy for the Xe-100 is integral to the design process being driven by the ARDP. This White Paper provides a preliminary look at X-energy's Maintenance Strategy for the Xe-100 plant. As the Xe-100 design progresses and moves into the final design phase, so too will the Maintenance Strategy. Furthermore, more analyses and design documents will become available, which are direct inputs into the strategy. As those documents become available, the Maintenance Strategy will be updated and refined. More broadly, the efforts to develop the PRA basis and Equipment Reliability Program will influence the Maintenance burden of Xe-100 systems and components. From a fully formed Maintenance Strategy will come training, software & information technology, supply chain, procurement, long-term service agreement, and many other needs that will be required to support a fully operational Xe-100 plant.

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APPENDIX A: LIST OF REGULATORY GUIDES AND INDUSTRY DOCUMENTS REVIEWED

- US NRC Regulatory Guide 1.160, Monitoring the Effectiveness of Maintenance at Nuclear Power Plants
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- NRC Reg Guide 1.182, Assessing and Managing Risk Before Maintenance Activities at Nuclear Power Plants
    - https://www.nrc.gov/docs/ML0036/ML003699426.pdf
- Regulatory Guide 1.175, An Approach for Plant-Specific, Risk-Informed Decision-making: Inservice Testing
    - https://www.nrc.gov/docs/ML2114/ML21140A055.pdf
- RG 1.129, Maintenance, Testing, and Replacement of Vented Lead-Acid Storage Batteries for Nuclear Power Plants
    - https://www.nrc.gov/docs/ML0634/ML063490110.pdf
- RG 1.52, Design, Inspection, and Testing Criteria for Air Filtration and Adsorption Units of Post-Accident Engineered-Safety-Feature Atmosphere Cleanup Systems in Light-Water-Cooled Nuclear Power Plants,
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    - https://www.nrc.gov/docs/ML1912/ML19128A261.pdf
- RG 1.233, Guidance for a Technology-Inclusive, Risk-Informed and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors
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- 10 CFR 50.120: Training and qualification of nuclear power plant personnel
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- 10 CFR 26, Fitness for Duty Program
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- 10 CFR 52, Licenses, certifications, and approvals for nuclear power plants
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- NRC Generic Letter 83-14, Definition of "Key Maintenance Personnel," (Clarification of Generic Letter 82-12)

  - https://www.nrc.gov/reading-rm/doc-collections/gen-comm/gen-letters/1983/gl83014.html

Institute of Nuclear Power Operations (INPO)

- INPO 18-003, Maintenance Fundamentals and Technical Skills
- INPO AP-928, Work Management
- INPO AP-913, Equipment Reliability Process Description
- ACAD 92-008, Guidelines for Training and Qualification of Maintenance Personnel
- ACAD 17-001, Guidelines for First-Line Supervisor Training and Development
- INPO 12-007, Guidelines for Tracking and Classification of Rework
- INPO 07-008, Guidelines for Achieving Excellence in Foreign Material Exclusion (FME)

World Association of Nuclear Operators (WANO)

- WANO Performance Objectives and Criteria
  - https://web.inpo.org/POCs/2019-1WANOPO_C.pdf

Nuclear Energy Institute (NEI)

- NEI NUMARC 93-01, Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants
  - https://www.nrc.gov/docs/ML1111/ML11116A198.pdf
- NEI 18-04, Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development
  - https://www.nrc.gov/docs/ML1924/ML19241A472.pdf
- NEI 18-10, Monitoring the Effectiveness of Nuclear Power Plant Maintenance
  - https://www.nei.org/master-document-folder/technical-reports/nei-18-10,-monitoring-the-effectiveness-of-nuclear
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US DOE

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  - https://www.directives.doe.gov/directives-documents/400-series/0433.1-EGuide-1/@@images/file

Canadian Nuclear Safety Commission

- List of regulations
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