KNF-
SF-01

Fuel Poolside Examination(PSE)

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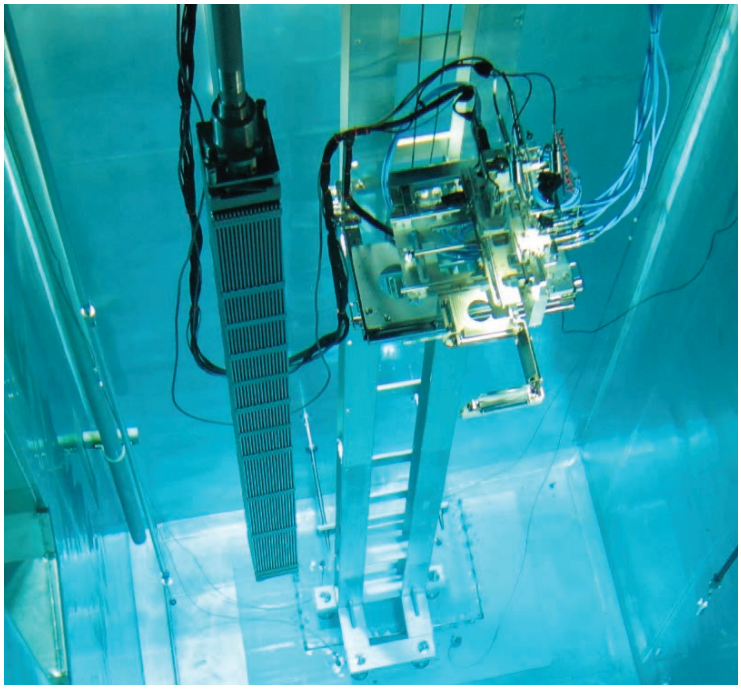
The figure of nuclear fuel is changed by neutron irradiation during the nuclear fission process at high temperature and high pressure as a burnup process inside of the reactor. PSE is to evaluate the irradiation performance in the reactor by measuring deformation / change of a burned nuclear fuel and a fuel rod.

This examination measures a dimension and deformation state of assembly by analysing video image, and a grid width and fuel rod diameter with LVDT method. Furthermore, it measures oxide layer thickness of fuel rod clad with ECT method.



Description

● Purpose and Necessity

- PSE is required to reflect the following things on the design and fabrication : proving reliability on irradiation performance in the fuel reactor, certifying suitability of fuel rod design code and model and producing irradiation performance data in the indispensable reactor for fuel development.

● Inspection Item

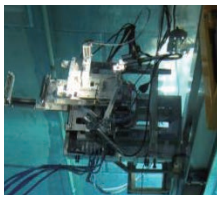
- **Dimension measurement of nuclear fuel**
  - Assembly irradiation growth : For length change of an assembly, evaluate irradiated assembly length after producing measured value by analysing video.
  - Fuel rod irradiation growth : Save a video about pitch between the end-plug and the top nozzle assembly, and evaluate irradiated fuel rod length by analysing video image.
  - Assembly bowing : For each spacer grid between the top nozzle and the bottom nozzle, evaluate assembly bowing by analysing video.
  - Assembly twist : For twist angle between the top nozzle and the bottom nozzle, evaluate deformed assembly by analysing video.
  - Fuel rod bowing : For pitch of each fuel rod, evaluate irradiated fuel rod bowing by analyzing video.
- **Measurement of grid width**
  - Measurement of grid width is performed by closing 2 jaws of equipment to spacer

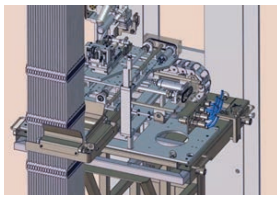
grid. It's measured by LVDT method which converts the jaw distance into voltage.

- **Measurement of fuel rod diameter**
  - Fuel rod diameter is measured as inserting the outer fuel rod between two finger probes. LVDT method is used to convert the probe distance with fuel rod inserted in it into voltage.
- **Measurement of oxide layer thickness**
  - Measurement of oxide layer thickness of fuel rod cladding is performed by passing an ECT probe between the fuel rods. Probe touches the fuel rod cladding surface, and probe evaluates the oxide layer thickness and produces result value after sensing changed impedance of probe coil.

