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Nondestructive Evaluation of Uranium-Plutonium Mixed Oxide (MOX) fuel elements by Gamma Autoradiography

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Abstract

Nondestructive evaluation of uranium-plutonium mixed oxide fuel elements is an important step ensuring the quality of the fuel encapsulated. Gamma Autoradiography (GAR) is used to extract information of uranium-plutonium mixed oxide (MOX) fuel in welded fuel elements. In this technique, radiation emitted by the fuel is captured on X-ray film kept in a cassette. Gamma autoradiographs reveal both qualitative and quantitative useful information about MOX fuel. Composition of MOX fuel in the welded fuel element is monitored by gamma autoradiography. Presence of plutonium rich agglomerates in the periphery of the pellets is also detected. Gamma autoradiography has been used at Advanced Fuel Fabrication facility, Bhabha Atomic Research Centre (BARC), Tarapur for non destructive evaluation of MOX fuel pins for various types of reactors. MOX fuel pins containing pellets of three different composition (0.9%, 1.55%and 3.25% of PuO_2) were irradiated in Boiling Water Reactors. Gamma autoradiography was used to monitor the composition, detection of wrong loading of pellets and presence of plutonium rich agglomerates lying in outer region of the pellets. The technique was successfully used in our facility for monitoring the compositional variation of MOX stack of nominal composition of 0.4% PuO_2. Gamma autoradiography was used as nondestructive evaluation technique for fuel elements for fast reactors also. Pellets of higher PuO_2 content are used in fast reactors. The technique has been applied for fuel elements with PuO_2 loading of 21%, 28%, 30% and 44% of PuO_2. This paper introduces the technique of gamma autoradiography, describes application of the technique for nondestructive evaluation of MOX fuel elements for both thermal and fast reactors containing PuO_2 content varying from 0.4% to 44% and the results of the experiments carried out for nondestructive characterisation of the fuel elements.

Keywords : Gamma autoradiography, Plutonium, MOX, Nuclear fuel, Nondestructive evaluation, reactors**.**

1. Introduction :

Advanced Fuel Fabrication Facility (AFFF), Bhabha Atomic Research Centre, Tarapur is fabricating Pu based mixed oxide fuel (MOX) for various types of reactors [1]. The quality of the fuel is ensured by following a detailed QC plan and process control steps at different stages of fabrication. MOX fuel pins for Boiling Water Reactors were fabricated at AFFF and irradiated in the Tarapur Atomic Power Station 1 & 2 reactor. Pellets of three different compositions (0.9, 1.55 and 3.25%) of PuO_2 were encapsulated and were used in making the fuel bundles consisting of 36 pins [2]. MOX pins used for Pressurised Heavy Water Reactor contained 0.4% PuO_2. Nineteen element PHWR MOX assembly consisted of 7 inner MOX pins and 12 outer natural UO_2 pins. A number of bundles were successfully irradiated in a commercial Pressurised Heavy Water Reactor and were discharged recently [3]. Fuel pins containing MOX pellets of higher PuO_2 content are used in fast reactors. MOX fuel pins containing 44% PuO_2 have been used as a part of the hybrid core for Fast Breeder Test Reactor (FBTR) at Kalpakkam. Our facility is at present fabricating fuel pins containing pellets with 21% and 28% of PuO_2 for the Prototype Fast Breeder Reactor coming up at Kalpakkam.

During the fabrication of MOX fuels of various compositions, the need for a nondestructive evaluation technique to be used as a final check of the composition of MOX pellets in the welded fuel pin was felt. The possibility of having PuO_2 agglomerates in the sintered MOX pellets cannot be ruled out during the manufacture of MOX fuel even though $UO_2 – PuO_2$ forms a complete solid solution. It is also required

