Radiation Protection Aspects Gained from the Operation of FBTR – Basis for Approach & Criteria for Future LMFBRs

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Abstract. Health Physics experience gained from the operation of Fast Breeder Test Reactor since more than twenty years is outlined. These include area monitoring, stack monitoring, annual discharge of activity released vis-à-vis technical specification limits, personnel monitoring that include man-rem expenditure, waste disposal etc. Basic aspects of Radiation and Air Activity Monitoring System (RAAMS), meant to monitor and record the radiation and air activity levels at various controlled areas in FBTR complex are given. Installation, calibration and usefulness of special monitors, unique to LMFBRs, such as gas flow ion chambers in the Clad Rupture Detection (CRD) argon circuit for detection of gaseous fission products, fume activity monitors in the ventilation ducts to indicate sodium leak / fire, sodium aerosol detection monitors in the primary double envelop sampling line and gas activity monitors are highlighted. Radiologically significant incidents such as minor sodium leak in the primary purification system in 2002 and special operations are reported. The experience gained during successful handling, treatment, and disposal of active primary sodium and decontamination of active sodium-bearing components following steam-nitrogen process is brought out. Towards controlling external exposures to occupational workers during maintenance work, the salient features of the study conducted to assess the deposition of radioactive corrosion and activation products and dose rates in the primary sodium pipelines and various components of FBTR, which are housed in B-cells, are highlighted. The environmental aspects of LMFBRs are also briefly outlined. The lessons learnt from the experience gained such as lowering of alarm limit for particulate activity monitors to enable detection of primary sodium leak within reactor containment building, identification of deposition of $^{54}$Mn in the interiors of primary sodium lines as a major contributor to the external dose component, the detector for gas activity monitors (unique for FBRs) should be compensated type ion chambers and not the NaI(Tl) based ones, the energy threshold criteria for the installed radiation monitors meant for detection of primary sodium, further possibility of reduction in man-rem expenditure etc., are presented. The experiences gained would serve as a guide for a safe approach and in determining the criteria from the point of view of radiation protection for future LMFBRs.

KEY WORDS: Radiation protection, LMFBR, FBTR, Health Physics

1. Introduction

Fast Breeder Test Reactor (FBTR) is a 40 MWt, loop type, sodium cooled, mixed carbide fuelled reactor situated at Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, India. Health Physics services commenced at FBTR in April 1985. To begin with, fuel assembly, neutron source assembly and core loading operations were carried out. First criticality was achieved in October 1985 with a mixed carbide core of 23 fuel sub-assemblies, making India the sixth country in the world and first developing country to build and operate a Liquid Metal Fast Breeder Reactor (LMFBR). Till December 1992, the reactor was operated at power levels upto 1 MWt without water in steam generators. Steam Generator was put in service at a power level of 10.2 MWt in December 1993. In July 1997, Turbo Generator was synchronized to the southern grid. The core has been progressively enlarged and the power level has also been progressively increased to 17.4 MWt. The irradiated fuel sub-assemblies after achieving a burn-up of 25 GWd/t, 50 GWd/t, 100 GWd/t and 155 GWd/t were discharged for post irradiation examinations (one each). There have been no fuel failure incidents so far. However, very few other incidents including a sodium leak in the primary system did occur, though all of them were minor. These and other operating experiences of FBTR since more than twenty years, solely from the point of view of radiological aspects, are presented.

