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by

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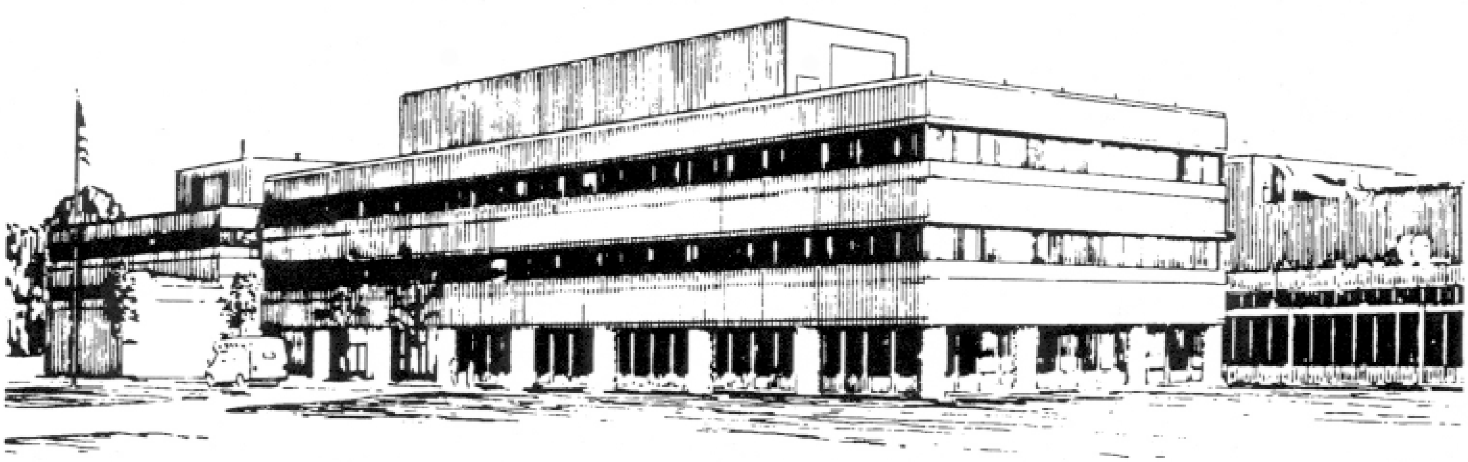

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IN-SITU IMAGING AND QUANTIFICATION OF TRITIUM SURFACE CONTAMINATION VIA COHERENT FIBER BUNDLE

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ABSTRACT

Princeton Plasma Physics Laboratory (PPPL) has developed a method of imaging tritium on in-situ surfaces for the purpose of real-time data collection. This method expands upon a previous tritium imaging concept, also developed at PPPL.[1] Enhancements include an objective lens coupled to the entry aperture of a coherent fiber optic (CFO) bundle, and a relay lens connecting the exit aperture of the fiber bundle to an intensifier tube and a charge-coupled device (CCD) camera.[2] The system has been specifically fabricated for use in determining tritium concentrations on first wall materials.

One potential complication associated with the development of D-T fueled fusion reactors is the deposition of tritium (i.e. co-deposited layer) on the surface of the primary wall of the vacuum vessel.[3] It would be advantageous to implement a process to accurately determine tritium distribution on these inner surfaces. This fiber optic imaging device provides a highly practical method for determining the location, concentration, and activity of surface tritium deposition. In addition, it can be employed for detection of tritium hot-spots and hide-out regions present on the surfaces being imaged.

I. INTRODUCTION

Princeton Plasma Physics Laboratory, Tritium Systems Group has developed and commenced fabrication of an in-situ tritium imaging system, capable of remote data collection. The system employs coherent fiber optic (CFO) bundle(s) to transfer signals from a photon-emission source to a charge-coupled device (CCD) camera interface. The image acquisition method is non-destructive (NDE) to surfaces, and implements real-time assessment for immediate data collection.

The prevalent technique used for determining the amount of tritium penetration into materials is autoradiography, in which a film emulsion is applied directly onto the material. This is both invasive and destructive to the material. The film exposure process involves leaving the material in an environment absent of ambient light for an extensive period of time (hours to tens of hours).[4] These criteria provide an initial motivation for the development of a NDE, real-time imaging method.

The governing principle of beta-luminescent imaging technology (method employed by PPPL) involves the use of photostimulable P31 Zinc Sulfide: Copper (green spectral response) phosphor, which has a very high luminous efficiency (46 lm/W) and has its peak radiant energy output at a wavelength of 530 nm. This phosphor is granulated into a very fine powder and dispersed thinly and evenly over an optical quality window. Any ionizing radiation (i.e. tritium beta particles) incident on the phosphor produces excited electron states in the copper, and causes photons to be emitted as the electron states de-excite. The phosphorescence is proportional to the type and activity of the incident radiation (tritium beta particles decay with an average energy of 5.6 keV), and can be converted to a digital image signal via the use of a charge coupled imaging device.

