Reactor Water Chemistry Research

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Preamble:

Indian nuclear power program is mainly centred on Pressurised Heavy Water Reactors (PHWRs). We have come a long way since the inception of nuclear power programme seven decades ago. The indigenous Indian PHWRs mainly fall into three categories viz., 220, 540 and 700 MWe PHWRs that make extensive use of water as a coolant in different circuits and at different purity levels. The degradation of materials due to corrosion, transport of radioactivity from core to out of core surfaces, efficiency of steam generators, performance of condenser circuits and overall availability of the nuclear reactors for power production depends on the strict adherence to water chemistry prescribed based on the laboratory studies and operational expertise gained. R&D studies related to water chemistry are in practice as early as the inception of nuclear power programme and at present Water and Steam Chemistry Division (WSCD), Chemistry Group, BARC, is the frontier in this field. WSCD is also undertaking R&D studies related to nuclear reprocessing facilities besides its major contribution to biofouling control, thermal ecology and development of biotechnologies for societal applications in the field of health and wastewater treatment. This article summarises in nut-shell, the various R&D activities carried out by WSCD.

Introduction:

In 1969, the then Head of the Chemistry Division, late Dr. Jagdeesh Shankar in consultation with late Shri. V. N. Meckoni and Shri. S. K. Mehta of Reactor Engineering Division (RED) decided to constitute a small working group on Power Reactor Water Chemistry with late Dr. K. S. Venkateshwarlu and Dr. P. K. Mathur as its core members. This core group in collaboration with RED carried out initial R&D in water chemistry. As the amount of R&D work increased many fold in due course, the water chemistry working group evolved into Water Chemistry Section and then to Water Chemistry Division in 1983, which was later named as Applied Chemistry Division (ApCD) in 1989.

A dedicated laboratory to carryout long term tests under the simulated conditions of reactor water systems was felt essential and hence Water and Steam Chemistry Laboratory (WSCL) under ApCD was planned and constructed at IGCAR campus, Kalpakkam, in 1987. Based on the useful and fruitful R&D under taken by WSCL, the status of the laboratory was raised to Water and Steam Chemistry Division (WSCD) in 2005.

In parallel, a DAE committee called Power Reactor Water Chemistry Group (PREWAC) was constituted, which discussed the issues related to water chemistry in power plants and was offering suitable suggestions to alleviate the issues. In 1978, PREWAC was metamorphosed to DAE Advisory Committee on Steam and Water Chemistry (COSWAC) with sufficiently increased scope of work programme with late Dr. M. D. Karkhanawala as its chairman. COSWAC activities are being carried out under the ambit of WSCD. COSWAC continues to exist till date and provides crucial solutions to reactor water chemistry related problems faced by Indian nuclear power plants.

R&D in water chemistry:

WSCD is a multi-disciplinary Division where R&D in chemistry and biology is undertaken with the support of fully fledged engineering group. Some of the major R&D activities are given as follows:

R&D related to primary heat transport (PHT) system:

The problem of radiation field in and around primary/reactor coolant system is unique to nuclear power plants unlike thermal/hydel power plants. Radiation field arises due to deposition of neutron activated corrosion products and fission isotopes released from the fuel. ^{60}Co, ^{58}Co, ^{51}Cr, ^{59}Fe, ^{54}Mn,^{122}Sb,^{124}Sb and ^{125}Sb are some of the important radioactive isotopes. In earlier days,^{60}Co with its 1.17 & 1.33 MeV γ-photons, was contributing maximum to the radiation field and thereby resulting in radiation exposure hazard to operating and maintenance personnel. After replacing some of the cobalt containing alloys in the reactor system, there was not much problem with ^{60}Co. In the present scenario, most of the activity build up in the power plants is due to antimony isotopes. WSCD has been working on the problem of activity release, activity transport and methods to alleviate activity build-up.

Modeling the radioactivity transport in nuclear power plants:

Studies have been carried out to mathematically model the activity transport phenomenon that involves sub-modeling the material corrosion, corrosion product dissolution, crud release, neutron activation of corrosion products and deposition of dissolved products and particles. The aim of this work is to make a computer program that would predict the build-up of radiation field as a function of time given the material composition and the reactor operating parameters.

Chemical decontamination:

Chemical decontamination is a process in which the metal oxide contaminated with radioactive nuclides, is dissolved by chemical formulations and the dissolved metal ions are removed over ion exchange resins. These resin columns are then sent to waste processing units for further management.

