International collaborations at JAEA/CLADS
toward decommissioning
of Fukushima Daiichi NPS

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Collaborative Laboratories for Advanced Decommissioning Science (CLADS), Japan Atomic Energy Agency (JAEA)

International Research Institute for Nuclear Decommissioning (IRID)

This paper includes part of the results obtained under the research program entrusted to International Research Institute for Nuclear Decommissioning (IRID) including Japan Atomic Energy Agency (JAEA) by the Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI) of Japan.
Japan’s Organizational Structure for 1F Decommissioning

Role of CLADS:
“Bridge” between Fundamental/Advanced R&Ds (international) and “Needs” or “Expectation” of TEPCO, IRID and NDF in near/mid/long-terms.
Main efforts of the CLADS

(I) Establishment of a platform to rally the wisdom of experts from around the world

- Inviting foreign researchers
- Collaborative research with overseas research institutes
- Forming a working group including external researchers and experts in the fields necessary to decommissioning.

At present, the research and development are conducted using existing facilities in JAEA.

Collaborative Laboratories for Advanced Decommissioning Science (CLADS)

Research Co-ordination and Promotion Office
Office for Tomioka Collaborative Laboratories Operation Management
Waste Management Division
Fuel Debris Handling and Analysis Division
Severe Accident Propagation Behavior Evaluation Division
Remote System and Sensing Technology Division

(II) Enhancement of international cooperation for decommissioning

- Inviting foreign researchers
- Collaborative research with overseas research institutes
- Forming a working group including external researchers and experts in the fields necessary to decommissioning.

Fukushima Research Conference

(III) Enhancement of human resource development in mid-and-long term

Integrating analysis technologies from various fields and developing human resources by opening cooperative course with institutions adopted for the "Decommissioning Basic Research: Human Resource Development Program" hosted by the Ministry of education, Culture, Sports,

In order to gather a variety of talented people, the cross-appointment system are utilized.

(IV) Establishment of an information dissemination function

In cooperating with the National Diet Library, JAEA arranges information released by the government and Tokyo Electric Power Company on the basis of IAEA’s nuclear accident information categories and transmit the information as the "JAEA Archive". Transmitting information on documents including JAEA’ original research results.
International Collaborative Research Building
(near 1F, Tomioka Town, Fukushima Prefecture, 2017.4~)

Utilizing JAEA’s special facilities for handling nuclear fuels and radioactive materials, and irradiation facilities at Tokai and Oarai in Ibaraki Prefecture.

Fukushima Environmental Safety Center
Research and development on environmental dynamics, radiation monitoring, etc.

From off-site to on-site

Utilization of results

Cooperation with academia, industry and government.
CLADS is organizing Fukushima Research Conference (FRC) at Tomioka-machi Tomioka Town Art & Media Center "Manabi no Mori" in Fukushima prefecture.

In these conferences, many researchers from around the world are gathering and discussing various topics for the decommissioning.

The FRC also provide opportunities to researchers and decommissioning operators for communication beyond their expertise.

Gathering worldwide excellent wisdom and expertise on Severe Accident (SA), decommissioning and related technologies.
Fuel Debris Handling and Analysis

① Fuel Debris Characterization and Condition Technology Development

Estimate the characteristics of fuel debris in the reactor using simulated fuel debris, and establish methods for handling and analysis of actual debris towards decommissioning work for the removal and storage of fuel debris.

② Dose Evaluation & Nuclear Material Accountancy

Study on dose evaluation method and nuclear material accountancy for fuel debris with non-destructive assay (NDA) technique.

③ Aging Mechanism Analysis on Fuel Debris

Understand the aging mechanism and estimate comprehensive aging behaviors on 1F fuel debris.
1. **Fission Product (FP) chemistry, release/transportation/sorption**

   【Main R&D theme】
   Estimation and evaluation of Cs chemisorption behavior in order to reflect it in the evaluation of Cs distribution and characteristics inside 1F. Cs distribution is important especially when viewing as radioactive source. The research will also focus on the boron effect on Cs-chemisorption behavior.

2. **Core melt/relocation behavior, core support damage/MCCI**

   【Main R&D Theme】
   Estimation and evaluation of important element processes on core material relocation behavior (melting and relocation of fuel assemblies/damage of core support plate/damage of lower plenum/MCCI, etc.) -> reflect on the evaluation of debris distribution and residual core structure situation.
Remote System and Sensing Technology

Radiation Imaging and Instrument Group
- Portable Gamma-Ray Imagers (Compton Cam., etc.)
  - To measure the spatial distribution of radiation in the high dose-rate environment.
- Detection of Gamma-ray and Neutron Fluxes from Fuel Debris in the High Dose-Rate Environment (MSGC, High-energy gamma-ray Det. etc.)
  - To measure neutrons and high-energy gamma-rays caused by fuel debris.

