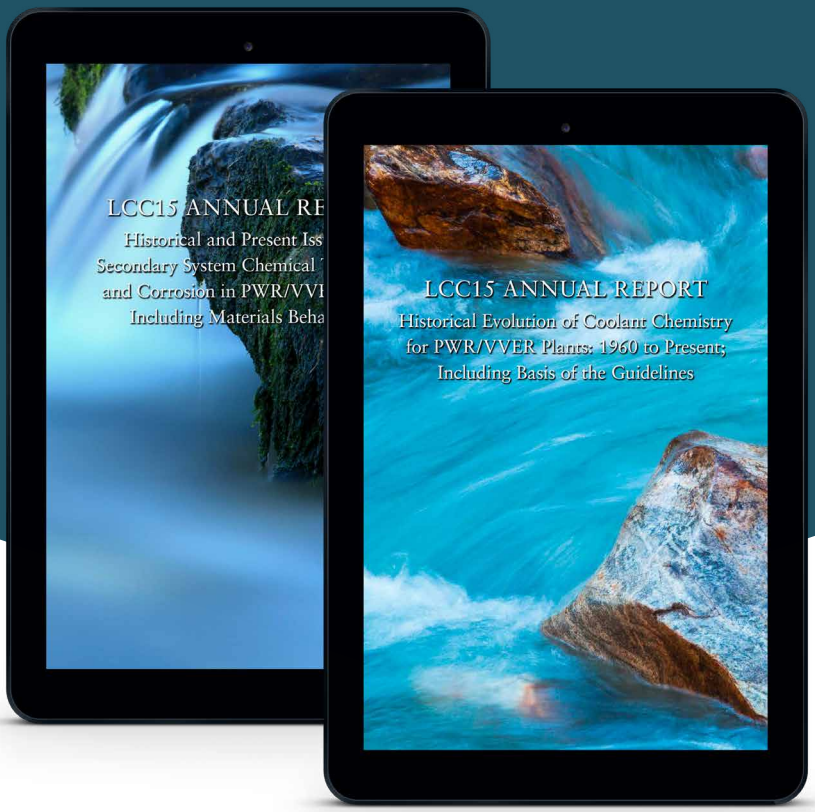
A.N.T. INTERNATIONAL®

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 LCC14 Programme, currently 17 organisations in North and South 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 provided that the source is provided in the caption.
- An e-book version which you can:
  - » Carry around in your favourite devices
  - » Mark and save specific phrases or paragraphs
  - » Bookmark pages you can come back to anytime
  - » Write your own notes and search through the entire text, during or after you read.
- Hardcopy, four colour reports will be provided if specifically requested by the customer. The printed Annual Reports will be provided as soon as they are printed.
- A Seminar will be held in Stockholm, 15-17 April 2020, 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 organisation.
- Before the seminars, you will have access to:
  - » The complete LCC Reports in digital format (PDF and E-book)
  - » 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

