Available at **URL:http://www.barc.ernet.in** **No. 183, April 1999**

ALTERNATE FUEL CYCLES IN THE INDIAN PHWR

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1. INTRODUCTION

The Indian Pressurised Heavy Water Reactor (PHWR) has so far been working on the natural uranium once through cycle. But this reactor, with its advantages of on-load refuelling and short bundle length, is a versatile system which admits of many other fuel cycles. Every fuel cycle has its own distinct advantages and its own constraints. The selection of a fuel cycle for a reactor will depend upon the time and place, the economics and politics. Some of the performance criteria based on which fuel cycles are designed are (a) fuel utilisation, (b) shrinking of spent fuel inventory, (c) reduction of long-lived actinide wastes, (d) operational ease for high burnup cycles, (e) retrofittability into existing systems, (f) fuel cycle flexibility, and (g) dispositioning of weapons plutonium. In the international arena, fuel cycles designed for non-proliferation and safeguards considerations, and inert matrix cycles for plutonium destruction are also receiving attention. These cycles will however, not be addressed in this paper.

From the Indian perspective, the most important characteristic of any fuel cycle is the energy obtained per ton of uranium mined. From this point of view, a number of fuel cycles have been examined. These include (i) slightly enriched uranium (SEU), (ii) natural uranium with self-generated plutonium, (iii) recovered uranium with self-generated plutonium, (iv) natural uranium with dismantled weapons plutonium, (v) recovered uranium with dismantled weapons plutonium, (vi) thorium-U233 self-sustaining cycle with U235 makeup, (vii) thorium-U233 self-sustaining cycle with reactor grade plutonium makeup,(viii) thorium-U233 self-sustaining cycle with weapon plutonium makeup, (ix) thorium with U235 in high burnup cycle, (x) thorium with reactor plutonium in high burnup cycle,

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Editorial

Ever since the Three Mile Island accident in 1979, considerable work has been done in many countries of the world to develop a reactor system with inherent safety features. This effort has resulted in a number of designs of both Pressurised Water Reactors and Boiling Water Reactors. In India a unique reactor system designated Advanced Heavy Water Reactor (AHWR) has evolved. From the safety point of view the most noteworthy feature of AHWR design is its ability to remove all the heat from the fuel channels by natural circulation without coolant circulating pumps. In fact, the AHWR design does not have coolant pumps. Apart from the reduction in the cost and complexity that is achieved due to the absence of coolant pumps, the ability to remove all the heat generated in the coolant channels by natural circulation from full power to shut down conditions is a remarkable achievement. The Advanced Heavy Water Reactor has the potential to exploit the exceptionally good characteristics of heavy water as a neutron moderator and yet obviate the need to handle high pressure heavy water in the coolant system. Replacing the heavy water with light water in the high pressure coolant circuit, with the possibility of its boiling inside the reactor, considerably simplifies the technology.

Although thorium is more than 3 times abundant than uranium in nature, India is perhaps the only country in the world with the reserve of high grade thorium being more than 5 times the natural uranium reserves, that too of very poor quality. As such, developing the technology for generating electricity from thorium is of utmost importance to India. During the third stage of the Indian nuclear power programme, thorium fuelled fast breeder reactors are expected to provide the bulk of the nuclear generating capacity. However, with the delay, not only in India but internationally as well, in the development of viable commercially available fast breeder reactors, it was felt desirable to develop a thermal reactor system which can exploit the energy potential from the vast thorium reserves available in India. The neutronic design of the AHWR core has been optimised in such a way that about 75% of the energy produced in the reactor comes from thorium.

AHWR, by all means, is an exceedingly beautiful concept both from the viewpoints of engineered safety features and from the neutronic design that allows the generation of about three-fourths of the energy from thorium. Once the prototype AHWR is built and successfully operated, I am sure that it will be recognised as a major achievement in the symbiosis of ingenous engineering concepts, and ideas in reactor physics. It will be internationally acclaimed.

The Facility for Integral System Behaviour Experiment (FISBE) is a versatile experimental facility that has been set up to simulate all the relevant conditions that will exist in the coolant system - the Primary Heat Transport (PHT) system - in the Pressurised Heavy Water Reactor (PHWR), both of the 220 MWe and of the 500 MWe designs. FISBE will be used to study a number of safety related features of the PHWR. Another experimental facility is being planned to demonstrate the feasibility of removing the heat from the AHWR without any coolant pump by means of thermosyphon experiments both in single phase and with partial boiling. It must be noted that while PHWR has horizontal coolant channels, the AHWR has vertical channels.

This month's Newsletter covers, among others, the different fuel cycles that are possible with the PHWRs. It also features an article on FISBE, which brings us closer to experimental demonstration of the safety features of the PHWR design.

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(xi) thorium with weapon plutonium in high burnup cycle. Then there are the various combinations that can be clubbed together as different versions of the once through thorium (OTT) cycle, viz., (xii) unenriched thorium and SEU in segregated channels, (xiii) unenriched thorium and natural uranium with reactor plutonium in separate channels, (xiv) unenriched thorium and natural uranium with weapon plutonium in separate channels, (xv) unenriched thorium and recovered uranium with reactor plutonium in separate channels, (xvi) unenriched thorium and recovered uranium with weapon plutonium in separate channels. Finally, we have also made a study of a BWR-PHWR tandem cycle.

In this paper, we describe all these cycles and the results of the studies. As mentioned, the major emphasis will be on the maximisation of energy from any given quantity of fissile material. But wherever a cycle offers other benefits, these have been pointed out.

The BWR-PHWR tandem cycle has been described in some detail. This has been done with the intention of showing the kind of studies that are needed before a cycle can actually be introduced into a reactor. Some of the problems that arise are pointed out and possible solutions discussed.

2. DESCRIPTION OF THE REACTOR

The Indian PHWR is a tube type reactor using heavy water as both coolant and moderator. The coolant is physically separated from the moderator by being contained inside the pressure tube where it is maintained at high temperature (~ 270 °C) and pressure (~92 bar). The moderator heavy water is at relatively low temperature (~ 55 °C) and is unpressurised.

The reactor core consists of 306 pressure tubes arranged along a square lattice of 22.86 cm pitch. The fuel pins and the coolant are contained within these pressure tubes. The direction of coolant flow in adjacent channels is in opposite directions. The fuel is in the form of a string of 12 bundles. Each bundle is a 19-rod cluster of 49.5 cm length. Of the 12 bundles, 10 are in the active portion of the core, the remaining 2, one on each end, are outside the core.

Refuelling is done on-power by simply pushing out 8 bundles from a channel on one end, while 8 fresh bundles are inserted from the other end. The direction of the bundle movement is the same as that of the coolant flow, so that alternate channels are fuelled in opposite directions. This helps in maintaining overall axial symmetry.

Table 1 gives a general description of some of the important physical parameters of the core of the Indian PHWR.

Table 1

DESCRIPTION OF THE PHWR REACTOR CORE

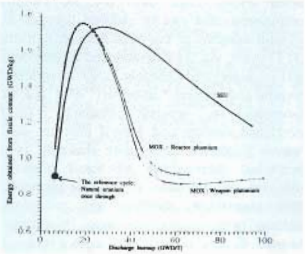
Number of fuel channels	306
Lattice pitch, cm	22.86
Calandria inner radius, cm	299.8
Calandria length, cm	500.0
Number of bundles per channel inside the active portion of the core	10
Extrapolated core radius, cm	303.3
Extrapolated core length, cm	508.5
Number of absorber rods (for xenon override)	4
Number of regulating rods (for reactor regulation)	2
Number of shim rods (to provide backup for regulation)	2
Number of mechanical shutoff rods (SDS-1)	14
Number of liquid poison tubes (SDS-2)	12
Total thermal power to coolant, MWth	756
Maximum channel power, MW	3.2
Maximum bundle power, kW	440
Maximum coolant outlet temperature, °C	297
Reactivity worth of SDS-1, mk	31.9
Reactivity worth of SDS-2, mk	32.1
Coolant inlet temperature, °C	249
Average fuel temperature, °C	625
Average coolant temperature, °C	271
Specific power, kW/kg	19.2

3. NATURAL URANIUM BASED CYCLES

Using natural uranium fuel as the base and increasing the fissile content by addition of external fissile material, a number of cycles are possible. The added fissile material could be self-generated plutonium or weapon plutonium (in which case the fuel is MOX), or U235 itself, leading to the most popular alternate cycle, viz., slightly enriched uranium (SEU). We consider SEU here in once through mode, and MOX is restricted to one recycle of plutonium.

Even though the correct way to evaluate resource utilisation is to express the results in terms of energy obtained per ton of uranium mined, the following difficulty arises. In the case of SEU, this conversion depends upon the amount of U235 lost in the enrichment plant tails. This value is sometimes quoted as 0.2%, sometimes as 0.1%, or at times even lower. In the case of weapon plutonium, one does not know how to make any assumptions on how it was produced or how much natural uranium was used to create it. It is only in the case of self-generated plutonium that any definitive numbers can be assumed. We obviate this difficulty by expressing our results in terms of energy per kg of U235 or plutonium. To make a meaningful comparison between SEU and MOX, we assume that the quantity of plutonium in the MOX is the sum of a certain "real" plutonium and "virtual" plutonium. This "virtual" plutonium is computed as the equivalent of the U235 content of natural uranium. It is defined as that amount of plutonium which would give a burnup equal to that of natural uranium.

Figure 1 shows this as a function of discharge burnup. Discharge burnup has been chosen as the independent variable since it is one of the most important performance criteria of any fuel cycle. The highest fuel utilisation is just above 1,700 MWD/kg fissile and is more or less the same for U235, reactor plutonium, or weapon plutonium. This comes in the neighbourhood of 27,000 MWD/T discharge burnup for SEU, and 20,000 MWD/T for plutonium. For high burnups, SEU gives much better utilisation than plutonium. This is only to be expected since higher initial enrichment will be needed for higher burnups. With the higher cross-section of plutonium, the MOX ends up burning more of the initial fissile material, while the SEU manages to convert more U238 to plutonium and burn it. There isn't much difference between the two plutoniums, but surprisingly, the reactor plutonium seems to have an edge over the weapon plutonium.



Fgure 1 : Fuel cycles in PHWR with natural uranium base.

Again, may be it need not be such a surprise since the reactor plutonium contains Pu241 and also Pu240 which gets converted into Pu241, and Pu241 is a better fissile material than Pu239. All these numbers may be compared to the value obtained for the reference cycle, i.e., the natural uranium once through cycle, which has a discharge burnup of 6,270 MWD/T and can be said to have a fissile material utilisation of 896 MWD/kg fissile. This point is indicated in the figure by an asterisk. One can see that all the cases presented here have fuel utilisation characteristics superior to the natural uranium once through cycle.

4. RECOVERED URANIUM BASED CYCLES

Similar studies can be made for fuel with recovered uranium as base. The discharged fuel from the PHWR natural uranium once through cycle contains 0.255% U235. Since this is considered as discarded material in the reference cycle, only the added fissile content is used in the calculation of energy from fissile material. The SEU cycle in which recovered uranium is base, thus shows a higher fissile utilisation than the one with natural uranium base. Obviously this is because the residual U235 in the discharged fuel is being burnt. Once again, all three curves lie totally above the asterisk representing our reference case. This can be seen from Fig. 2.

