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FUEL-07

Accident-Tolerant Fuel

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Accident-tolerant fuel(ATF) innovatively reduces the possibility of a large amount of hydrogen generation and explosion due to the rapid oxidation reaction between cladding tubes and water vapor in a high-temperature steam environment, which is the condition of a nuclear power plant accident. It reduces the amount of nuclear fission gas release. It is a nuclear fuel technology that can secure the time to deal with an accident by maintaining the integrity of the nuclear fuel for a long time in the event of a nuclear power plant accident.

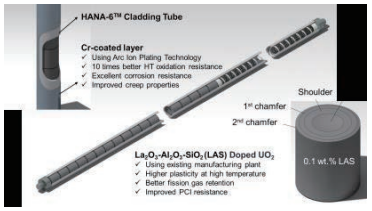
Description

● Background

- ATF is a nuclear fuel that can maintain the integrity of nuclear fuel for a long time in a state where the active cooling function of nuclear power plants is lost compared to the current Zr-UO_2(zirconium cladding-uranium dioxide pellet) nuclear fuel. It delays development of a severe accident, securing time to respond to an accident.
- Accident-resistant nuclear fuel is a technology to prevent or delay the expansion of severe accidents, such as hydrogen explosions, radioactive leakage, and core melting, in the event of a nuclear power plant accident. Further, this technology can improve the economic feasibility. After the Fukushima nuclear power plant accident, to upgrade the safety of nuclear power plants, an accident-resistant nuclear fuel is being developed as a national policy in most leading countries in nuclear power generation, such as the United States, France, Japan, and Russia.
- Especially, the EU-Taxonomy Act which counts nuclear power plants with accident-tolerant nuclear fuel as “green energy”, was passed in 2022. was passed in 2022, which included nuclear power plants with accident-resistant nuclear fuel in green energy. Accordingly, technology development is underway, with the goal of submitting a license report in 2029 to commercialize accident-tolerant nuclear fuel.

● Technology Composition

- Accident-Tolerant Fuel Cladding Tube
  - The HANA-6 cladding tube is coated with chromium, which is excellent in high-temperature oxidation performance, with a thickness of several microns on the outer surface of the HANA-6 cladding tube.
  - The cladding tube showed improved resistance to corrosion, hydrogen withdrawal, and oxidation inhibition performance in case of accidents through a dense coating layer applied using the Arc Ion Plating(AIP) method.
- Accident Tolerant Fuel Pellet
  - Less than 0.1 wt% of LAS(La2O3-Al2O3-SiO2) elements was added to UO2 to suppress fission material release and increase the strain rate of the sintered body, thereby maintaining the properties of the existing UO2 sintered body and improving reduction performance of Fission Gas Release (FGR) and PCI(Pellet Clad Interaction, the interaction between sintered cladding) to enhance



< Schematic diagram of accident-tolerant nuclear fuel >

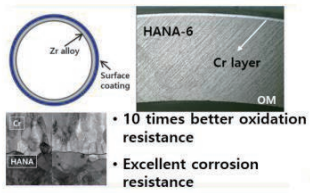
Distinctiveness

● Technology for Accident-Tolerant Fuel Cladding Tube

- AIP technology is a physical vapor deposition(PVD) method that generates coating particles(plasma) using an arc discharge in an argon gas atmosphere and then accelerates ion particles in an electric field to deposit the coating particles on the base material. Compared to general vapor deposition and sputtering techniques, arc discharge generates plasma in large quantities under low voltage/high current conditions, resulting in a high coating speed(10 μm/h). Therefore, it is easy to mass-produce. Further, the adhesion of the coating interface is excellent.