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2. Radiation and Air Activity Monitoring

The Radiation and Air Activity Monitoring System (RAAMS) consists of 10 particulate activity monitors (PAM), 12 Area Gamma Monitors (AGMs), six Gas Activity Monitors (GAM), three in-duct gas activity monitors, and one discharge flask high range gamma monitor. Calibration and performance testing of RAAMS were given emphasis at the early stage of the commissioning of the reactor itself. Continuous monitoring of Reactor Containment Building (RCB) air for particulate and gas activity by Particulate Activity Monitors and Gas Activity Monitors respectively inside RCB is unique for FBTR. Experience on the performance of AGMs and PAMs is very good. However, the alarm threshold for PAMs was optimized (drastically reduced) at 10 times the background value from the earlier set value of 10 DAC-h (Derived Air Concentration-hour) correspond to $^{90}\text{Sr}$ on the basis of inferences made and feedback obtained during the minor sodium leak incident in the primary purification system. The gas activity monitors and the in-duct monitors are NaI(Tl) based scintillation detectors, which monitor the gross gaseous radioactivity in the RCB and in the ducts leading to the exhaust stack respectively. For gas activity monitors, some major modifications were carried out. Initially, all these monitors were commissioned with Differential Ion-Chambers (DIC). But these detectors were replaced in a phased manner by NaI(Tl) based ones due to difficulty in maintenance (moisture pickup) and giving rise to frequent spurious alarms. However, our experience shows that for gas activity monitor to be sensitive and dependable, DIC type monitors are essential at RCB where the leakage of cover gas is a definite possibility and also persistent, albeit low.

Special purpose radiation monitors were introduced in FBTR for primary sodium leak detection, fuel clad failure detection and decay heat measurements etc. Many modifications were done based on the inferences and experience gained over the years by health physicists and plant management. Four numbers of sodium fume activity monitors were installed in B-cell ventilation ducts, meant to detect the leak of active primary sodium from the pipelines into the shielded concrete cells. It should be noted that no information on these monitors was available from Rapsodie reactor experience and no design note was also available. Based on the operating experience, these detectors were relocated in the duct away from the mouth to B-cell and provided with lead shielding around the detector. On the basis of experience, gamma energy threshold was slowly raised from 200 keV and currently kept at 1 MeV to ensure the detection of $^{24}\text{Na}$ gammas only. These modifications helped in obtaining better signal to noise ratio while at the same time avoiding the spurious annunciation of alarms.

A gas activity monitor ($^{24}\text{Na}$ activity monitor) to detect sodium aerosol in the double envelope (filled with nitrogen gas) of reactor vessel and a particulate activity monitor for detecting primary sodium leak in purification cabin were introduced. During reactor operation, the increase in activity as registered by the $^{24}\text{Na}$ activity monitor could be correlated to $^{41}\text{Ar}$ produced from trace amount of $^{40}\text{Ar}$ impurity present in the nitrogen. The increase of threshold energy to 1 MeV helped in reducing the counts in the Compton continuum due to other radionuclides and detecting the intended $^{24}\text{Na}$ peaks alone (1.369 MeV and 2.753 MeV) without compromising much on the sensitivity factor.

Reactor cover gas activity is monitored continuously using two gas flow ionization chambers known as Clad Rapture Detection (CRD) monitors for the early detection of fuel pin failures. Sensitivities of these monitors were estimated by measuring the concentration of $^{41}\text{Ar}$ in the cover gas vis-à-vis the monitor reading. In the nineties, CRD system was not in continuous service and also the sampling rate was erratic. Of late, after improving the flow controlling needle valve, CRD system is in service continuously at an optimum sampling rate (20 to 50 cc/s) to avoid the release of $^{23}\text{Ne}$ produced by $^{23}\text{Na}(n,p)^{21}\text{Ne}$ reaction which could otherwise lead to inadvertent higher discharge values.

The discharge flask is provided with a high range gamma monitor to prevent any inadvertent removal of fuel sub-assembly with more than 400 W of decay power. Two portal monitors, plastic scintillator based ones, are installed at the Fresh Fuel Storage Area (FFSA) and at the final exit point of FBTR.

The readings of all the installed radiation monitors are fed to a dedicated industrial PC. It has capabilities to retrieve data and analyze for the preceding 9h (at 3 min interval) and one-hour (at 1 min interval). It has provision to choose data from any three monitors at a time for graphic display as a
trend chart. The features provided have proved to be useful for the instrument maintenance group too, in carrying out the surveillance on RAAMS to meet the technical specifications requirement and in detecting any malfunction. A need was felt to further improve the system by including the remaining few radiation monitors also into the software. The software is rewritten in visual basic and successfully commissioned. Facility to have the history data in a floppy diskette is also provided. The calculation of gaseous effluent discharged through stack on the basis of readings of the exhaust induct monitors of RCB has also been incorporated.

