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# Remote NDT for Inspection of Reactor Vessel Components of Fast Breeder Test Reactor

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**Abstract** Fast Breeder Test Reactor (FBTR) is a 40 MW (thermal) / 13.2MW (electrical), Plutonium - Uranium mixed carbide fuelled, sodium cooled, loop type nuclear reactor operating at Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam. Its main aim is to generate experience in operation of fast reactors and sodium systems and to serve as an irradiation facility for development of fuels and structural materials for fast reactors. Nuclear reactors pose difficulties to the NDT techniques used to monitor the conditions of the internal components. Sodium cooled fast breeder reactors have their own typical difficulties in using the NDT techniques. These are due to the need for operation in aggressive environment of nuclear radiation and sodium (molten/vapour), as well as the need to maintain leak tightness of a very high order during all states of reactor operation and shutdown for fuel handling, maintenance and remote inspection. This paper discusses the following NDT techniques, which have been successfully used for the past 15 years in FBTR: (i) Periscope and Projector, (ii) Core Co-ordinate Measuring Device and, (iii) Optical fiberscope. The inspection using these techniques have given confidence for further reactor operation at high power by giving useful data on the conditions of the components inside the reactor vessel.

**Keywords:** fast breeder reactor, remote visual inspection, periscope and projector, coordinate measurement, fiberscope, fuel handling

## 1. Introduction

Fast Breeder Test Reactor (Fig. 1) is a 40 MWt / 13.2 MWe Plutonium - Uranium mixed carbide fuelled, sodium cooled, loop type reactor. Its main aim is to generate experience in operation of fast reactors and sodium systems and to serve as an irradiation facility for development of fuels and structural materials for fast reactors. The heat produced in the core is removed by two hydraulically coupled primary sodium loops, which in turn transfer the heat to two independent secondary sodium loops through intermediate heat exchangers. Each secondary sodium loop has been provided with two once through serpentine type steam generator modules. The steam water system has 100% steam dump capacity to facilitate reactor operation when turbine generator is not in service. The reactor was made critical in 1985 and synchronised to the grid in 1997. It is presently operating at maximum power level of 13 MWt.

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This paper details the visual inspection of reactor vessel components carried out with the help of visual aids like periscope and projector, core co-ordinate measuring device and optical fiberscope.

## 2. Requirements

The technical specification for FBTR operation stipulates visual inspection of reactor vessel internals periodically to assess the extent of sodium oxide deposition on the vessel walls, ascertain non-plugging of small pipes and general examination of vessel and internals for any abnormalities.

At high level of neutron irradiation, bowing of subassemblies could occur and create difficulties in their gripping/release during fuel handling operations. Hence it is necessary to measure the misalignment of subassembly heads with respect to fuel handling canal axis.

Leak tightness of the reactor vessel during the rotation of top shields, for fuel handling purposes, is ensured by liquid metal seals. If liquid metal alloy gets oxidised, leak tightness efficiency of the seal reduces and also higher torque will be required to rotate the plugs. Hence it is necessary to visually inspect the condition of liquid metal seals for satisfactory operation.

## 3. Visual Inspection Devices - Design Features

### 3.1. Periscope and Projector

The periscope (Fig. 2) essentially comprises of optical system, prism drive system and lead shielding. The design provides for scanning through 90° in any vertical plane. By rotating the periscope assembly about its own vertical axis, it is possible to scan the entire solid angle of $2\pi$ sterdians. The periscope has an instataneous field of view of about 0.04 steradians i.e, a cone of semi-angle of 6.5 deg. The optical system comprises two objective prisms near the viewing window and a set of lenses and prisms which transmit the image to the top. Leak tightness is achieved by oil seal, 'O' rings and gaskets. Shielding is provided with lead of about 750 mm thickness in three different blocks. The optical path through the shielding is given a lateral offset to prevent radiation streaming through the penetrations in the shielding.

