NERVA JOINT DOCUMENT - NJD 15

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**XE-2 Safety Evaluation Report
Phase IA
May 1968**

MASTER

Prepared by:

Aerojet - General Corporation
Sacramento, California
and

Westinghouse Astronuclear Laboratory
Pittsburgh, Pennsylvania

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AUTHORIZED CLASSIFIER DATE

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1. INTRODUCTION AND SUMMARY

The purpose of the XE-2 Safety Evaluation Report, Phase IA is to summarize the safeguards which will prevent accidental criticality during the sequence of E-MAD assembly operations on XE-2 up to, but not including, central poison wire removal. These operations will be performed in the facilities, with the equipment, and in the manner that are essentially equivalent to those followed for XE-1. These operations include: Receiving and Inspection of the Reactor, Assembly of the Test Article and Peripheral Poison Wire Removal. A block diagram indicating the sequence of these operations is shown in Figure 1. As shown, peripheral poison wire removal operations may be conducted before or after installation of the control drum actuators.

In order to prevent fuel hydrolysis similar to that which occurred in the XE-1 reactor, it is planned to have the Pressure Vessel/Reactor Assembly under a continuous, high-purity gas purge during all periods of E-MAD storage, inspection and assembly operations.

The administrative and technical boundaries within which the assembly operations will be performed are specified in the "XE-2 Operating Limits Document, Phase IA", NJD-16.

The potential mechanisms which could lead to an accidental criticality of the XE-2 reactor subassembly in the E-MAD Assembly Area are identified and discussed in Chapter 7 of the XE-SAR⁽¹⁾. These are accidental insertion of moderation, particularly hydrogenous material after removal of the peripheral poison wires, loss of shutdown margin through excess reflection, and accidental rotation of the control drums.

For the E-MAD assembly operations evaluated in this document, accidental criticality situations are prevented by the following safeguards:

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(1) NJD-9, "XE Safety Analysis Report", July 1967.

Figure 1 XE-2 SER Phase IA Operations

- 1) The control drums are retained in the full-in position by the shipping locks, the locked control drum actuators and/or control drum scram springs installed on each drum. Following removal of the control drum drive shaft shipping locks and before the actuators are installed, all control drum drive shafts, but one, are removed from the reactor subassembly and stored in a secured area. The procedural safeguards in effect permit an outward rotation on only one (1) drum at any time. After installation of the control drum actuators, a maximum of three actuator key locks are unlocked at any time. However, even if all the control drums were rotated to the full-out position, the central poison wire system, which will be retained during these operations, will maintain the reactor subcritical.
- 2) The peripheral poison wires are removed in a safe and pre-planned manner accompanied by subcritical multiplication which establishes that an acceptable reactivity shutdown margin exists.
- 3) The reactor subassembly is protected against the introduction of extraneous material, especially hydrogenous fluids, by performing the work on the reactor in a controlled area and/or use of closures for the reactor subassembly.
- 4) The movement of the reactor and engine components, auxiliary equipment, personnel, or additional reactors that may be in the vicinity of the XE-2 assembly are limited through controls established in the Criticality Control Manual, NTO-A-0029, Revision 1.

2. OPERATIONS PRIOR TO CENTRAL POISON WIRE REMOVAL

The E-MAD Facility is described in Chapter 3 of the XE-SAR. The pertinent engine handling equipment and assembly operations are discussed in Chapter 6, and a safety evaluation of these operations is given in Chapter 7. Following is a safety evaluation of the XE-2 assembly operations to be completed prior to removal of the central poison wires.

2.1 Condition of the Reactor as Received at the Assembly Area

The XE reactor subassembly is shipped with the shipping poison wire system installed in the core. The assembled reactor components include the core, reflector system, pressure vessel, shield, leak test closure and dome end closure. The poison wire system is described in Section 4.1.3.4 of the XE-SAR. It is capable of maintaining the reactor subcritical under all credible accident conditions which may occur during shipping. Although the poison is distributed throughout the entire core, it is generally considered to be in two sections - the peripheral section and the central section. The central section (114 fuel elements) contains adequate poison to maintain the reactor at least \$2 subcritical even if all control drums are rotated to 180°. In addition to the shipping poison wires, the control drums are mechanically locked in the full-in position during shipment by the control drum drive shaft locks. Prior to the initiation of E-MAD Assembly Operations the XE-2 PVARA and associated equipment may be stored in a controlled area of the E-MAD Building. The reactor subassembly is maintained under a high purity gas purge which prevents fuel hydrolysis from occurring.

2.2 Operations Prior to Poison Wire Removal

Prior to the removal of the shipping poison wire system, the reactor is protected against all credible accident conditions which could lead to a nuclear excursion. No further safeguards are required except those which insure that the mechanical integrity of the poison wire retention system is maintained and that the reactor is handled in accordance with the

guides established by the Criticality Control Manual, NTO-A-0029, Revision 1.