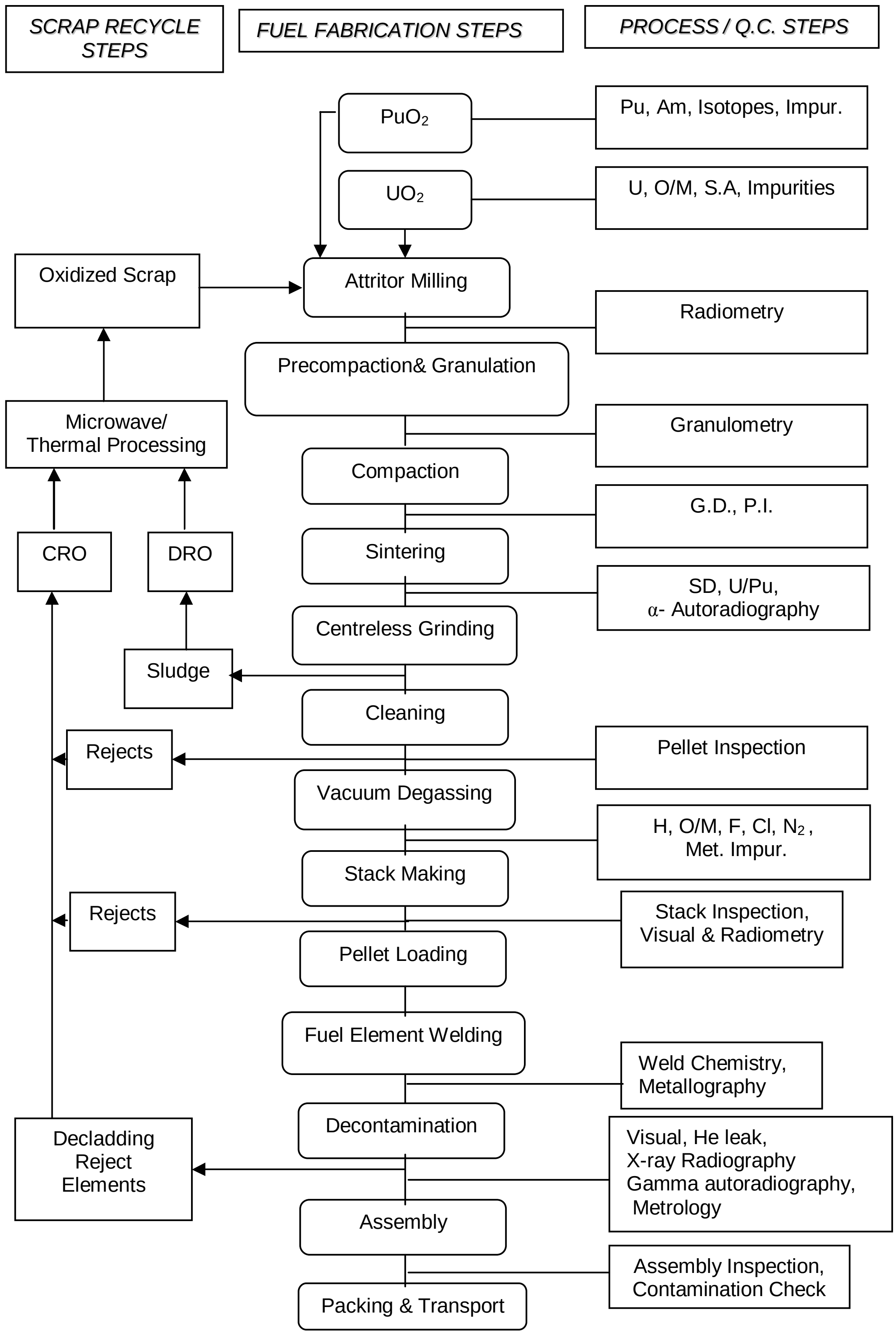


Fig.1 Flowsheet for fabrication of MOX fuel

to ascertain that PuO_2 agglomerates more than the specified size are not present in the pellets [4]. This is an important specification requirement for Pu based fuels. Alpha autoradiography is the standard quality control check carried out on sample pellets to detect agglomerates [5]. Use of neutron radiography [6] which can reveal the presence of PuO_2 agglomerates irrespective of their position and composition is not practical in a fuel fabrication facility. Thus a need was felt for NDT technique capable of detecting PuO_2 agglomerates and verifying the composition of the pellets in the welded fuel pins for effective quality control of MOX fuel pins. Gamma autoradiography has therefore been used as a simple nondestructive check to monitor the percentage of PuO_2 and to detect the presence of agglomerates in the MOX fuel stack. This paper presents in detail the technique of gamma autoradiography and its application during the fabrication of MOX fuel pins for both thermal and fast reactors.

