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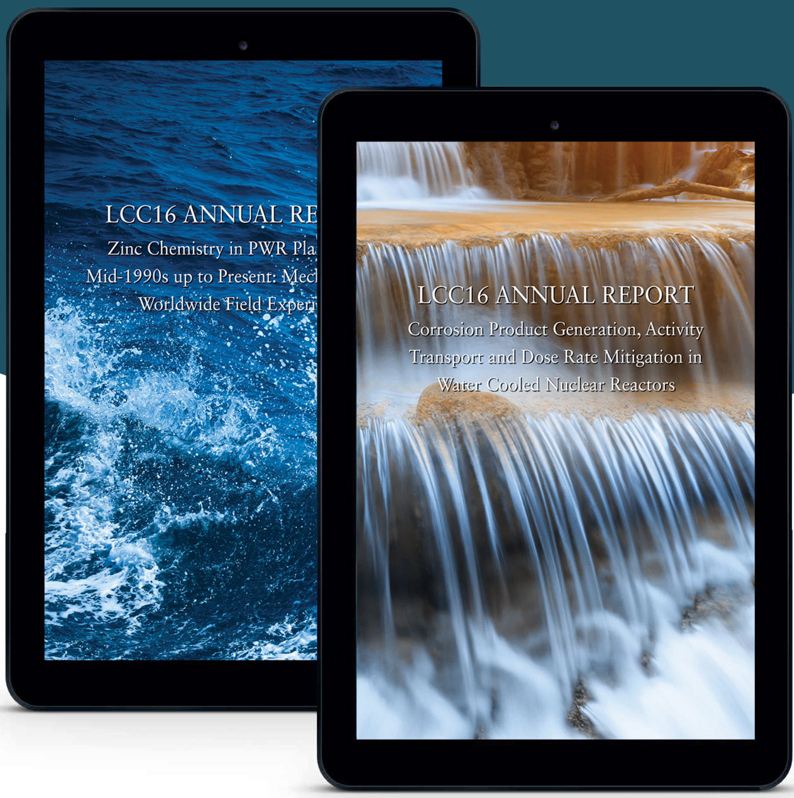
Boosting your Excellence through Knowledge and Training

LCC™

LWR Chemistry and Component Integrity Programme



The annual LCC Programme is focused on reactor coolant, secondary chemistry and material issues and open to nuclear utilities, manufacturers and vendors, research and engineering organisations as well as regulatory agencies. In the LCC15 Programme, currently 17 organisations in North America and Europe are members. The Programme was started in 2004.


A.N.T. INTERNATIONAL®

Deliverables

A.N.T. International will provide the LCC Members with the following:

- Searchable electronic report version with the following contents:
  - High-resolution pdf files with complete LCC Annual Reports in colour.
  - The files can be copied to a company server, and be available to everyone with access to the server.
  - The contents from the Annual Reports in pdf-format can be printed. Also, the contents from the pdf-files can be copied and pasted electronically into other documents, e.g. Word files.
  - All figures and tables with A.N.T International copyright can be used by the member both internally and externally provides that the source is provides in the caption.
- A Seminar will be held in Madrid, in April 2021, to present the results of the LCC Programme. The number of full-time employees per Member that may attend the seminar is limited to eight (8) people per organization.
- Before the seminar, you will have access to:
  - The complete LCC Reports in digital format (PDF).
  - The contents of all the seminar presentations in high-resolution PDF format.
- The language of the LCC Programme will be English.
- The authors will be available for consulting throughout the year. A few telephone or e-mail consultations requiring no additional work are provided at no additional cost to Members.

"The long experience of the LCC Expert Team provides useful information for 'sunny and cloudy days' of a chemist's job!"

MICHAEL BOLZ
NPP Philippsburg

"A.N.T. International provides excellent material for education, this supports the very important transfer of knowledge in times when alternation of generation becomes a problem in many nuclear power plants."

BERNT BENGTSSON
Vattenfall

Find more feedback at: www.antinternational.com/LCC

LCC Programme Content and Description

Nuclear utilities must reduce costs for operation, maintenance and fuel, keep the highest level of safety and lowest possible level of radiation exposure to employees and the public and minimize environmental impact of liquid and solid effluents and wastes.

