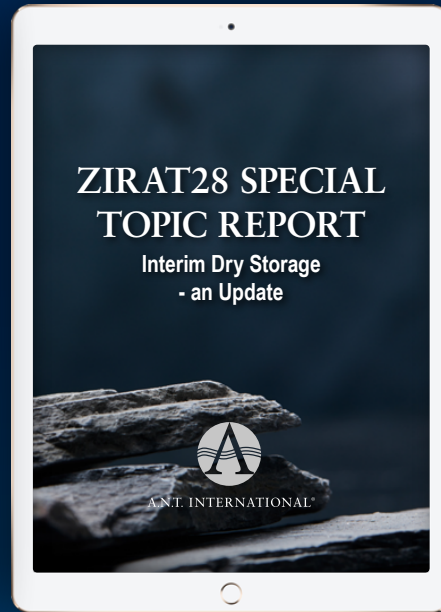
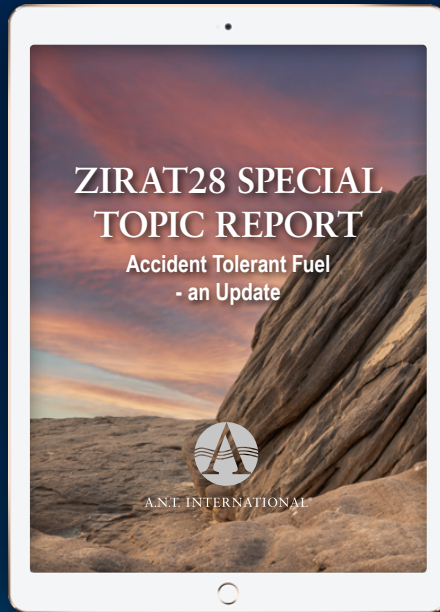




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ZIRAT™

Zirconium Alloy Technology Programme

The Annual ZIRAT Programme is focused on fuel assembly material issues and open to nuclear utilities and laboratories. In total, 34 organisations were members in 2021.

This programme was started in 1996.

ZIRAT28 Programme

Objective

The overall objective of the ZIRAT Programme is to:

Interpret published R&D results and nuclear plant experience on Zr alloy materials to help the customer to make informed decisions for the improved reliability, safety and economics of operations.

Point out areas where more R&D is needed to resolve potential issues (indications just seen but no problem yet).

The objective is met through review and evaluation of the data on zirconium alloys, identification of the most important new information, and discussion of its significance in relation to fuel performance now and in the future.

The ZIRAT28 Programme consists of Reports and presentations related to the Reports and on other topics not covered in the ZIRAT28 reports.



ZIRAT28 Special Topic Report

The Special Topic Report will cover the range from basic information to current knowledge and be written and explained in such a way that engineers and researchers not familiar with the topic can easily follow the STR, find and grasp the appropriate information. This means that the STR could be used by the organisations in the training of their internal staff with or without the additional assistance of A.N.T. International staff. The background and proposed content of the Report is discussed in detail below.

ZIRAT28 Reports

Accident Tolerant Fuel

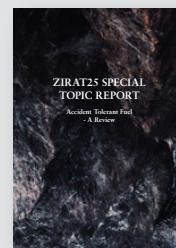
Accident tolerant fuels (ATF) are a series of new nuclear fuel concepts researched to improve fuel performance during normal operation, transient conditions, and accident scenarios, such as loss-of-coolant accidents (LOCA) or reactivity-initiated accidents (RIA).

During the last decade the development of various Accident Tolerant Fuel (ATF) concepts has come into focus of both research and industry communities in the USA, Europe and Asia. The ATF had become of even higher interest after the Fukushima incident as those emerging fuel concepts offer a potential for improvement of the safety of commercial power reactors.

There is a wide spectrum of various ATF concepts currently under development, some being just an improvement of the current cladding and fuel concepts, such as the coated cladding or metal-doped fuel pellets. Other designs present long-term ATF approach, which require considerable research, development, and licensing efforts.