The projector (Fig. 2) provides illumination for viewing and is of modular type. The lighting module is fixed at the bottom of the projector body. The lighting module utilises a 400 watts mercury iodine lamp and an optical collimating system consisting of a rhodium

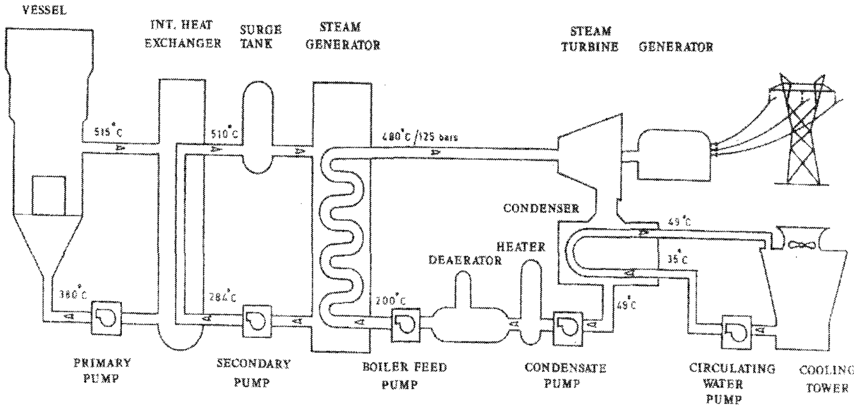


Fig. 1 Schematic sketch of various components of FBTR

coated ellipsoidal reflector, three quartz lenses and an aluminium coated mirror. The illumination of the lighting system is about 1500 lux at a distance of 2.5 m. The beam is conical with semi-angle of 6.5°. The lamp, holder and cables are cooled with argon. Shielding is provided with a lead plug of 500 mm thick and leaktightness is achieved through 'o' rings and gaskets. Penetrations in the shield plug for the cables, thermocouples and argon passages are made at an angle to the axis to avoid radiation streaming. Both periscope and projector have been developed by Division of Remote Handling and Robotics (DRHR), BARC.

Visual inspection campaign is carried out with reactor in shutdown state and reactor sodium at 180℃. The periscope and projector are each designed for installation in (Fig. 2) experimental canals in top shield of the reactor vessel housing large and small rotating plugs (LRP & SRP). Each of the canals is fitted with a air to operate valve, over which a preheating chamber and a leak tight chamber are installed. The projector/periscope is supported on the leak tight chamber through a cylindrical thrust bearing, which enables rotation about their own axis. The leak tight chamber is meant to prevent leakage of reactor vessel cover gas to reactor containment building and is achieved by pressurising the chamber with argon to 50 mb above cover gas pressure. The preheating chamber is meant to preheat the glass dome of the projector and glass window of periscope to avoid thermal shock to the glass on introduction into reactor and to minimise the aerosol deposition on their otherwise cold surfaces.

### 3.2. Core Co-Ordinate Measuring Device

This device (Fig. 3) operates under sodium with reactor in shutdown state and sodium temperature 180℃. It consists of a guide sleeve which fits into the fuel handling canal and a flexible target tube penetrating through this sleeve. The bottom of the target tube carries a cone which enables the target tube to 'seek' any sub-assembly head with a misalignment upto 16mm with respect to the fuel handling canal. The target tube can be raised or lowered and in the lowered condition it rests on the

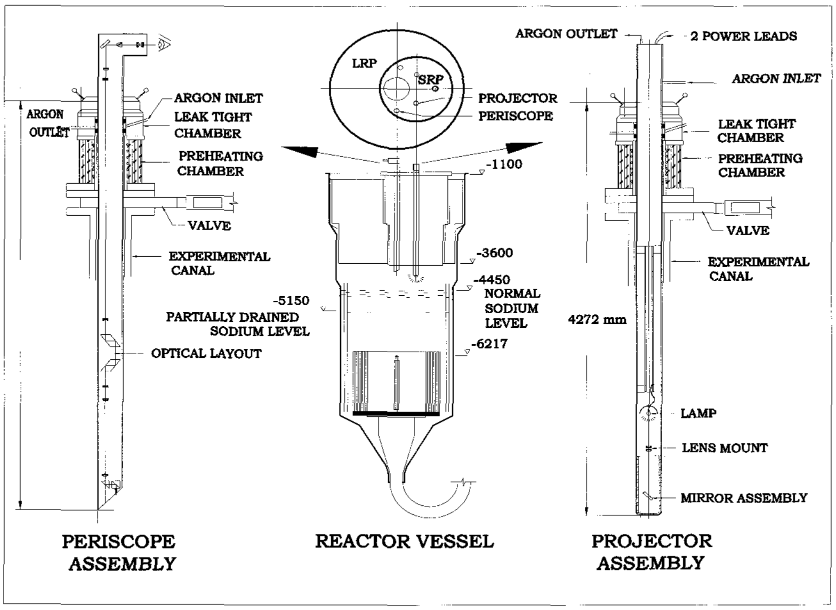


Fig. 2 Location of periscope & projector in reactor vessel

sub-assembly head. A telescope and a lighting source are mounted on top of the sleeve and are used for illuminating and viewing the target. The misalignment between the fuel handling canal axis and sub-assembly head is measured by simple geometric procedures. The lighting source, consisting of a transformer, a 6V, 10W lamp, reflector and condensing lens, is capable of throwing 100 lux uniform light on the target. The raising/lowering lever of the target tube is wired to the plug rotating logic. The telescope is K & E make optical alignment telescope with a focussing range of zero to infinity and line of sight accuracy of 1 sec.