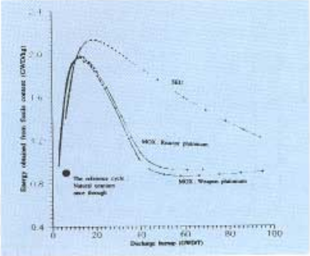


Figure 2: Fuel cycles in PHWR with recovered uranium base.

5. THORIUM CYCLES

The PHWR is one of the best reactors to use thorium, second probably only to the MSBR. Possible thorium cycles fall into three categories, which can be called the self-sustaining equilibrium thorium cycles (SSET), the high burnup open cycles, and the once through thorium (OTT) cycles.

5.1. THE SELF-SUSTAINING EQUILIBRIUM THORIUM CYCLE (SSET)

The fuel in this cycle is thorium-U233. The discharged fuel should contain enough U233 to provide the fissile content for the next fuel charge. Thus this cycle, once initiated, can go on indefinitely without any external fissile input. In the limit, its energy potential is theoretically infinite until thorium runs out.

There is the question of how the SSET is to be initiated. There are two ways of doing this. The first is to enrich the thorium with U235, extract U233 from the spent fuel and use it for the first charge of the SSET. About 250 tons of natural uranium will be required to place one PHWR on the SSET. The alternative route is the plutonium route, in which the reactor is first fuelled with natural uranium. The plutonium extracted from the discharged fuel is mixed with thorium and fed back into the reactor. This fuel when discharged, will contain U233, which can be retrieved and used to initiate the SSET. This route will require about 500 tons of natural uranium for one PHWR.

The discharge burnup possible with the SSET is rather low being about 11,000 MWD/T. For a cycle that depends on reprocessing and refabrication of highly active U233 bearing fuel, this is too low a value to be economical. The burnup can be improved by adding a certain amount of makeup fissile in the new fuel along with the extracted U233. We have carried out studies with U235 makeup, reactor grade plutonium makeup, and weapon plutonium makeup. Figure 3 gives the results obtained with all the three. The weapon plutonium gives results that are marginally superior to reactor plutonium, while U235 is superior to both plutoniums.

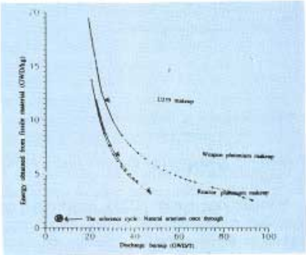


Figure 3 : Utilisation of makeup fissile material in SSET

Some safety related parameters of interest are as follows. The positive void coefficient of reactivity (on complete voiding) is 5.98 mk as compared with the value of 10.84 mk for the natural uranium core. The effective delayed neutron fraction is 2.75 mk (6.91 mk for the natural uranium core). In the event of a LOCA followed by over power trip, the peak power reached is 2.005 times full power (cf. 2.15), peak fuel temperature is 866 °C (cf. 864 °C).

As for operational parameters, the adjustor rod worth reduces from 8.25 mk for the natural uranium core to 6.28 mk for the SSET core.

5.2. THE HIGH BURNUP OPEN CYCLE

Here we do not close the cycle, and the intent is to get as high a burnup as possible. If direct disposal of spent fuel is contemplated, this cycle assumes importance in shrinking the spent fuel inventory. This cycle is also suitable for destroying the accumulated civil and military plutonium. The economics of this cycle is very favourable as compared to that of the SSET. Fuel utilisation is significantly lower. One possible way to improve resource utilisation is to store the spent fuel so that if at any time in the near or distant future there is a change in the position of cheap uranium, this fuel can be reprocessed to recover U233.

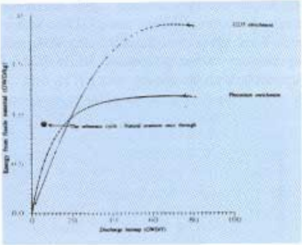


Figure 4 : Energy from thorium fuel without recycling.

Whether one prefers U235 enrichment or plutonium enrichment will, among other things, depend on the objective. If shrinking the spent fuel inventory is the objective, U235 enrichment is more advantageous in that it gives better fissile utilisation. This can be seen from Figure 4 where the energy obtained from 1 kg of fissile material is compared for U235 and plutonium. On the other hand, if plutonium dispositioning is sought, this cycle is a very effective one. Figure 5 shows that this cycle can destroy up to 95% of the fissile plutonium.

5.3. THE ONCE THROUGH THORIUM (OTT) CYCLE

This scheme is based on reasons not really related to either fuel utilisation or fuelling costs, but rather on operational acceptablity. Two main arguments can be advanced for this cycle.

1. Because of a general slowing down of the nuclear power programme the world over, it is difficult today to persuade utilities to load thorium. In the OTT scheme, we have a way of introducing thorium that causes the least disruption in the normal fuelling of the reactor.

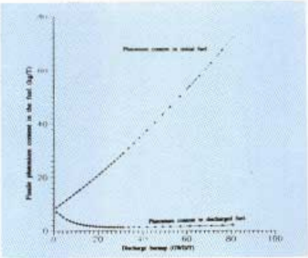


Figure 5 : Plutonium destruction in thorium-plutonium fuel

2. One of the advantages of the thorium cycle over the uranium cycle has been the level of long-lived actinides which pose a waste disposal problem. This is orders of magnitude lower in the thorium cycle. But to take advantage of this, there is a need to keep thorium from being "contaminated" by the uranium cycle, i.e., direct mixing of the thorium with any part of the uranium cycle, e.g., U235 or plutonium, should be avoided.

The principle of this cycle therefore is to use plain unenriched thorium along with SEU in segregated channels of the PHWR. Being in different channels, their burnup can be varied independently. The presence of thorium acts as a load on the SEU, which will therefore have to be discharged at a lower burnup. The total energy extracted will be the sum of the energy

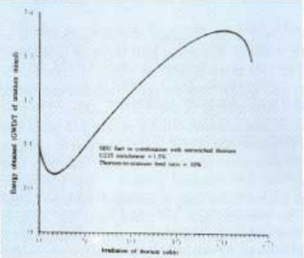


Figure 6 : Once through thorium (OTT) cycle in PHWR

obtained from the thorium and the SEU. As the residence time of thorium in the core increases, the energy obtained from unit mass of mined uranium will first decrease, then increase, and finally become higher than it would have been had no thorium been present in the core. Figure 6 shows this graphically. Similar results are also seen when thorium is combined with MOX, i.e., natural uranium with either reactor or weapon plutonium.

6. THE LWR-HWR TANDEM CYCLE

Some work is being done in India on the possibility of using the discharged fuel from LWR as feed for the PHWR. At present, India has only two units of light water reactors of 160 MW(e) capacity each. They are boiling water reactors. The proposal is to subject the discharged fuel from the BWRs to a process known as coprocessing, in which the fission products are removed, but all the actinides are precipitated together. There is thus no separation of plutonium and uranium, a fact which enhances the value of this process from the point of view of non-proliferation. This mixture of heavy metals is then fabricated into the19 rod bundles of the Indian PHWR, and introduced into the heavy water reactor. A brief description of the BWR lattice is given in Table 2. The isotopic composition of the fuel which is discharged at a burnup of 21,000 MWD/T is as given in Table 3. Fuel of this composition, fabricated into 19 rod clusters and loaded into the PHWR can give a discharge burnup of 37,200 MWD/T.

Table 2
THE BWR LATTICE

Number of fuel assemblies	284
Mass of UO2 in one assembly, kg	160
Mass of heavy metal in one assembly, kg	141
Total uranium inventory, ton	40.0
Specific power, kW/kg	17.5
Fuel pellet radius, mm	6.18
Clad inner radius, mm	6.34
Clad outer radius, mm	7.15
Pin-to-pin pitch, cm	1.79
U235 enrichment (average), %	2.4
Discharge burnup, MWD/T	21,000

This means a support ratio of about 1.7, which means that 1 GW(e) of BWR can support the fuelling requirements of 1.7 GW(e) installed capacity of PHWR. This ignores losses during

Table 3

ISOTOPIC COMPOSITION OF BWR DISCHARGED FUEL (%)

Uranium-235	1.02
Uranium-236	0.28
Uranium-238	95.15
Plutonium-239	0.92
Plutonium-240	0.21
Plutonium-241	0.13
Plutonium-242	0.026
Americium-241	0.006

fabrication, coprocessing, etc., but if all those factors were also taken into account, one can still expect a support ratio of 1.5.

The void coefficient of this lattice is about 6.7 mk (positive). This is lower than the value (+10.8 mk) for natural uranium. However, the delayed neutron fraction is 4.12 mk as opposed to 6.5 mk in the case of natural uranium. An approximate LOCA analysis was carried out to evaluate the effect of this. It was assumed that the PHT voiding process, at least in so far as the reactivity effect is concerned, is complete in 1 sec., so that the total void coefficient can be considered to have been added to the reactivity in 1 sec. Blowdown is supposed to last for 10 secs., during which period there is improved heat transfer. Thereafter, the ECCS will come in. However, in this calculation, this has been neglected and so beyond 10 secs. the heat transfer has been assumed to be negligible.

The shut down in this LOCA calculation is initiated by the over-power trip. Shut down is by moderator dumping. Among Indian PHWRs, there are four units built in the early days, which have shut down by moderator dumping. Later units have two independent fast acting shut down systems. The tandem cycle which we are examining is supposed to be introduced into one of the earlier reactors. Hence the use of moderator dumping for reactor shut down in the studies presented here.

The peak power in the tandem fuelled PHWR under LOCA reaches 1.93 times nominal power and peak fuel temperature of 862°C. This may be compared with peak power of 1.6 times nominal power and peak fuel temperature of 856°C in the case of the natural uranium equilibrium core and peak power of 2.15 times nominal power and peak fuel temperature of 864°C for the fresh natural uranium core.

The PHWR has a set of eight rods called adjuster rods (AR) to provide xenon override. A set of four rods called regulating rods (RR) are used for reactor regulation. In, the natural uranium core, the ARs have a reactivity worth of 8.2 mk, and the RRs have a worth of 4.8 mk. In the tandem fuelled core, the AR worth is 5.2 mk, and the RR worth is 3.2 mk. This reduced AR worth is however, compensated by a change in xenon worth. Whereas the 8.2 mk in the natural uranium core could give a xenon over-ride time of 30 minutes, the 5.2 mk in the tandem fuelled core gives an over-ride time of about one hour. So the AR worth reducing to 5.2 mk is of no concern.

The reduction in RR worth may have some implications for operability, but with some backup worth provided by boron in the moderator, this can be managed.

The reactivity of the initial core will be very high, of the order of 200 mk. It is possible to suppress this either by loading a number of thorium bundles, or by using boron in the moderator. The boron level will have to be very high. But the major disadvantage of boron will be that power peaking in the initial core will necessitate the derating of the reactor. As core burnup proceeds, the flux will tend to flatten. By about 90 effective full power days, both bundle power and coolant outlet temperature will have reached acceptable values. Refuelling however, will be required only after about 900 EFPD and continued burnup will worsen the power distribution, because the low flow channels towards the periphery of the core will now produce more power than can be removed by the flow which has been designed to cater to the power distribution of the natural uranium equilibrium core.