2. Fabrication and Quality Control of fuel pins :

Mixed oxide fuel pellets are made from the mixture of UO_2 and PuO_2 powders which are weighed in the required proportion and then milled together in an attritor. Milling of the MOX powder in the attritor is carried out to get the required homogeneity. The milled material is pre-compacted and the pre-compacts are granulated in the size of 400 – 2000 microns. These granules are used for final compaction to make the green pellets. The compacted pellets are sintered at reducing atmosphere (N_2 – 7%H_2) at high temperature of 1600 ° C. The over sized pellets are centrelessly ground. Pellets of appropriate dimensions and density are loaded into the clad tubes after inspection and encapsulated. The diameter of the sintered pellets for thermal reactors is in the range of 12 to 14 mm and the pellets for fast reactors is of the order of 5 mm. The clad material for thermal reactors is zirconium alloys and that for fast reactors is stainless steels. Fig. 1 shows the flowsheet for manufacture of MOX fuel .

The main steps followed in the quality control and fabrication of MOX fuel are also given in Fig. 1. A suitable QC plan has been drawn up based on the specification of the fuel. A number of new and advanced techniques have also been used to increase the

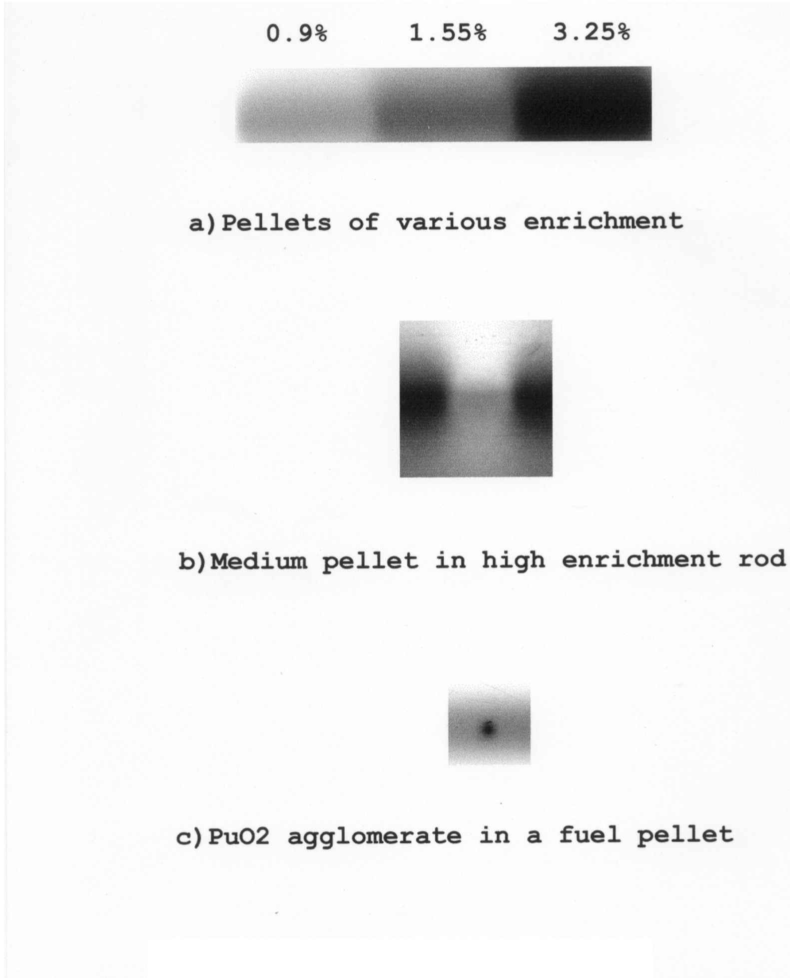


Fig 2. Gamma Autoradiograph of BWR MOX pellets

confidence and reliability of process. The homogeneity of distribution of Pu and composition are two important characteristics to be checked during the fabrication of MOX fuel. A number of destructive and nondestructive techniques are used for this purpose. Gamma autoradiography has been used for the evaluation of these two characteristics of all the fuel pins.