### 3.3. Optical Fiberscope

The optical fiberscope used for Liquid Metal Seal inspection is $\phi$ 6 mm, 3 m long 'OLYMPUS' make fixed focus, direct viewing with a field of view of 100°.

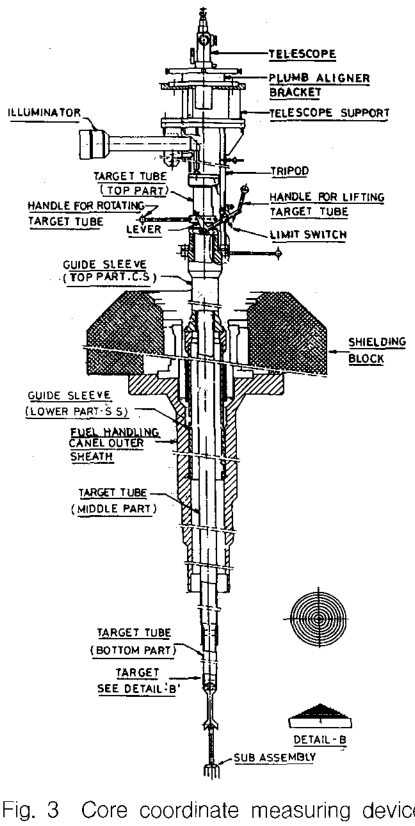


Fig. 3 Core coordinate measuring device

## 4. Inspection and Results

### 4.1. Reactor Vessel Internals

Reactor vessel internal inspection is carried out to assess the extent of sodium oxide deposition on the vessel walls and thermal shields, to ascertain non-plugging of small pipes viz. siphon break, argon, sodium purification return, emergency injection, overflow pipes and generally examine for any abnormalities. The inspection has been carried out four times in the past 15 years. The small pipes were found clear and non-plugged. Sodium deposits were seen at a few spots. Siphon break pipe, provided to prevent automatic draining of sodium from reactor vessel in the event of any rupture in the primary sodium piping, was checked for non-plugging. This was checked by establishing flow through the pipe after partially draining sodium in the reactor vessel below the bottom level of siphon break pipe and running one primary pump. Clear sodium flow was observed. In case of sodium leak from reactor vessel, sodium will be injected from flooding circuit through emergency injection pipe into reactor vessel to keep the core completely submerged and avoid overheating of the core. Non-plugging of this pipe was checked by establishing sodium flow from flooding tank to reactor vessel. The sodium column flowing down this pipe was seen with the help of periscope.

### 4.2. Measurement Of Subassembly Head Location With Respect To Fuel Handling Canal Axis

Due to irradiation induced bowing, the subassembly heads may deviate from its theoretical location. Top shields, called as large and small rotating plugs located eccentric to each other, are provided in the reactor assembly mainly to provide access to all the subassembly locations in the reactor core for fuel handling purposes, to ensure leak tightness and containment of the reactor vessel cover gas and sodium and to provide adequate biological shielding above the reactor vessel. The position of each subassembly is defined by the angles '$\alpha$' and '$\beta$' of the rotating plugs. Theoretically the vertical line through the centre of fuel handling canal should fall on the centre of the subassembly. The Core Coordinate Measuring Device (CCMD) is used for measuring this deviation and it is measured as follows. The target tube is lowered and allowed to rest on the subassembly head (Fig.4). The centre of the target, C represents the centre of the subassembly heads. Let B represents the intersection of axis of fuel handling canal on the horizontal plane at subassembly head top. The line of sight of telescopic intersects the above horizontal plane at point, A. If the sleeve of CCMD is rotated about its axis, the point, A describes a circle with B as centre. BC represents the deviation of the subassembly head. In practice the centre B is found out by noting the location of the cross-wire w.r.t target centre for every $90^{o}$ rotation of the sleeve. Plotting these four points, the centre of a circle passing through these points is geometrically worked out as the point of intersection of the perpendicular bisectors of the lines joining diagonal points. This centre being the centre of rotation of the line of telescopic sight, represents B. The vector BC gives the misalignment of the head.