The poison wire retention plate may be detached and poison wires from selected fuel clusters temporarily removed prior to the actual planned poison wire removal operation. Such operations are conducted with the partially-assembled engine installed in the Engine Assembly Stand with the core axis horizontal or the nozzle end inclined upward as much as ninety degrees from the horizontal. As discussed in the following section on peripheral poison wire removal, when the poison wire retention plate is removed, the Engine Assembly Stand is locked with the reactor horizontal or nozzle end inclined upward to prevent accidental rotation of the partially-assembled engine which could lead to complete loss of poison wires. Also, an approved support stand prevents downward rotation of the poisoned assembly when it is not in the vertical position. Removal of poison wires at this time is limited such that the remaining poison maintains the reactor subcritical even if flooded with water.

With the XE reactor subassembly in the PVARA Stand, the torque required to rotate each of the controls drums is measured. A shipping control drum drive shaft housing is removed. The measurement is made and it is verified that the control drum has returned to the full-in position. The XE-2 control drum drive shaft housing guide is then installed and capped with an external engine shield guide cap before proceeding to the next control drum. After measuring the drum torques and capping all drum shaft housings, the Lower Thrust Structure (LTS) is mated to the PVARA. The external shield, which has previously been assembled, leak checked and drained of water in another area of the E-MAD Facility, is attached to the LTS. This area is sufficiently remote from the clean controlled area to assure that water cannot enter the reactor(s) located in the assembly area. A pressure cap capable of sealing against 68 psig pressure is then clamped and bolted to the top of the control drum drive shaft housing to perform a leak test. As an option, the control drum actuators may then be installed on the test assembly which is mounted on either the PVARA Stand or Engine Assembly Stand. If installed, ten (10) of the twelve actuators will be key-locked in the full-in position (nominally

15 degrees), and two of the actuator key locks will remain unlocked (keys inserted) at all times due to the inaccessibility of the mechanical locks after the Upper Thrust Structure Moduel is installed. Control Drum actuator and electrical checkout tests would then be performed prior to peripheral poison wire removal operations. During actuator checkout operations, a maximum of three (3) actuator key locks may be unlocked. However, only one control drum is rotated at any time.

2.3 Peripheral Poison Wire Removal

Peripheral poison wire removal is carried out with the partially-assembled engine installed in the Engine Assembly Stand with the nozzle end horizontal or inclined upward from the horizontal. The gear box design of the Engine Assembly Stand drive mechanism is such that electric power to the drive is required to rotate the Engine Assembly. A key switch prevents the drive motor from being inadvertently energized. Therefore, without the key being inserted, the Engine Assembly Stand cannot be rotated, which prevents inadvertent loss of poison wires. As a procedural safeguard, the Manager, E-MAD or his designated alternate retains control of this key at all times when the poison wire retention device (peripheral or central) is not installed. An approved support stand prevents downward motion of the poisoned assembly whenever the assembly is not vertical with the nozzle end up and the poison wire retention fixture is removed. If the control drum actuators have not been installed, the control drum scram springs will prevent rotation of the control drums during and following removal of the peripheral poison wires. If the actuators are installed, the mechanical key locks on ten (10) drums and the twelve (12) pneumatic locks also prevent drum rotation. At the conclusion of peripheral poison wire removal, the central poison wires, which are designed to be capable of maintaining the reactor at least \$2 subcritical even if all the control drums were rotated full-out, are retained.

The peripheral poison wire removal operations are initiated upon authorization from the Manager, NTO and the Manager, Engine Test Operations. They are conducted in accordance

with formal detailed procedures as required by the applicable Test Specification as supplemented by NTO Standard Operating Procedures under the management cognizance of the Manager, Engine Test Operations and under his direct supervision or under the direct supervision of a person designated by him, who has the background, experience and competence to perform the operation. The NTO Criticality Control Engineer will be present during the wire pulling operations to assist in obtaining and evaluating the inverse multiplication data.

Neutron multiplication data during poison wire removal is obtained with a minimum of three (3) neutron detector-scaler channels. Positioning of the neutron detectors and source will be in accordance with an approved XE-2 assembly procedure. This procedure is based on experimental multiplication data obtained from WANEF and at NRDS during previous peripheral poison wire removal from similar reactors. The assembly procedure will include a minimum value of inverse multiplication which, if reached, will require review of the data by the TS & PRB.