3. Personnel Monitoring

About 350 personnel are provided with personnel monitoring services in the form of Thermo Luminescent Dosimeters (TLDs). All these occupational workers undergo routine wholebody monitoring annually and periodic medical examination as prescribed by Atomic Energy Regulatory Board (AERB). There has been no significant case of internal exposure. The man-rem expenditure for FBTR has been consistently low. Since the regular operation of reactor at high power level was mainly started after 1990, the exposure data as well as group-wise dose distribution are given for the period commencing from 1991 to 2007.

The collective dose for the period 1991 to 2007 (seventeen years) is given in Table 1. Since 1991 upto 2007, the cumulative collective dose was 79.02 person mSv with the maximum of 9.9 person mSv in the years 2003 and 2007. The highest individual dose of 4.25 mSv was received in 2003 during the inspection of sodium service valves located in the primary sodium cells in the aftermath of minor primary sodium leak incident. The annual average per-capita dose is 0.023 mSv. Major contributors to personnel exposure are due to inspection work in the primary sodium cells, fresh fuel assembly operations and retrieval cum disposal of leaked radioactive sodium from primary purification cabin. Group-wise dose distribution for the 17-year period from 1991 to 2007 is given in Table 2.

Table 1: Personnel exposure data of FBTR

<table>
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<th>Year (person-mSv)</th>
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<td>2002</td>
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Table 2: Group-wise dose distribution for the period 1991 to 2007

1. Operations 16.75 person-mSv (21.17 %)
2. Health physicists 9.77 person-mSv (12.35 %)
3. Mechanical maintenance 13.23 person-mSv (16.72 %)
4. Technical services 7.16 person-mSv ( 9.05 %)
5. Instrumentation maintenance 5.21 person-mSv ( 6.58 %)
6. NFC personnel (fuel assembly operation) 8.36 person-mSv (10.57 %)
7. Electrical maintenance 5.70 person-mSv ( 7.20 %)
8. Contract workers 7.05 person-mSv ( 8.91 %)
9. Non-FBTR (IGCAR) employees 5.79 person-mSv ( 6.65 %)

*NFC-Nuclear Fuel Complex

4. Augmentation of Shielding

Immediately after the first criticality in 1985, meticulous radiation surveys carried out at all accessible locations of RCB at very low power operation (10 kWt) helped in spotting the i) streaming locations
of concern, ii) locations where the shielding was not incorporated by oversight during commissioning stage and, iii) locations that needed augmentation of shielding [1]. Concerted efforts were taken in improving the shielding both by design and operation groups to augment the shielding expeditiously so that the radiation levels could be brought down to acceptable values for sustained high power operations.

The major streaming location was noticed over the sodium sampling plug and argon supply line above Over Flow Tank (OFT). The projected dose rate for 10.5 MWt at the location was calculated to be as high as 1 Gy/h. This streaming was due to the deficiency in the design of central straight-line thimble opening of dia 100mm for cover gas supply/discharge. A SS-316 shield plug of dia 94mm with staggered hole of dia 36mm for argon supply was designed, fabricated and installed. Additional lead shielding weighing about 2.5 Te was also provided over the OFT. The measured dose rate at 17.4 MWt has drastically come down to background level of less than 1µGy/h at -2.81 level with narrow streaming of 50 µGy/h.