Remote Technology and Robotics Group
- Environment Data Collection Technology (Simultaneous Localization Mapping (SLAM), High Permeability Laser in the Contaminated Water, etc.)
- Environment Data Management Technology (Environment Model Construction, Relational Spatiotemporal Database)
- Environment Data Utilization Technology (Integration with Virtual Reality I/F and Simulators)

Data Visualization Technology Group
- 3-D Visualization Technology of Radiation Source Distribution
- Inverse Problem Analysis on the Contamination Source Information Obtained from Monitoring Data
- Radiation Risk Evaluation for the Reduction of Workers’ Exposure
  Visualization by a 3D Image
Waste Management for 1F Decommissioning

**Characterization**
- Analysis of various wastes
- Evaluation of the amount and composition of radioactivity
- Collection of physical/chemical data
- Development of analysis method

**Storage**
- Soundness of stainless steel vessel used for cesium adsorption apparatus
- Safety technology for storing a nuclear accident-derived wastes

**Processing**
- Technology survey
- Fundamental test of solidification
- Technology selection

**Disposal**
- Understanding of the existing disposal concepts
- Examination of disposal concept of accident-derived wastes
- Examination of new disposal concept

**Examples**
- Distribution of contaminated tree
- Sampling of waste specimen
- Vessel and Brine tank
- Solidified materials (TiNa 40% content)
- Example of safety assessment model
International Cooperation for 1F Decommissioning
The CLADS has been carried out above research and development encountered 1F decommissioning with concentrating wisdom and expertise from national and international cooperation.

◆ Major international collaboration in CLADS is as follows;

➢ Radioactive waste management in the decommissioning,
➢ Characterization of fuel debris and MCCI product, damaged fuel handling and treatment and storage,
➢ Investigation on severe accident phenomenon and core degradation process and etc.

◆ Multinational cooperation as IAEA and OECD/NEA are conducting.
Collaboration with JAEA and French Atomic Energy and Alternative Energies Commission (CEA)

Engineering scale MCCI Test Facility: VULCANO @CEA

Image of cross section of MCCI
Calculation results by TOLBIAC-ICB
MCCI Test Results in Fukushima sim. conditions

Concrete rich area
Metal grain
Mixture of corium and Concreate
Corium rich area

Oxide phase
with Zr rich
Oxide phase
with Si rich
Oxide phase
with U rich
Metallic phase
with Fe rich

Intact Concreate
Thermally-degraded concrete
Lower Crust
Metallic Layer
Metallic extraction
Corium oxide
Upper crust
Cavity

SEM/EDS analysis

Collaboration on MCCI product analysis

MCCI sample

Calculation results by TOLBIAC-ICB

Thermally-degraded concrete
Upper crust
Cavity
Corium oxide
 Metallic extraction
Metallic Layer
Lower Crust

Calculation results by TOLBIAC-ICB

MCCI Test Results in Fukushima sim. conditions

Collaboration on MCCI product analysis
Chemical alteration of debris

- Chernobyl’s “LFCM: Lava-like Fuel-Containing Materials” is still leaving in the reactor area, hence LFCM slowly react with moisture and air. 1)
- Secondary chemical species are generated on the surface, including dissolvable uranium.

Aerosol generation

- Aerosol is generated on the surface of LFCM continuously. 2)
- Major radio nuclides are $^{137}\text{Cs}/^{241}\text{Am}$, $^{241}\text{Am}/^{154}\text{Eu}$, $^{137}\text{Cs}/^{154}\text{Eu}$

Concerning for Fukushima Daiichi NPP

- Potential of similar alteration on the fuel debris & MCCI production in 1F conditions.
- Treatment of the aerosol generated by the fuel debris & MCCI production.

1) B. Burakov “Material Study of Chernobyl “Lava”and“Hot”Particles”, International Experts’Meeting on Decommissioning and Remediation after a Nuclear Accident, Vienna, Austria, 28 January-1 February 2013.
2) http://www.jsme.or.jp/pes/Research/A-TS08-08/index02.html
JAEA/CLADS agreed with SAFEST (Severe Accident Facilities for European Safety Targets) members on information exchange in July 2017, aiming at:

- Collaborative development of “corium research roadmap”
- Discussion of prioritization of corium-related R&D
- Information exchange of specification of test facilities of corium-related R&D
- Information exchange of existing/planned test results
- Discussion toward mutual utilization of test facilities
BWR control blade degradation, including its influence to channel box and fuel rods degradation is a key issue which Japan and EU are interested in (as a trigger of fuel degradation).

Steam flow rate highly influences the tendency on co-degradation between molten control blade (SS-B₄C) and Channel box (Zry)

In steam-starved condition, co-degradation more likely happens and it leads inhomogeneous distribution of molten metallic material in the early phase of fuel degradation.

Quoted from H. Shibata et al., presented at TOPFUEL2016, Sep. 2016 @Boise, ID, USA.

Strongly degraded bundle after air ingress and quenching

Air ingress scenario, degradation of Zry highly accelerated.