Dilute chemical decontamination process:

WSCD took the responsibility of developing indigenous decontamination process, known as Dilute Chemical Decontamination (DCD), which was originally evolved by Canadians. Since the details of the DCD process were not available, extensive experimental works were carried out with inactive and active specimens to understand the process, required modifications were made and applied to 7 reactors comprising of 11 campaigns. The first decontamination was carried out in 1993, in MAPS#1 with EDTA (Ethylene diamine tetraacetic acid) based formulation known as EAC formulation (EDTA, Ascorbic acid and Citric acid). Around 350 kg of iron oxide and 346 Curies of ^{60}Co were removed from the PHT system, with an average decontamination factor (DF) of 10. Subsequently, two decontaminations with same formulation were carried out in MAPS#2 and RAPS#2. The process though gave expected results (DFs) in MAPS#2 as obtained in MAPS#1, in RAPS#2 DFs were not satisfactory. Therefore, R&D activities were continued to improve the process of DCD and the EAC formulation was replaced with NAC formulation. The NAC formulation is a mixture of Nitrilo triacetic acid (NTA), ascorbic acid and citric acid. NTA had several advantages over EDTA with respect to DCD such as:

- Low pick-up over cation resin column
- Effective removal of dissolved metal ions over cation resin column and
- Less decomposition in the radiation field

Table:1 Summary of the 11 decontamination campaigns

#	Year	Plant	Formulation	Fe removed kg	^{60}Co removed Ci	Sb removed Ci	Other activities Ci
1	1993	MAPS#1	EAC	233	346	--	--
2	1995	MAPS#2	EAC	203	121	--	--
3	1996	RAPS#2	EAC	318	--	--	--
4	1997	MAPS#1	EAC	163	154.8	--	56
5	1999	MAPS#2	EAC	254	50	--	42
6	2002	MAPS#2	NAC	222	12.9	--	25.6
7	2002	RAPS#1	NAC	232	40.3	--	10.5
8	2003	MAPS#1	NAC	305	30.1	--	16.4
9	2005	NAPS#1	NAC	262	8.3	--	37.7
10	2007	NAPS#2	NC + NAC	NA	20	--	--
11	2008	KAPS#1	NC + NAC	NA	20	5.2	8.83

During the decontamination of NAPS#1 in 2005, it was observed that there was problem with the release of antimony activity, which was not observed in earlier campaigns and got re-deposited over out-of core surfaces especially on carbon steel surfaces. This led to the increase in the dose rates at many places after decontamination. However, since the half-life of ^{124}Sb is 60.2 days, after lapse of 6 months, the dose rates decreased and the benefit of

DCD was realised. Owing to the antimony problem, WSCD under took R&D to develop decontamination process suitable for antimony contaminated surfaces.

Decontamination process for antimony contaminated surfaces:

Efforts were made to understand the phenomenon of antimony re-deposition on carbon steel surfaces. A corrosion inhibitor, Rodine 92B, was found to inhibit deposition of antimony on carbon steel surface and accordingly, the process of dilute chemical decontamination was modified by introducing an antimony removal step before the decontamination. This modified process was implemented in NAPS#2 and KAPS#1 with moderate success.

Peroxide based process:

Dissolution of antimony activity requires oxidative conditions and hence a two-step process; an oxidation step with peroxide followed by reducing step, which is nothing but the normal DCD step, was evaluated. Laboratory experiments at WSCD were carried out and a methodology was evolved. The system needs to be exposed to 50 mg/l peroxide formulation at pH 10.2 (pH during normal operation) and 60 °C. The released antimony will be picked up over a mixed bed containing predominantly anion exchange resin. Once all the antimony is picked up, the system temperature is proposed to be increased to 85 °C to carry out the normal DCD with NAC formulation. This process is recommended to carry out trial decontamination on antimony contaminated carbon steel specimen.

Decontamination of stainless steel surfaces:

The DCD process is effective for carbon steel surfaces with magnetite film. For stainless steel systems like in the case of BWR, where the oxide film is mixed ferrite containing chromium, the DCD process is not suitable. R&D was therefore necessary to:

- Couple classical permanganate process with ozone
- Ozone based decontamination process
- High temperature decontamination

Decontamination process for TAPS#1&2:

TAPS#1&2 are Boiling Water Reactors (BWR) and the material of construction is stainless steel. Presently, both the reactors are under shutdown owing to failure of main recirculation pipes. Decontamination process prior to major maintenance work was required and hence classical Acid Permanganate process followed by DCD by NAC formulation was recommended after experiments at WSCD and at plant site.