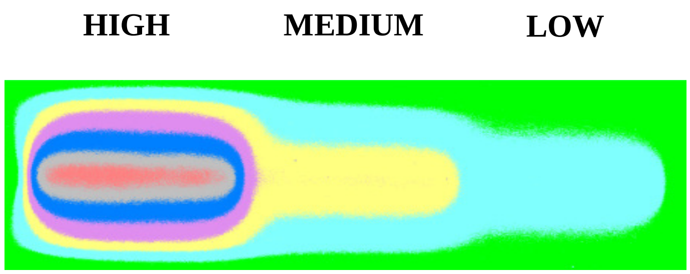
3. **Gamma Autoradiography :**

In Gamma Autoradiography, the fuel pins are kept in contact with X ray films in a cassette. The radiation coming from the fuel pellets affect the film to different extent depending on the PuO_2 composition. The optical density of the image of the fuel stack of the processed radiograph is proportional to PuO_2 enrichment. Qualitative and quantitative information is available from the gamma autoradiographs. The combination of X ray radiography and gamma autoradiography (XGAR) is also being used for checking the correct loading of pellets and hardware in the fuel pins. The gamma autoradiographs are digitized and the colour segmentation technique is applied to get characterization colour contours for regions of similar optical density level Any change of composition or enrichment is manifested as a change in colour in the colour gamma autoradiograph.

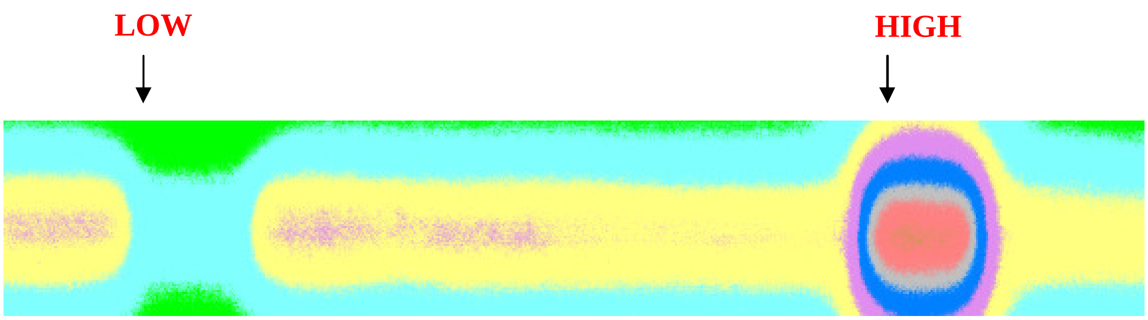
4. Fuel elements for thermal reactors :

Gamma autoradiography was used during the fabrication of MOX fuel pins for the Boiling Water Reactors. The fuel bundle consists of MOX fuel pins of three enrichments of PuO_2 namely 0.9%, 1.55% and 3.25%. Gamma Autoradiography is used to detect loading of pellets of wrong enrichment and presence of PuO_2 agglomerates and compositional variation. Experiments were carried out with experimental fuel pins for this purpose. Fig. 2 presents a gamma autoradiograph distinguishing the pellets of different enrichment and presence of PuO_2 agglomerate. Fig. 3 presents colour gamma autoradiograph of pellets of three different enrichments. The optical density of the gamma autoradiograph gives quantitative information about the PuO_2 composition..

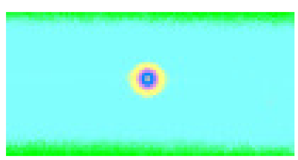
The optical density of the gamma autoradiograph varies linearly with the PuO_2 composition. It was possible to monitor compositional variation as low as 0.3% absolute in fuel pin containing pellets of medium enrichment of nominal composition of 1.55% of PuO2 as shown in Fig. 4.