Emphasis is put on safety, longer fuel cycles, higher burn up of fuel, increased fuel duty with more nucleate boiling in Pressurised Water Reactor (PWR's). Plant power up rates as well as more technical issues like Axial Offset Anomaly (AOA also called Crud Induced Power Shift/CIPS), Stress Corrosion Cracking (SCC) all point to the increased importance of high quality water chemistry and control and safe long term operation of the Nuclear Power Plants.

It is our goal that the LCC Programme shall assist the LCC Members in meeting all these water chemistry and material related challenges in the most efficient way. This Programme reviews and evaluates the developments and trends in the Light Water Reactor (LWR) primary coolant and secondary side chemistry and structural materials technology (excluding fuel materials). This is accomplished by identification of relevant information and a discussion of its significance for the Programme. The Programme reviews all relevant information through publications and international conferences and, when necessary, comments and background information are added.

Additional benefits for the LCC Members can be seen in that the Members gain an increased understanding of power plant water chemistry and material integrity to facilitate more efficient plant operation. Furthermore, the LCC Members can be assisted in the training and education of a new generation of chemistry and material experts in their organizations.

The overall objectives of the LCC Programme are to enable the LCC Member to:

Increase understanding of reactor water chemistry related to a successful plant operation and continued integrity of Reactor Coolant System (RCS) materials while keeping radiation exposure low

Guide the plant operators to apply adequate PWR secondary side chemistry for safe, economical and environmentally friendly plant operation with high availability and without significant steam generator degradation or fouling problems or carbon steel Flow Accelerated Corrosion.

Improve plant operation and chemistry control and monitoring

Assist in the training and education of a new generation of chemistry and materials experts.

Establish an independent meeting point for experts to enable free and critical discussions and experience exchange

These objectives are met through critical review and evaluation of the most recent data related to reactor water and secondary side chemistry, identification of the most important new information, and discussion of its significance in relation to water chemistry now and in the future.

The evaluations are based on the large amount of non-proprietary data presented at technical meetings and published in the literature with added point of view of LCC experts.

LCC16 Programme

Annual Reports will be prepared within the LCC16 Programme as follows:

- Corrosion Product Generation, Activity Transport and Dose Rate Mitigation in Water Cooled Nuclear Reactors
- Zinc update

Presentation without Reports will be prepared within the LCC16 Programme as follows:

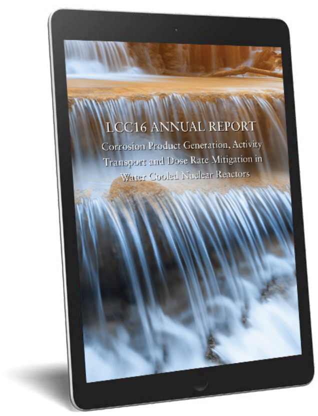
- Faulted chemistry in flow restricted areas - A potential materials killer

Presentations of LCC 15 will be made in a slightly shortened way as follows:

- Historical evolution of coolant Chemistry for PWR and VVER plants: 1960 to present; Including Basis of the Guidelines
- Report on Historical and present issues on secondary system chemical treatment and corrosion in PWR/VVER units; including materials behaviour
- The impact of water chemistry transients on Nuclear Power Plant materials and plant performance
- Fuel Crud in LWR

At the LCC16 Seminar, the Annual Reports will be presented, described more in the following.

LCC16 Reports



Corrosion Product Generation, Activity Transport and Dose Rate Mitigation in Water Cooled Nuclear Reactors

In water cooled nuclear reactors, corrosion product generation in the coolant heat transport circuit is inevitable due to structural material interaction with the high temperature reactor coolant. The corrosion product generation is a complex multistep process that involves release of ionic species from the structural material in contact with the high temperature reactor coolant, hydrolysis of cations leading to hydroxides, oxides, oxyhydroxides and other metastable species, generation of colloids and then formation of particles of different dimensions and sizes.

These initial basic physicochemical steps apply to all water-cooled nuclear reactors regardless of the reactor type BWR, PWR or VVER.

