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AEC Research and Development Report

DEVELOPMENT OF AN OPTICAL
INSTRUMENT AND TECHNIQUE
TO INDICATE TAMPERING
WITH REACTOR FUEL ASSEMBLIES

PART I

August 1971

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AND TECHNIQUE TO INDICATE TAMPERING
WITH REACTOR FUEL ASSEMBLIES
PART I

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SUMMARY

The International Atomic Energy Agency (IAEA) and the United States Atomic Energy Commission (USAEC) have jointly sponsored research to develop a prototypic optical instrument to indicate tampering with reactor fuel assemblies. The instrument is intended to detect surface tampering in the form of minute markings or scratches which indicate that the fissionable material which was originally packaged might have been removed or diverted without authorization. This report describes the conceptual design for the optical instrument. The conceptual design includes features for split-image comparison, two-color comparison, chopped-image comparison and eye-to-eye comparison. The instrument is designed to be portable and compact, to require minimal operator training, and also to provide the capability for making permanent records.

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INTRODUCTION

The International Atomic Energy Agency (IAEA) and the United States Atomic Energy Commission (USAEC) have jointly sponsored research to develop a prototypic optical instrument to permit detection of tampering with reactor fuel assemblies. The instrument is intended to detect alteration of surface "fingerprints" which are in the form of minute markings or scratches. Any alteration of the "fingerprints" would be an indication that the assembly had been tampered with and that fissionable material might have been removed or diverted without authorization. This report, Part I, discusses the survey of reactor fuel assembly designs conducted to establish the requirements and conceptual design of the prototype instrument. Part II, the final report, will be prepared by December 31, 1971, at the conclusion of the program.

PROGRAM OBJECTIVES

The objectives of this research program are to develop a conceptual design, fabricate and demonstrate an easily portable prototypic optical viewing instrument to detect surface markings which indicate that a reactor fuel assembly has been tampered with. The program is divided into two parts of two and four steps, respectively.

- Part I - completed June 30, 1971
 1. Review basic fuel element designs presently used and planned for commercial power reactors to assure that the tamper indicating instrument is applicable to all designs. Criteria for an instrument will be developed from this review.
 2. Develop a conceptual design for a tamper indicating instrument based upon the above criteria.
- Part II - to be completed December 31, 1971
 1. Based on the conceptual design, design and fabricate the prototype.
 2. Test and debug the instrument to meet specifications.
 3. Demonstrate for IAEA and USAEC representatives the performance of the instrument on an actual or model fuel element.
 4. Prepare final report and operating manuals for the prototype.

REACTOR FUEL ELEMENT DESIGN SURVEY

We performed a survey of the most common commercial reactor fuel assembly designs to develop criteria for identifying surface tampering. The criteria for the instrument were established to detect tampering from the time of completion of fabrication to the time the fuel assembly is installed in the reactor and at any selected point in between. These criteria are:

- Alteration of the reactor fuel fabrication process should not be required.
- The tamper-indicating instrument should not impose real or imagined effects on fuel performance.
- Handling of the fuel while using the instrument should be minimal.
- Use of the tamper-indicating instrument should require minimal training.

- The instrument should be low cost, highly reliable, and easily implemented.
- The instrument should not utilize techniques and methods which are susceptible to countermeasure fraud.
- The instrument should be portable and compact.

The approach taken in the investigation of the various fuel assembly designs was to identify susceptible areas on each assembly design that would necessarily be disturbed to remove or open individual fuel rods for the purpose of diverting material. Any alteration of the unique surface features of a susceptible area would be an indication that tampering had occurred.

Fuel assembly designs for four major reactor types were evaluated: Boiling Water Reactors (BWR), Pressurized Water Reactors (PWR), Gas Cooled Reactors (HTGR) and Liquid Metal Fast Breeder Reactors (LMFBR). The vital statistics related to the various fuel assembly designs studied are summarized in Table 1.