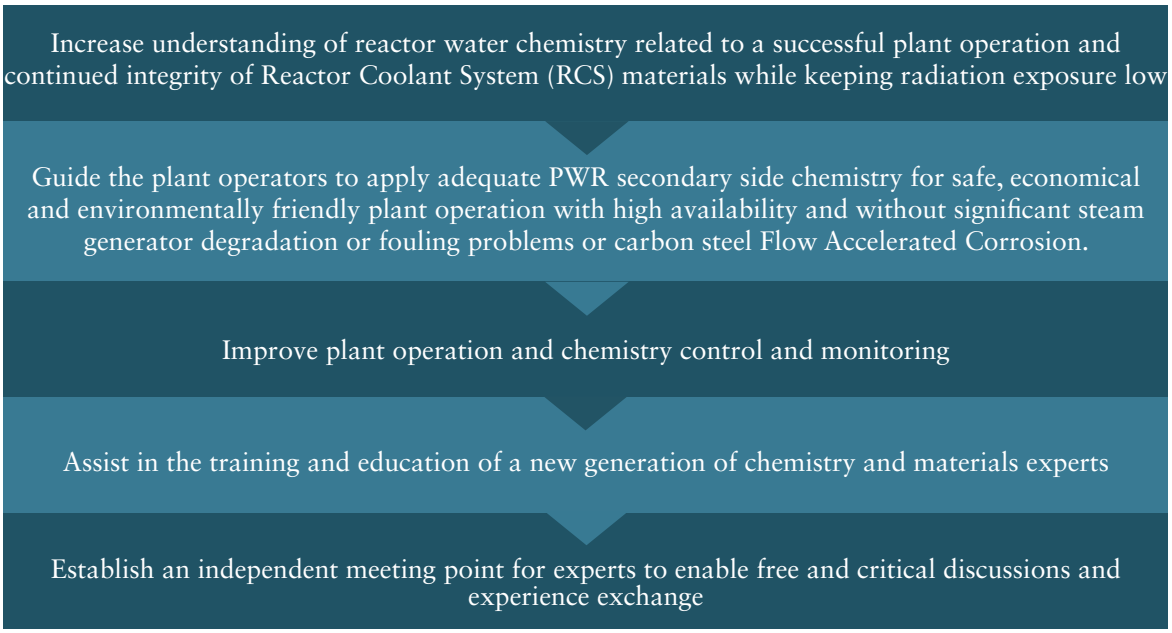
Nuclear utilities must reduce costs for operation, maintenance and fuel, keep the highest level of safety and lowest possible level of radiation exposure to employees and the public and minimise environmental impact of liquid and solid effluents and wastes.

Emphasis is put on safety, longer fuel cycles, higher burnup of fuel, increased fuel duty with more nucleate boiling in Pressurised Water Reactor (PWR's). Plant power uprates 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 organisations.

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



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.

LCC Programme

Annual Reports will be prepared within the LCC15 Programme as follows:

- Historical evolution of coolant Chemistry for PWR and VVER plants: 1960 to present; Including Basis of the Guidelines
- Historical and present issues on secondary system chemical treatment and corrosion in PWR/VVER units; including materials behaviour

Presentations without Reports will be prepared within the LCC15 Programme as follows:

- The Impact of Water Chemistry Transients on Nuclear Power Plant Materials and Plant Performance
- Fuel Crud in LWR

At the LCC15 Seminar, the Annual Reports will be presented, described more in the following.

LCC15 Reports

Historical Evolution of Coolant Chemistry for PWR and VVER Plants: 1960 to Present; Including Basis of the Guidelines

This report describes the historical development of the water chemistry in primary side of the PWR and VVER plants since 1950s up to present. Starting with the first research PWR plants in USA without applying any water chemistry addition of neither alkaline reagent nor hydrogen, lot of fuel performance degradations were experienced in 1950s and 1960s, such as heavy fuel deposits, flow restrictions across the core, reactivity losses and high radiation fields. Even the first AOA indications were experienced in a PWR with low core duty operating without applying water chemistry treatment.

Due to all these degradations experienced at field, intensive root cause analysis and research work were performed to mitigate and counteract these degradations. These investigations revealed also the influence of the structural materials, especially the steam generator tubes, on the experienced degradation phenomena. Based on the

field experience and the results of the investigations with respect to plant corrosion and radiation performance in the primary circuit, the water chemistry for primary circuit had to be modified and improved stepwise to counteract these performance degradations. In this report, the root cause of the experienced degradations will be discussed and the water chemistry mitigation steps will be explained. This explanation includes also how the concentration of the coolant chemistry additives, e.g. dissolved hydrogen and lithium hydroxide and also the strategy of their application was changed with time. Especially, the improvements of the coolant chemistry by Utilities was stringently necessary after 1990s due to economical reasons in the light of the trend towards extended fuel cycles, higher duty core, increasing stringent dose rate control, decreasing the refuelling outage duration, and reducing operating cost.