Colour GAR of standard BWR pin



Colour GAR of mixed enrichment BWR pin



GAR showing PuO_2 agglomerate

Fig. 3 Colour GAR of BWR MOX pellets

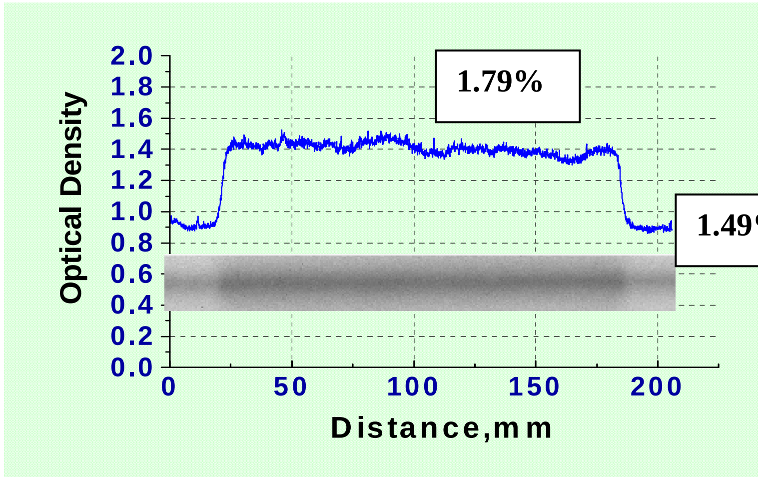


Fig 4 Density scan of GAR showing compositional variation

5. Fuel pins for fast reactors :

Gamma Autoradiography combined with X radiography has been used for nondestructive evaluation of fuel pins for fast reactors. The fuel used for the hybrid core of FBTR consists of pellets containing 44% of PuO_2. XGAR clearly revealed the compositional variation, correct loading of MOX and UO_2 stack and presence of agglomerates in the annulus of the pellets .

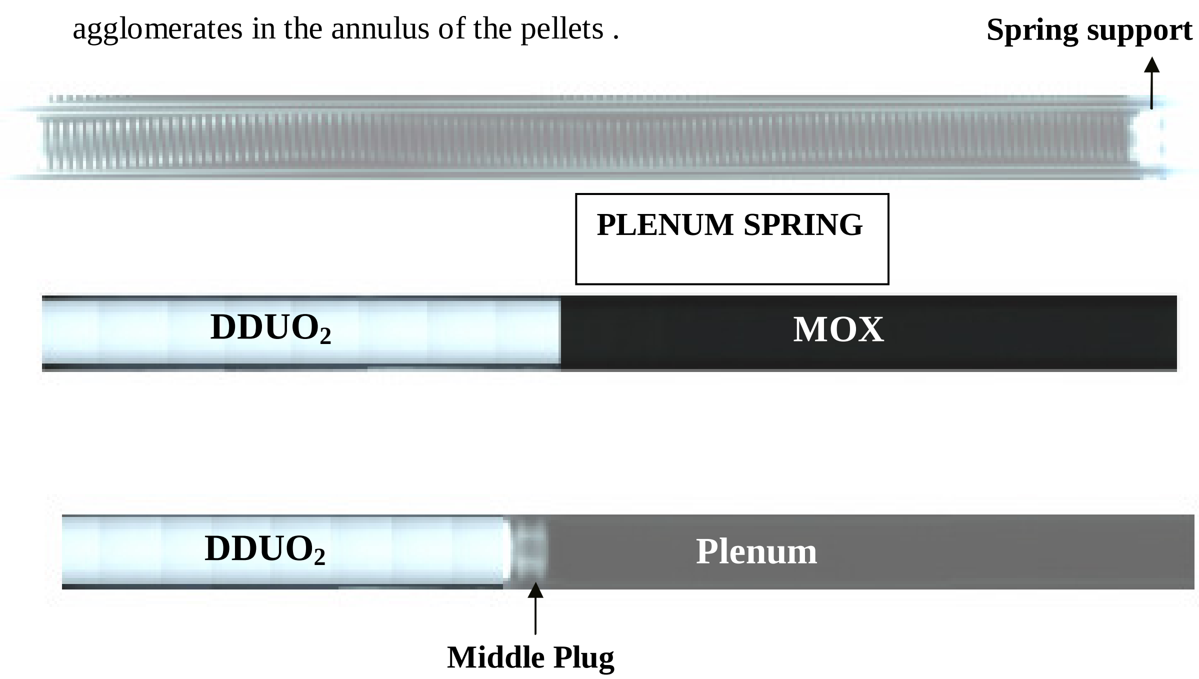


Fig. 5   XGAR of PFBR fuel pin

The core of Prototype Fast Breeder Reactor consists of fuel pins of two different composition namely 21% and 28% PuO_2. The MOX fuel stack is 1000 mm long and with depleted UO_2 stack of length 300 mm on either side. Gamma Autoradiography /X Gamma Autoradiography are being used routinely to confirm the correct loading of fuel and the hardware like plenum spring and spring support. Fig. 5 presents X Gamma autoradiograph (XGAR) of a typical PFBR fuel pin.

6. Conclusion :

Use of Gamma Autoradiography for nondestructive characterization of fuel pins for both Fast reactors and Thermal reactors are demonstrated. It is possible to verify the correct loading of pellets of specified composition, hardware and also to detect the presence of PuO_2 agglomerates in the periphery of the pellets. This technique has increased reliability and confidence in the quality of the fuel elements being fabricated at our facility.

7. Acknowledgement :

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