In addition to the scientific community all over the world, the main nuclear fuel vendors have ATF programs under development. The vendors offer short-time solutions at various stages of maturity, which provide an improvement of safety margins for nuclear fuel.

This report is an update of previously issued Accident Tolerant Fuel- A Review, issued in 2021.



The purpose of current report is to present the most promising ATF concepts currently under development at various fuel vendors, research institutions and nuclear laboratories around the world and to provide the reader an independent assessment of the state of the art and potential for development and implementation related with each type of the ATF.

This report is divided into different sections, each of which address a different aspect of ATF such as:

- background for the need for development of ATF.
- ATF fuel pellet concepts,
- performance of various ATF concepts under normal operation, AOO and during design-basis and beyond design-basis accidents.
- some aspects of the ATF fuel cycle.
- cost aspects based on the available analysis.
- plans and criteria for licensing accident tolerant fuel for operation in nuclear power plants that are regulated by the U.S. NRC.
- analysis of gaps identified between the “ideal” concepts and the current stage of development for the various types of cladding materials, fuel materials and operating conditions.



“The ZIRAT meeting exceeded my expectations. The most valuable component of the meeting was the ability to speak directly with the A.N.T. International experts. The depth of knowledge and understanding of all speakers in the A.N.T. network is terrific. The size of the meeting was perfect.”

Markus Piro
Canadian Nuclear Laboratories

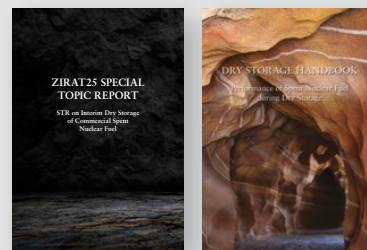
Interim Dry Storage - an update

Except for a few countries (such as Finland, Sweden, France, and possibly Canada) the timing for establishing a geologic repository has been shown to be unpredictable. Therefore, spent fuel storage will remain the last backend operation for the foreseeable future. With proper attention, the radiological impact of storage is very low, but regulatory agencies have placed a heavy burden on licensees because of concerns related to the highly negative public perception related to the presence of spent fuel storage facilities in our biological environment. Therefore, in the absence of concerns about siting a geologic repository, the actual locations where spent fuel is or will be are receiving all the attention.

Originally dry storage was intended to serve as a temporary solution for a few decades until final disposal, now dry storage period is to be extended to 100 years and beyond.

The focus of this review is on the spent nuclear fuel rods, and not on the storage system components such as the casks or the canisters and their internal hardware elements.

This report is an update of previously issued ZIRAT25/IZNA20 STR on Interim Dry Storage of Commercial Spent Nuclear Fuel, issued in 2021 and Dry Storage Handbook issued in 2017.



More specifically, the following topics will be addressed in the ZIRAT28/IZNA21 based upon ZIRAT/IZNA customer feedback:

1. Update on "Back-end" issues
2. Thermal creep behavior in relation to hydride reorientation
3. PWR fuel rod cladding failure due to the hydrogen migration in spent fuel assembly
4. Supporting any work on storage, transportation, long term issues
Correlation between cooling rate and hydride reorientation

"Excellent presentation material given in a thoroughly professional manner. Excellent interaction with regard to answering the questions raised by the audience."

Christopher Smith
Rolls-Royce

Deliverables

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

- Two similar Seminars will be held in Spring 2024 in Europe, in Madrid, Spain, and US to present the results of the ZIRAT Programme. The number of full-time employees per Member that may attend the seminar is limited to eight (8) people per organization.

