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REMOTE REAL TIME X-RAY EXAMINATION OF FUEL ELEMENTS IN A HOT CELL ENVIRONMENT

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ABSTRACT - The Remote Real Time X-ray System will allow for detailed examination of fuel elements.[a] This task will be accomplished in a highly radioactive hot cell environment. Two remote handling systems will be utilized at the examination station. One handling system will transfer the fuel element to and from the shielded x-ray system. A second handling system will allow for vertical and rotational inspection of the fuel elements. The process will include (1) removing a single nuclear fuel element from a element fabrication magazine(EFM), (2) positioning the fuel element within the shielding envelope of the x-ray system and transferring the fuel element from the station manipulator to the x-ray system manipulator, (3) performing the x-ray inspection, and (4)then transferring the fuel element to either the element storage magazine(ESM) or a reject bin.

INTRODUCTION

The x-ray system is a IRT MX-125A Microfocus X-ray System. The purpose of the x-ray system is to (1) verify the location of the fuel slug within the fuel jacket, (2)locate the sodium meniscus and measure its height above the fuel slug, and (3) interrogate the plenum area for sodium deposits (see figure 1). The fuel elements arrive at the element inspection station in a element fabrication magazine(EFM). The station manipulator will pick one element from the EFM and transfer it to the x-ray system manipulator. The station manipulator consists of a XYZ rail system and a gripper head. The gripper head is a solenoid operated collet type manipulator. The x-ray manipulator will be composed of a cylindrical cup mounted on a motorized lead screw. The cup can also rotate while translating vertically. The element will be lowered into the x-ray shielding envelope and properly positioned in front of the x-ray tube. The in-cell components of the x-ray system include the x-ray tube, the image intensifier, and a camera. The x-ray system will be manually turned on and the fuel element interrogated.

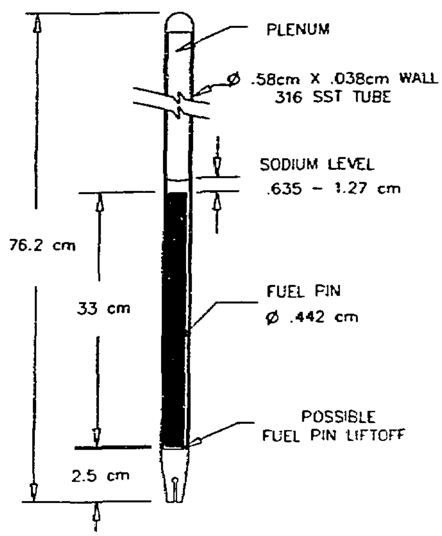

Figure 1. Fuel Element

Due to the high background radiation (design

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requirements are 100 Gy/hr, 10^6 Gy cumulative), the x-ray system will be in a shielded container. Presently steel is being consid···ed but lead and possibly tungsten or depleted uranium may be investigated as shielding material.

Presently, (1) the x-ray system has been procured and is undergoing initial qualifications, (2) the element inspection table including the station manipulator is ready for fabrication, and (3) the x-ray shielding is under design.

COMPONENT OVERVIEW

The Fuel Element Inspection Station will be composed of three main subsections; (1) the work table, (2) the x-ray system, and (3) the shielding for the x-ray system (see figure 2 below).

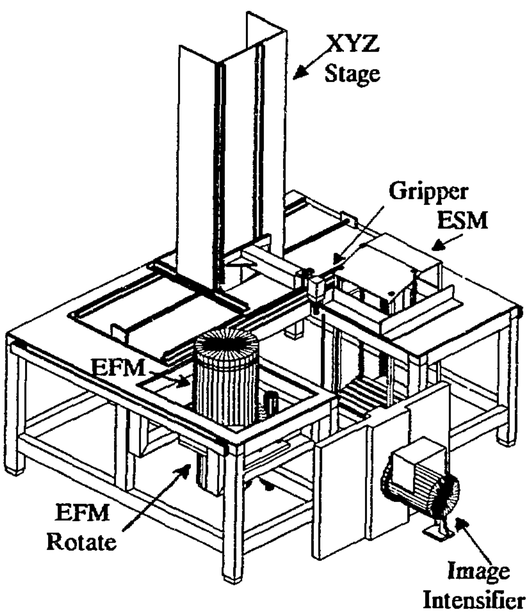

Figure 2. Inspection Station

The work table will house the (1)EFM, (2)the ESM, (3)station manipulator, and (4) reject receptacle. The in-cell x-ray system consists of an (1) x-ray tube, (2) image intensifier, and (3) camera. The out-of-cell components of the x-ray system consists of a (1) vcr, (2)monitor, (3) power panels, (4)x-ray controller, and (5)keyboard. The x-ray shielding will consist of several modular steel containers. However, lead is also being investigated at this time. An element manipulator will be placed in the shielding for translational and rotational capabilities.