● Constitution of Equipment

- **PSE equipment consists of a manipulator and control system that controls and operates it with a program.**
- **Manipulator**
  - Manipulator device can move to the X-Y-Z directions and directly touches the nuclear fuel. It is equipped with a camera which can obtain video footages.
  - Nuclear fuel inspection is performed by several devices installed on X-Y inspection table. The X-Y inspection table is operated by air pressure motor and the installed devices are used to measure assembly dimension, outer fuel rod diameter, grid width and oxide layer thickness of cladding.
  - PSE is performed in a spent fuel pool as nuclear fuel hanging in the water. To get a video data, underwater camera and light are installed on X-Y-Z inspection table. To measure each inspection items of assembly, LVDT(Linear Variable Differential Transducer) and ECT(Eddy Current Technique Instrument) methods are used. During the PSE, temperature change and location of nuclear fuel can be monitored.
- **Control System**
  - Control system consists of a computer system that can analyze measured signal and video image, and Amplifier, PLC, camera controller and real-time monitoring device. The program enables an inspector to get a reliable test result through a certain algorithm of equipment calibration, measurement and verification process, and these test results can be printed out immediately once the measurement is completed.





Distinctiveness

● Characteristics

- Nuclear fuel decomposition is not necessary since the inspection is performed in the spent fuel pool
- Equipment is relatively small and various inspections are available by replacing some devices
- The PSE is proven efficient by multiple inspections

● Benefits

- Improve stability of the power plant operation by producing irradiation performance in reactor data
- Improve nuclear fuel capability by giving design feedback to irradiation performance in reactor data
- Reduce cost from burnout capability in reactor inspection by performing the inspection in the plant

Experience

- Provide LTA and commercialized fuel inspection to verify irradiation performance after developing fuel, material, etc.
- Exported 1 set of PSE equipment to Nuclear Power Institute of China(NPIC)

Deliverables

- Perform inspection service for burnout capability in reactor of nuclear fuel
- Supply inspection equipment for burnout capability in reactor of nuclear fuel

Technology Readiness Level (TRL)

Actual system proven through operation

Business Model

Technology Transfer
Licensing
Joint Search
Service Execution
Others

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SF-02

Failed Fuel Repair

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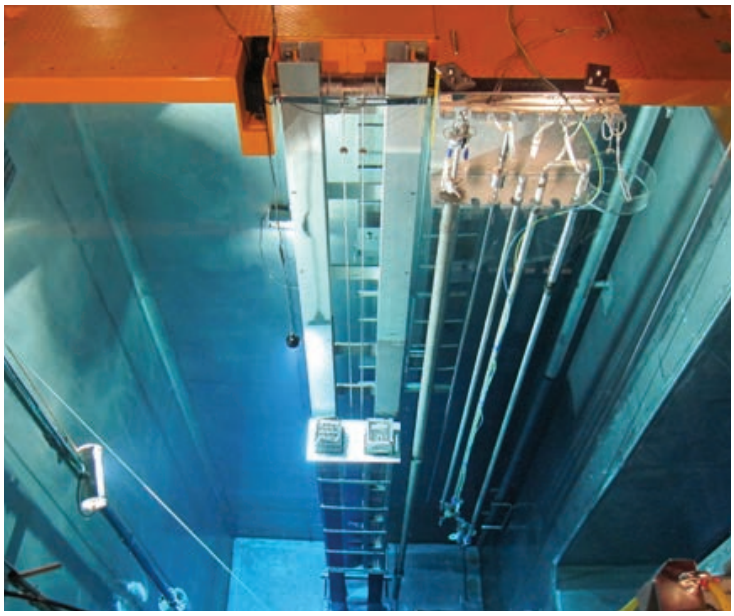
Failed fuel repair is a recovering technology to restore the fuel function as the original ones. Failed fuel rods are replaced with dummy fuel rods and damaged fuel components are replaced with new ones when nuclear fuel is damaged during the operation. There are two kinds of fuel repair methods depending on the nuclear fuel type. One is using a multipurpose fuel repair system and the other one is using spent nuclear fuel storage rack. Tools used in repair process are particularly designed for each fuel types.