Studies have shown that while the maximum bundle power in the core goes on decreasing until the core reactivity falls to zero at about 925 EFPD, the maximum coolant outlet temperature reaches a lowest value of 295.0°C at 116 EFPD, and thereafter starts increasing again. At 925 EFPD, it has touched 311.9°C. The three constraints on power are the bundle power, channel power, and coolant outlet temperature. Figure 7 shows, as a function of EFPD, three quantities, which we have chosen to call bundle ratio (B), channel ratio (C), and temperature ratio (T). The bundle ratio is defined as the ratio of the highest bundle power in the core to the maximum permitted bundle power. C is a similar quantity for channel power, and T for coolant outlet temperature.

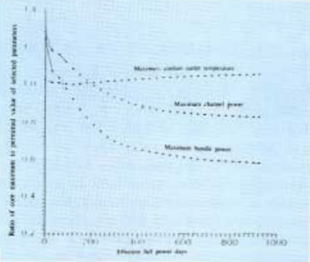


Figure 7 : Variation of power constraints wth burnup

For full power to be possible, all three of them should be less than unity. When any of them exceeds unity, it also is the factor by which the reactor power needs to be derated in order to stay within design constraints. We see from Figure 7 that whereas B and C start from values exceeding unity at zero EFPD, and decrease consistently right up to the first refuelling at 925 EFPD, T goes through a minimum and then rises again, reaching quite high values towards the end. The reason for this is that we are retrofitting the tandem fuel into a core originally designed for natural uranium, in which the coolant flows have been already fixed through appropriate orificing to suit the natural uranium fuel. Over the extremely long pre-fuelling life of the tandem core, burnup induced power flattening reaches such proportions that the low flow channels at the core periphery end up producing much more power than they were designed to cater to.

Figure 8 shows the variation of maximum coolant outlet temperature with effective full power days of operation in the core without any thorium bundles. Also shown in Figure 8 is a similar curve for a core in which thorium bundles have been deployed to give full power

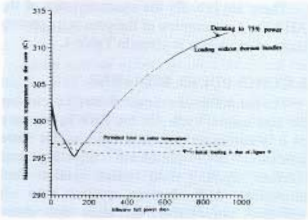


Figure 8 : Variation of maximum channel outlet temperature with burnup

in the beginning. (This loading is shown in Figure 9). While in the core without thorium bundles, the coolant outlet temperature crosses its permitted limit again by about 180 EFPD, in the core of Figure 9 this never happens. The core can give full power right up to the time that fuelling starts, beyond which of course, the power distribution is controlled by proper fuelling.

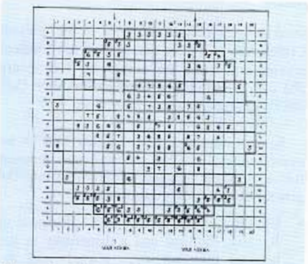


Figure 9 : Thorium bundle distribution in the tandem loaded core.

7. THE ADVANCED HEAVY WATER REACTOR (AHWR)

While the thorium cycle in the PHWR offers many attractive possiblities, the fact remains that all of them are retrofits into the PHWR which was designed with the uranium cycle in mind. The AHWR was designed to take advantage of the specific nuclear characteristics of thorium.

If we look at the SSET as a starting point for a thorium cycle, we should address its main weakness, viz., its low burnup. The burnup can be increased by adding plutonium makeup. The capture-to-fission ratio of Pu239 is rather high in the soft spectrum of the PHWR. A harder spectrum and tighter lattice are therfore

Table 4

DESCRIPTION OF AHWR AT THE PRESENT STAGE OF EVOLUTION

Reactor power, MWth	750
Reactor power, MWe	220
Fuel description:	
Number of pins	52
Number of Pu bearing pins	20
Number of thorium-U233 pins	32
Number of water tubes for ECCS injection	8
Plutonium content in MOX, %	2.7
U233 content in thorium	self sustaining
Coolant water density, (varies in the range)	0.50-0.55
Total number of channels	428
Number of seeded clusters	344
Number of clusters with all "thorium-U233" pins	84
Number of fuelling zones	2
Number of reconstitutions	1
Thorium pins discharge burnup MWD/T	20,000 approx.
MOX pins discharge burnup, MWD/T	20,000 approx.
Lattice pitch, cm	29.4
Active fuel length, cm	350
Moderator and reflector	D2O
Scatterer balls in the moderator	pyrocarbon
Calandria radius, cm	430
No. of adjustor rods	4
Worth of adjustor rods, mk	5.77
No. of regulating rods	4
Worth of regulating rods, mk	4.53
No. of SDS-1 rods	32
Worth of SDS-1, mk	54.5
Performance data in the equilibrium core Radial form factor	1.41
Hot spot factor in the seeded cluster	1.42
Hot spot factor in the thorium-U233 cluster	1.36
Maximum channel power, MWth	2.45
Maximum-to-minimum channel power factor	1.88
Fraction of power from thorium, %	75.4

advisable. In a uranium system, the harder spectrum will be to the detriment of the U235, but the eta of U233 is almost flat and so it does not matter.

Thermal absorption of thorium is about three times as large as that of U238. So parasitic absorption is less of a problem in thorium systems and one could try light water coolant. With light water coolant, it is possible to have boiling coolant and direct cycle. Since the spectrum is hard, things could be so managed that the coolant void coefficient is negative.

With boiling coolant, the reactor has to be vertical. In this case, it can be designed to have 100% heat removal by natural circulation and also to have passive safety.

These are broadly the characteristics of the AHWR. A description of the core at its present stage of evolution is given in Table 4.

8. CONCLUDING REMARKS

The natural uranium once through cycle was the first natural cycle for the PHWR, but may be it is now time to look at other cycles more seriously. Both plutonium recycling and thorium cycles yield much better fuel utilisation, high burnup cycles help in shrinking spent fuel inventory for those countries for whom direct disposal is a constraint. These cycles are also very efficient in constraining plutonium where that is of importance. The choice of a cycle will depend upon the compulsions of any country or company or utility, but an array of options is available to choose from.

CONTRIBUTORY HEALTH SERVICE SCHEME

Medical Division

HISTORY

The history of our medical services dates back to 1955 when the Health Division of the then Atomic Energy Establishment, Trombay (AEET) was founded. To start with Dr P.D. Darne was looking after clinical work, with Dr (Mrs.) C.Y. Lavande doing pathology work.

By 1958, the Division started expanding with the recruitment of Dr K. Sundaram, Dr R.D. Ganatra, and Dr V.R. Shah. Those days initial medical examination of new recruits, periodical medical examinations of the staff members and outdoor treatment given to the employees constituted much of the work.

By 1959 more clinical work was started and three dispensaries were set-up : one at the Training School Hostel at Bandra, the main dispensary at the Old Yacht Club, and one dispensary at South Site, Trombay. There were no hospital facilities of our own and there was no facility for treatment of family members of the employees.

It was during 1960-61 Dr Homi Bhabha, the perfectionist and visionary, implemented a separate scheme of our own - the present CHSS. His idea was that a well run medical scheme will make the employees feel secure and with their families being looked after, they can concentrate better on their work.

Several administrative hurdles had to be overcome and in 1962 sanction was obtained for a separate scheme, different from the general Central Government scheme.

- By 1963 indoor facility at J.J. Hospital in Byculla, Mumbai and a dispensary in the hospital premises were started, and the family members of the staff started receiving treatment at OYC dispensary and J.J. Hospital dispensary. The expansion of CHSS continued with opening of new dispensaries in various locations –

- Chembur (1964)
- Anand Bhavan (1965)
- Bandra and Ghatkopar (1966)
- Matunga (1967)
- Deonar (West) (1969)
- Deonar (East) (1975)
- Vashi (BRIT) (1985)
- Vashi (1987)

- Andheri (1992
- Mandala (1999)

As the number of beneficiaries increased, so did the staff strength of Medical Division. The indoor facilities at the J.J. Hospital were now not enough and in 1976 the BARC Hospital was shifted to the present premises at Anushaktinagar. The beneficiaries are offered various facilities and medical treatment with the help of many advanced investigations in our hospital. It is a fulfilment of Dr Bhabha's dream. At present Medical Division and Radiation Medicine Centre cater to the medical needs of about 72,200 beneficiaries with the help of 12 dispensaries and a 250 bed hospital.

- First Hepatic transplant performed in Mumbai was on our beneficiaries, costing Rs 1 million.
- Three bone marrow transplants have been performed on our patients, each costing Rs 700,000.
- 330 Angiographies, 80 angioplasties and 70 bypass surgeries were done in 1998 alone.
- Five kidney transplant patients are on immuno-suppression therapy - costing Rs 3000/- month/patient, apart from the transplant cost.

CHSS DISPENSARIES

At present, the 12 CHSS dispensaries, spread all over Mumbai, are rendering medical services to 72,200 beneficiaries. These dispensaries are run by 38 doctors and are important and strong pillars of our health scheme. These dispensaries are engaged in the following activities :

1. Prompt and efficient initial care of all patients;
2. Regular follow ups of Diabetes, Hypertension, Coronary Heart Disease, Pulmonary Tuberculosis and Asthma patients;
3. Antenatal care, Well Baby care clinics;
4. Immunization,
5. Displaying educative posters and lectures - to provide information and positive message regarding health care.

These dispensaries are going to be updated with equipment like glucometer, nebuliser, ECG machine and computers. The daily attendance of CHSS beneficiaries is about 1820, with more than 45 patients/day/doctor.

TROMBAY DISPENSARY

Apart from the 12 peripheral CHSS dispensaries, there are two special medical units for the health care of employees in relation to their work.

Trombay Dispensary is playing an important role in this field. It is especially involved in the practice of occupational health medicine and also deals with curative, preventive and emergency medical care. It carries out initial medical examination of new recruits and trainees; periodical medical examination; examination of over exposure cases from DAE and all over India; Management of radiation injuries all over India; and consultancy on radioactivity problems all over India.

VASHI INDUSTRIAL DISPENSARY

Vashi Industrial Dispensary, Turbhe carries out periodic medical examinations of staff of Board of Radiation and Isotope Technology working with radioisotopes; and staff of Powder Metallurgy Division and Beryllium Machining Facility. It also conducts annual spirometry evaluation of Beryllium employees; routine medical care for illness and injuries; motivation of employees to give up alcohol/smoking/tobacco chewing; ergonomic advice for proper methods of lifting weight for prevention of backache; safety education of employees; and emergency management and transfer of patients after stabilisation.

The dispensary is equipped with Electro-cardiograph, Spirometer, Computer and Oxygen cylinder. Ambulance is available round the clock for transfer of serious cases. Record keeping is uptodate and details about past/present illnesses along with their pathology and radiology reports are maintained on the computer for easy retrieval and reference. The follow up for patients suffering from chronic diseases is done regularly.

BARC HOSPITAL

Frontview of BARC Hospital

E.N.T.