The primary sources of information were Preliminary Safety Analysis Reports (PSAR) and Final Safety Analysis Reports (FSAR) which are public record. In some cases, personal contacts with fuel fabricators were used to provide supplementary information to clarify the PSAR's and FSAR's. A notebook was assembled which summarizes reactor type and fuel manufacturer information and denotes areas susceptible to tampering. Fortunately, from an inspection viewpoint, the basic fuel assembly designs for different sized plants are similar for each reactor vendor (Figure 1).

One of the major concerns related to the development of a fuel assembly tamper-indicating instrument is to detect tampering of assemblies designed with replaceable rods. To our knowledge, replaceable rod fuel assembly designs are presently used in two reactors: Big Rock Point (GE-BWR) and Saxton (W-PWR). It is highly probable that future fuel assemblies will be designed with replaceable rods; however, these design details are presently unknown. It is expected that each individual replacement fuel rod can be identified by the uniqueness of the machined

TABLE 1. Reactor Plants for Which Fuel Assembly Designs Were Evaluated

Reactor Plant	Type	Power, MW*	Manufacturer	Fuel Description
Big Rock Point	BWR	75(e)	General Electric	Reload 9 × 9
Browns Ferry	BWR	1118(e)	General Electric	7 × 7
Brunswick	BWR	821(e)	General Electric	7 × 7
Enrico Fermi #2	BWR	1127(e)	General Electric	7 × 7
Saxton	PWR	22(t)	Westinghouse	70 rods/ assembly
Prairie Island	PWR	550(e)	Westinghouse	14 × 14
Turkey Point	PWR	721(e)	Westinghouse	15 × 15
Zion Station	PWR	1100(e)	Westinghouse	15 × 15
Sequoyah	PWR	1176(e)	Westinghouse	15 × 15
Calvert Cliffs	PWR	875(e)	Combustion Engineering	14 × 14
Davis-Besse	PWR	872(e)	Babcock and Wilcox	15 × 15
Three Mile Island	PWR	900(e)	Babcock and Wilcox	15 × 15
Fort St-Vrain	HTGR	330(e)	GGA	Hex. graphite blocks
FFTF	LMFBR	400(t)	USAEC	Hex. 217 pins/assembly
SEFOR	LMFBR	20(t)	General Electric, et al.	Hex. 6 rods/assembly
Enrico Fermi #1	LMFBR	60.9(e)	PRDC	Square 12 × 12

*
e = Megawatts-electrical
t = Megawatts-thermal

FIGURE 1. Typical Fuel Assembly and Fuel Rod Design

surface and/or identifying marks on the quick-disconnect assembly. The tamper-indicating instrument will thereby be capable of detecting whether an individual fuel rod has been either tampered with or replaced.

OPTICAL COMPARISON TECHNIQUES

Detection of fuel element tampering by stereographic comparison is based on the fact that fuel element assembly components may be individually identified by unique microscopic marks and blemishes. These marks result from tooling scratches and handling during manufacture or assembly and constitute "fingerprints" peculiar to each fuel element assembly.⁽¹⁾ The uniqueness of individual "fingerprint" markings is readily apparent under magnification of 5X to 20X.

Two examples of "fingerprints" on machined surfaces are shown in Figure 2. The "fingerprints" on nuts, fasteners, retainer clips, rods,

FIGURE 2. Examples of Machine Tool and Handling Marks Which Identify Individual Components

plates, or other critical regions of fuel assemblies can be used to detect a change of orientation or the occurrence of new markings which would indicate that tampering may have occurred.

We evaluated four basic types of optical comparison techniques to determine the most suitable methods for use in a tamper indicating instrument:

- Split-Image Comparison - A portion of one image is aligned with the mating portion of a second image. This method is particularly well-suited for comparing "fingerprint" patterns.
- Two-Color Comparison - The images of two similar objects are superimposed using two different colors such as red and green. Identical portions of the two objects appear yellow, but differences show up as red or green. This method is also suitable for comparing "fingerprints" of a fuel element assembly and photographing the new mark or blemish area.
- Chopped-Image Comparison - The images of two objects are superimposed but presented alternately to the observer. Differences between the two objects appear to flicker. Although this method is suitable for detecting differences in handling marks or blemishes, it does not lend itself to photographic recording of the detected mark or blemish.
- Eye-to-Eye Comparison - The image of one object is presented to one eye and the image of a similar object is presented to the other eye. Differences between the two objects tend to stand out because the brain cannot correlate those portions of the two images. This method is not suitable for alignment of two images because the brain compensates for misalignment.