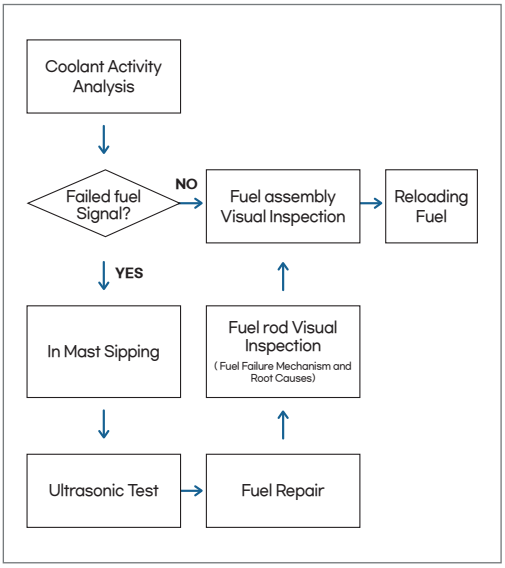


Description

● Purpose and Necessity

- Save time in emergency core design and improve operating efficiency of a nuclear power plant
- Reuse the failed fuel
- Maintain the fuel integrity for interim storage of a spent nuclear fuel

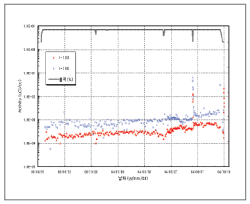
● Flowchart of the main services regarding failed fuel



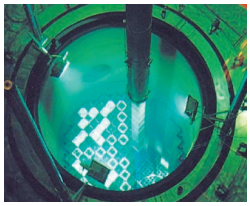
- The nuclear power plant in-operation monitors the nuclear fuel failure by analyzing the reactor coolant activity. All nuclear fuels can be re-loaded for the next cycle if the coolant analysis says there is no sign of fuel failure.

However, once there is a sign of it, IMS and UT must be executed on all nuclear fuels in core to find where it happened. After removing the failed fuel rod and inserting a dummy rod by fuel repair, the failed fuel is recovered its mechanical integrity and can be reloaded in the following cycle core.

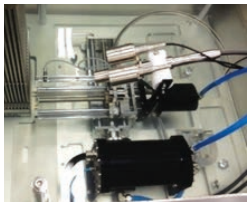
- With the purpose of analyzing the root cause of the fuel failure and preventing the fuel failure recurrence, accurate visual inspection for the extracted failed fuel rod is performed by using the radiation tolerant underwater camera.



< Coolant Analysis >



< In Mast Sipping >



< Ultrasonic Test >

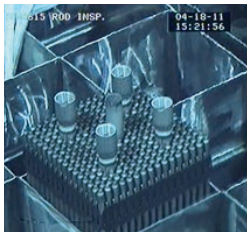
< Fuel Repair >

● Main equipment for fuel repair

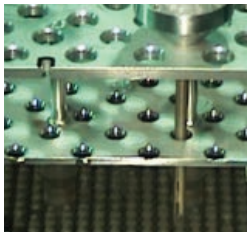
- Top nozzle handling tool
- Fuel rod handling tool
- Fuel rod guide plates
- Fuel rod storage basket
- Fuel rod visual inspection system
- Cameras to monitor repair service
- Multipurpose nuclear fuel repair system [for WH type NPP]

● Main process to repair

- Failed fuel repair is processed by the following order.
  ① Nuclear fuel visual inspection before repair, ② Top nozzle removal, ③ Failed fuel rod extraction, ④ Failed fuel rod visual inspection, ⑤ Dummy rod insertion, ⑥ Top nozzle assembling, ⑦ Nuclear fuel visual inspection after repair.