The department has widened its scope from diagnosis and management of diseased conditions of the ear, nose, throat, head and neck, by including also preventive and rehabilitative medicine. At-risk patients such as those working in noisy areas, aged patients and children are regularly screened for hearing problmes. Early detection of such cases helps in their proper management and rehabilitation. Patients are trained in proper use of hearing aids. Patients with speech defects and chronic conditions like allergies and giddines require considerable training, support and follow up in addition to medications. A great deal of stress is laid on these aspects.

The ENT department is equipped with state of the art diagnostic aids such as the flexible and rigid endoscopes, a sophisticated operating microscope and an ENT work unit. The Audiology set up at the department is relatively new, but very good with a sound treated room, modern audiometer and impedence audiometer. All these are invaluable in effective diagnosis and management of the patients. The departent not only caters to routine ENT surgical conditions but also head and neck malignancies, plastic surgery of nose and conditions like sleep apnoea. Lasers in ENT and functional endoscopic sinus surgery are two other fields of rapid development to the great satisfaction of ENT surgeons.

Dr Nalini Bhat, ENT Specialist, examines a patient

PATHOLOGY

In 1976 the Pathology laboratory was shifted from Richardson & Cruddas building and J.J.Hospital to the BARC Hospital. The Laboratory is equipped with a range of sophisticated equipment procured to perform latest blood investigations possible in the centralised laboratory located in the BARC Hospital, with two extensions at Anand Bhavan Diagnostic Centre and at Trombay Dispensary.

The Pathology unit has a team of three doctors, 30 technicians, one administrative staff and six Helpers fully engaged in performing approximately 300,000 blood investigations each year. The laboratory functions on round-the-clock shift basis.

Keeping pace with changing times, the laboratory geared up to accept the latest technologies and techniques and thereby introduced investigations like ELISA testing for AIDS, Hepatitis, TORCH, Blood Gas Analysis and other tests like Fine Needle Aspiration Cytology (FNAC), etc. We also got our Blood Bank approved from Food and Drug Administration and opened a new Cytogenetic Laboratory. Our latest acquisition was the two fully automated Biochemistry Analysers which are sophisticated equipment. With the installation of these biochemistry analysers, we have vastly improved the accuracy, quality and speed of investigations. The quality control programmes are carried out on these machines every day for attaining perfect, reliable and consistent results. Additionally, we have semi-automatic bio-chemistry analysers in our laboratory as well as at our Diagnostic Centres at Anand Bhavan and Trombay Dispensaries. The Blood Gas Analyser with us is a vital equipment meant for critically ill patients whose blood gas analysis greatly helps our doctors in assessing the prognosis of the patient and deciding the line of treatment. Plans are afoot to have automated systems for Haematology, Diagnostic Molecular Biology and Blood Component facilities.

Our blood bank has been meeting the blood requirements of our patients to a large extent. Topmost priority is given to screen the blood for diseases like AIDS, Hepatitis B & C, Malaria and Syphilis before the blood is issued to the patient. The Laboratory has facilities for histopathological examination of biopsies and tissues received from the Operation Theatre or Surgical OPD which helps in diagnosis of cancers and non-cancerous diseases. Additionally we have Fine Needle Aspiration Cytology (FNAC) and Frozen Section examination done regularly to carry out rapid and intra-operative diagnosis of cancer.

Pathology laboratory

The cytogenetic laboratory was established in 1994 to screen newborns and patients attending genetic counselling clinic for any chromosomal aberrations.

Computerising of all reports, with all report forms designed by color coding, helps our consultants to speedily reach the required report in the medical file of a patient being attended to. Aproximately 350 to 400 reports are generated daily which are despatched to the concerned OPDs, Wards and Dispensaries.

PAEDIATRIC

The Paediatric department has four consultants and three residents who offer preventive and curative care to about 15,000 children (about 20% of CHSS beneficiaries). We aspire to offer the best patient care possible and in turn aim to achieve high patient satisfaction.

We have a ward and neonatal intensive care unit (NICU) equipped with paediatric ventilator, pulse oximeter, vital sign monitors, defibrillator, neonatal rescuscitation trollys etc.. We are ably assisted by efficient nursing staff in offering routine as well as critical care. We run a well baby clinic once a week and our OPD functions 6 days a week. We also conduct genetic clinic and school health clinic. Most of the patients are managed in the BARC Hospital. A few patients requiring super speciality care are referred to referral hospitals. We are a referral centre for other DAE units and we manage their patients with complex problems. Vaccine preventable diseases like diptheria, pertussis (whooping cough), tetanus, and poliomyelitis are not seen for the past 15 years in our set up due to our high immunisation coverage. Incidence of diseases like measles, mumps and rubella also has drastically reduced because of the introduction of MMR vaccine for over 10 years.

Our hospital was recognised as "BABY FRIENDLY HOSPITAL" by National Task Force in 1990. We trained our medical and paramedical staff to promote exclusive breast feeding. We have trained medical personnel in other hospitals too. Breast feeding promotion has resulted in increased awareness amongst mothers thus resulting in decreased incidence of upper respiratory tract infections and gastro enteritis.

With optimal preventive and curative care the neonatal, infant and under five mortality is much less than the national figures and is comparable to figures in western countries. The incidence of congenital anomalies in our population is very low, thus allaying fears about radiation exposure leading to malformations.

An infant in the Paediatric unit

OBSTETRIC & GYNAECOLOGY

Prenatal examination of a patient

Over the years Obstetrics & Gynaecology department has shown progress in terms of adaptation of innovative changes and additions to its field of work. Right from its inception, a lot of emphasis has been laid on preventive programmes like antenatal surveillance and annual gynaec check-ups. High risk antenatal clinics are being conducted. The thrust areas in the clinic are intra-uterine growth retardation (IUGR) and pre-eclamptic toxemia. Intensive antenatal and intrapatum monitoring is being done with the aid of electronic foetal heart rate monitoring, cardiotocography, ultrasonography - doppler and level II. The achievements in the obstetrics have been no eclampsia, no septic cases, decreased instrumental and complicated delivery and decreased maternal morbidity. There has been no maternal mortality in the last 10 years. Annual gynaec check-up including pap smears, colposcopy and transvaginal sonography have helped in early detection of pelvic disease/cancer. Hormone replacement therapy clinics are being conducted. This has drastically improved the quality of life in postmenopausal women. Facilities like electro and cryo surgery and CO_2 laser are available in the outpatient department.

The department has a fully equipped operation theatre. The use of endoscopy (laparoscopy and hysterscopy) has extended to operative procedures from the diagnostic one. Video assisted endoscopic surgeries are presently being performed, which are minimally invasive and has definitely reduced the operative morbidity and hospital stay.

The challenges being faced now are congenital abnormalities and metabolic disorders and this has called for the introduction of genetic counselling clinic and prenatal diagnosis. With the strict ante and intranatal surveillance and the back up facility of intensive neonatal care, the perinatal mortality is comparable with international statistics. The small family norms are being encouraged and modern methods of contraception are being advocated.

PHYSIOTHERAPY

Of the 60-70 cases daily attending the department (including ward patients) approximately 50% are for management of pain and musculoskeletal disorders. The goal is to evaluate and to reduce impairments and disabilities. For pain management, apart from using usual modalities like short wave diathermy, ultrasound, transcutaneus electro neuromuscular stimulator, techniques of manual therapy are applied. Manual therapy introduced since the last three years is used to

A patient being treated in physiotherapy unit restore functions of joints and spine and reduce pain.

Manipulations for cervical spondylosis and low frequency currents in peripheral nerve injuries and facial palsy are important procedures performed in the department.

Various sets of exercises and procedures are carried out in different conditions and disorders.

Follow up of patients depending upon course of disorders is done regularly

It is proposed to start the following

- Pain clinic,
- Obesity clinic, and
- Computerisation of the patients data.

SOCIAL SERVICES

Since its inception in 1965, this department has been engaged in psychosocial diagnosis, treatment and rehabilitation of variegated social problems and medico social problems arising due to various illnesses. Appropriate psycho-social therapies and counselling methods are utilised for resolving these problems to a maximum possible extent to restore their psycho-social functioning and to alley anxiety and stress by mobilising human as well as material resources. A number of preventive programmes were organised by the Social Services unit.

Work related to Benevolent Fund and Family Relief Scheme is also carried out by Social Service unit.

PSYCHIATRY

The Psychiatry deparatment has two full time Psychiatrists, one Psychiatric Social-Worker, one Part time Clinical Psychologist and one Panel Psychologist handling an average of 600 patients every month.

The Department has extended its services in area of occupational health on preventive basis by undertaking the Preliminary Aptitude Test (PAT) as a part of pre-recruitment analysis for Trainees and Post-Graduate Trainees recruited every year. As an extension of this programme, the recruited Trainees are followed up regularly for guidance and support since the last five years.

RADIOLOGY

The Radiology department of BARC Hospital provides diagnostic radiological services to the beneficiaries of CHSS comprising of employees of DAE and their dependants.

The department provides the following services :

- Radiography,
- Ultrasonography, and
- Colour Doppler Studies.

The department is equipped with three X-ray machines including Image Intensifier for daylight fluoroscopy and five Mobile X-ray Units for bedside and Intra-Operative Radiography. The department works round the clock and one technician is always available after OPD hours. One X-ray Unit is installed in Casualty department for immediate attention of patients coming to Casualty.

Dr Subhash Narang, Radiologist supervises the investigation of a patient

The services provided are Conventional Radiography i.e. X-Rays of all types and special investigative diagnostic procedures comprising of oral and intravenous contrast studies viz. Barium Studies like Barium Swallow for evaluation of patients having problems of swallowing and tumors of the food-pipe; Barium meal & Follow Through studies for diagnosis of diseases like ulcers and growth in the stomach, tuberculosis of the small intestine and malabsorption syndrome, etc. Barium Enema studies for the evaluation of patients suffering from diseases of large bowel and rectum like long standing constipation,ulcerative colitis, growths and tumors of large bowel. Intravenous pyelograms for evaluation of patients of ailments of kidneys, hysterosalphingograms for evaluation of patients of infertility and diseases of the uterus, and fistilographies for patients suffering from fistula-in-ano before undergoing surgical procedure for its treatment are some of the services rendered by this unit.

The Ultrasonography Unit is equipped with:

1. Two Ultrasonography Machines for Routine Sonography and Colour Doppler Studies for Whole Body applications including 2 D echocardiography

2. One Portable Ultrasonography Machine for bedside sonography.

Studies are carried out for assessment of diseases of liver, gall bladder, pancreas and spleen and other mass lesions in abdomen. Ultrasonography of chest for evaluation and follow up of patients having accumulation of water or blood in chest cavity, and gynaecolgical studies to visualise and assess disease of uterus and ovaries, are also done.

SURGICAL

The surgical services consisting of General Surgery, supported by the Anaesthesiology unit deal with surgeries like Hernia, Hydrocele, Swelling excisions, Gall bladder and Renal stone surgeries, breast tumors and other Urological work. There were fewer cases of benign and malignant tumors of various organs. Emergency cases such as Appendicitis, Bowel Perforations and obstructions and other Urological cases were an occasional problem which were handled. The Minor Surgical Operation Theatre handle cases of Vasectomy with other minor excisions.