Coupling of permanganate process with ozone:

The process based on permanganate is cumbersome and involves multi-steps with generation of large active waste. Hence, studies were undertaken to reduce the waste by coupling the permanganate process with ozone. It was observed that ozone can oxidise Mn^{2+}/Mn^{4+} formed during the process of dissolution back to permanganate. Thus, the amount of permanganate is reduced. It was calculated that the permanganate requirement can be reduced to one fifth and the temperature of application is reduced to 50 °C.

Ozone decontamination:

Ozone is one of the good oxidizing agents and hence its use as a decontaminant was studied. Preliminary studies were carried out with a mixture of ozone and nitric acid for the decontamination of stainless steel surfaces. Powder dissolution experiments were also carried out to know the dissolution behaviour of chromites and chromium containing ferrites. The process was demonstrated in cleaning a stainless steel tube exposed in an autoclave for several months.

High temperature decontamination:

Studies were also carried out by altering the decontamination process parameters like temperature in developing efficient process for stainless steel decontamination. The formulation was a mixture of NTA and hydrazine and the temperature of application is 160 °C. The process was demonstrated in chemical cleaning of the High Temperature High Pressure (HTHP) Loop at WSCD, which was contaminated with magnesium release from a failed heater pin.

Special substrates for the selective removal of radioactive nuclides:

Success of decontamination depends on the efficient removal of dissolved radioactive nuclides. The main challenge is that the chemical concentration of these radioactive nuclides is low when compared to other non-active metal ions, such as ferrous ions. Hence, enhanced selectivity towards the targeted radioactive ions would play a major role in significant reduction in the generation of active waste. Similar challenges are present in the nuclear fuel reprocessing plants as well, wherein active nuclides are to be removed from harsh solution matrices. Some of the major active nuclides that are dealt with are Co, Sb, Cs, Sr and iodine.

WSCD has carried out R&D in developing special substrates through various methodologies such as molecular imprinting, synthesis of organic, inorganic, and composite sorbents, modification/functionalization of biosorbents, etc., for effective removal of radioactive nuclides from various solution matrices.

The first ever cobalt imprinted polymer was synthesised by WSCD in 2006, which showed exclusive selectivity for cobaltous ions (present in ppb to ppt levels) in presence of excess ferrous ions (over 200 ppm).The novelty and importance of this work featured in prominent national and international media. The cobalt specificity against ferrous ions was achieved through molecular imprinting technique, which involved design of polymers with predefined binding site geometry. The stability advantage in binding cobaltous ions over ferrous in the imprinted binding sites were also proven through theoretical studies.

This '*selectivity by design*' concept was further extended towards development of multitude of sorbent materials, some of which are summarised as follows:

- Methodologies were developed to reverse the selectivity of chitosan, a biosorbent. This was achieved through two different approaches – molecular imprinting and rational functionalisation.
- Using ionic liquids as functional monomers, cross linked co-polymers of ionic liquids were synthesised as sorbents for the first time and shown to be excellent for removal of antimony, iodine and chromium. The iodine immobilisation, in particular, was shown to be excellent in terms of very high capacity and immobilisation.
- Methodology for the synthesis of sorbents in the form of robust composite beads has been evolved. This has helped in taking lab scale investigations to possible plant level applications.
- Chitosan based composite beads of nano-titania were prepared and shown to be effective in the removal of antimony from various solution matrices, in particular from highly acidic (4M HNO_3) High Level Waste (HLW) generated in the reprocessing plants. This was shown using actual active effluents and under flow conditions as would be required in plant level applications.
- Chabazite, zeolite with binding affinity towards Cs and Sr, were synthesised from industrial flyash (combustion product generated in the thermal power plants). Chabazite was also synthesised in the form of beads suitable for column application.
- A better methodology for the synthesis of Cs removal agent NaETS-4 (Sodium Engelhard Titano-Silicate-4) was brought out.