The poison wires are removed in increments starting at the periphery of the core and progressing towards the center of the reactor in a manner which maintains approximate radial symmetry. After each increment is removed, the neutron count rate is determined and the neutron multiplication with respect to the initial count rate is calculated. The reciprocal of the neutron count rate is plotted after each increment as a function of the number of poison wires removed. The maximum number of wires removed in each increment, to the nearest whole cluster, is limited to the smaller of either:

- 1) Ten per cent of the originally installed number (total poison wire loading), or
- 2) Ten per cent of the number of wires which, if removed, would lead to criticality, as indicated by the extrapolated curve of inverse multiplication versus number of wires removed. Poison wire removal is terminated and conditions are reported to the Manager, Engine Test Operations if extrapolation of the inverse multiplication data indicate a shutdown margin

less than \$2 with all the poison wires removed. The central poison wire system in the core is designed to provide a reactor shutdown in the order of \$10 which is adequate to maintain the Engine Assembly subcritical for all normal and abnormal reactivity additions except flooding.

Following removal of the peripheral poison wires, the reactor is monitored with the reactor neutron multiplication monitor as described in the NTO Standard Operating Procedure for Neutron Multiplication Detection, NTO-SOP-0017, Revision 2. Prior to nozzle installation, the nozzle-end opening of the core is sealed against the introduction of extraneous material at all times by the nozzle end closure, except when actual work is in progress which requires its removal.

2.4 Nozzle and Upper Thrust Structure Installation

With respect to nuclear safety, installation of the nozzle and Upper Thrust Structure Module has a negligible effect on the reactivity of the core. The central poison wire retention fixture is attached to the nozzle cover (Section 3.3), and the nozzle cover assembly is then attached to the nozzle torus. Following removal of the peripheral poison wires, the nozzle unit is installed on the Engine Assembly. As an alternate, the nozzle plug-central poison wire retention fixture (Section 3.3) may be attached to the nozzle throat. The poison wire retention fixture retains the central poison wires in the core when the Engine Assembly Stand trunnions the engine to the down-firing position prior to installation of the Upper Thrust Structure. If not already installed, the control drum actuators are installed and checked within the constraints of Section 2.2. The Upper Thrust Structure is then installed.

2.5 Test Assembly Leak Checks

During operations following nozzle installation, the Test Assembly and Engine Systems are leak checked using pressurized gas at ambient temperatures. During leak check operations, the nozzle cover with the central poison wire retention fixture or the alternate

nozzle plug-central poison wire retention fixture remains in place, and the control drum actuators remain locked. Gas pressures up to 68-70 psig in the nozzle chamber are planned, which are well below the 100 psig proof test pressure of the nozzle closure assembly or the alternate nozzle plug assembly. Safety against a potential over-pressurization is obtained with a pressure relief valve set to open approximately 10% over the planned operating pressure. An additional safeguard against potential loss of the central poison wires if the nozzle cover or the alternate nozzle plug fails during pressure tests performed with the nozzle in the down-firing position is provided by a safety pedestal which is positioned between the base of the Engine Assembly Stand and the nozzle closure or plug assembly during such tests.

3. OPERATIONAL SAFEGUARDS

A brief summary of the mechanical features and the administrative and procedural controls which are in effect to insure against accidental criticality of the X-Engine assembly operations as previously described in Section 1, Introduction and Summary, are described below.

3.1 Safeguard Against Entry of Water or Hydrogenous Material

The XE-2 reactor subassembly upon receipt from shipping or from the storage area is prepared for assembly into the engine module in a clean area of the E-MAD Building where the water outlet lines are drained and locked. The entry and use of hydrogenous liquids is controlled within the clean room when nuclear fuel is present and is subject to the guideline of the NTO Health and Safety Criticality Control Manual. Prior to nozzle installation, the nozzle is sealed against the introduction of extraneous material by the PVARA nozzle end leak test closure. After nozzle installation, the nozzle is sealed by having a central poison wire retention fixture with the nozzle cover or the alternate nozzle plug in place. The appropriate enclosure may be removed when required by work in progress.

The external engine shield is filled with steel balls and hydrostatically tested in a separate area in the E-MAD facility. The water is then drained from the shield and cover plates are mechanically locked over the central port holes of the shield. The residual moisture is sealed in the shield and does not constitute a potential safety hazard when installing the shield on the engine assembly.

3.2 Control Drum Safeguards

Inadvertent or unauthorized motion of control drums is prevented at all times when such motion could potentially lead to criticality. The reactor is received with the control drive shaft locks installed. The shipping control drum drive shafts, guide tubes and locks

are removed one at a time. The control drum scram springs then provide the force that prevents outward rotation from the full-in position, until the actuators are installed.

Before actuator installation, a mock-up drive shaft is available for measuring the torque required to rotate each drum from the full-in to the full-out position. Under all conditions, not more than one control drum is rotated at any time. After each drum is torque-checked, the XE-2 control drum drive shaft housing is installed and the opening is sealed with an external engine shield guide cap. After all 12 control drum drive shaft housings are installed and sealed, the external engine shield is installed and a pressure cap is clamped and bolted to the top of the control drum drive shaft housing. This cap is capable of sealing against 68 psig and prevents extraneous material from entering the assembly through the control drum guide tubes. The shipping and permanent XE-2 drive shafts are retained in a locked repository under supervisory control until required for use in conjunction with control drum actuator installation.