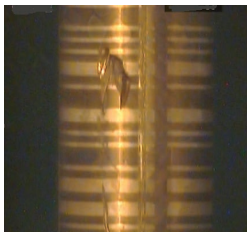


< Decomposition of top nozzle >



< Remove leakage fuel rod >

< Insert dummy fuel rod >



< visual inspection for leakage fuel rod >

Distinctiveness

● Characteristics

- Fuel repair using spent nuclear fuel storage rack
- Fuel repair using multipurpose nuclear fuel repair system

● Benefits

- Enhance plant operation efficiency by preventing emergency core design which requires a lot of time
- Reduce cost by reusing the failed fuel
- Meet the requirement of fuel integrity for interim storage of a spent nuclear fuel

Experience

- Repaired total 532 assemblies (1998~2018)
- Applied to WH-type and Korea Standard Nuclear Power Plant

Deliverables

- Failed fuel repair equipment
- Failed fuel repair service

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SF-03

Fuel Failure Detection Using IMS (In Mast Sipping)

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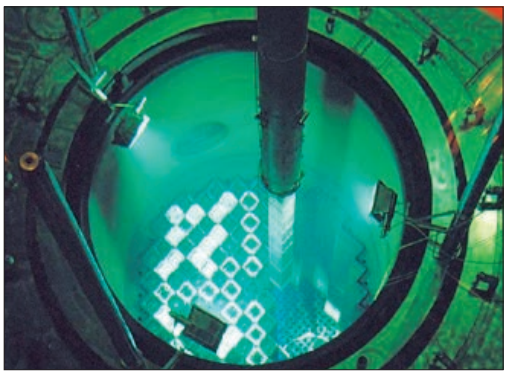
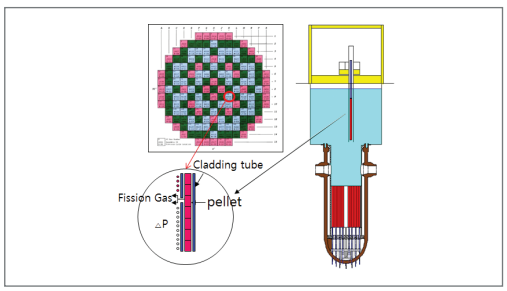
IMS(In Mast Sipping) is a technology to detect the leakage by collecting and analyzing fission gas that leaks from inside of the fuel rod in the event that nuclear fuel is failed. When fuel is extracted from the reactor, it vertically rise about 10 m generating 15 psig water pressure difference. This pressure drop causes the fission gas inside of the fuel rod to leak out of the fuel rod. Fission gas has a variety of nuclide such as Xe-133 and Kr-85, etc. IMS technology enables us to detect and analyze these nuclides.





Description

● Background

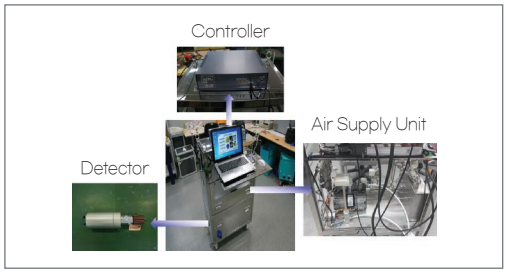
- Domestic nuclear power plants relied on the VT(Visual Testing) and UT(Ultrasonic Testing) to detect the leakage in nuclear fuel in the past. Since VT and UT can be carried out separately after the fuel is withdrawn first which means there is a time gap between the actual leakage event and detecting it. Moreover, it is difficult to detect the leakage inside the fuel with VT, and with UT, it is impossible to detect the leakage if there is no water inside the leaking fuel rod. For this reason, KEPCO NF developed IMS equipment that can perform a reliable test.