Support table -- The support table will be approximately 188cm x 152 cm x 76 cm tall. The table top will have a .95 cm thick top plate with dowel pins to accurately position and level the XYZ stage. The front of the table will have a 53 cm slot to accommodate the x-ray system and its shielding.

EFM Rotation Device -- The EFM Rotation Device will support and rotate an EFM during element inspection. The EFM Rotation Device has been designed to rotate the EFM so the stage assembly gripper only has one position to index from during the element examination pick cycle. A stepper motor is used to rotate the EFM to each element jacket location. A resolver and a position indicating switch will be used to keep track of the rotational position of the EFM.

Stage assembly -- The major components of the Fuel Element Inspection Stage Assembly are a XYZ stage and a gripper device. The XYZ stage is a three part linear positioning table which positions the fuel element in the necessary locations. The XYZ stage is capable of the following motion: the X axis travels left to right 102 cm, the Y axis travels in and out 36.2 cm, and the Z travel up and down 96.5 cm. The Z axis will have a bracket that holds a gripper device that grapples the fuel element for transport during examination. The Z axis also has an "on board" funnel the can be positioned directly under the gripper centerline to help guide the fuel element into the inspection devices and ESM. The funnel guide is positioned under the gripper by a pneumatic cylinder. The funnel guide is a split half unit that opens and closes around the element during insertion. The guide jaws are pneumatically operated.

The gripper is a three-jaw collet type gripper that is spring loaded. The spring is compressed by a solenoid operated plunger. The spring operated gripper fails in the closed position. The gripper has a linear transducer that indicates whether or not an element has been inserted into the collet.

All motors and resolvers that drive the XYZ stage or magazine rotate fixture have been designed for remote replacement by master slave manipulators. The remote coupling is a mated spline design. Motors and resolver housings have built-in guide features that guarantee coupling alignment. The vertically designed couplings are held together with gravity. The horizontal design has a master slave activated clamp to assure the coupling is engaged.

CONTROL

The fuel element inspection station shall be controlled and monitored by a Allen Bradley programmable logic controller (PLC), via a communication and software link with the operator control station (OCS). The fuel element inspection station can be operated in manual, semi-automatic, and automatic modes.

The OSC/PLC shall provide for monitoring and controlling of the following element inspection activities:
1. Control of the stepper motors for the XYZ stage and the EFM rotate drive.
2. Monitoring the position of the XYZ stage and the magazine rotate drives.
3. Monitoring end of travel limit switches for the XYZ stage and magazine rotate.
4. Monitoring both gripper open and closed position indication switches.
5. Monitoring speed of the XYZ drives.
6. Monitoring x-ray examination.
7. Controlling the emergency shutdown at the operator control station.

X-RAY SYSTEM

The x-ray system is made up of a x-ray generating system, a image forming system, and a image processing system. The x-ray generating system is an IRT MX-125 X-Ray System (see Figure 3 below).