Following control drum actuator installation, both the actuator locks and the control drum scram springs are available to prevent an outward rotation of the drums. As discussed in Section 2.2, only ten (10) of the actuators are normally key-locked in the full-in position. During control drum actuator checkout operations an additional key is supplied so that three (3) actuators may be manually unlocked. The keys for the manual locks will be under the control of the Manager of NERVA Test Operations and Manager of Engine Test Operations. In addition to the manual key locks, each actuator has a pneumatic lock which requires pneumatic pressure and an electrical command signal to open. During drum checkout, the pneumatic actuator checker provides the signals to release the pneumatic lock and rotate the drum. The pneumatic actuator checker provides for unlocking only two pneumatic locks at a time and provides demand signals for outward rotation of these two control drums. However the assembly procedures permits only one (1) control drum actuator to be rotated from the full-in position at any time. After rotation is completed it will be verified that the drum

has been returned to the full-in position and the pneumatic lock engaged. In addition to these safeguards, as stated before, the central poison wires which are retained during Phase IA operations are designed to prevent accidental criticality even if all control drums were rotated to the full-out position.

3.3 Poison Wire Retention

The poison wire retention plate is described in Section 4.1.3.4 of the XE-SAR. It is originally installed during assembly of the XE-2 reactor subassembly at WANL and remains on the reactor subassembly during all early movements of the reactor. When the XE-2 reactor subassembly is retained in the engine assembly stand with the nozzle end horizontal or inclined upward from the horizontal, this plate may be removed, provided the stand is locked against rotation of the engine. An approved support stand also prevents downward rotation of the poisoned assembly whenever the assembly is not vertical with the nozzle end up. After peripheral poison wire removal, the poison wires are retained in the core by means of a central poison wire retention fixture. This fixture is attached either to the nozzle closure plate which is clamped to the nozzle torus (Section 6.1.1.5, XE-SAR) or the nozzle plug clamped to the nozzle throat⁽¹⁾. Thus with the nozzle assembly installed on the PVARA, positive retention of the central poison wires is assured.

3.4 Monitoring of the Assembly

The XE-2 reactor subassembly is continuously monitored during and after its removal from the shipping container. Special monitoring is performed with portable instruments during removal from the container for detection of any released contamination. The E-MAD Criticality Alarm System (gamma detectors) and the E-MAD Process Area Monitoring System (PAMS - gamma detectors) are utilized for continuous monitoring of the subassembly during storage and handling. A battery-operated neutron multiplication alarm monitor (popper) is also provided for continuous monitoring for assembly operations. An additional neutron

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(1) Addendum 2 to NJD-10 - Revision 1, "XE-1 Safety Evaluation Report - Phase IA" - Review of Nozzle Plug and Central Poison Wire Retention Fixture.

multiplication monitor (without alarm) is utilized for obtaining neutron multiplication data during control drum rotation or poison wire removal. Operation of these neutron monitors is described in NTO Standard Operating Procedure for Neutron Multiplication Detection, NTO-SOP-0017, Revision 2.

3.5 Excess Reflection

Safeguards against the potentially large reactivity worth of neutron reflector material in the immediate vicinity of the XE-2 reactor subassembly vary with the particular operation involved. During the receipt and assembly phases when the reactor subassembly is transferred from one location to another in the assembly area, the shutdown margin provided by the full poison wire system is more than adequate to override any reactivity introduced by external reflection. Following removal of the peripheral poison, movement of the engine assembly, personnel, auxiliary equipment, or additional reactors that may be in the vicinity of the XE-2 assembly are limited by controls established in the Criticality Control Manual. These controls are established to maintain, at all times, at least a \$2 reactor shutdown margin.

3.6 Administrative and Procedural Controls

The Administrative and Procedural Controls covering operations with the X-Engines are inherent in the NERVA Organization for XE testing and are described in detail in Chapter 2 of the XE-SAR. They are not limited to those listed below. Rather, those listed below are particularly applicable to the operations covered by this evaluation.

The controls basically establish that operations are carried out in a pre-planned manner with review, depending on the operation, being made by the NTO organization, e.g., NTO Health and Safety, or externally by WANL, AGC and SNPO-C, as may be required.

The pertinent controls during assembly operations include the NTO Criticality Control Manual (NTO-A-0029, Revision 1), the Test Control Documents (Section 2.3.1.1), Operational Documents (Section 2.3.1.2), and XE Test Specification and Procedure Review Board (Section 2.3.2), discussed in the indicated sections of Chapter 2 of the XE Safety Analysis Report.