The expertise developed in the design and synthesis of materials with selective binding sites was exploited further in devising solutions for other applications which are not directly related to the nuclear power plant operations. For example, WSCD played key role in devising a robust sorbent, and methodology, for selective removal and extraction of gallium from alumina liquor generated in aluminium industry. The challenge in this work was the very low levels of gallium being present with large excess of aluminium and sodium in a highly alkaline matrix. This work, done in collaboration with other divisions in BARC, has led to MoU between BARC and NALCO, and is in the process of implementation.

Studies related to nodular corrosion in KAPS zircaloy tube:

WSCD played a vital role in understanding the chemistry and corrosion aspects of Zr-2.5 Nb alloy coolant channel outer surface, post the failure of pressure tube at KAPS#1 in 2016. It was reported that impurities like ethylene along with other organics were present in the carbon dioxide gas used for purging the annulus space. Corrosion studies on Zr-2.5 Nb alloy were carried out under simulated conditions prevalent in Annulus Gas System (AGS) to explore the possibility of nodule formation. CO_2-O_2 mixture, with added nitric acid, ethylene and moisture at 300 °C, was used as test gas in presence and absence of gamma radiation.

An experimental facility, for carrying out corrosion studies in the gamma cell, designed and fabricated in-house was used for the experiments. In the absence of gamma radiation, no nodule formation on Zr-2.5Nb alloy was observed in the presence of nitric acid. Further, radiolysis modelling under the conditions prevalent in the AGS ruled out the existence of HNO_3. The presence of ethylene and moisture also did not cause any changes in the corrosion behavior. The corrosion of the Zr-2.5Nb alloy under the above mentioned conditions manifested only uniform oxidation. However, in the presence of gamma radiation, the CO_2-O_2 mixture with ethylene, was found to initiate an enhanced corrosion in certain regions of the Zr-2.5Nb alloy specimen leading to nodules and cracks on the nodules. Focused Ion Beam (FIB) cross section on nodule showed oxide thickness of ~ 3.5 micron whereas uniformly corroded area showed oxide thickness of only ~ 0.8 micron. From the experimental studies, it was concluded that the presence of ethylene in the AGS could be one of the causes for nodular corrosion of pressure tube.

Flow accelerated corrosion (FAC) in PHWR:

Experimental work on FAC was carried out in High Temperature High Pressure (HTHP) loop and SIM Loop at WSCD under simulated conditions of reactor. It was believed that in a bend pipe, the extrados of the bend undergoes FAC. However, through experiments at WSCD, it was proved that intrados of the bend undergoes more corrosion than extrados due to FAC. Thin Layer Activation (TLA) technique was devised to measure rate of FAC. This on-line technique that involve converting ^{57}Fe into ^{57}Co using TIFR Pelletron accelerator and installing the proton irradiated pipe/specimen in HTHP or SIM loop helped to bring down the time required to make measurements on FAC.

Modeling of flow accelerated corrosion (FAC) was carried out using Computational Fluid Dynamics (CFD).Hydrodynamic conditions prevailing in the bend pipes of carbon steel feeders were modeled and flow conditions were mapped (2008). Parameters such as velocity profile, shear stress etc., were obtained and rates of FAC at different locations were theoretically arrived, which compared well with the experimental data.

A computer modeling of the entire primary and secondary coolant systems of PHWR would go a long way in assuring the power plant operators that they have a prior knowledge of wall thinning taking place and plan at right time for the replacement of pipes.

Studies related to secondary system:

Evaluation of process for chemical cleaning of steam generators:

During normal operation of the reactor, however stringent may be the water chemistry, due to normal corrosion and impurity ingress through condenser tube failure, steam generators get fouled by scales and sludge accumulation. Periodical chemical cleaning of the steam generators ensures a clean steam generator. R&D in developing chemical cleaning formulation was undertaken by WSCD. Sludge collected from reactors were characterized, suitable chemical formulations were evaluated for their dissolution. A two-step process consisting of a copper-step, to dissolve metallic copper and oxides of copper and an iron-step to dissolve oxides of iron, nickel were developed and demonstrated on a failed Hair-pin heat exchanger of MAPS in 2000. Following is the composition of chemical formulations:

Copper step: 5% EDTA and 2% hydrogen peroxide, pH adjusted to 9.5 and temperature of application below 20 °C.

Iron step: 10% EDTA, 1% Hydrazine and ammonia, pH adjusted to 6 and temperature of application ≥ 90 °C.