Similar streaming location of concern was noticed at sodium flooding line at -10.5 level where there was straight penetration into the B-cell. After the augmentation of additional shielding, the dose level was brought down by two orders. The radiation surveys have also revealed few points where shielding materials should have been placed during commissioning but missed. There were two such locations viz., i) nitrogen valve penetration from B$_3$ to D$_5$ at -2.81 level and ii) penetration B$_2$D$_2$S$_1$ at -2.81 level; at both these locations, lead shots and colemanite were introduced. Augmentation of lead shielding brought down the field at few more places such as i) above DND pits (east & west) at zero level, ii) OFT top, iii) complementary shielding above sodium filters at -2.81 level, iv) above B$_6$ cell (purification cabin) at -2.81 level v) B$_7$C$_1$V$_1$ duct (near A$_1$ cell man-hole) below -10.5 level and, v) B$_8$ cell doors (east and west). Neutron field over top of pile was 20 µSv/h.

5. Radioactive Waste Disposal

Generation of solid waste in FBTR is very minimal. Category-III solid wastes were disposed only once so far during 1994 and consisted of cut portions of damaged CRDM. The surface dose rate on the waste bag was 500 mGy/h and it was essentially due to $^{60}$Co. Category-II wastes were disposed only twice so far i) SS cut pieces of CRDM with a maximum surface dose rate of 0.5 mGy/h due to $^{60}$Co; and, ii) activation of defective cables used for neutron detectors, containing 447 MBq of $^{110m}$Ag]. The potentially active wastes are mostly the High Efficiency Particulate Activity (HEPA) filters removed from RCB exhaust.

Liquid effluent from decontamination facilities and condensates from air handling units located in potentially active areas are stored in separate SS tanks and pumped to Centralized Waste Management Facility (CWMF) for disposal. Before disposal, sample from the liquid effluent is collected and analyzed for activity. The beta-gamma activity of the liquid effluent has so far been below the detection level (18 kBq/m$^3$). However, samples from the sediment accumulated in the liquid effluent tanks showed the presence of $^{60}$Co (980 kBq/kg), $^{137}$Cs (750 kBq/kg), $^{54}$Mn (250 kBq/kg), $^{134}$Cs (1300 kBq/kg) and $^{125}$Sb (300 kBq/kg). Radioactive sodium removed from primary purification cabin was treated and disposed to CWMF as liquid waste containing cumulative activity of 188 MBq of $^{22}$Na.

Radioactive gaseous wastes of FBTR are diluted, filtered and released to the environment through a 65-m tall stack. The major and only radioactive component expected to be present in the gaseous effluent of FBTR under normal operating conditions is $^{41}$Ar. A portion of the cover gas argon is sampled continuously by CRD circuit to detect any clad rupture is vented out through the stack. Continuous monitoring of the stack discharge is carried out with the help of induct and stack monitors. Besides, spot samples are periodically collected from different sampling points provided along the exhaust duct and the stack to identify the radionuclides and estimate their activities. Though $^{41}$Ar is the only radionuclide identified all the times, $^{22}$Ne was found additionally in the early nineties when the sampling rate of CRD system was higher and non-continuous. Under failed fuel-pin conditions, provision exists in the design to store the radioactive gaseous isotopes in the form of four storage tanks.
for controlled release of activity. Each tank is of 4-m$^3$ volume and can be pressurized up to 5 bars. The $^{41}$Ar release data up to 2005 is given in Fig.1. These releases are negligibly low compared to the Technical Specification limit of 3330 TBq per annum for $^{41}$Ar and fission product noble gases. The integral release is consistent with reactor operation history; i.e., the release of $^{41}$Ar per EFPD is 17.5 GBq till date indicating no uncontrolled release. Indeed, the CRD system, which is the major contributor for $^{41}$Ar discharge was in service continuously during reactor operation, especially in the last five years. Though, this was not the case in the early stages of operation, the release rate of $^{41}$Ar per EFPD remained constant.