The design of the tamper indicating instrument to be developed incorporates all four of the basic types of optical comparison to provide a versatile instrument capable of functioning under a wide range of conditions. The tamper indicating instrument is based on a comparison of a

photographic record of a fuel assembly taken at the time of fabrication to detect any alteration in the "fingerprint."

DESIGN CONCEPTS OF THE TAMPER INDICATING INSTRUMENT

The basic function of a tamper indicating instrument is to examine areas on a fuel element assembly to determine whether or not tampering has occurred. To implement this function, it is necessary to compare the photograph of the original condition of the area at the time of first inspection to the actual condition at subsequent inspections. The tamper indicating instrument is a single portable instrument capable of making the original photographic record of susceptible areas on a fuel element assembly and subsequently comparing the original record to the same areas utilizing all four basic methods. Also, a photographic record of the comparison may be recorded by the two-color method.

The major components of the conceptual stereographic instrument (Figure 3) include: the image superpositioning optics, the recording 35 mm camera, the reference slide projector, and the viewing stereo-microscope. Comparison of an area on a fuel element assembly to an original photographic record (reference slide) requires that the alignment of the instrument with respect to the fuel assembly exactly duplicate the original alignment. To reduce the number of variables which affect alignment, the image optics are a fixed-focus system, with recording camera and reference slide projector positions fixed and calibrated to exactly reproduce the viewed area of the fuel assembly. The comparison method may be selected and the viewing microscope may be focused or the viewing magnification changed independently of the image superpositioning optics. Alignment is achieved by manipulating the instrument with the aid of the visual alignment projectors and observing the reference and real images. The instrument has position and attitude adjustments for final alignment (Figure 4) after the tripod base is set up.

The image superpositioning optics contain a beam splitter which combines half the light from the target image with half the light from the

image of the reference slide to form superimposed images at the recording camera and the viewing microscope. The target illuminator lamps and slide illuminator are calibrated for equal intensity in the two images.

The two-color image comparison method is implemented by inserting a red filter into the reference slide optical path and a green filter into the target optical path. The superimposed red and green images are presented to the camera and the viewing microscope.

The split-image, chopped-image, and eye-to-eye comparison methods are implemented by polarizing the light from the target image perpendicular to the light from the reference slide image. For split-image comparison, a crossed polaroid image selector is placed at the secondary image plane in the viewing optics. The image selector masks part of each image so that the observer views the target image joined to the reference image at a dividing line. The dividing line may be moved across the image plane or rotated in 45° increments by manipulating the image selector filter.

Chopped-image comparison is implemented by inserting a motor-driven polarizing filter in the viewing optics. The rotating polarizing filter alternately masks the target image and the reference image. The rotation rate of the chopper is adjustable from 2 to 20 rps to optimize the flicker of differences in the two images.

Eye-to-eye image comparison is implemented by inserting a crossed polaroid beam selector in front of the viewing microscope. The beam selector transmits the target image to one eye and the reference image to the other eye. The eye-to-eye comparison method may be used in combination with either or both the split-image and chopped-image comparison.

The viewing microscope is a standard Bausch & Lomb stereo-microscope with 100 mm working distance and a 0.7X to 3X zoom magnification. When 20X eyepieces are used, the overall magnification range of the microscope is 14X to 60X. The viewing optics in the instrument present a 0.25X image to the microscope resulting in an overall system magnification ranging from 3.5X to 15X. This range is sufficient for comparing "fingerprints" of components on fuel elements assemblies.

FIGURE 3. Conceptual Design of Optical Compator for Fuel Cluster Inspection

FIGURE 4. The Stereographic Comparison Instrument in Position for Inspection of a Fuel Assembly. Position and Attitude Controls are Used to Align Target Image and Reference Image.

ACKNOWLEDGEMENTS

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