Fracture and Trauma cases were handled by the unit, with major trauma cases of hip and long bones. Except for cardiac and neuro-surgical operative procedures, this unit undertakes a!l surgical procedures pertaining to general surgery, urology, plastic surgery, cancer surgery, maxillo-fascial surgeries etc. The unit regularly carries out endoscopic procedures, involving upper gastro-intestinal area, urinary system and abdomen. As this unit has updated urological instrumentation, endourological procedures like endoscopic resection of enlarged prostate, bladder tumours, crushing of bladder stones and removal of renal stones by PCNL are routinely carried out.

The C.H.S.S population has been increasing with many of the employees aging and developing chronic diseases like Diabetes, Hypertension and Respiratory Diseases. Hence to cater to the needs of these high risk groups the surgical unit has developed strict protocols and has also been laying emphasis on day care surgeries with the help of key hole surgeries and other interventional surgeries. This has contributed in reducing the morbidity and the nosocomial infections with strict aseptic precautions and a rigid and ethical antibiotic policy.

The surgical unit has four full-time consultants, four residents and two house surgeons. The Surgical Unit is recognized to train post-graduates for the national board of examinations.

A view of action in the Operation Theatre

ORTHOPEDIC

Besides treating routine fracture and trauma cases, orthopaedic problems like chronic arthritis, backaches and neckaches, congenital bone defects and bone deformities and bone infections and tumors are also being handled by this unit.

The monthly outpatient attendance of this unit has increased to about 700-800 from about 80-90 during the earlier years. Whereas the major Orthopaedic Surgical procedures in the main theatre in a month were about 3-4, we are performing now about 15-20.

Keeping in touch with the latest techniques of operative treatment of fractures, which lay emphasis on faster mobilization of the patient, reduction of morbidity and reduction of bed occupancy by way of extensive physiotherapy, we have acquired operative instrumentation sets for various fractures of the long bones and have used them successfully in a series of patients achieving results which can compare with those of any trauma management centre.

This unit undertakes major orthopedic procedures like partial hip replacements, interlocking nailings, external fixators, spinal surgeries, and arthroscopies with the help of an image intensifier system. With the increase in the geriatric population among the CHSS beneficiaries, the occurences of trauma in the elderly has been on the rise leading to many cases of hip, knee, ankle, shoulder, elbow and wrist joint fractures along with long bones. This unit carries out major challenging operative procedures successfully on patients even beyond 90 years of age, giving them quality of life with independence in activities of daily life.

With a complement of two orthopedic surgeons, a part time consultant and one resident and a house-surgeon, this unit has ten beds for inpatients and a regular OPD.

ANESTHESIOLOGY

With a strength of five experienced and qualified anesthesiologistsand a resident trainee in anesthesia, this unit caters to the requirements of surgical operative procedures and intensive care.

Anesthesia unit offers its expertise to various units which include surgical, orthopedic, ophthalmology, ENT, dental, psychiatry and gyaenacology & obstetrics units. The unit renders pre operative assessment, planning and administration of anesthesia and analgesia requirements, and post operative management .

This unit handles about 3,500 patients who require surgical care. Besides catering to the elective and emergency operative procedures, it conducts day time anaesthetic procedures, for ECT's in Psychiatry O.P.D. and for Dental patients in its O.P.D.

The hospital has four major and four minor operating rooms. These areas are well equipped with all the mandatory safety monitoring devices In recent years, by acquiring latest equipments, such as ventilators and patient monitoring devices, the anesthesia unit is meeting the International mandatory monitoring Standards.

Recently the unit has acquired two sophisticated Multi parameter patient monitoring systems for the intra-operative management of the patients. From this year Anesthesia unit started offering "Labour analgesia services" to the young expectant mothers. Service offered is optional hence will require patient acceptance and availability of manpower in the unit.

ICCU

Dr Balbir Singh attends to a patient in the ICCU

The Intensive Cardiac Care Unit has eight beds which takes care of acute cardiac emergncies like different cardiac arrhythmias, LVF, cardio genic shock, different types of heart blocks and bradycardia.

Invasive procedures like CVP monitoring, Trans Venous Pacing, etc. are also being done in the ICCU. Cardiac arrhythmias are treated with Cardirone and DC Defibrillation.

Thrombolytic agents like Streptokinase and Urokinase are very frequently used to dissolve the thrombus. Many acute complicated cases of cardiogenic shock and malignant arrhythmias were treated by the above measures.

Coronary angiograms are regularly reviewed with the help of DACARNO which is available in the ICCU.

Facilities for ABP Monitoring and Holter Monitoring are also available.

As preventive cardiology work up, average of 8-10 stress tests are being performed in the ICCU. This helps us in detecting Coronary Heart Disease at the very early stage and can take preventive measures.

Ambulance of the Heart Brigade

A **Bombay Heart Brigade 105** is also stationed in the ICCU which takes care of acute cardiac emergencies in the near vicinity. A fully equipped ambulance with a doctor and nurse is being sent to the house of the needy cardiac patients on receiving a call on 105. Emergency medical treatment is being given at home and the patient is transferred to the nearest hospital of their choice.

OPTHALMOLOGY

The Ophthalmic departament is well-equipped. The outpatients eye department and the Ophthalmic thheatre are situated next to each other. This helps in the smooth running of the department especially in case of emergencies where surgery is required.

In the OPD mostly patients complaining of visual disturbances are seen along with patients complaining of redness, irritation, itching, etc. Referrals from other OPD's and dispensaries are seen daily on appointment basis.

The Ophthalmic Department receives referral from units of DAE all over India for diagnosis of complicated cases, surgeries and specialised eye investigations like automated perimetry, indirect opthalmoscopy and 'A' scan biometry.

In the operation theatre besides routine cases like cataract extraction with intraocular lens implantation other surgies like anti-glaucoma surgery, squint correction, lacrimal sac surgeries are done.

Dr V. Karira, Opthalmologist, examines a patient

DENTISTRY

With the commissioning of the BARC Hospital in 1976, the then Dental facility consisted of total four units - two of them at the hospital and one each attached to Trombay and Anand Bhavan Dispensaries.

With the ever-increasing demand on the unit, in the span of a short period, three more operatories were commissioned within the Dental OPD Complex at the hospital. Hence, today the expanded facility has grown to seven full-fledged operatories. A full-time Dental Hygienist is available at the hospital taking care of patients needing Dental prophylaxis and guidance on the maintanance of oral hygiene procedures. A highly experienced Maxillo-facial and oral surgeon has also been appointed on the panel for specialised surgical procedures.

The employees as well as their family members are distributed zonewise to either the hospital or Anand Bhavan & Trombay dental facilities in order to ensure maximum convenience to the large population of beneficiaries.

Most of the Dental operatories are equipped with a state of the art instrumentarium and the rest are expected to be upgraded in the near future. The Department of Dentistry has always been and more so today, a model of efficiency and one of the most well-run units in the Division. It is comparable to the best anywhere and offers the latest procedures in the various Dental specialities such as :

Restorative Dentistry, Endodontics, Cosmetic Dentistry, Orthododntics, Prosthetics and Crown & Bridge, Oral and Maxillofacial Surgery, Orthognathic Surgery, Pedodontics, Periodontics, Dental Radiography and Dental Implants.

Dr K.R. Munim, Dental Surgeon, working on a patient

The Dental Unit is a self sufficient unit, having all treatment modalities available in-house, thus negating any external reference requirements.

INFORMATION MANAGEMENT

To keep pace with growing patients information it was decided to induct modern information management technology for processing of hospital information. The advantages of such a system would be availability of an orderly set of patient information, faster retrieval of documents, decentralised access to data bank, systematic archival, uniformity in information format, reduced duplication, better clarity, higher accuracy, etc. Computer Division of BARC, was entrusted with installation and commissioning of computer system. The computer system comprises of Landmark-486 CPU with 16 MB RAM, 27 terminals, 15 local printers, UNIX Operating System and ORACLE Data Base Managaement System. In consultation with the end-users, more than 80 computer screen forms has been developed and integrated to the patients' database for use in the hospital. Various user departments have been provided with the computer terminal & local printer for their daily use.

FACILITY FOR INTEGRAL SYSTEM BEHAVIOUR EXPERIMENTS (FISBE)

Reactor Design and Development Group

Introduction

The course of events during accident scenarios and operational transients in Pressurised Heavy Water Reactors (PHWRs) involves complex single-phase and two-phase thermal hydraulic phenomena like flow coast-down, thermosyphon, blowdown, reflux condensation, rewetting etc. The effect of such phenomena occurring in isolated components can be studied by making a model of the component and conducting appropriate experiments on it. Theoretical models can then be developed based on the results of such experiments. Such tests are termed as separate effects tests. Separate effects tests have been conducted to study some of the phenomena mentioned above and theoretical models have been developed. Such component/subsystem models are integrated into system models/codes for complex systems like nuclear reactors. The response of such a multi-component system could be different from the response of individual components studied separately, because of interaction effects.

Hence, it becomes necessary to have integral test facilities for carrying out studies on multi-component systems like reactor loops. A number of integral test facilities have been constructed, mainly in advanced countries. The integral test facilities in countries like the USA, France, Italy, Germany, Japan and Hungary are related to Light Water Reactors. For PHWR type of reactors, integral test facilities have been built in Canada, where, presently the RD-14M facility is operational. To generate data related to Indian PHWRs, an integral test facility, the Facility for Integral System Behaviour Experiments (FISBE) has been set up in the Annexe to Hall-7 at Trombay. This facility closely simulates the Primary Heat Transport System and associated components of the secondary system of the Indian Pressurised Heavy Water Reactor. This facility will be used for Loss Of Coolant Accident (LOCA) and other operational transient experiments in a phased manner over a period of time. Fig. 1 depicts the building housing the facility.

Fig 1 Annexe to Hall 7 that houses FISBE

Objectives

The objectives can be summarised as follows :

1. To understand the physical phenomena that occur during accidental conditions and operational transients.
2. Creation of data base for the assessment and validation of thermal hydraulic computer codes used for predicting the transient behaviour during accidents and operational transients.
3. To test recovery methods and operational procedures to bring prototype PHWRs to a safe shut down state following possible abnormal situations.

Scaling

Appropriate scaling philosophy is adopted, maintaining the same elevations as in the reactor. Because of this, the total loop height is 39 m. Power to volume scaling philosophy is followed in the design of the facility. Volume scaling in respect of 220 MWe PHWR units is 1:76.5. For the 500 MWe unit, the volume scaling is 1:98 with respect to one of the two Figure of Eight loops of the Primary Heat Transport (PHT) system. The design pressure and temperature of the facility enables obtaining initial operating conditions same as in the PHWRs. Time scale is preserved.

Description

Flow sheet of the facility is shown in Fig. 2. The facility consists of the following main systems:

(1) Figure of Eight Primary Coolant Loop,
(2) Feed and Bleed System,
(3) Emergency Core Cooling System (ECCS),
(4) Steam Generator (SG) Feed Water System
(5) Break Flow System.