At the 2-3 day Seminars, the two ZIRAT28 reports will be presented by the authors. In addition there will be a number of other nuclear fuel related presentations. To be announced later

- Before the seminars, you will have access to:
 - » High-resolution searchable pdf-files with the complete Reports as well as the presentation material in colour.
 - » The files can be copied to a company server, with full read access for everybody with access to the server.
 - » The contents from the Reports and presentation material 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 stated in the caption.
- The language of the ZIRAT 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.
- ZIRAT members have an option to purchase:
 1. [Previous ZIRAT reports](#) at a 50% discount and
 2. 12 months access to [A.N.T. International Online Education Courses](#) at a large discount.
 3. Consulting hours related to large projects for a discounted hourly rate. [For more information, click here.](#)
 4. The A.N.T. International Fuel Reliability Handbook and Code at a large discount, [please click here for more information.](#)
 5. Sign up for access to A.N.T. International Wikipedia (AWIKI), [please click here for more information.](#)

Bios of ZIRAT28 Report Authors



Dr. Audrius Jasiulevicius had completed his Ph.D. in the Nuclear Power Safety in 2003. Since then he had been working in the nuclear industry. He had been working with various aspects of the nuclear technology: thermal hydraulics system code development and applications, safety analysis, nuclear fuel licensing, nuclear fuel materials and material performance, nuclear fuel manufacturing processes and supplier quality evaluation. In 2003-2007 Audrius worked as a researcher and nuclear engineer at Paul Scherrer Institute in Switzerland. In 2007-2019 he was employed at Vattenfall Nuclear Fuel AB company in Sweden. In his free time Audrius enjoys spending time with his children, travelling to new places and reading. His is an experienced diver and this activity is still on the top of his preferences of leisure activities.



Dr. Albert Machiels retired in June 2017 from the Electric Power Research Institute [EPRI] located in Palo Alto, California, where he was responsible for providing technical expertise on topics related to spent fuel management, fuel cycles, and advanced generation technologies. Dr. Machiels has 50 years of involvement in various fields of nuclear technology R&D, including faculty and program direction positions at several universities and EPRI. In 2012, Dr. Machiels received a Lifetime Achievement Award for his numerous technical contributions to nuclear technology. He holds Chemical and Nuclear Engineering degrees from the Université of Liège, Belgium and a PhD degree in Engineering from the University of California, Berkeley.



Mr. Peter Rudling 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. Peter is now Chairman of the Board of ANT International. Peter has authored/co-authored more than 150 publications as well as 50+ A.N.T. International Reports during 2000-2020. In 2016 Peter got the Kroll Award. The William J. Kroll Zirconium Medal has been established to recognize outstanding achievement in the scientific, technological or commercial aspects of zirconium production and utilization, and to encourage future efforts, studies and research. The award is given to one person per year.





Dr. Martin Steinbrück graduated in chemistry at the Friedrich Schiller University Jena and received his Doctor of science in 1990. He has been at Karlsruhe Institute of Technology (formerly Forschungszentrum Karlsruhe FZK) since 1991; in that time he worked mainly in the field of Nuclear Safety Research. Dr. Steinbrück is leader of the group High-Temperature Materials Chemistry at the Institute for Applied Materials. He is in charge of the KIT project QUENCH dealing with hydrogen source term and coolability during quenching of an overheated core in the framework of the KIT program on Nuclear Safety. His special interest is the materials behaviour as well as oxidation of and interactions between the various core components at very high temperatures. Dr. Steinbrück is organiser of the annual International QUENCH Workshop (<https://quench.forschung.kit.edu/index.php>).



Dr. Nicolas Waeckel has worked in the Nuclear Engineering Branch of Electricité de France (EDF) from 1984 to 2020. In 2011 he becomes EDF Corporate Expert regarding Fuel & Core safety analysis and related international R&D activities. He spent 3 years at EPRI in Palo Alto in the late 1990 as Project Manager of the Fuel Regulatory Committee of the Fuel Reliability Program. He is Chairman of the international Nuclear Fuel Industry Research program (NFIR) since 2001 and was member of the HALDEN Board (Halden Reactor Project) and of the Studsvik Cladding Integrity Project (SCIP) Board of Management. Nicolas has a PHD and a post-PHD Thesis on Structural Mechanics and heretired from EDF in 2020.

GENERAL CUSTOMER FEEDBACK



A.N.T. International gets the highest appreciation by our customers, please click below for more information.

Terms and Conditions

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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 re-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.

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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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