It may be seen from the Fig.1 that the maximum observed $^{41}$Ar activity released through stack so far has been 4750 GBq in the year 2000 when the reactor was continuously operated at 13.4 MWt. If one rounds off this to 5000 GBq and further multiply it by a factor of three (since the maximum designed power level of FBTR is 40MWt), it would come to 15 TBq and the dose to the public due to $^{41}$Ar release would be 0.000225 mSv only against the apportioned 0.05 mSv. Even if one adds release of fission product noble gases (FPNG) due to fuel pin failure, if any, it is considered adequate to have a figure of 0.01 mSv for FPNG release including $^{41}$Ar.

**Figure 1:** Gaseous effluent release data ($^{41}$Ar)

$^{131}$I release is monitored continuously by a NaI(Tl) detector based gamma ray spectrometer installed at the exhaust duct in the stack. Because of the retention of iodine by the coolant Na, special equipment for removal or control of iodine is not required for FBTR off gas system. Efficient iodine filter system provides adequate control of the release of radioiodine, even in the event of substantial clad failure. Estimation of $^{90}$Sr and other particulate fission products are done by continuous filter paper sampling of stack exhaust air. There had been no release of $^{131}$I and $^{90}$Sr so far due to reactor operation.

**6. Incidents and Special Operations**

**6.1 Fuel Handling Incident**

In the initial stages of commissioning, after the first criticality, a fuel-handling incident has been encountered in 1987; when a fuel element was being transferred from one location to another under the liquid sodium pool, there was maloperation leading to the damage of a guide tube component. To rectify the damage, a special remotely operated cutting tool was devised which could be used without interruption of liquid sodium circulation to cut the damaged component into two and remove it, to enable replacement with a new component. Around one fuel sub-assembly and 28 SS/Ni sub-
assemblies were removed from the reactor. The maximum dose seen was 400 mGy/h on the bent fuel SA, 10 mGy/h on the Ni SA and 2.5 mGy/h on SS SA. The man-rem expenditure for the whole operation was 26.45 person-mSv. The outer sheath of the bent fuel SA was cut in Fresh Fuel Assembly Shop inside the specially erected enclosure and fuel pins were retrieved.

6.2 Sodium Leak Incident and its Disposal

During April 2002, sodium leak occurred in the primary sodium purification system when reactor was in operation at 17.4 MWt [2]. During the incident, five out of six particulate activity monitors situated in RCB showed increasing trend of air activity level coinciding with the first alarm annunciation by wire type leak detector. The release of sodium aerosols into the RCB atmosphere had come down after about six hours since shutdown. The maximum air activity during the incident was 0.1 DAC of $^{24}$Na only. Totally about 75 kg of active sodium was removed. The purification cabin was decontaminated with alcohol. Effective radiological surveillance was provided throughout the three months operation. The total dose expenditure was 2.25 person-mSv only. The spectral analysis of the sodium sample collected from inside the purification cabin indicated the presence of $^{203}$Hg (4342 Bq/g), $^{22}$Na (2023 Bq/g), $^{110m}$Ag (4.55 Bq/g), $^{124}$Sb (4.44 Bq/g) and $^{65}$Zn (4.19 Bq/g) isotopes. While the presence of $^{22}$Na is expected, the mercury contamination had come long back to the primary sodium from the relief pot connected to the cover gas system. Presence of activation products $^{110m}$Ag and $^{124}$Sb are due to the impurities present in the sodium and activation product $^{65}$Zn is due to the presence of zinc in the paint used for coating the ferritic steel components. The purification system was normalized after replacing the defective valve.

The sealed MS drums containing the retrieved primary active sodium were stored in transit waste storage room. In FBTR, sodium-steam reaction method was adopted with suitable modification of the decontamination vessel with introduction of a tray, provision of an on-line hydrogen meter and modified top lid. This is a two-fold process involving conversion and neutralization of sodium. Conversion of sodium into sodium hydroxide is carried out with mixture of steam and nitrogen. Since sodium-water reaction is highly exothermic and violent, the reaction rate was controlled by controlling steam production. The products of this fast reaction were aqueous sodium hydroxide and hydrogen gas. Caustic aqueous sodium hydroxide was converted into sodium phosphate in reaction with orthophosphoric acid ($H_3PO_4$). The products of this acid-base neutralization are non-corrosive and highly water-soluble thereby making it suitable for disposal as liquid effluent.