● Purpose and Necessity

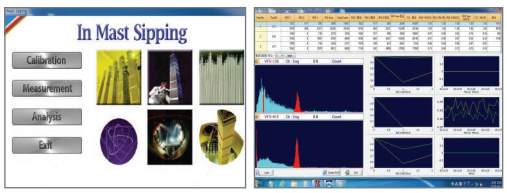
- Since IMS is performed simultaneously as fuel is unloaded from the core, there is no additional fuel transfer for the inspection minimizing the possibility of damaging the fuel. Fuel that is determined to have leakage defects can be repaired and reloaded into core or safely stored in the nuclear fuel pool. In addition, inspection results can be reflected in redesigning the core.
- IMS can detect leaking fuel even if there is no water inside the fuel rod unlike UT. In addition, since IMS is completed during the fuel withdrawal process, the leaking fuel can be classified as a assembly group before the UT. The UT will be executed on the classified assembly group to find which fuel rod is leaking. This process improves the accuracy of detecting leaking fuel than the UT does.

● System Configuration

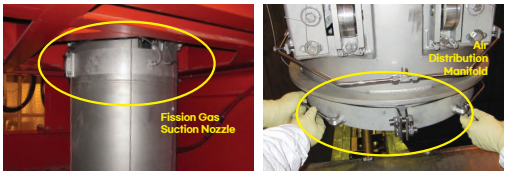
- **IMS Equipment**
  - The control system controls MCA(Multi Channel Analyzer), vacuum pump, solenoid valve, humidity sensor, pressure sensor and flow sensor. It consists of a DAQ(Data Acquisition Board) which acquires signals and data, digital system which simultaneously controls air supply devices and detection analysis device, and a laptop to process the acquired signals, display them on screen and make database out of them.
  - The air supply system captures the fission gas inside the mast, sends it to the detection analysis device, and discharges the gas back to the atmosphere. It consists of vacuum pump, valve, air dryer, regulator, gauge, air transfer tube and various sensors and connectors.
  - The detection analysis system analyzes the fission gas captured from the mast to determine whether the fuel is leaked or not. It consists of detector, MCA, lead shield, and laptop.



- **IMS Program**
  - All devices installed on IMS device can be controlled by IMS program. The program provides calibration, leaking fuel inspection and analysis services. Using 1,024 channels of MCA, a various nuclide in the range of radioactive energy from 10 ~ 1,000 keV can be analyzed. Not only the radiation measurement value of the detector but also the pressure and flow of the inhale line in real time can be checked.



- **Mast Fixing Device**
  - Mast fixing device is an auxiliary device installed on the outer mast of the reactor for IMS, consisting of suction nozzle installed on the upper part of the mast and an air distribution manifold installed on the lower part of the mast. The suction nozzle is connected to the detector of the IMS device by an air hose and the vacuum pump starts to inhale the fission gas when the inspection is started.
  - The air distribution manifold is connected to the service air line of the power plant. From the beginning of the inspection, service air is injected into the bottom of the fuel assembly to activate the collection of leaking gas.



Distinctiveness

● Characteristics

- Reduce the fuel transfer and fuel damaging factors
- Various nuclide in the range of radioactive energy from 10 ~ 1,000 keV can be analyzed by using 1,024 channels of MCA
- Identify leaking fuels in real time while the inspection is executed at the same time
- Improve resolution by blocking noise from natural radiation and electromagnetic waves
- Increase reliability of leaking fuel detection by simultaneous analysis of gamma and beta energy

Experience

- 7 times IMS inspection for domestic pressurized water reactor(as of June 2021)

Deliverables

- Design and manufacture of IMS equipment
- IMS service performance for power plant
- IMS training and manual

KNF-
SF-04

SPADE:
SPent Fuel Assessment solution for Dry storage Engineering

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SPADE is an assessment technical solution that can evaluate SF mechanical integrity during the transportation and handling under the dry storage condition. In particular, This technology is a dry storage transport evaluation technical system reflecting the SF degradation characteristics of long-term dry storage and can reliably evaluate the requirements of relevant laws and regulations. SPADE has been developed through verification · validation(V&V) procedures such as various tests, analyzes and evaluations to enhance the its reliable performance.