II. THEORY OF OPERATION

In order for visual tritium monitoring to occur, the thin film phosphor-coated plate (Type P-31, zinc sulfide: copper) is placed directly above a tritiated surface (adjacent to ~1mm above). Beta particles emitted from the surface directly interact with the phosphor, thus generating electromagnetic radiation in the form of photons. These photons are detected by the highly sensitive CCD (charge-coupled device) and are converted to a digitized graphic signal.[5]

The CCD imager is made from silicon, enhancing its effectiveness when exposed to electromagnetic radiation of the visible spectrum. In crystalline silicon, the atoms are covalently bonded to form a lattice structure. Incident photons that penetrate the lattice can break these bonds, thus generating electronic charge. To measure the electronic charge produced by the incident photons, a potential well is used to collect the charge. Charge can accumulate over an extended period of time. The total amount of charge is proportional to the product of the light intensity and the exposure time. The charge collected in a potential well must be brought to an output amplifier, which produces a signal proportional to the charge.[6]

It is important that the camera's readout and signal processing electronics be optimized so that low read noise is maintained, otherwise the dynamic range will be negatively affected. Therefore, Primary Point Digitization (PPD) is implemented by the camera system to improve sensitivity, increase dynamic range, and reduce signal degradation. The PPD design positions the analog-to-digital converter (ADC) in the camera head as close to the CCD as possible, thus reducing the distance the analog signal must travel.[7] This greatly improves the charge transfer efficiency (CTE), which is of special concern at low charge levels where a small loss of charge can cause substantial degradation of the image. As a result, the analog signal reaches the 12-bit ADC as a high-quality signal that can optimally make use of the full range of gray levels (4096 gray levels).

The CCD in the camera is cooled and temperature regulated to 10 degrees Celsius through a forced air, thermoelectric cooler (single-stage Peltier cooler) and operates in multi-pinned-phase (MPP) mode. MPP mode reduces the rate of dark current generation by a factor of 20 or more and thus lowers CCD cooling requirements to the level where a thermoelectric cooler is sufficient for most applications.[6]

III. SYSTEM CONFIGURATION

The in-situ tritium imaging system is designed for use inside tritium-fueled fusion reactors. Imaging plate (affixed to objective lens mount — see Fig. 1) is positioned above in-situ surface via manual operator or articulated robotic arm. Imaging hardware (i.e. CCD camera interface, computer interface — see Fig. 1) is situated at an area outside of the reactor. The system implements precision digital optics software for image/data acquisition. The key components of the system are a phosphor-coated imaging plate; an opaque enclosure; an objective lens; a CFO bundle; a relay lens (more than one may be required if employing more than one CFO bundle); an image intensifier tube; a CCD camera; and a computer interface (see Fig. 1).[3]

Assembly and/or positioning of the components involves consideration of several parameters (optimized via calculation/experimentation). There are two sub-systems that are of concern: (1) emissions hardware, and (2) optics. Emissions hardware is comprised of the surface being imaged, the phosphor-coated imaging plate, and any associated enclosure/flight tube. Emissions hardware parameters include atmospheric conditions (i.e. pressure, temperature, composition), distance between surface and phosphor coating, thickness/uniformity of phosphor coating, extent of ambient light shielding, and optical quality of transfer window. Optics is comprised of all lenses, CFO, intensifier tube, CCD camera, and computer hardware/software interface. Optics parameters include lens working distances/focal lengths, CFO specifications (i.e. length, spectral transmittance, resolution, etc.) relay configurations, lens iris diameters, CCD camera gain, and signal-to-noise ratio.