A dedicated PAM located near the decontamination pit did not indicate any increased particulate activity during the operation. The off-gas system from the decontamination vessel and the associated active-building area were allowed to pass through the HEPA filters located in the downstream of active-building filter bank to remove the particulates. Radiation field and air-borne activity levels in the decontamination hall were continuously monitored. Personnel protective equipment was used and no personnel or area contamination occurred during the operation. The liquid effluents generated in the decontamination vessel were transferred to the low-level liquid effluent waste storage tank, adequately diluted, transferred to the FBTR delay tank and latter pumped to CWMF. In all, 188 MBq of liquid effluent was generated and disposed [3].

6.3 Decontamination of components

During the two decades of operation of FBTR, decontamination of several components such as lower portion of Control Rod Drive Mechanism (CRDM), micro filters, sodium centrifugal pumps, irradiated fuel sub assemblies etc., were carried out. Decontamination of the damaged CRDM was carried out to reuse part of the mechanism having lesser radioactivity and dispose the rest having higher activity. Intense gamma field of 500 mGy/h was measured on contact, which is essentially due to $^{60}$Co due to activation of stellite portion. The outer surface of the CRDM was cleaned to remove the $^{60}$Co contaminated sodium deposits by steam-nitrogen process. The liquid waste generated indicated the presence of $^{60}$Co with maximum activity of 2 MBq/m$^3$. Electro decontamination was done to remove the active surface layer of lesser active portion of the CRDM that was meant for reuse. Decontamination of the guide tube was successfully carried out in the decontamination pit and the
liquid effluent had shown activity due to the isotopes $^{203}$Hg (776 Bq/m$^3$), $^{22}$Na (2616 Bq/m$^3$) and $^{60}$Co (1702 Bq/m$^3$). Sodium sampling canal plug was decontaminated using alcohol to remove the deposited sodium over the plug.

7. Study on Deposited Activity in Primary Sodium Pipelines

Measurements were undertaken to assess the deposition of radioactive corrosion and activation products in the primary sodium pipelines and various components of FBTR, which are housed in B-cells [4]. Such an assessment would guide health physicists in controlling the exposures to occupational workers of FBTR during their maintenance work. In 2002, draining of Na from the primary pipelines was done. Immediately after draining, the ambient gamma radiation levels in the B-cells came down by five times from 200 µGy/h to 40 µGy/h. This is essentially due to the presence of $^{22}$Na (78%) and soluble radioisotopes such as $^{203}$Hg (10%) in the sodium coolant. Spectral investigation studies revealed that deposited activity in the primary sodium pipelines consists of $^{54}$Mn (93%), $^{22}$Na (2.5%), $^{60}$Co (2%), $^{58}$Co (1.5%), $^{124}$Sb (trace), and $^{65}$Zn (trace) isotopes. Presence of $^{58}$Co and $^{54}$Mn in the lines confirm that the corrosion and transport of core material activation products to the primary sodium pipelines.

8. On-line Monitoring of Gaseous Effluent

An on-line GM tube based system was developed to estimate the specific activity of the gaseous effluent vented through stack. In view of its low minimum detectable activity [MDA: (27 kBq/m$^3$)], the system is useful in analyzing gaseous activities of lower levels [5]. To estimate the $^{41}$Ar activity in the cover gas without any uncertainty, the detector was calibrated with $^{22}$Na liquid source. Necessary corrections for self-absorption were applied to arrive at conversion factors for gas measurements. This system is currently under use [6]. Experiments were carried out to find out the conversion factors for liquid and gaseous activity measurements for other energies also.