Studies with dispersants:

High temperature dispersants such as poly acrylic acid (PAA) and poly acrylic-co-maleic acid (PAMA) were investigated for their use for on-power cleaning of steam generator. It was proved that in presence of PAA etc., the deposit on the steam generator tube material did not contain iron that was normally transported from steam generator shell and feed water. It was thus established that addition of PAA at ppb level would drastically reduce iron deposition in the steam generator tubes and tube sheets.

Film forming amines(FFA) for corrosion control:

The film forming amines (FFAs) are being explored worldwide to control the corrosion of secondary system of nuclear reactors, both during layup as well as during normal operation. It has been shown to complement the existing water chemistry treatment for protection of surfaces against general corrosion and other kinds of corrosion including FAC. They act by forming a hydrophobic layer on the metal surface. The efficiency of film formation depends on several factors such as type of material, metal surface area, temperature, pH of the medium, time duration, and the excess of the FFA in the water phase.

In this regard, investigations are being done to evaluate one such FFA, viz., octadecylamine (ODA) for corrosion inhibition of structural materials in PHWR. ODA is yet to be envisaged in Indian scenario. The ultimate goal of this study is to develop a process/technology that not only minimizes the corrosion product transport into the steam generators but also help in preserving the structural materials in case of long term outage. Before applying to the real facilities, efforts are being made to thoroughly understand the benefits of ODA through various laboratory experiments and loop studies.

Studies related to tertiary cooling system:

Huge amounts of natural waters are continuously drawn by the nuclear power plants for cooling condensers and removing waste heat. The natural water contains micro-organisms (bacteria, fungi and algae) and larvae of macro-organisms. The organisms present in water attach and grow on the material surfaces in the cooling water system (CWS). The unwanted growth of these micro and macroorganisms in CWS is termed as biofilm and biofouling, respectively. Biofilm refers to attachment and growth of micro-organisms along with production of sticky biopolymers on structural materials and biofouling refers to growth of biofilms, attachment of larvae of higher organisms and growth of macrofouling organisms in the CWS. Biofilms and biofouling is associated with many operational issues such as reduction in heat transfer efficiency, microbiologically induced corrosion, reduction in water flow etc. Biofouling by macrofouling organisms such as barnacles and mussels is a severe problem in seawater cooled power stations. A combination of oxidizing and non-oxidizing biocides along with mechanical/physical cleaning methods is regularly employed for biofouling control. WSCD has a dedicated research team for carrying out R&D on:

- Assessment and biofouling control in power plants and allied units
- Evaluation of biocides (chlorine, chlorine dioxide, active bromide etc.) and formulations for biofouling control
- Development of novel antibiofilm and biofouling control methods.

Some of the macrofouling organisms (barnacles) are reared in the laboratory to obtain settling stage larvae for evaluating biocides, synthetic/natural compounds and coatings. The societal outcome of this research include development of nitric oxide based wound dressing and chlorine dioxide based disinfection for applications in antimicrobial therapy and water disinfection, respectively. Although biofilms are unwanted in cooling water systems, there are several beneficial applications for bacterial and algal-bacterial biofilms in bioremediation, water and wastewater treatment. The knowledge accrued as part of the biofilm research has helped in developing a bio-granule based technology (Hybrid Granular Sequencing Batch Reactor) for sustainable wastewater treatment.

Work related to the moderator system of PHWR:

Decontamination of hot spots in moderator system due to stellite particles:

Hotspots, regions of high radiation field, were observed in various components of moderator system of NAPS. Similar observations were made in KAPS. This was attributed to the stellite particles released from the adjustor rod drive mechanism. Stellite, a hard-facing material, is an alloy of cobalt and hence neutron activation of stellite particles and its accumulation in various components of moderator system leads to high radiation field. No chemical formulation was available to decontaminate the components having `Hotspots'.

Efforts were made to devise a chemical formulation to dissolve the hotspot causing stellite particles. Systematic work carried out in the laboratory helped to understand the factors favoring and interfering in the dissolution of stellite particles. It was observed that hydroxides and nitrate were interfering in the dissolution of chromium from stellite particles. Hence, permanganic acid ($HMnO_4$) was chosen. Detailed studies with permanganic acid indicated that permanganic acid passivates the stellite metal thereby inhibiting the dissolution. The efficiency of dissolution vs concentration curve showed a maximum in the range 150 – 300 ppm. Thus, it was established that permanganic acid in a narrow concentration range of 150 – 300 ppm was found to effectively dissolve chromium from the stellite particles that caused the 'Hotspots'. The other metals such as cobalt and nickel were dissolved later by the EAC formulation.