These improvements were reflected also in continuous modifications of the coolant chemistry guidelines. However, these modifications in international coolant chemistry guidelines (e.g. EPRI, EdF, VGB, MHI and VVER coolant chemistry guidelines), were somehow not exactly the same based on the used structural materials, and the field experienced gained with the plants. In this report, existing guidelines (especially EPRI, EdF and VGB guidelines) will be described in comparison with each other. The similarities and differences in these guidelines and the reasons for these differences will be explained. Finally, recommendations will be given with respect to application of the coolant chemistry strategies with a specific focus on the optimum lithium and hydrogen concentration during the fuel cycle based on the core duty design of the plants, the fuel cycle length and the structural materials used in the reactor coolant system.

The advantages and inconveniences of KOH versus LiOH for PWRs and VVERs will be discussed.

This report is intended to provide a detailed background description of the PWR/ VVER Primary Side Coolant Chemistry for more understanding of the coolant chemistry strategies and the chemistry guidelines. Furthermore, it should provide a strong support to the utilities for establishing a responsive plant specific chemistry program. It may also help the Manufacturers and Regulators at having a detailed approach of primary water chemistry and corresponding issues.

"For new engineers and chemists, this could be a very useful training tool. For experts in a given field, 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

Historical and Present Issues on Secondary System Chemical Treatment and Corrosion in PWR/VVER Units; Including Materials Behaviour

This report describes and explains the past and present issues related to secondary system chemistry and materials behaviour.

It starts with the relation between design and material evolution influence on chemistry selection, as well as guidelines for the secondary system. It also explains the behaviour of added reagents and of impurities in the secondary system. The integrity and long-term behaviour of the plant is largely considered.

The evolution of design on materials includes the condenser tubing and tightness, the steam generator blowdown flow rate and location, the tube support plate, and the very important steam generator tubing material (Alloys 600 MA, 600 TT, 800, 690 TT, and 18-10 of VVER). The link with various degradations (wastage, denting, Inter-granular Attack/Stress Corrosion Cracking) is explained.

The reagent selection is detailed, based on design and material evolution and encountered degradations and new issues. The advantages and inconveniences of H-AVT and various amines treatments are explained. The optimum hydrazine concentration depending on various parameters is described. The distribution of the reagent within the secondary system is covered as well as the behaviour of various impurities (Na, Cl, organic acids, etc.).

The important issue of corrosion products generation, deposition and elimination is reminded with the selection of adequate treatment, while other remedies are briefly listed (dispersant addition, film forming amine, chemical cleaning, sludge lancing etc.).

Another issue on liquid and solid wastes, as well as sometimes associated operating cost, is explained. This covers the best selection of reagents and purification system (limitation of the use of condensate polishing plant, operating mode of steam generator blowdown).

It finally clarifies the potential influence of lead on various steam generator tubing materials, and different chemical environments.

"I find the Seminars very useful, not only for the presentations but also to meet the speakers and other colleagues for some fruitful discussions"

FRANK HOLZGREWE
BKW

"You get a condensed experience, or knowledge, about all recent conferences and the newest technology updates"

BERNT BENGTSSON
Vattenfall, Sweden

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

LCC15 Presentations without Reports

Additional presentations will be given on the following topics.

The Impact of Water Chemistry Transients on Nuclear Power Plant Materials and Plant Performance

Unintended water chemistry transients/intrusions in Nuclear Power Plants (NPPs), though not common, can occur periodically during power operation. Consequently, damage to plant materials and components, and the radiological impact to the plant can result in severe economic impact to the plant owners, regardless of whether it is a BWR, PWR or VVER. The methods adopted to overcome the impact of transients are not very different for plant type, subject to the specific guidelines that need to be adhered to depending on the type of NPP because of the different water chemistries used in BWRs, PWRs and VVERs.

The common structural materials used in nuclear power plants consists largely of Type 304 or 304L SS, 316 or 316L SS, 321 SS, Alloy 600, Alloy 690, Alloy 800, and weld metals Alloy 182 and Alloy 82 or equivalent for BWRs, PWRs or VVERs. All of these materials are resistant to general and other forms of corrosion in the respective aqueous environments at plant operating temperatures and pressures. However, they can be susceptible to stress corrosion cracking (SCC) and in some cases to crevice corrosion if exposed to undesirable impurities for significant periods of time during plant operation. The impurity ingress into operating NPPs can occur due to a variety of reasons from multiple sources which are often common for BWRs, PWRs and VVERs. Controlling impurity ingress is critically important for overall plant health, longevity and economic sustenance of the plant.