The Figure of Eight loop comprises the test sections/Fuel Channel Simulators, feeders, headers, pump simulators, steam generators and the pipe lines connecting the pump simulators and steam generators with the headers. The feed and bleed system is provided to maintain the PHT system pressure and inventory. The components in the feed and bleed system include the PHT system storage tank, primary feed pump, bleed cooler and ion exchange columns. The emergency core cooling system consists of the high pressure accumulator, the nitrogen tank and the ECCS pump. The SG feed water system is provided to feed water into the secondary side of the coolers. The break flow system is provided for simulating breaks of different sizes as part of LOCA studies and to collect / discharge the break flow. Components like feed control valves, bleed control valve, instrumented relief valve, motorised valves, ASDV etc. are provided at appropriate locations in the facility, as in the prototype, for effective simulation of the transients. Also, the electrical power supply system of the facility is designed to simulate the effects like power setback in the prototype reactor.

The test facility is extensively instrumented to measure temperature, flow rate, pressure/ differential pressure, level, density etc., at various points in the loop. Provisions have been made in FISBE for pressure measurements at 33 locations and temperature measurements at 230 locations. The transients that are to be measured are very fast. Hence, a Fast Data Acquisition System (FDAS) with a capacity of 256 channels and a scanning speed of 10000 channels per second is provided for FISBE. The FDAS has provision for programming different scanning rates for different parameters as well as during different phases of the transient under investigation.

Description of FISBE Flow Sheet

The heat input is given to the Test Sections/Fuel Channel Simulators through the DC power supply. The water gets heated up and flows up to the outlet headers. The outlet headers are connected to the SGs wherein the heat is transferred to the secondary side of the loop. The primary coolant leaving the SGs is led through the pump simulators to the inlet headers. From the inlet headers, water flows back to the Test Sections thus completing the loop. The primary side of the loop is provided with a Feed and Bleed system. Under normal operating conditions, a constant bleed flow is maintained through the purification system for chemistry control which is put back into the loop through the storage tank. A bleed cooler is provided to cool the bleed to lower temperatures acceptable to the purification system. Depending on the outlet header pressure, the system inventory is adjusted by the bleed and feed control valves. The feed is pumped from the storage tank to one of the outlet headers. An Emergency Core Cooling System is provided as in the prototype reactor. It consists of a High pressure Accumulator which, in case of LOCA experiments, would inject water into both the inlet headers. Actuation of HPA is through a motorised valve. Provision for simulation of injection of water from fire-fighting system, as in the prototype reactor, is also provided. For this purpose, water from a storage tank is pumped into the SGs in case depletion of inventory occurs in the secondary side of the SG. The secondary side feed is from a reciprocating pump, drawing water from a storage tank. A break flow system is also provided in the facility to enable carrying out LOCA experiments simulating different break sizes. It consists of an orifice whose size simulates the required break size and a valve, the opening of which simulates a 'break' in the system. The discharge from this break can be collected and cooled in a storage tank.

Experiments Planned

Experiments planned in the facility in the first phase include:

1. Single-phase natural circulation,
2. Two-phase natural circulation,
3. Reflux condensation behaviour,
4. Station black-out and
5. LOCA with single-phase natural circulation as initial condition.

It is planned to further augment the facility during the ninth plan period. The range and type of experiments will be enhanced in the augmented facility.

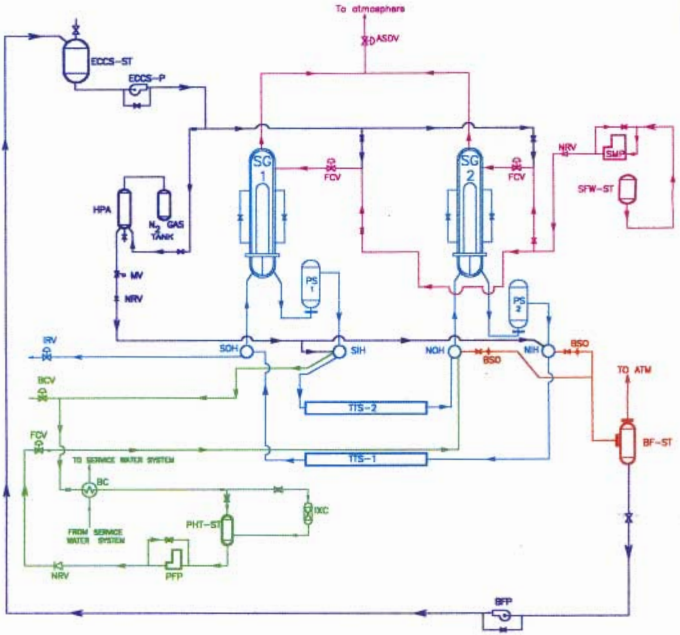
MAIN PARAMETERS

(a) Primary Side

Design Pressure	:	125 kg/cm^2
Design Temperature	:	343°C
Fluid handled	:	Demineralised water
Power supply	:	Maximum of 3 MW DC

(b) Secondary Side

Design Pressure	:	70 kg/cm^2
Design Temperature	:	285°C
Fluid handled	:	Demineralised water



LEGEND

PHT-ST	:	PRIMARY HEAT TRANSPORT SYSTEM STORAGE TANK
ECCS-ST	:	EMERGENCY CORE COOLING SYSTEM STORAGE TANK
BF-ST	:	BREAKFLOW STORAGE TANK
SFW-ST	:	SECONDARY FEED WATER STORAGE TANK
BCV	:	BLEED CONTROL VALVE
IRV	:	INSTRUMENTED RELIEF VALVE
FCV	:	FEED CONTROL VALVE
NRV	:	NON-RETURN VALVE
ASDV	:	ATMOSPHERIC STEAM DISCHARGE VALVE
BSO	:	BREAK SIMULATING ORIFICE
SG	:	STEAM GENERATOR
TTS	:	TUBULAR TEST SECTION
SMP	:	SECONDARY MAKE UP PUMP
ECCS-P	:	ECCS PUMP
PFP	:	PRIMARY FEED PUMP
BFP	:	BREAK FLOW PUMP
HPA	:	HIGH PRESSURE ACCUMULATOR
IXC	:	ION EXCHANGE COLUMN
SIH & NIH	:	SOUTH & NORTH INLET HEADERS
SOH & NOH	:	SOUTH & NORTH OUTLET HEADERS
BC	:	BLEED COOLER
PS	:	PUMP SIMULATOR
MV	:	MOTORISED VALVE

PHT SYSTEM (FIG. OF EIGHT)

PHT SYSTEM (FEED & BLEED)

SECONDARY SIDE

ECCS & FIRE FIGHTING SYSTEM

BREAK FLOW SYSTEM

FIG.2 SCHEMATIC OF FISBE FLOW SHEET

DIGITAL IMAGING OF NEUTRONS AND ITS APPLICATIONS

Amar Sinha
Condensed Matter Physics Division

Introduction

Neutron imaging finds applications in many branches of science and industry such as in nondestructive testing, material science etc. Conventional imaging of neutrons has been carried out mostly using analogue technology such as screen film imaging. Making transition from analogue to digital could bring several advantages such as fast image acquisition and display, implementation of image processing, quantitative interpretation of data etc. Such digital imaging techniques also open up possibility to carry out certain new class of experiments such as dynamic imaging which are quite difficult or impossible to carry out with the conventional analogue technology.

We have been working on digital imaging of neutrons for various applications using Charge Coupled Device (CCD) based detectors. A number of such systems have been developed at BARC for applications like two and three dimensional neutron tomography, two phase flow visualization and void fraction measurement inside metallic pipes, neutron radiography with non reactor sources etc. In this article we describe some of the prototype systems developed using CCD based digital neutron imaging techniques.

Electronic imaging technique of neutron radiography

Conventionally neutron radiography has been carried out using film based techniques. However with the advent of digital imaging technique, the film based techniques have been complimented with digital CCD based imaging method. One of the techniques of electronic imaging of neutrons is to use a large area image intensifier tube with neutron sensitive material directly deposited onto the photocathode of intensifier. However such a camera system is at present quite costly and not easily adaptable for different types of applications. We have adopted a relatively cheaper approach of using an image intensifier/CCD combination coupled through a lens to a large area neutron scintillator. A real time neutron radiography system based on this approach has been developed and tested at APSARA reactor. The schematic diagram of this setup is shown in Fig.1. The neutron beam passing through the sample is absorbed in a scintillator screen made up of ^{6}LiF+ZnS (NE-426). The optical photons generated by the scintillating screen are reflected at 90 degrees and focussed onto the input fibre optic face of an image intensifier tube. The scintillation light is intensified by the image intensifier tube and the output of intensifier is optically coupled to a CCD camera. The output of CCD camera is digitized and processed using a frame grabber cum processor and simultaneously displayed on a video monitor[1].

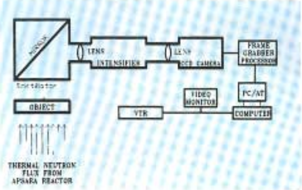


Fig.1 Schematic diagram of a prototype electronic imaging system at APSARA

Some of the radiography images obtained using this setup are shown in Figs 2 &3. Fig.2 shows the image of a carburetor and Fig.3 that of an experimental fuel pin. These images are obtained after few seconds of integration time. In fact this imaging system is so sensitive that even real time movement of objects can be visualized on video screen. This opens up the possibility of examining moving parts of the object or visualizing flow pattern of a fluid.

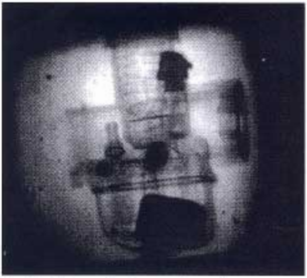


Fig.2 Radiography image of a carburetor

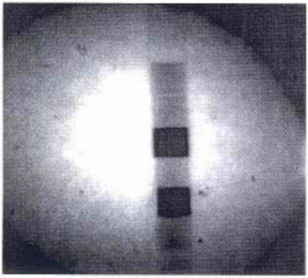


Fig.3 Radiography image of an experimental fuel pin provided by Radio Metallurgy Division

(b) Two phase flow visualization inside metallic pipes

Visualization and analysis of water/air or water/vapour two phase flow inside metallic pipes under high temperature and pressure is of considerable importance in thermal hydraulics design of nuclear reactors. Conventionally visualization experiments on two phase flow are conducted using transparent glass sections which do not permit simulation of high pressure and temperature conditions. Similarly other methods like conductance probe or gamma ray based techniques do not permit real time visualization of flow pattern. Neutrons have the unique property that they can penetrate inside dense material such as steel but get attenuated easily by water. This makes them an unique probe to visualize water/air flow or water vapour flow condition inside metallic pipes. This property of neutrons has been utilized for developing an electronic imaging setup for real time two phase flow visualization and void fraction measurement inside SS or aluminum pipe (optically opaque channels).