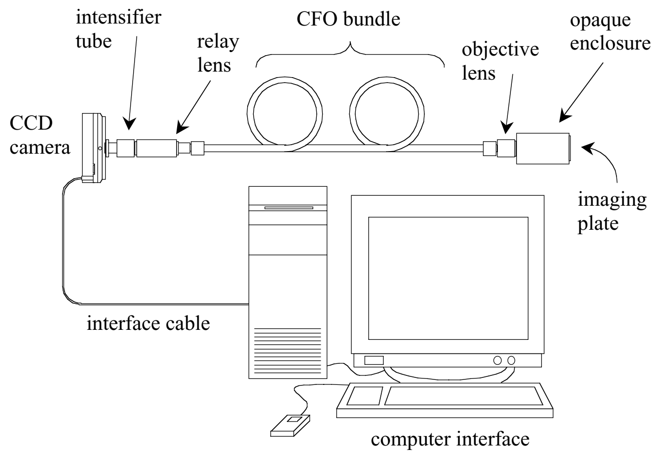

Figure 1 Schematic of the In-Situ Tritium Imaging System

IV. IMPLEMENTATION

In July of 2000, Princeton Plasma Physics Laboratory conducted a scheduled TFTR vacuum vessel entry as part of the Decontamination & Decommissioning (D&D) process. During this entry, a prototype CFO imaging configuration was implemented for assessment of tritium deposition on the primary wall surface of the vacuum vessel. The acquired image depicts significant tritium deposition within the column spaces between adjacent tiles (Fig. 2).

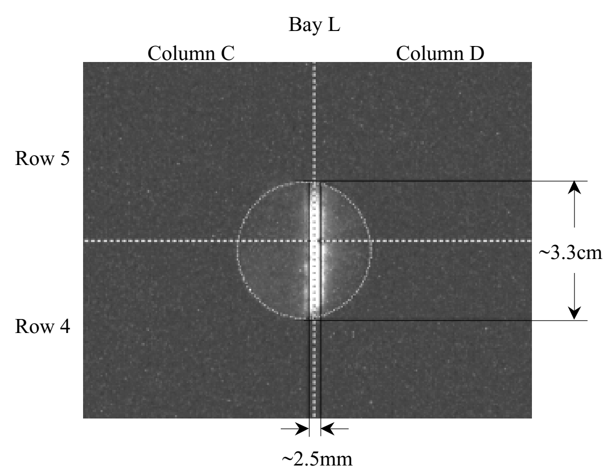

Figure 2 Image taken with CFO imaging system of primary wall inside the TFTR. Bright area indicates elevated level of tritium activity relative to the surrounding (darker) areas. Dotted lines indicate separation between tiles.

V. ALTERNATIVE METHODS FOR APPLICATION OF PHOSPHOR THIN FILM COATING

Among the possible techniques for phosphor thin-film deposition onto fused silica optical window, the one currently employed for this system is application of fine mesh phosphor powder directly to the surface via anti-static brush. Microscopic analysis, however, indicates that the seemingly uniform layer of phosphor is actually a very rough surface consisting of hills and craters (see Figure 3a, 3b). New methods have been researched for possible use for this application.

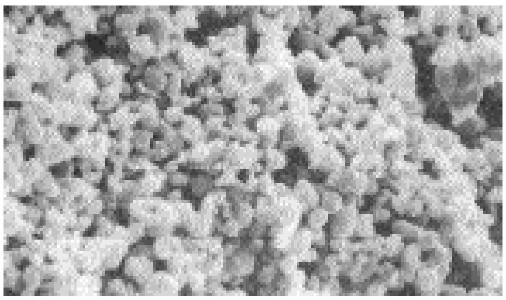

Figure 3a Microscope image of phosphor coating (top view)

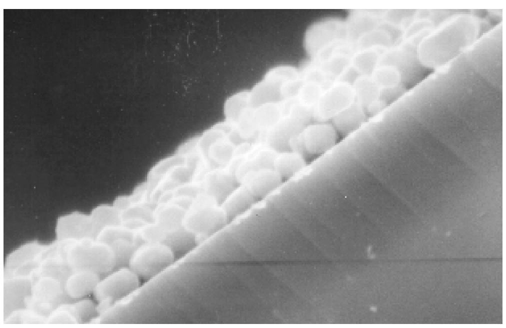

Figure 3b Microscope image of phosphor coating (side view)

Physical Vapor Deposition is one such alternative to solid state deposition. The process involves substrate surface interaction with plasma under vacuum condition. The process can generally produce coating of 2 to 5 microns thick. Chemical Vapor Deposition has also been considered as a promising alternative to solid state deposition. The process involves a series of chemical reactions in which gaseous state molecules (called precursor) are reacted to solid state material. The substrate surface thus accumulates a uniform thin-film coating.

Atomic Layer Epitaxy (ALE) is a specific chemical method for producing thin films, which consists of sequential surface reactions at the substrate surface. This is a surface controlled method with film characteristics that include near unity packing densities, absolute thickness and uniformity control to within an atomic layer even over large and nonstandard shaped substrates.[8]

V. CONCLUSION

The development of an imaging system employing CFO provides a method for the in-situ analysis of surfaces, both qualitative and quantitative. Such technology can assist with determining tritium surface concentrations on first wall materials. The operator of this system is able to determine tritium location, activity, and concentration in real-time, while maintaining NDE conditions.

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