9. Environmental Aspects of FBRs in Brief

Environmental impact is an important global issue for any energy option. The release of radioactive materials from FBRs is negligible. Several features in the FBR design make this possible. A blanket of inert gas, a protective envelope, covers the primary sodium vessels and pipelines. Escape of primary sodium into the RCB atmosphere is therefore virtually ruled out. Design features of FBRs also serve to minimize significantly the generation of liquid and solid wastes. Generation of solid wastes in the form of spent ion exchange resins used in water purification in thermal reactors is not applicable to FBRs. By the simple technique of lowering the Na temperature, oxide impurities are precipitated out in cold traps. The purified sodium is put back into circulation. These cold traps are designed to last for the entire life of the reactor.

The collective exposure of the occupational workers has remained consistently lower. The mining and milling operations are reduced by a factor of atleast 50 and hence the considerable reduction in dose rates from these operations. The thermal impact on the environment is less for FBRs due to higher thermal efficiency. The low operating pressure of FBRs virtually precludes the possibility of a catastrophic failure of sodium pipes or vessels as an accident initiator. FBR designs are also characterized by negative feedback mechanism. The considerable quantity of sodium in the main vessel serves as a large heat sink by virtue of the thermal properties of sodium. The boiling point of sodium being relatively high, a very large amount of heat can be absorbed without leading to bulk boiling of sodium in the core. By separating the long-lived actinide group of elements from the high level liquid waste (HLLW) and adding them to the fresh fuel loaded into FBRs, relieves the problem of long-term storage of the vitrified HLLW.
10. Conclusion

Health Physics Unit, FBTR acquired expertise in tackling unique situations such as sampling and estimation of activity in the double envelope, annunciation of frequent alarms from the installed monitors due to leakage of cover gas and subsequent increase in ambient radiation levels etc. For monitors meant for detecting radioactive sodium, the energy threshold should be set at 1 MeV. The detector for Gas activity monitors, unique for FBRs, should be of compensated type (for background) differential ion chambers and not the NaI(Tl) based ones.

Although the presence of $^{24}$Na has a marked influence on shielding requirements, its short half life makes the life easier after ten days of the shutdown of the reactor. Impurities in the sodium, which are at ppm level, are not major contributors except like $^{65}$Zn, which originate from other sources such as protective coatings and pump oil.

The lessons learnt from the management of primary sodium leak incident were unique. In case of the sodium leak in the primary sodium system, it is proved beyond doubt that radiation monitors are more reliable than even the most established sodium leak detectors of different types. This is due to the fact that both $^{22}$Na and $^{24}$Na have high-energy gammas. Installation of a dedicated particulate activity monitor to monitor the increase in activity inside the primary purification cabin as recommended by Safety Committee in the aftermath of the leak incident, fume activity monitors in B-cell ventilation ducts to detect the leak of active primary sodium from the pipelines into the shielded concrete cells, $^{24}$Na activity monitor for monitoring ingress of sodium from the reactor vessel into the double envelop are few examples.

Alarm limit for all particulate activity monitors has been reduced to ten times the background value so that they can also annunciate alarm earlier in case of primary sodium leak, instead of having the set value for 10 DACH of $^{90}$Sr as in other nuclear facilities.

The radiological concerns in the removal of leaked radioactive sodium from the primary purification cabin, decontamination of various parts, disposing of the radioactive sodium as sodium hydroxide etc., have all been properly addressed and successfully executed. This experience would enable plant as well as Health Physics personnel to handle more confidently such rare unforeseen situations in the future operation of FBRs.

The dose apportionment for FBTR can definitely be reduced to 25% of the present value (0.07 mSv) which itself is a conservative estimate.

Isotope $^{54}$Mn has been identified as the major deposited one (94%) in the interiors of primary sodium pipelines and the remaining are $^{58}$Co, $^{60}$Co, $^{22}$Na and $^{65}$Zn. The spectral measurements studies indicated that handling of components for maintenance work in B-cells, if warranted, is not much of a radiological concern.

The low man-rem expenditure and impeccable safety record set in FBTR have reaffirmed the fact that fast reactors are radiologically and ecologically clean and have very little impact on the radiation workers and on the environment.

REFERENCES