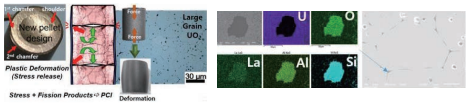
- High-temperature oxidation resistance: It is a characteristic factor that directly affects the amount of hydrogen generated in the event of a power plant accident. KNF's coated cladding tube exhibits similar or slightly superior properties to competitor's.
- Corrosion during normal operation: The amount of cladding corrosion is a key characteristic that harms the cladding integrity during the normal operation of the nuclear power plant.
- Creep strain rate in normal operation: It is a crucial characteristic that causes the deformation of cladding pipes in the normal operation of nuclear power plants. The amount of creep deformation is expected to reduce significantly compared with existing zirconium-clad tube.
- High-temperature rupture resistance: It indicates the damage resistance of the cladding under the conditions of a nuclear power plant accident and is as effective as competitors' coated cladding.

< Cr-coated cladding >



● Technology for Accident-Tolerant Fuel Pellets

- This technology increases the particle size of UO_2 through the eutectic liquid phase of La_2O_3-Al_2O_3-SiO_2(LAS). It places LAS at the grain boundary and triple point(junction).
- Compared with Cr-based compositions with high solubility in UO_2, the crystal homogeneity of UO_2 can be improved through compositions, such as Al and Si, with low solubility in UO_2. These compositions can lower the UO_2 diffusion coefficient, effectively suppressing fission gas diffusion. Additionally, the high-temperature deformation of UO_2 appears rapidly due to grain boundary sliding.
- UO_2 particle size: A key characteristic that acts as a primary mechanism to suppress the release of fissile material during the normal operation of a nuclear power plant. UO_2 developed by KNF tends to be smaller than competitors, however, by applying the additive composition, reported as a substance that suppresses the diffusion of fissile material from UO_2 particles, it is expected to exhibit the same level of fissile material release behavior.
- High-temperature plastic strain: A characteristic factor that directly affects the risk of failure arises from the stress applied to the cladding due to swelling of the sinter during normal operation or in the event of a nuclear power plant accident.



< LAS doped UO_2 sintered body >

- Safety reinforcement shape: The contact stress between the cladding and sintered body can be alleviated by applying a double chamfer shape instead of the existing single one.

Main Features	Cr-coated cladding	LAS doped UO_2 Pellet
Compatibility	Usage of current commercial manufacturing/ design technology	same as left (0.1 w% trace amount added)
Normal Operation	Corrosion/hydrogen absorption resistance increased by 10 times	Internal pressure reduced by 1/3
Accident Condition	High-temperature oxidation rate(hydrogen generation) reduced by 10 times	Probability of fuel rod rupture is reduced by 1/3, and 7-fold improvement in water vapor oxidation resistance
Response Time for Critical Accidents	Securing 50 min of additional response time for critical accidents (Current 2 h ⇒ 2 h 50 min)	

< Main characteristics of accident-tolerant nuclear fuel >

● Benefit

- Improve nuclear power plant safety and economic feasibility by applying accident-resistant nuclear fuel
- Commercialize safety-enhanced nuclear fuel to meet the requirements of domestic and foreign nuclear power plants and increase public acceptance
- Enter overseas markets by meeting the requirements for commercialization of accident-tolerant nuclear fuel in the EU Green Taxonomy
- Stably supply nuclear energy at home and implement energy conversion policy by improving nuclear power plant safety

Experience

- Completed the development of accident-resistant nuclear fuel cladding(~'21.12)
  - Completed construction of 4-m coating equipment for Cr coating(~'20.12)
  - Developed manufacturing process for 1-m coated cladding tube and completed off-site test evaluation(~'21.12)
  - Optimized 4-m coating manufacturing process and secured commercial manufacturing technology(~'22.12)

- Completed development of accident-resistant nuclear fuel pellets(~'21.12)
  - Obtained original patent for KNF's proprietary sintered body(LAS doped UO2)(May 2018)
  - Secured commercial manufacturing technology for LAS doped UO_2 sintered body(~'22.12)

Deliverables

- Accident-resistant nuclear fuel applies to various types of nuclear reactors
- Coated cladding manufacturing technology and inspection technology
- Doped UO2 sintered body manufacturing technology and inspection technology