However, the nature and extent of the corrosion products generated will be different, depending on the reactor type due to the different reactor structural materials used, reactor temperature, water chemistry including pH, fluid dynamics and thermal hydraulics

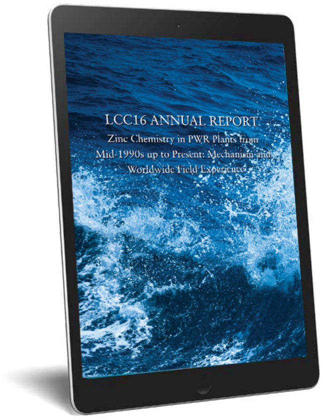
Once the corrosion products are generated, they undergo activation on fuel surfaces generating a variety of undesirable activated corrosion products, some of which have high gamma energies and long half lives creating an adverse radiological condition in the plant. Some of the key activated corrosion products include Co-60, Co-58, Mn-54, Cr-51, Fe-59, Zn-65, Ag-110m, Sb-122 and Sb-124. The main source of Co-60 is the stellite hardfacing alloys used in control rod drive systems, valve seats and jet pump wedges (BWRs). The main source of Co-58 are the nickel alloys like Alloy 600 and Alloy 690 used in steam generator tubing, upper and lower head penetrations, core support and pressurizer nozzles (PWRs), and transition attachment materials used between stainless steel and reactor pressure vessel material, shroud head bolts, access hole covers and shroud support (BWRs). The main source of antimony activation products are the bearing materials and main pump seals impregnated with antimony (PWRs and VVERs). Once the activated products are generated, they get transported throughout the heat transport circuit depositing on out of core surfaces creating undesirable dose rates and “hot spots”. The contributions coming from of each of these activation products to plant dose rates are different for different reactor types due to the usage of different structural materials and water chemistries.

The report will discuss in detail, the steps involved in, generation including colloid formation, activation on fuel, transport through the coolant, deposition including zeta potential effects, release from surfaces and removal of activated corrosion products in light water reactors. The report will also discuss activity transport that will include basic steps involved and models used. The report will largely be devoted to BWR experiences, however some examples of PWR and VVER experiences will also be included, for the benefit of non-BWR participants, since the basics and physical principles involved in dose rate generation and management are common to all reactor types. A discussion of dose rate mitigation technologies used to control radiological consequences to nuclear power plants including material replacements, water chemistry controls/modifications and decontamination approaches will also be included in the report. The report is expected to be a comprehensive summary of dose rate generation and mitigation approaches that will be of benefit to nuclear power plant personnel.

“For new engineers and chemists, this could be a very useful training tool. For experts in a given filed, knowledge of experience in other related fields facilitates improvements in their own fields. A.N.T. International plays an important role in fulfilling this need in the nuclear industry through the LCC program.”

MS. JAYASHRI N. IYER
Westinghouse Electric Company, USA

Find more feedback at: www.antinternational.com/LCC



Zinc Chemistry in PWR Plants from Mid-1990s up to Present: Mechanism and Worldwide Field Experience

In 2010/11 a report, with the title “Effect of Zinc in BWR and PWR/VVER on Activity Build-up, IGSCC and Fuel Performance” was issued for LCC6, which covered all published knowledge about zinc chemistry in BWR and PWR plants as of 2010.

Since that time, within 10 years lot of new knowledge and field experience was published especially by PWR industry, which contributed to understand much better the zinc chemistry mechanism.

In 2010/11 a report, with the title “Effect of Zinc in BWR and PWR/VVER on Activity Build-up, IGSCC and Fuel Performance” was issued for LCC6, which covered all published knowledge about zinc chemistry in BWR and PWR plants as of 2010. Since that time, within 10 years lot of new knowledge and field experience was published especially by PWR industry, which contributed to understand much better the zinc chemistry mechanism. Therefore, ANT decided to issue an updated report on zinc chemistry in PWR plants for LCC 16 program. The basis of this report is the published information including the proceedings of the recent International Conference on Water Chemistry of Nuclear Reactor Systems (NPC 2020). The personal opinions and interpretations of the author are written in *italic* letters.