Description

● Background

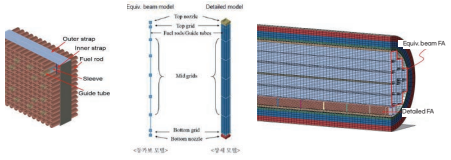
- SF stored temporarily in the wet storage of domestic nuclear power plants is gradually reaching the storage saturation point. This status is one of the most important problems to be solved urgently for the sustainable development of nuclear industry field. Interim dry storage of SF is a promising measure for SF management.
- SF integrity evaluation technology is the key item for the interim dry storage, and it is expected that the demand for this SF management technology will be continuously increased in the near future from the managerial and technical points of view.

● Purpose and Necessity

- For dry storage of SF management, SF integrity specified in the related laws and licensing regulatory requirements abroad(IAEA, US etc.) and domestic(Nuclear Safety Acts) should be evaluated · approved. In order to perform the evaluation required by these related laws and regulations, it is necessary to develop a system reflecting domestic SF characteristics credibly.

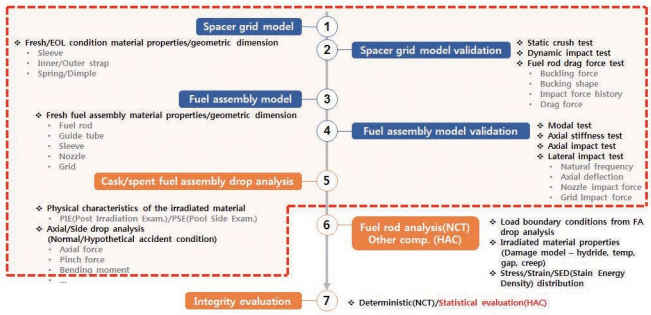
● Principle

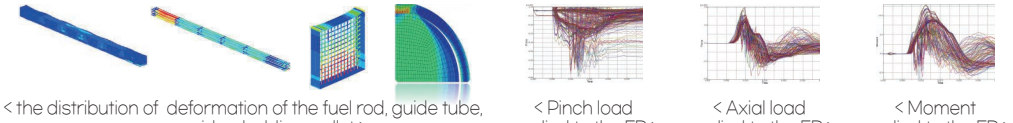
- For SF evaluation, a mathematical model based on data base with destructive inspection(hot cell) and non-destructive inspection[simulated and accelerated test, pool side examination(PSE)] is required, and an analytical model that can define geometry and physical properties of SF is required.
- In particular, the verification&validation (V&V) for each stage of modeling was conducted to enhance the reliability.



< The model of spacer grid, fuel assembly, transport cask >

KNF SF integrity evaluation methodology





< the distribution of deformation of the fuel rod, guide tube, spacer grids, cladding-pellet >

< Pinch load applied to the FR >

< Axial load applied to the FR >

< Moment applied to the FR >

● System of SPADE

- SPADE consists of several models such as a transport cask, an equivalent beam and a detailed SF of fuel assembly, a detailed fuel rod damage evaluation built by the commercial finite element code, ABAQUS.
- The evaluation is performed in two steps. Firstly, the boundary conditions such as the stresses of the SF parts are derived by performing the SF-cask global evaluation. In the second step analysis, the boundary condition derived from the first step is applied to the fuel rod considering the dry storage degradation characteristics, and the detailed analysis is performed to perform the quantitative damage rate evaluation.
- Identifying the worst cell location boundary conditions in the transport cask
- Applying SF characteristics(deformation, irradiation behavior, oxidation corrosion thickness reduction, etc) to SPADE model

● Result

- SF mechanical integrity such as vibration, impact and abnormality can be assessed under normal and hypothetical accidental environments, which are the most critical damage modes during dry storage transport · handling of SF.

● Benefits

- Leading the domestic technology in SF evaluation field
- Fresh nuclear fuel-SF total solution service
- Applicable to other fields(Failed SF evaluation, HWR SF etc.) and new SF such as HIPER, ATF etc.

Experience

- Government projects(1)
- National Lab project(1)
- Utility project(1)
- Future plan: high burn-up SF, HWR SF, and new nuclear fuel(HIPER, ATF etc.)