The permanganic acid ($HMnO_4$) – EAC combination was applied to several adjustor rod drive mechanisms, in KAPS#1&2 (2005) and NAPS#1&2 (2006) that were removed during shut down and was found to effectively remove the 'Hotspots'.

Removal of gadolinium from the moderator system:

Gadolinium as gadolinium nitrate is used as neutron poison in the moderator system for regulating and controlling the power generation of 540MWe and 700MWe owing to its high neutron absorption cross section. Removal of the added gadolinium nitrate (Gd^{3+} and NO_3^-) from the system after its intended use is done using ion exchange resins.

Studies were carried out in the laboratory with table-top 20L glass loop set-up to optimize the ion exchange process for generation of low radioactive waste and maximize utilization of the ion exchange resins by employing different types of resins and different modes of operation. The investigations revealed use of mixed bed resin column consisting of Strong Acid Cation (SAC) resin and Strong Base Anion (SBA) resin followed by SAC resin column is efficient in removing the Gd^{3+} and NO_3^- from the system besides maintaining the pH of the moderator system in the desirable regime, where gadolinium does not get precipitated as its hydroxide. The experiment was scaled-up to 200L.

Thermal ecology studies:

Nuclear power plants draw large amount of natural water (about 3 m^3 per min per megawatt of electricity (MWe)) for removing waste heat during steam condensation. Coastal areas are considered for power plants to make use of the abundant seawater for condenser cooling using once through cooling water system (CWS). The planktonic organisms (bacteria, algae, fungi, and larvae) present in the coastal waters are drawn into the CWS and exposed to biocides and temperature. The large number of organisms present in the receiving water body (coastal waters) may also experience chemical and thermal stress even if they are not drawn into the CWS. Temperature being an important environmental parameter for survival, growth and reproduction in aquatic organisms, it is important to study the impact of heated effluent from power plants on the ecology in receiving waters. The water discharged after cooling the condenser has a higher temperature (about 7°C) as compared to the water drawn from the sea. The dissipation of heat during its travel to the mixing zone and further drop in the temperature as a function of distance from the shore were measured and the temperature profiles obtained by making measurements in the sea using boats and ship. A coordinated research program (CRP) involving several universities concluded that the effect of heated effluents on the marine organisms is not significant.

Thus, more than four decades of work in the field of reactor water chemistry has helped our department in taking forward the nuclear power program in our country.

Work related to Advanced Heavy Water Reactor (AHWR):

As part of chemistry task force of AHWR, several investigations were carried out. The following is the list of work undertaken:

- ^{16}N transport in the Main Heat Transport system
- Radiolysis of moderator water in presence of gadolinium
- Comparative evaluation of natural B, enriched B and gadolinium as neutron poison
- Hydrazine as alternative to hydrogen as additive in Main Heat Transport (MHT) coolant
- Possibility of applying high temperature decontamination in MHT system

R&D related to reprocessing plants:

Dissolution of DBP complexes:

Nuclear fuel reprocessing facilities that use tributyl phosphate (TBP) and nitric acid tend to develop a sticky coating of metal complexes of dibutyl phosphate (U-DBP) on their surfaces. This sticky coating also gets formed on the reprocessing waste storage tanks on long standing, which results in radiation exposure hazard. It is therefore required to periodically dissolve such complexes to minimize the risk of radiation exposure to operating and maintenance personnel. In this connection studies on the dissolution of various DBP complexes such U-DBP, Zr-DBP, Ce-DBP and Fe-DBP were carried out.

Dissolution of U-DBP was attempted by two-step process; initial step is oxidation with nitric acid permanganate followed by normal DCD with NAC formulation. Investigations were also carried out with Na-EDTA with and without hydrogen peroxide and with simple Na_2CO_3. Results showed 0.5% Na_2CO_3 at 35 °C, brought of 90% dissolution of U-DBP. In the case of dissolution of Zr-DBP, mixture of oxalic acid and hydrazine was found to be very effective.