This presentation will describe various sources responsible for impurity ingress in to NPPs such as:

- Leakage from main condenser
- Leakage due to resin intrusions
- Leakage from maintenance chemicals and solvents
- Leakage from lubricants and oils
- Species release from weld fluxes
- Releases from electro-hydraulic control fluids (EHC) used in turbine control systems
- Leakages from radwaste systems
- Releases from condensate storage tanks (CSTs)
- Releases from suppression pools
- Releases from RHR systems
- Impurity release into the coolant due to unanticipated accidents

In some instances impurity ingress can occur through chemical transients during plant start-up, shutdown or due to unanticipated accidents releasing large amounts of undesirable ionic impurities into the reactor coolant. Thus, there need to be preventive measures and reactive measures in place that can be readily adopted to recover from such situations with minimal adverse effects on plant materials.

The presentation will address these with a few examples from operating plants that have experienced such transients, some with very serious consequences, but recovered with appropriate counter measures.

The presentation will focus on the following topics:

- Why control impurities, discussion of potential impurities & their breakdown products
- Impurity entry pathways in to the reactor coolant
- Leakage from maintenance chemicals and solvents
- Materials used in NPPs, their chemical composition and the locations used in the plant
- Some data on the impact of impurity ingress on the integrity of NPP materials
- Detection of impurity intrusions using conductivity – limited to ionic impurities
- Detection of non-ionic impurities
- Effect of impurity ingress on steam line contamination and steam affected systems
- Long-term cleanup procedures if consequences are serious (e.g. from one plant)
- Proactive counter measures to alleviate impurity ingress
- Reactive counter measures to achieve plant operation within guidelines
- The elements of justification for continued operation (JCO), if the event is serious

Fuel Crud in LWR

Fuel crud in LWR may cause various plant problems such as Crud Induced Localised Corrosion (CILC), plant radioactivity elevation or Crud Induced Power Shift (CIPS). Therefore, there is a strong need to understand its formation mechanisms and to bring it under control through effective water chemistry management.

Over decades Swedish nuclear power utilities have performed numerous crud scrape campaigns and collected a large number of data about fuel crud chemical compositions and radioactivity in relation to fuel scrape locations, fuel burn-up and water chemistry applied. Some of the fuel scrape samples and fuel rods have been further examined at Studsvik for their phase compositions and microstructures with advanced analytical techniques.

This presentation will discuss some published results of the trend analysis from the plant fuel crud database and the laboratory examinations.

LCC15 Experts

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

Dr. Francis Nordmann has 49 years of experience in 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 intermediate circuits)
- 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 polishers strategy
- Optimisation of secondary water chemistry for various objectives
- Steam Generator experience feedback and relation with chemistry
- Tutorial sessions and workshops for various organisms (France, IAEA)
- International projects with various countries and organisations: IAEA, USA, EPRI, 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.

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.

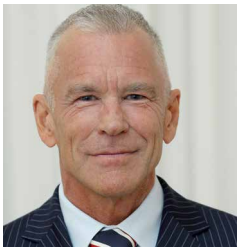
Dr. Suat Odar has 49 years of experience in power plant chemistry. He retired from AREVA NP GmbH (Former Siemens and KWU) in February 2008, where he has held since mid of eighties various service and managerial positions for power plant chemistry. In the last seven years he was responsible for the water 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 to improve Steam Generator Performance

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 Chalmers University of Technology during 2014-2016.

His recent research interests include microstructural characterisation 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. Peter Rudling is the President of A.N.T. 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 Swe-dish 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 LCC15 Programme starts from the date of the purchase order and lasts 12 months onwards.

A.N.T. 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 A.N.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.

A.N.T. INTERNATIONAL®

CONTACT

For more information and/or an offer
welcome to contact us at
sales@antinternational.com

Please also visit our website
for the latest updated information
www.antinternational.com

A.N.T. INTERNATIONAL®

Advanced Nuclear Technology International
info@antinternational.com www.antinternational.com