Zinc addition into the reactor coolant in PWR plants is now one of the most important considerations regarding coolant chemistry. The main objectives of zinc injection are: a) the control of radiation fields and b) the mitigation of Primary Water Stress Corrosion Cracking (PWSCC), in particular at PWR plants that used Alloy 600MA as construction material (SG tubes, Reactor Pressure Vessel (RPV) penetrations, nozzles and welds). This strategy of the zinc addition into reactor coolant started in the 1990s in PWR plants. The field experience of about 30 years confirmed that Zinc chemistry is the most powerful tool for radiation field control in PWR plants.

This updated report reviews, as of 2020, the of laboratory and field results of zinc injection technology in PWR plants worldwide. The review covers the range from basic information to current knowledge and understanding of operational behaviour. This information on PWR plants given in this report is also applicable for VVER plants. So far publicly known, zinc addition is not yet applied in VVER plants. However, lots of preparatory investigations such as laboratory tests were performed. The results of these investigations might be also useful for the PWR units. Therefore, a review of the available laboratory work results applicable to VVER plants is also included in this report. Accordingly, content of this report is very useful for both PWR and VVER plants to establish their own plant specific coolant chemistry strategies. ANT is also convinced that the information given in this report will highly support the Authorities in performing their regulatory work.

LCC16 Presentations without Reports

Additional presentations will be given on the following topics.

A materials killer: faulted chemistry in flow restricted areas

There is a material killer hidden in NPPs, its name: **chemistry deviations**!

Engineers in charge of the design of NPPs' components, have to select materials according to some constrains such as: mechanical loads (tensions, compressions, vibrations, pressure…), thermal loads or effects (high temperature, temperature variations (thermal shock), thermal cycling, thermal ageing…), resistance to the environment, etc.…

After having compiled all these constrains, an appropriate material, capable of more or less withstanding all of them, is selected.

However, if one of the design parameters is not correctly assessed, the material can deteriorate in an unexpected way. One of the best examples of this, is thermal fatigue. Most of the thermal fatigue failures that have occurred in NPPs are due to the undervaluation of thermal cycling at the design stage.

The story is the same regarding the environment in contact with materials. As mentioned previously, any selected material should withstand the design environment. However, if for any reason, the environment composition deviates from what it was supposed to be, then corrosion, cracking, leak, failure… can occur. Some such examples of chemistry deviations, leading to field failures are detailed in this presentation.

LCC16 Experts

The experts are: Dr. Francis Nordmann, formerly at Électricité de France, Dr. Suat Odar formerly at AREVA, Dr. Samson Hettiarachchi, formerly at GE Hitachi, Dr Jiaxin Chen Senior Specialist at Studsvik Corrosion and Water Chemistry Laboratory, Mr . François Cattant, formerly at Électricité de France, Mr. Peter Rudling, president of A.N.T. International,

Dr. Francis Nordmann has 50 years of experience in nuclear power plant chemistry. He is retired from Électricité de France (the French Utility) in 2007, where he was an international expert in charge of chemistry and corrosion in the corporate offices. He was in charge of managing the engineering studies for the French fleet of 58 PWR units and of several international programmes. His Ph. D degree was obtained at the French Atomic Energy Commission, in connection with the University of Mulhouse in 1973.
He also worked for 8 years within the French manufacturer Framatome.

He has been active for example in the following areas:

- Water Chemistry evolution and studies for the various systems (primary coolant, secondary steam-water system, condenser cooling systems, and auxiliary systems)

- Developing the Chemistry Specifications for the French NPP and some others
- Interface with Manufacturers and Regulatory Body
- Chemistry and corrosion training
- Steam Generator blowdown and condensate polishing plant strategy
- Optimisation of secondary water chemistry for various objectives
- Steam Generator experience feedback and relation with chemistry, maintenance and safety
- Tutorial sessions and workshops for various organisms (France, IAEA, China)
- International projects with various countries and organisations: IAEA, EPRI, USA, Japan, South Africa, China, Germany, Sweden, Spain, Russia, Ukraine, Bulgaria, Hungary, etc.
- Organising committee of several International Conferences on Chemistry for Nuclear Reactors. He was Chairman of this Conference in Avignon, France.
- Experience in PWR and VVER chemistry and corrosion in many different countries

Dr. Suat Odar has 50 years of experience in power plant chemistry. He retired from AREVA NP GmbH (Former Siemens-KWU) in February 2008, where he has held since mid of eighties various service and managerial positions for power plant chemistry. In the last seven years he was responsible for the water chemistry of the nuclear power plants in his company. His degree as Ph.D. in Physical Inorganic Chemistry was obtained from the Technical University of Darmstadt, Germany, in 1970.