Decontamination of ceramics in Joule Melter:

Studies were carried out to decontaminate ceramic present in Joule Melters used in reprocessing plants. The ceramic materials (majorly aluminium silicate (AS) and aluminium zirconium silicate (AZS)) were collected from the different segments of the simulated melter and were characterised by XRD. The ceramic materials in the form of powders were subjected to dissolution by simple acid dissolution and alkali and phosphate fusion methods, followed by metal ions acid leaching. The fusion method for dissolution was found to be promising.

COSWAC related activities:

Committee on Steam and Water Chemistry (COSWAC) is an advisory committee constituted by Department of Atomic Energy (DAE), which advises on all aspects of steam and water chemistry and related material compatibility problems. The members of the committee are chemists, metallurgists and engineers who are experts in reactor water chemistry, cooling water management, metallurgy and plant operation. COSWAC ensures proper control of the chemistry parameters of steam and water systems of all the nuclear power plants, test reactors, research facilities and in other industrial projects setup by the constituent units of DAE.

WSCD plays a vital role in COSWAC activities. Under the direction of COSWAC, WSCD under took many R&D studies, which has helped in understanding the problems faced by the power plants. Based on the outcome of such studies, COSWAC has advised the power plants accordingly. Following are some of the recent and important tasks under taken:

- Nodular corrosion in zircoloy
- FAC of carbon steel feeders
- Development of better magnetite coating during hot conditioning
- Tailor-made two step decontamination process for TAPS#1&2
- Development of hydrogen peroxide process of antimony contaminated surfaces
- Decontamination of Hot spots in moderator system
- Gadolinium removal from the moderator system
- Chemical cleaning of Steam Generators
- Evaluation of dispersion addition to Steam Generators to control fouling
- Radiolysis calculations for moderator system of AHWR

Way forward:

Research activities at WSCD, brought out in the previous sections, have been aligned with the needs of the nuclear industry. While majority of the activities have been taken to the field application, some of the studies are in their advance stages. Further, development of effective workable solutions for current and emerging problems unique to the nuclear industry will form the major portion of the future activities of WSCD.

WSCD will undertake R&D to devise improvised water chemistry control in nuclear reactors to ensure tighter impurity levels that are on par with the international standards and cater to the challenges as we diversify into new reactors of higher power. This proactive control regime demands a mechanistic insight into the response of structural materials to the modified water chemistry using *in situ* analytical and characterization techniques. Thus, the measures/techniques employed would have to constantly evolve with the operating experience and ever growing research accrued knowledge base. The improvised water chemistry program will minimize the impact on structural materials and thus realizing design life and a highly desirable Plant Life Extension.

Nuclear facilities and decontamination are inseparable. The decontamination process to be adopted and the decontaminants are site specific. Thus, the decontamination studies demands intense R&D to evolve modified/improvised/new processes, which will be one of the main tasks of WSCD in coming decades. The experience gained by WSCD in the field of decontamination will help in developing suitable techniques for decommissioning of reactors in future. By employing suitable decontamination for decommissioning techniques, components of retired reactors can be safely disposed or re-used.

WSCD is also moving in the direction to develop receptors for active metal ions. Studies will be carried out towards devising stable sorbent materials with mixed binding sites. The objective is to have a system with less number of sorbent columns for selective removal of multitude of active elements in presence of excess non-radioactive elements from various effluent matrices. The expertise gained through designing various types of metal ion binding agents will be put to use in devising such systems. This will also be used in our attempts towards devising safe and effective methodologies for treating active coolant solutions generated under accidental conditions. Such systems will help in the mitigation activities and ensure absence/minimization of any interaction of low level radioactivity with the environment.

In the field of Biofouling research, future R&D is aimed towards characterization of marine biofilms, biofilm-larvae interactions and development of novel methods for biofouling prevention. This include investigations on biology of biofilms, larval rearing of biofouling organisms, prospective research on anti-larval compounds, impact of cooling water treatment and thermal ecology studies. The knowledge accrued on biofilm biology and biofilm control would be utilized for development and deployment of innovative biotechnologies for societal applications in health care, water and wastewater treatment. The ongoing research on microbial biofilms and biogranules is aimed at development of novel and high-impact technologies for bioremediation and wastewater treatment.

Under the ambit of COSWAC, WSCD will be actively involved in co-ordinating its activities besides bridging the gap between laboratory R&D studies and field application.