Distinctiveness

● Characteristic

- Enhancing the reliability of analysis through various verification · validation procedure

Deliverables

- Engineering service related to SF integrity
- Spent Fuel integrity evaluation licensing support

Technology Readiness Level (TRL)

Actual system proven through operation

Business Model

Technology Transfer
Licensing
Joint Search
Service Execution
Others

KNF-
SF-05

SAFER: Safely Adapting FastenER

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Among the Westinghouse type spent fuel(SF) stored in spent fuel pools(SFP), there are many SFs which are concerned about the separation of top nozzle(TN) and guide tubes(GT) due to the corrosion of GT sleeves connecting TN and GT.
SAFER is a supplementary tool to handle these fuels. It is installed at the SF GT bulge and fastens the TN and GT with high clamping force.

Description

● Background

- NRC Information Notice 2002-09
  - In 2001, there was a fuel drop accident caused by TN separated from GT during handling the fuel for SF inspection in the SF Pool in North Anna power plant, USA.
  - The NRC investigated the cause of the accident and surveyed the similar cases. It turns out there were several similar accidents including the fuel for Kori 1 unit.
  - The IGSCC(Intergranula Stress Corrosion Cracking) made of SS304 material was found to be the main cause of the top nozzle separation. SS304 is a GT sleeve material that contains high carbon.
  - Supplementary tool is necessary to handle the SF with SS304 GT sleeve safely.(Latest nuclear fuel have replaced the related material with SS304L to prevent the same type of damage)
- SFP storage tank saturation
  - The capacity of the domestic SFP storage tank is expected to be saturated in the near future.
  - All of the SF with risk of top nozzle separation must be checked before the dry storage in accordance with decommission of Kori 1 unit.

- The SFs with top nozzle separation risk require precautionary measures.

● Purpose and Necessity

- To enhance the SF handling integrity with top nozzle separation risk stored in domestic SFPs.
  - Currently about 1,500 bundle of SF with the top nozzle separation risk are stored in SFP.
  - To handle these fuels safely, it is necessary to install a supplementary tool.

- SAFER is about 15 cm in length and is convenient for storage and handling.

● Benefits

- Prevent TN separation during SF removal.
- For the domestic SF dray storage project followed by SFP saturation, for a start, SAFER can be applied to the about 1,500 bundle of SF with TN separation risk
- SAFER's excellent function can attract overseas markets

Distinctiveness

● Characteristic

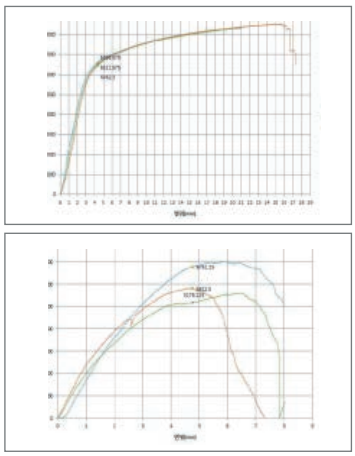
- SAFER is installed at the GT bulge to provide high-strength fastening force with dual structure fastening force of friction and geometric interference force.
- Installation of four SAFERs provides high-strength fastening force that is more than 3 times the weight of the fuel assmebly(3g), and superior performance compared to other products.(2g for 6 installations)
- Since SAFER uses screw fastening method, it contributes to the improvement of SF integrity compared with the conventional method which requires excessive installation force to the GT to obtain high friction force.

Experience

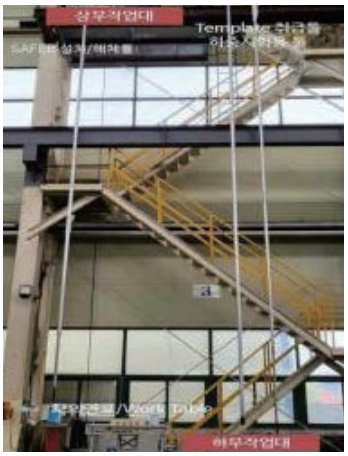
- Factory and Site Acceptance Test of SAFER was completed
- The development of Installation/Removal tools was completed
- Promo tion of licensing and commercial application(KORI2)