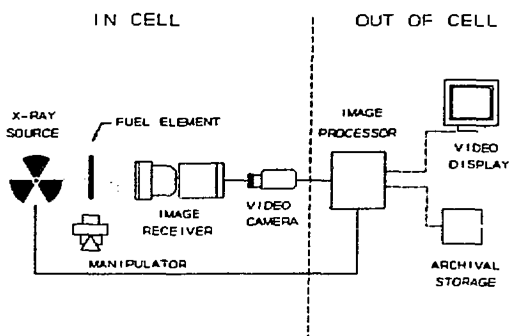

Figure 3. X-Ray System

The MX-125A is a microprocessor-based microfocus x-ray generating system. The system comprises a sealed microfocus x-ray tubehead, low-stored-energy, high-frequency, high-tension generator, and auxiliary chassis. The microfocus x-ray tubehead basic operating parameters are; target voltage of 20 to 125 kV, electron beam current of .5 mA maximum and maximum tube housing temperature of 55°C. A high resolution intensifier and CCD camera are used to generate the realtime x-ray image. Real-time fluoroscopic imaging is provided by means of a dual field 10/15.2 cm field cesium iodide phosphor image intensifier with aluminum input window. The camera is a charge-coupled device(CCD). However, due to radiation concerns this component may be replaced with a more radiation resistant camera. The image processing system includes a graphics system processing based image controller with real-time image integrator. The initial qualification of the system has shown that the shift subtract technique with the voltage set at 125kv and current set at .153 mamps optimizes the resolution of the sodium meniscus. The shift subtract option involves capturing and averaging 257 frames then physically moving the fuel element less than .157 cm and averaging another set of frames. The computer then compares the two images and displays the results on the monitor. The image filters/enhancement options allow for such options as smooth, sharpen, and contour relief.

SHIELDING of X-RAY SYSTEM

The element inspection x-ray system has unique requirements in shielding and imaging due to the hot-cell environment and the radioactivity of the fuel element that is being inspected. The main concern with the system is to achieve a signal to noise ratio (signal: x-ray source, noise: hot cell background + fuel element) adequate to obtain the needed images and to limit the equipment dosage to prolong its life (Adequate is considered to be a signal to noise ratio of at least 10).

The expected background radiation in the hot cell of 100 Gy/hr will be attenuated by a steel box around the equipment. Significant background illumination in the image intensifier occurs at $2X10^{-2}$ Gy/hr. To limit the total background dose (hot cell background +fuel element) on the intensifier as much as possible , the shielding should attenuate the hot cell background to no more than $2X10^{-3}$ Gy/hr. The initial shielding design is shown in figure 4.

INITIAL RESULTS

The x-ray system has undergone initial out of cell qualifications on cold dummy fuel elements. Basically, a dummy fuel element utilizes a steel slug rather than a