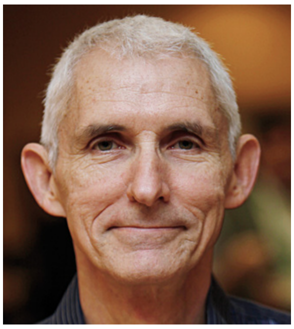
He has been active for example in the following areas:

- Water Radiolysis and Post LOCA Hydrogen Control in PWR Containment
- Commissioning of PWR plants
- Developing Chemistry Control concepts for PWRs
- Water Chemistry Guidelines
- Consulting in Power Plant Operation (Chemistry part)
- Improvement of Steam Generator Performance
- Man-Rem-Reduction
- Plant Life Extension (Chemistry measures)
- Steam Generator Chemical Cleaning
- Plant Chemistry Training Programs
- Secondary Side System Design & Material Review and modifications to improve Steam Generator Performance
- Experience in PWR and VVER chemistry and corrosion in many different countries

Dr. Samson Hettiarachchi has 40 years of experience as a college lecturer, researcher, innovator and a technologist. He has held a variety of technical positions at GE Nuclear Energy as Chief Engineer/Physical Sciences, Chief Technologist/Chemistry, Engineering Fellow and Principal Engineer prior to his retirement from GE in February 2011. Prior to joining GE, he held the position of Electrochemist/Senior Electrochemist at SRI International (formerly) Stanford Research Institute) and the position of Lecturer/Senior Lecturer in Chemistry at the University of Colombo, Sri Lanka

Two of his innovations at GE Nuclear Energy, NobleChem™ and On-Line NobleChem are widely used in the US, Japan, Spain, Mexico and Switzerland to extend the life of Boiling Water Nuclear Reactors. Dr. Hettiarachchi's research experiences include Physical Chemistry, Electrochemistry, Surface Chemistry, Catalysis, Corrosion and Mitigation of materials, Battery Technology, Sensor Technology, and In-situ Generation of Nano-particles. He has worked in the nuclear power industry related work for 30 years. His specific experiences in this industry include, Development of ECP sensors, ECP monitoring, High Temperature pH Measurements, Zeta Potential Measurements, HWC Benchmark Tests, Water Chemistry Guidelines, Dose Reduction, Fuel Corrosion, SCC Mitigation, NobleChem Applications, On-Line NobleChem Applications, Inspection Relief Criteria Development, and Plant Chemistry/Materials Education and Training. For many years he has participated in EPRI BWRVIP Mitigation Committee Meetings and several IAEA Meetings. He has over 100 publications in International Journals and International Conference Proceedings and holds 29 issued US patents. He has been a peer reviewer for the Corrosion Journal and the Journal of Nuclear Science and Engineering.

Dr. Jiaxin Chen joined Studsvik in 1997 and currently works as Senior Specialist in fuel crud and oxide characterisation in Studsvik Corrosion and Water Chemistry Laboratory.
He was adjunct professor at Department of Physics, during 2014-2016, and now at Department of Chemistry and Chemical Engineering (from 2020), Chalmers University of Technology.
His recent research interests include quantum chemistry study on coolant zinc interaction with oxides; microstructural characterization of fuel crud and solids in LWR coolant; corrosion kinetics of reactor material surfaces in LWR primary coolant; characterisation of radioactive deposit on LWR piping surfaces; stability of neutron absorber materials in reactor coolant
In the field of PWR fuel crud, he and his colleagues at Studsvik have made some significant experimental findings that are of high value for the industry.