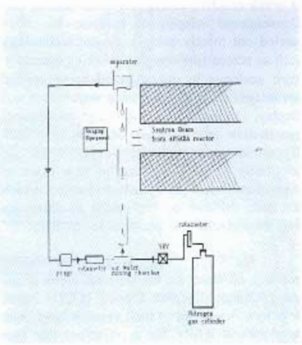


Fig.4 Calibration test loop for study of two phase flow at APSARA reactor

This system has the capability to compute online void fraction for air/water two phase flow using image processing techniques. The accuracy of this method of void fraction calculation has been tested by using several test pieces of perspex having a number of holes simulating varying void fractions. A test loop to simulate various flow conditions like annular, slug or bubbly inside aluminum/SS pipe has been fabricated. The schematic diagram of this test loop is shown in Fig.4. The imaging system for two phase flow visualization has been successfully tested at APSARA reactor using this test loop. Fig.5 shows images of different flow patterns of water/air flow inside aluminum pipe. Fig.6 shows result of online computer plot of void fraction measured over a small section of pipe.

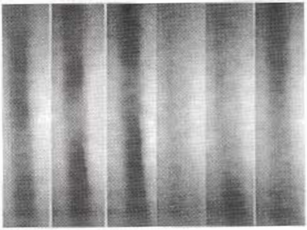


Fig.5 Real time images of different types of two phase flow pattern inside aluminum pipe (dark shades indicate water)

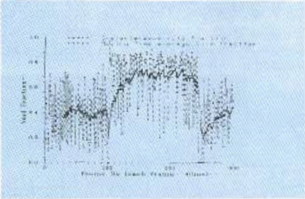


Fig.6 Picture of on-line plot of void fraction of two phase water/air flow inside the test loop

The dashed curve shows instantaneous values of measured void fraction over this small section of pipe. The instantaneous values are expected to fluctuate as the flow of mixture of air and water passes over this section. We have also plotted moving time averaged void fraction values which are shown in the plot as solid lines. In collaboration with Reactor Engineering Division, a second test loop to simulate flow condition in a natural circulation loop like those envisaged for Advanced Heavy Water Reactor has recently been fabricated which contains various other sensors such as conductance probe for void fraction measurement. This loop is presently being assembled and tested. This experiment is designed to test the neutron radiography method of two phase flow visualization and void fraction calculation and its inter-comparison with other methods under realistic conditions of high temperature and pressure.

Two dimensional (2D) tomography

Though radiography is being routinely used for nondestructive evaluations, computed tomography is a relatively recent addition to NDE. It overcomes many of the limitations of radiography and makes possible visualization of physical structures in their relative spatial positions and orientations. Conventionally tomography has been carried out using first generation translate-rotate system consisting of photomultiplier based detectors. However such systems are not especially suited for neutrons as the time taken in obtaining just one scan (slice image) is in hours. It also results in using a small part of neutron beam (only a pencil beam) which is otherwise quite costly to produce. We have developed [1] a neutron tomography system based on CCD technique and successfully used it at APSARA reactor for obtaining neutron CT scan of several test and industrial samples. The main advantage of CCD based tomography system over conventional translate-rotate tomography is the speed of data acquisition as even for fairly large samples only rotation steps are required for sample manipulation.

Fig.7 Aluminum test piece containing 9 SS rods & 10 brass rods (diameter of aluminum piece 60mm and of rods 3mm)

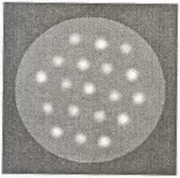


Fig.8 Neutron CT scan of the object described in fig.5

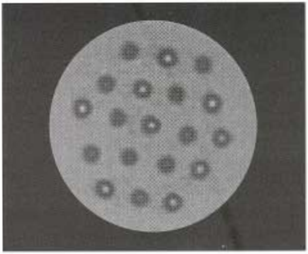


Fig.9 Processed CT scan image to highlight differences of attenuation coefficient between SS and brass rods

In this method, the sample to be imaged is placed on a stepper motor controlled rotary platform. Images of the sample are obtained at various angles by rotating the sample. The neutron tomography system developed for this purpose is fully automatic with integrated image acquisition using electronic imaging technique and stepper motor control. These images are preprocessed and subjected to reconstruction algorithm developed in house for obtaining CT scan images. Fig.7 shows picture of an object made up of aluminum of 60mm diameter and containing 9 SS rods of 3mm diameter and 10 brass rods of 3mm diameter. Fig.8 shows CT scan of this object. We have been able to distinguish between SS and brass rods. This is shown in Fig.9 by adjusting the contrast and suitably thresholding the CT scan image.

The spatial resolution obtained with this CT system is better than 1mm. Test samples made up of different materials and containing holes and rods of various sizes as low as 300 micron in diameter have been used for characterization of this tomography system. The resolution of this technique is limited by characteristics of CCD and demagnification used and can be further improved by using high resolution cooled CCD. Care has also to be taken in minimizing or correcting for the effects of scattering which results in cross correlation of different imaging elements.

Three dimensional (3D) tomography:

In recent years with the advent of CT scan systems capable of giving multiple slices in short time and availability of fast computers, reconstruction techniques of obtaining 3D images from 2D tomography slices is at the forefront of investigation in medical imaging and has a become a very powerful simulation tool for surgeons. It is now possible to interactively examine and see through the interior of an object in three dimension by combining 2D CT scan data into a 3D volume data. Applications of such techniques for industrial purpose have been rather limited. We have extended this technique to the three dimensional visualization of the interior of industrial objects. The CCD technique of tomography is particularly suitable for this purpose as multiple slices of an object can be obtained in very short time.

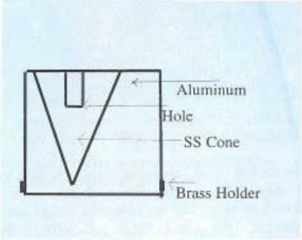


Fig.10 Schematic diagram of test object with offcentered SS cone inside aluminum matrix

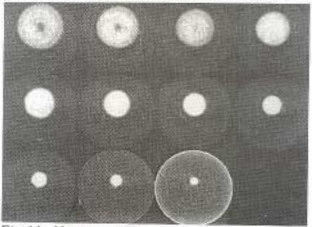


Fig.11 Neutron CT scan of the object at various heights (11 slices)

To test this technique, we have used a test object in the form of an off centered cone made up of stainless steel (SS) embedded inside aluminum matrix of diameter 50mm. Fig.10 shows schematic diagram of this test object. The base diameter of the cone is 34mm and length 35mm. At the base of the cone there is a 3 mm diameter hole extending upto 10mm along its length. At the lower end of the sample there is also a brass ring for holding the object. Fig.11 shows some of the CT scan images of this object taken at various distances from the base of cone. Fig.12 shows a 3D volume rendered image of this object obtained by combining the multiple 2D CT scan images into a volume data. The transparency of outer layer has been increased for the visualization of SS cone inside aluminum matrix. Fig.13 shows a vertical cutaway view of this object showing half aluminum cylinder and half SS cone.

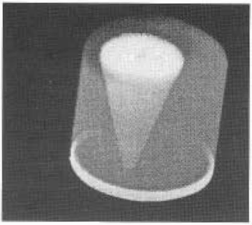


Fig.12 Stacked slices using volume rendering technique

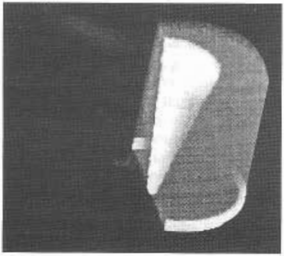


Fig.13. Cut away view to show the hole inside SS cone

This helps in examining interior of object such as the length of hole inside SS cone. The object can be opened layer by layer or cut at any angle using such a visualization technique without physically cutting the material. This is like doing reverse engineering to an object. The example shown here is only a representative one to demonstrate the powerful features of the 3D tomography technique.

Neutron radiography with small neutron sources

Neutron radiography has been shown to be an excellent tool for many nondestructive evaluation purpose. Unfortunately making images from neutrons using conventional film radiography technique requires large thermal flux. Therefore practical neutron radiography has been mostly carried out at nuclear centers having nuclear reactors with high thermal neutron flux. This has limited the utility of neutron radiography technique which is otherwise an excellent tool and in some cases only tool for many of the NDT applications. Neutron radiography can be developed for field applications provided a mobile neutron source can be deployed and a more sensitive method of neutron imaging be used so that the effect of low neutron strength of mobile sources can to some extent be mitigated by more efficient detection technique. To develop imaging techniques for a portable neutron radiography system, we have developed a high sensitivity neutron imaging system which can make images by detecting each individual neutron scintillation.

To test the efficiency of this detector, we have assembled a small neutron radiography assembly using Pu-Be sources of total strength 10^7 n/s [2-4]. The collimated thermal neutron flux from this assembly is ≈70 n/cm^2/s at a L/D ratio of 10. Fig.14 shows radiography image of a glass test tube half filled with water which has been obtained using this small neutron radiography assembly. Fig.15 shows image of a broken piece of hydrogen loaded zircaloy tube. The darker portion in this image indicate presence of hydrogen. These images have been made by accumulating individual neutron scintillation for a few minutes. The somewhat poor quality of these images is mainly due to low neutron flux (≈5 orders of magnitude lower than those available in radiography beam holes of nuclear reactors).

Though the radiography assembly described here is meant only for demonstration of small source neutron radiography using a sensitive neutron detector, it can still be used for many qualitative radiography applications such as checking the filling level of charge inside ammunition shells and for applications like examining blockages in pipes located in inaccessible areas.

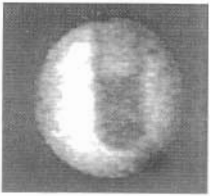


Fig. 14 Image of a glass tube half filled with water

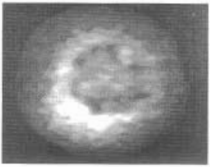


Fig.15 Image of a broken piece of hydrogen loaded zircaloy tube.

We have also used this detector system to obtain images from a small neutron radiography assembly designed especially for the 14 MeV neutron generator located at Purnima Lab, BARC[5]. The aim of this work is to develop tools and techniques which can be extrapolated for designing imaging system for a mobile neutron radiography system using transportable 14 MeV generators (sealed tubes) or other small accelerator based neutron generators. Such mobile systems are being extensively used abroad particularly for military applications such as the detection of corrosion in the structure of military aircraft.

Position sensitive detection of neutrons

Position sensitive detection of neutrons finds applications in many areas of physics such as in neutron diffraction studies, fusion plasma diagnostic, neutron beam profile monitoring, radiography etc. Though there are few offline position sensitive detection methods such as track etch detectors, photographic method etc. these are quite slow and in many cases difficult to interpret quantitatively. Similarly there are a few methods of online position sensitive neutron detection such as multiwire proportional counters, CCD based detectors etc. Multiwire proportional counters though have an excellent time resolution, their spatial resolution is limited. In this context CCD based detection method offers a relatively cheaper, easy to assemble, position sensitive online neutron detection technique with a moderate time resolution but with a high spatial resolution. We have assembled a position sensitive neutron detector using a neutron scintillator coupled to an image intensifier/CCD and frame grabber. The digitized neutron scintillation images are displayed online on a video monitor and can be recorded on PC or a VTR for further analysis. We have used various kinds of scintillators for this purpose ranging from plastic scintillator for fast neutron detection to ^{6}LiF+ZnS (NE-426) based detector for thermal neutrons. One or two image intensifiers are used depending upon the neutron detection efficiency required and the type of scintillator used. We have been able to detect individual scintillation images of neutrons from neutron sources of low strength such ≈10^3 n/sec (^{252}Cf neutron source) on real time basis. Fig.16 shows images of individual thermal neutron scintillations on a 25mm detector area from a thermalized Pu-Be source[6]. In case the neutron detection efficiency is required to be increased, a large size neutron scintillator can be lens coupled to intensifier input face. The CCD/intensifier based thermal neutron detector using ^{6}LiF+ZnS is relatively insensitive to gamma and x-ray radiation and can be used in places of high gamma or x-ray background.