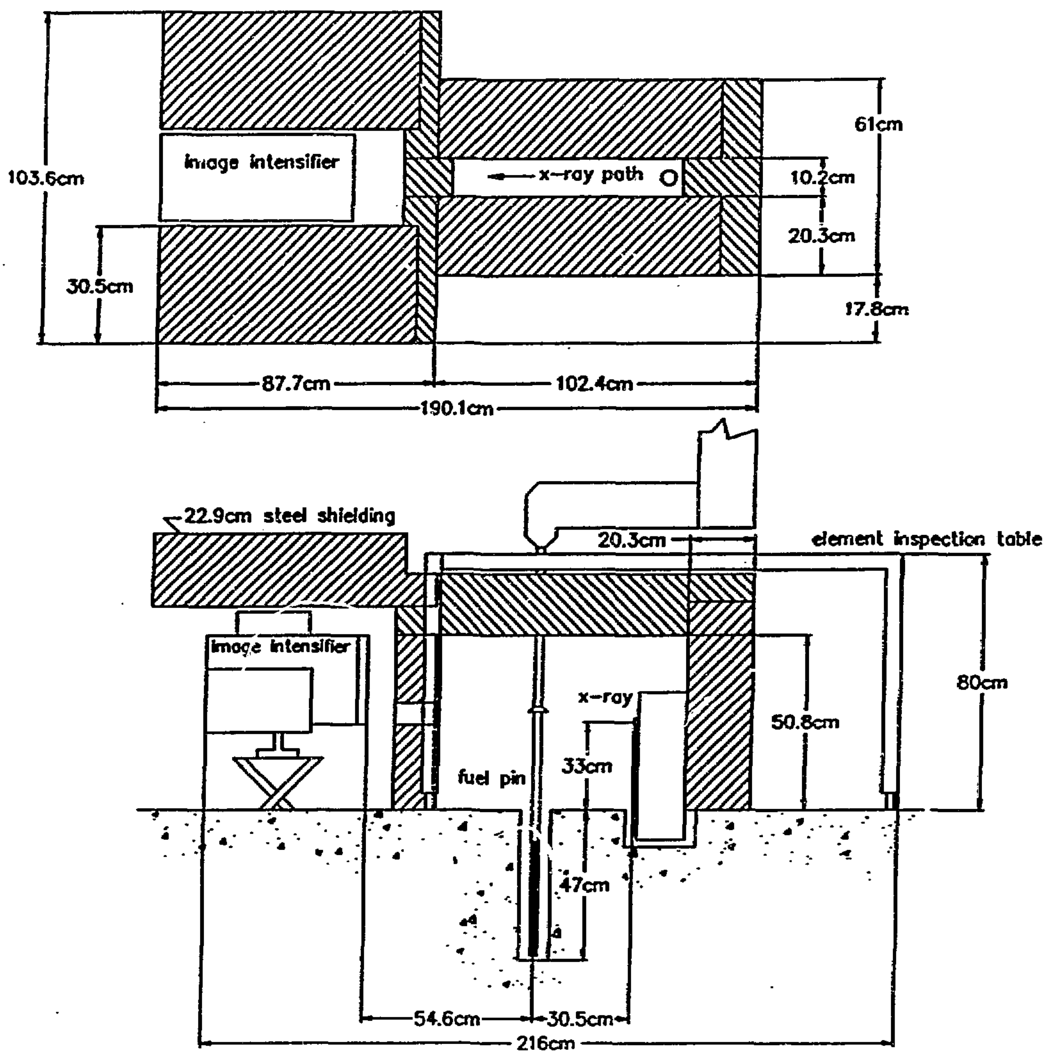

Figure 4. Conceptual Sketch of X-ray Shielding

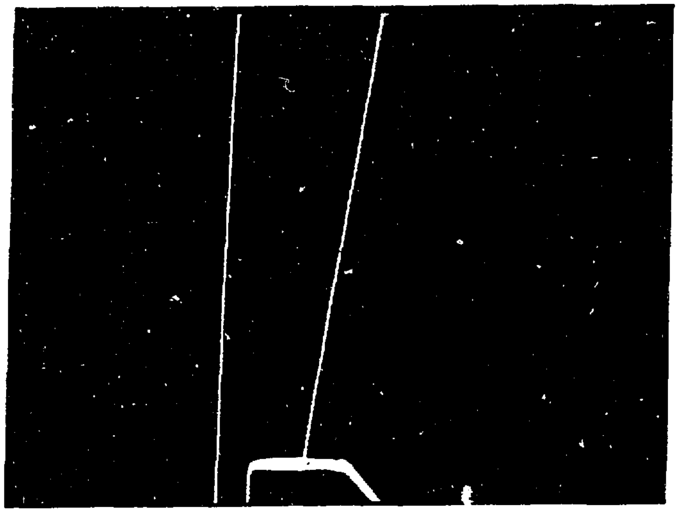

Figure 5. A shift-subtraction image-enhancement routine makes the edge of the sodium level stand out clearly in this real-time x-ray image.

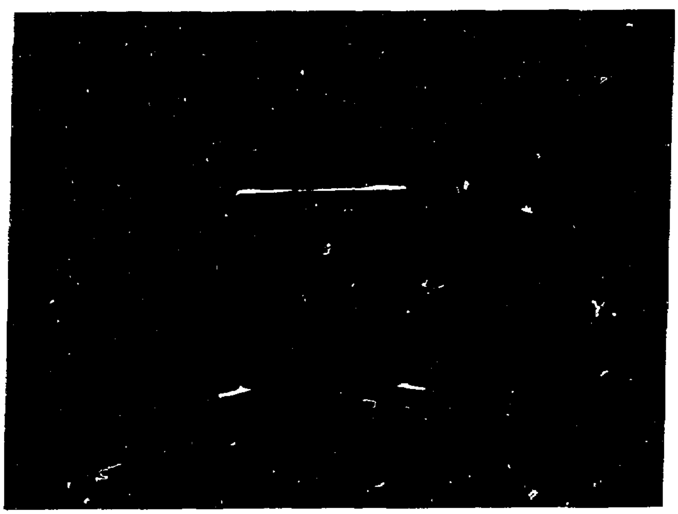

Figure 6. The junction of fuel pin at the bottom of the fuel element

actual fuel slug. However, the steel slug has been settled and bonded in sodium. Ten separate dummy fuel elements were examined for fuel pin lift-off and sodium meniscus level. Figures 5 and 6 detail the results.

CONCLUSIONS/ON GOING WORK

The complete element inspection table components have been designed and detailed drawings have been completed. The shielding is in the conceptual design phase. Though steel has initially been the material of choice lead, tungsten, and possibly depleted uranium will be investigated. The x-ray system has been undergoing initial qualifications with dummy fuel elements. These initial qualifications have shown that the major advantage of real time x-ray over other non-destructive testing such as eddy current and film x-ray is increased resolution with no time lag. These benefits outweigh the challenges posed by the shielding needs of the x-ray system and its associated remote handling systems.

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