Quoted from M. Steinbrueck, presented at FRC in July 2017 @Tomioka, Japan.
**Outcomes**

- Decommissioning
- SA research & AM

**Work Scopes**

**Task 1**

- Sharing information on current status of 1F and estimate the debris location and its properties.
- Identifying and prioritizing needs for analysis of fuel debris
- Hot testing facilities and technologies (as preparation of future R&D framework)

**Task 2**

- Discussing and summarizing suggestions for analysis of fuel debris samples from 1F NPS
- Discussion on reasonable methodologies for safety assessment

**Task 3**

- Create draft proposal of future international cooperation using sample of 1F fuel debris.

**Purpose**

- Summarizing knowledge and expertise that contribute to understanding fuel debris characteristics
- Creating appropriate, optimal methodologies for future safety assessment on fuel debris sampling, retrieval
**Purpose**

- Enlargement / improvement of thermodynamic databases (TD) for core materials and FPs under various conditions by analytical and experimental studies, by referring accident progression in FDNPS
- Contribution to evaluation of fuel degradation progression, FP-behavior, and debris characterization from material science viewpoints

**Work Scopes**

**Task 1 (Corium and fuel)**

- Identification of priorities on improvement / enlargement of TD on fuel debris, based on benchmark exercises
- Re-assessment / updating of thermodynamic functions and phase diagrams on corium and fuel debris
- Updating knowledge of physical chemistry of corium / MCCI, in particular on the deviations between quasi-equilibrium systems and the real phase observed in sim-tests
- Identification and improvement of decommissioning activities using the thermodynamic approach

**Task 2 (Fission Products)**

- Performing thermodynamic evaluations of Cs-deposits, and identification of concerns for updating related TD, including potential kinetic effects
- Updating the knowledge on long-term leaching behavior of FP
- Assessment of thermodynamic data for important radionuclides which can have a long-term radiological impacts, Sr, Ba, Pu, MA

**Participants**

- Czech: CVR
- EC: JRC-Karlsruhe
- France: CEA, IRSN
- Germany: KIT
- Japan: CRIEPI, JAEG, TITECH
- Korea: KAERI
- Netherlands: Delft Univ.
- Russia: IBRAE, NITI
- Sweden: KTH
- Switzerland: PSI

Project coordinator: NEA
Technical advisor: JAEG

**Elements to be treated in TD**

- Control rod
- Corium
- MCCI

**Benchmark exercises of TD**

by referring FDNPS conditions based on various in-kind contributions

**Collaborative improvement of TD**

Efficient updating on physical-chemistry of corium, debris and FP

**Outcomes**

Contribution to decommissioning material science standpoints
Radioactive Waste Management Committee

Purpose

- The NEA seeks to assist its member countries in developing safe, sustainable and societally acceptable strategies for the management of all types of radioactive materials, with particular emphasis on the management of long-lived waste and spent fuel and on decommissioning of disused nuclear facilities.

- The program of work in these areas is carried out for the most part by the Radioactive Waste Management Committee (RWMC).
- JAEA participate to discuss management policy for radioactive waste generated in severe accident reactor as Fukushima Daiichi NPS.

In 2014, RWCM established the Expert Group on Fukushima Waste Management and Decommissioning R&D (EGFWMD).

- The EGFWMD providing as follows;
  - Information on post-accident waste management and decommissioning challenges
  - Lessons learnt from past nuclear accidents or site remediation and summarized important points in post-accident waste management

Expert Group on Fukushima Waste Management and Decommissioning R&D (EGFWMD)

- Participation
  - France, Norway, Russian Federation, UK, Ukraine, US, and Japan (NRA, JAEA, TEPCO)

Table of Contents of the Report *

1. General Description of Case Studies
2. Regulator / Implementer Interaction
3. Stakeholder Involvement
4. Physical and Chemical Nature of the Waste
5. Radiological Characterisation
6. Waste Classification and Categorization
7. Waste Conditioning, decontamination, and reduction
8. Destination (storage / disposal)

* OECD/NEA, “Management of Radioactive Waste after a Nuclear Power Plant Accident”, NEA No. 7305@OECD2016
JAEA is conducting R&D to support to decommissioning and seeking safe and efficient early decommissioning with enhancing of safety nuclear energy.

CLADS is carrying out R&D into medium-to-long-term issues such as fuel debris handling techniques, elucidation of accident progression scenario and present status of damaged cores, waste processing and disposal for decommissioning Fukushima Daiichi NPS.

Also, CLADS is promoting R&D and human resources development in unison with industry-academia-government by forming human resource exchange networks with people from worldwide universities, research institutions, and industry, etc.

For international cooperation, CLADS has already launched several collaborative activities with international communities as bilateral and/or multinational cooperation and is planning to launch several new projects.

The collaborative fields are expanding to radioactive waste management, characterization of fuel debris and MCCI product, damaged fuel handling and treatment, investigation on core degradation process, etc.

In April 2017, JAEA/CLADS built the International Collaborative Research Building at Tomioka-machi which will be served as a core of CLADS R&D activities. CLADS is aiming to act as a center of excellence for basic and fundamental research for decommissioning.
Thank you for your attention
Organization established in April 2015 at Tokai Village, Ibaraki Prefecture

CLADS

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