Deliverables

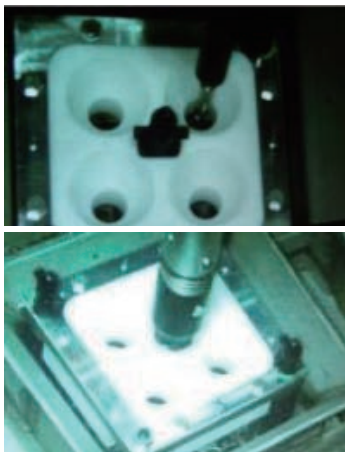
- SAFER, A package of SAFER Installation/ Removal Tools
- Engineering services for SAFER installation, related integrity and safety assessment technology



< Fastening Strength Test >



< Factory Acceptance Test >



< Site Acceptance Test >

Technology Readiness Level (TRL)

Field demonatration of Prototype

Business Model

- Technology Transfer
- Licensing
- Joint Search
- **Service Execution**
- Others

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EUP (Enriched Uranium Product) Supply Management

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It is a procedure that manages an overall system of supplying EUP, which is the most important raw material for manufacturing nuclear fuel. EUP Supply Management not only manages schedules but also performs management work for the supply system as a whole including prediction and analysis of uranium quantity, analysis of proper time of uranium purchase, and proposing various plans for supplying uranium.

Based on experience of performing ESM services in the BNPP project, our company was able to develop capabilities in every part of the front-end fuel cycle project ranging from uranium supply to manufacture and supply of nuclear fuel. When exporting nuclear fuel in the future, it is possible to become more competitive.

Description

● Background and Necessity

- Based on experience for purchasing and management plan for uranium, which is essential for manufacturing nuclear fuel, the scope of the company's business has expanded to include the front-end fuel cycle of all nuclear fuels
- Available to successfully perform the fuel supply project through an integrated management system from uranium to nuclear fuel manufacturing
- Improve competitiveness and ability to negotiate when exporting nuclear fuel
- Available to accumulate skills to manage nuclear materials of front-end fuel cycle

● Work Contents

- Management of uranium supply contract
  - Develop and manage quantity and schedule of uranium delivery based on uranium supply contract
- Establish and operate a short- and long-term management plan for EUP delivery
  - Establish an annual EUP supply management plan
  - Establish a mid- and long-term EUP supply management plan
  - Predict and manage an operating budget for annual EUP management

- Appropriate inventory management for uranium
  - Calculation of uranium quantity and inventory management in the U3O8–Conversion–Enrichment process
- Management of EUP transport
  - Domestic customs clearance of EUP and performing inland transport
- Performing inspection, acceptance and Book Transfer of EUP
  - Receiving inspection of EUP delivered by supplier(s)
  - Effective uranium management through Book Transfer

Experience

- The field(s) which requires EUP procurement necessary for supplying nuclear fuel
- Competitors in nuclear fuel manufacturing have been performing services for EUP supply management
- The service is necessary if a nuclear power plant performs supply and demand of uranium on its own

Distinctiveness

● Characteristics

- Perform effective management of front-end fuel cycle(field of nuclear fuel supply) project through uranium supply management
- Available to provide a solution related to uranium supply to nuclear fuel supplier(s) by utilizing related projects
- Demonstrate performance for uranium supply management through successful BNPP project experience

● Benefits

- Available to effectively manage projects in the field of overall nuclear fuel manufacturing through uranium supply management
- Retain complete project experience and skills as a front-end fuel cycle company
- Improve competitiveness when exporting nuclear fuel in the future

Deliverables

- Various reports for EUP supply management(mid- and long-term report, analysis report for annual uranium supply management, budget operating report, etc.)
- Uranium inventory management and analysis report
- Services for EUP supply management
- Performing acceptance, inspection, and book transfer of EUP
- Issuance of EUP supply notice(Preliminary, Final), etc.

Technology Readiness Level (TRL)

Actual system proven through operation

Business Model

Technology Transfer

Licensing

Joint Search

Service Execution

Others