Mr. François Cattant graduated in chemical engineering in 1974 and joined Electricity of France (EDF) in 1975 as chemist engineer at the chemical department of the corporate laboratories (Plants Operation Division). At that time, he was involved in power plants water and steam conditioning.
Up to 1995 he worked in the following technical fields as an expert in the following areas

- Failure root cause analysis of gas-cooled reactors components, including fuel
- Water & steam chemistry, chemical cleaning and NDE for fossil fired stations
- Failure root cause analysis of nuclear power plants irradiated or contaminated parts & components and reactor pressure vessel (RPV) irradiation programs monitoring
- Examination of Dampierre 1 retired steam generator, to the examination of RPV head penetrations, to the study of thermal embrittlement, to the analysis of wear.

Between 1995 and 1998 he was loan-in to the Nuclear Maintenance Application Center at EPRI Charlotte (NC, USA). He was involved in various maintenance guides such as those of pumps or diesel generators. He also acted as EPRI expert for the examination of Ringhals 3 retired steam generator.
In 1998 he moved back to France, at the R&D Materials and Mechanics of Components department where he stayed until his retirement in 2009. He served there as scientific advisor and senior engineer. His area of expertise was again chemistry, corrosion, and metallurgy, with special attention to primary water chemistry, source term reduction, primary water corrosion (Alloys 600/182/82, SSs), PWSCC mitigation and repair, fuel cleaning, innovation strategy. He also served as the EDF representative to the EPRI Materials Reliability program.
From 2004 to 2008, he was the President of the "Materials, Non Destructive Testing and Chemistry" section of the "French Nuclear Energy Society".
During his career he made many presentations and papers in international conferences and scientific journals.
In 2010, he was sponsored by the MAI to write a "Handbook of Destructive Assays", a 1100 pages' document putting together extended summaries of hundreds of destructive examinations performed on LWRs' NSSSs, in France, US, Japan and Sweden.

Mr. Peter Rudling is the President of ANT International, managing the ZIRAT/IZNA/LCC Programmes as well as providing seminars and Handbooks on various fuel related topics to the nuclear industry. Peter was a senior consulting scientist at Vattenfall, the largest Swedish power company. Earlier he has also been a Specialist of Fuel Materials at ABB Atom (now Westinghouse) and a Project Manager at EPRI.

Price and Terms of Payment

The fixed nominal price for the LCC Membership appears in the associated Proposal.

Terms and Conditions

The term of LCC16 Programme starts from the date of the purchase order and lasts 12 months onwards.

ANT International shall exercise its best efforts to meet the objectives in this assignment and shall apply to the work professional personnel having the required skills, experience and competence. If the assignment is found to be significantly deficient by the customer within 6 months of its completion, A.N.T. International shall modify the work done within this assignment in such a way that it will become satisfactory to the customer. This modification shall be done without incurring any additional costs to the customer. The total amount of such additional costs due to the modification shall be limited to be less or equal to the amount originally paid to A.N.T. International for this assignment.

It is understood that AN.T. International is not responsible for any damage, incurred to the customer, their employees, or their plants or to a third party due to the use of the information or the recommendations given within this assignment.

The compiled information and the conclusions, as a result of this work, may be used by the purchasing party for its own use for any purpose provided that the source is given. A.N.T. International retains the rights to the compiled information and the conclusions for other uses.

Nuclear Liability

A.N.T. International and its sub-suppliers, including also suppliers of information and services, of every tier and kind, and everyone engaged by any of them, shall have no liability whatsoever (irrespective of negligence or gross negligence) for any damage or loss whatsoever (including also consequential and indirect loss) resulting from a nuclear incident (as such term is defined in the Paris Convention on third party liability in the field of nuclear energy, as amended from time to time). This shall apply for damage or loss suffered by third parties or the owner and for damage and loss to the nuclear installation, on site property and any other property of any kind, and until the nuclear installation has been decommissioned and irrespective of any termination or cancellation of the proposed work.

Insurances of the owner and of others in respect of a nuclear incident shall exclude any right of recourse against the supplier and his sub-suppliers of every tier and kind.

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