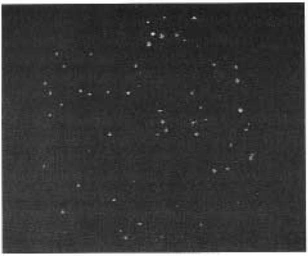


Fig.16 Neutron scintillation images

One of the potential applications of this detector is in the field of pulsed neutron monitoring. In this application a burst of the neutron pulse bunched within a few nano seconds which are otherwise difficult to separate electronically, are detected by using their spatial separation. Feasibility of the CCD detector for such pulsed neutron detection has recently been tested. Further work in this area is continuing.

Concluding Remarks

In this article, we have presented some of the work being carried out at BARC in the field of digital imaging of neutrons and their applications. The techniques developed for neutrons can also be used for imaging other types of radiations such as x-ray and gamma ray. We have indeed used these techniques for applications such as CCD based gamma tomography[7], x-ray diffraction imaging[8-9] and medical imaging. The techniques developed here is being applied to several new areas such as emission tomography which can help in providing three dimensional map of radiation emitting source such as fusion plasma, coded aperture imaging technique which can map neutron emission from laser fusion targets or imaging related to shocked targets.

ACKNOWLEDGEMENTS

The author would like to thank Dr. S. K. Sikka for encouragement and suggestions given during the course of this work. The contributions of several of my colleagues in various aspects of this work is acknowledged in particular to Drs. B.D. Bhawe, A. M. Shaikh, P.K.Vijyan, Shri C.G. Panchal, L.V. Kulkarni, Drs. A. Shyam, S. B. Degweker, T.K. Basu, R.P. Anand and V.M. Joshi. The author also acknowledges the suggestions given by Dr S.K. Kataria for pulsed neutron detection. The author wishes to thank Shri S.C. Ojha and his staff at NPD workshop for fabricating most of the precision components required in this work.

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37TH TRAINING COURSE ON RADIOIMMUNOASSAY AND ITS CLINICAL APPLICATIONS

The 37th course on "Radioimmunoassay (RIA) and its Clinical Applications" was conducted by the Isotope Division at the Institute of Medical Technology (IMT), Surat from 8th to 27th February 1999. Dr. (Mrs.) A.M. Samuel, Director Bio-Medical Group, inaugurated the course. Dr. Girish Kazi, Chairman, Sarvajanik Education Society, Surat, presided over the inaugural function. Dr P.K. Desai, Director, Institute of Medical Technology welcomed the participants of the course on behalf of Bhabha Atomic Research Centre and the Institute of Medical Technology. Dr. Meera Venkatesh, Course Co-ordinator gave an overview about the genesis of the RIA training course and its metamorphosis into the present form. She also mentioned that it was for the first time the course is conducted exclusively for medical doctors. Of the twenty-four participants, eighteen had post graduate degree in one of the specialities such as pathology, endocrinology or microbiology. Dr. S.M. Rao, Head, Isotope Division remarked on the importance of the RIA course and the keen interest shown by the medical fraternity towards the establishment of RIA practice in their laboratories. Dr (Mrs.) A.M. Samuel in her inaugural address gave a glimpse of the history of the RIA technique and the great advances in medical research and diagnosis that were made possible thanks to the RIA. She also touched upon the simplifications that has come in the RIA technique over the years, which has made RIA one of the most widely used medical radioisotope technique in the world. Dr. Samuel also mentioned about the future techniques such as the multianalyte microspot immunoassays, which will have the capability of analysing multiple analytes in a single automated assay. Dr Kazi in his presidential address spoke about the need for conscientious medical practice that the doctors have to perpetuate in order to give quality service to the patients. He also emphasised the need for judicious application of RIA training by the participants so that needy patients will derive maximum benefit from this sophisticated tool.

The course included lectures on radioimmunoassay, immunoradiometric assay (IRMA), radioactivity, radiation detection and radiation safety. The participants also carried out several practicals on RIA and IRMA. At the end of the course both theory and practical examinations were conducted. Prof. S.D. Bhandarkar, Former Head, Department of Endocrinology and Diabetes, G.S. Medical College and K.E.M. Hospital presided over the valedictory function. Dr. N. Ramamoorthy, General Manager, BRIT spoke on the efforts taken by BRIT in making the RIA and IRMA kits available in India at a very competitive price. Dr. M.R.A. Pillai, Head, Radio-pharmaceuticals Section, Isotope Division congratulated all the participants for successfully completing the training course which will enable them to get a license for starting Radioimmunoassay laboratory in an approved premise.

Dr. (Mrs.) A.M. Samuel, Director, Bio-Medical Group addresses the trainees of the 37th RIA course. Dr. P.K. Desai, Director, Institute of Medical Technology and Dr. Girish Kazi, Chairman, Sarvajanik Education Society, Surat are also seen.

The Isotope Division conducts the training course on "Radioimmunoassay and its Clinical Applications" twice a year for the benefit of the medical and paramedical professionals. In the past 19 years, around 850 candidates have been trained in this course and almost all the 500 RIA laboratories in India are managed by BARC trained RIA professionals. Over the past 19 years, nearly 30 fellows from different developing countries of Asia and Africa region sponsored by the IAEA also underwent this training course.

TECHNOLOGY TRANSFER FROM BARC

BARC has transferred the technologies on Foldable Solar Dryer and Triode Sputter Ion Pumps to M/s Chinar Enterprises, Pune and M/s Technovac Corporation, Pune respectively. The Technology Transfer Agreements were signed on 12th February, 1999 in the office of Director, Technical Coordination and International Relations Group.

Foldable Solar Dryer : This technology was developed by Food Technology Division (FTD) and was patented in October 1994. The solar dryers are useful for accelerated sun drying of grapes, jack fruits pulp, ginger, green pepper, herbal medicines, etc. These dryers are with input capacities of 25, 50, 75 and 100 kg.

The technology transfer ceremony was attended by Mr A. K. Anand, Director, TC&IRG; Dr Paul Thomas, Head, FTD; Mr K.K.V. Nair, FTD; Mr A.K.Kohli, TT & CD and Mr S. Nawathe, TT & CD from BARC and Mr Sudhir Raje, Proprietor and Mr P.K. Shilotri from M/s Chinar Enterprises. M/s Chinar Enterprises have paid Rs 5000/- as Technology Transfer Fee.

Triode Sputter Ion Pumps : This technology was developed by Technical Physics & Prototype Engineering Division (TP & PED). These pumps are used to create Ultra High Vacuum (UHV) in charged particle accelerators, surface analytical spectrometers, mass spectrometers, etc. This technology is for manufacture of 35, 70, 140 and 270 LPS capacity pumps. These pumps provide very clean operation and have no moving parts or pumping fluids. The operating pressure range is 10^{-3} to 10^{-10} torr.

The Technology Transfer Agreement signing ceremony was attended by Mr A.K. Anand, Director TC&IRG; Dr V.C. Sahni, Head, TP&PED; Mr S.R. Halbe, Mr A.N. Garud, and Mr Korgaonkar, TP&PED; Mr A.K. Kohli, and Mr S. Nawathe, TT&CD; BARC and Mr M.J. Bhide, Proprietor and Dr A.S. Bhave from M/s Technovac Corporation, Pune.

M/s Technovac have paid the first instalment of Technology Transfer Fee (Rs 62,500/-) as per the terms and conditions of the agreement. The total transfer fee is Rs 250,000/-.

A Memorandum of Understanding (MoU) has been signed between BARC and M/s Nicco Corporation Ltd., Calcutta on 24th March 1999 for "Development of Indigenous technology for the manufacture of radiation cross-linked cables and heat shrinkables accessories. M/s Nicco Corporation Ltd. Is an established manufacturer of variety of cables such as PIJFT, XLPE, PVC & other cables and has a number of manufacturing facilities in India.

The MoU has been signed with the objective of achieving self sufficiency in materials of vital importance to the industry.

In Electro-Beam Processing of wires & cables, E-beam radiation brings polymer modification in the form of cross-linking in suitable insulation or sheath materials. This results in improved properties for example, increased tensile strength, increased form stability at higher temperatures, improved deformation resistance, reduced swelling behaviour, increased abrasion resistance etc. Further, EB processing has a number of advantages over conventional chemical cross linking technology such as very high throughputs, no use of chemicals so environment friendly, simple, reliable and better quality product with minimum or no start up scrap and there will be absolutely no radioactive residues.

BARC will provide technical consultancy in the area of EB curable formulations. EB process and product dosimetry, shielding, underbeam equipment, layout for installation and other related areas. Indigenous developments of this technology will be vital for several sectors of Indian Industry.

The technology for the manufacture of TLD Badge Reader (TLD BR) has been transferred on non-exclusive basis to M/s Kaustubh Industrial Pvt. Ltd., Mumbai on 12th March, 1999. The technology of TLD Badge Reader has been developed by RS&ID of BARC. TLD Badge Reader is exclusively designed to measure the radiation dose absorbed on BARC make TLD Badge which is used for routine personnel monitoring of radiation workers. The reader basically provides controlled heat to TLD disc, senses the instantaneous light coming out of TLD (glow curve signal) and displays the total integrated light output in terms of R (Rontgen) on a panel meter. TLD-BR covers vide disimetric range from 10 m Rem to 1000 Rem. It features auto readout cycle and safe inter-locking operations.

An agreement has been signed on March 12th, 1999 between Bhabha Atomic Research Centre and Orion Electronics, Mumbai to Transfer Technology for "Mini/Micro Stepping Control Drive and Associated Algorithms and Software."

This technology is useful in any servo control or electronic gearing application. The objective of this technique is to position rotor of the stepper motor at demanded micro steps for a normal stepper motor, which is not ideally suitable for Mini/Micro Stepping. An algorithm makes to move stepper motor upto 1/50 of its full step without any rotor positional errors achieving the resolution upto 0.036 degrees in position control. Technology Transfer covered circuit diagrams, software and detailed algorithms, which can be incorporated in OEM Products.

This technology has been developed by Reactor Control Division of BARC and used successfully in different servo control and electronic gearing applications with normal stepper motors.

TT&CD guided preparation of technology transfer documents and co-ordinated complete Technology Transfer procedure.

BARC SCIENTIST HONOURED

Dr V.K. Madan of Electronics Division has been appointed as an Adjunct Professor by Birla Institute of Technology and Science, Pilani. He is a recognised guide for M.S. and Ph.D. degrees from BITS.

Edited and Published by Dr M. R. Balakrishnan, Head, Library & Information Services Division, Bhabha Atomic Research Centre, Mumbai 400 085. Editorial Assistance : Mr V. L. Kalyane and Mr P. A. S. Warriyar

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