This device is also used for periodic surveillance of selected subassemblies for bowing as a function of fluence. This device measures the misalignment between the head of a subassembly and the projected axis of the fuel handling canal for the set values of '$\alpha$' and '$\beta$' of the rotating plugs.

This device was commissioned outside fully simulating the in-reactor conditions. The accuracy of measurement was found to be $\pm$ 0.5mm. This device was used three times and measurements taken were compared with earlier values for any deviation/shift of the subassembly heads. The inspection carried out so far revealed that after a burn up (energy generated per tonne of fuel) up to about 45000 MWd/t, the bowing of the subassembly is very less and will not cause any problem during fuel handling.

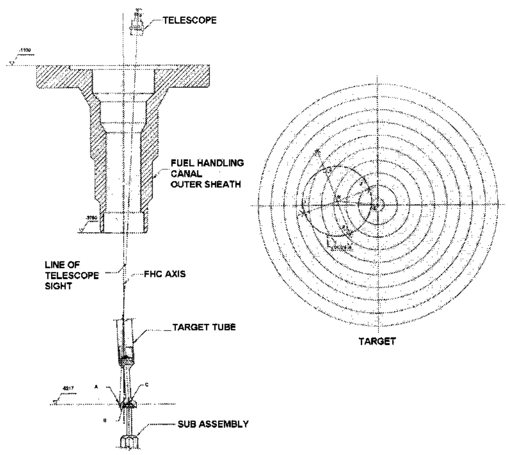


Fig. 4 Principle of measurement of CCMD

### 4.3. Liquid Metal Seals

During the rotation of plugs for fuel handling, the liquid metal seals ensure leak tightness of the reactor vessel. These seals remain solid during reactor operation and are melted for plug rotation during fuel handling. If liquid metal alloy gets oxidised, leak tightness efficiency of the seal reduces and also higher torque will be required to rotate the plugs. To prevent oxidation of the liquid metal seal, silicone oil is maintained above the liquid metal seal surface on one side whereas the other side is protected by inert cover gas. Hence, it is necessary to visually inspect periodically the condition of the liquid metal seals.

The liquid metal seals of large and small rotating plugs were visually inspected with the help of fiberscope to check the condition of the seal, measure the height of the liquid metal column and to check the condition and level of silicone oil present on one side (Fig. 5). This inspection has been carried out thrice. Reduction in silicone oil column was observed which was due to evaporation when liquid metal seal is in molten condition. Silicone oil was topped up to the required level. Liquid metal surface was

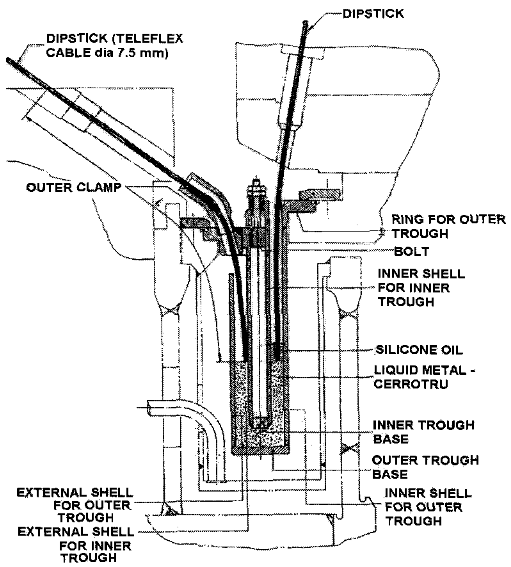


Fig. 5 Measurement of liquid metal seal levels

found to be shining, indicating no oxidation of metal. The depth of top surface of liquid metal seal was also measured.

## 5. Conclusion

Visual inspection, the first and oldest NDT method, was effectively utilised with the help of various visual aids for the inspection to assess the condition of the Reactor Vessel internals. The inspection carried out so far revealed that the Reactor Vesssel and internals are in healthy condition and this has increased the confidence level to further operate the reactor at higher power levels.

To improve the inspection capabilities further, certain modifications to the periscope viz. zooming facility, better resolution, swiveling of bottom prism to about 120° in vertical direction to view the bottom of the rotating plugs, video attachment to the eye piece for recording of observations have been incorporated by DRHR, BARC and the new periscope is presently in advanced stage of fabrication.