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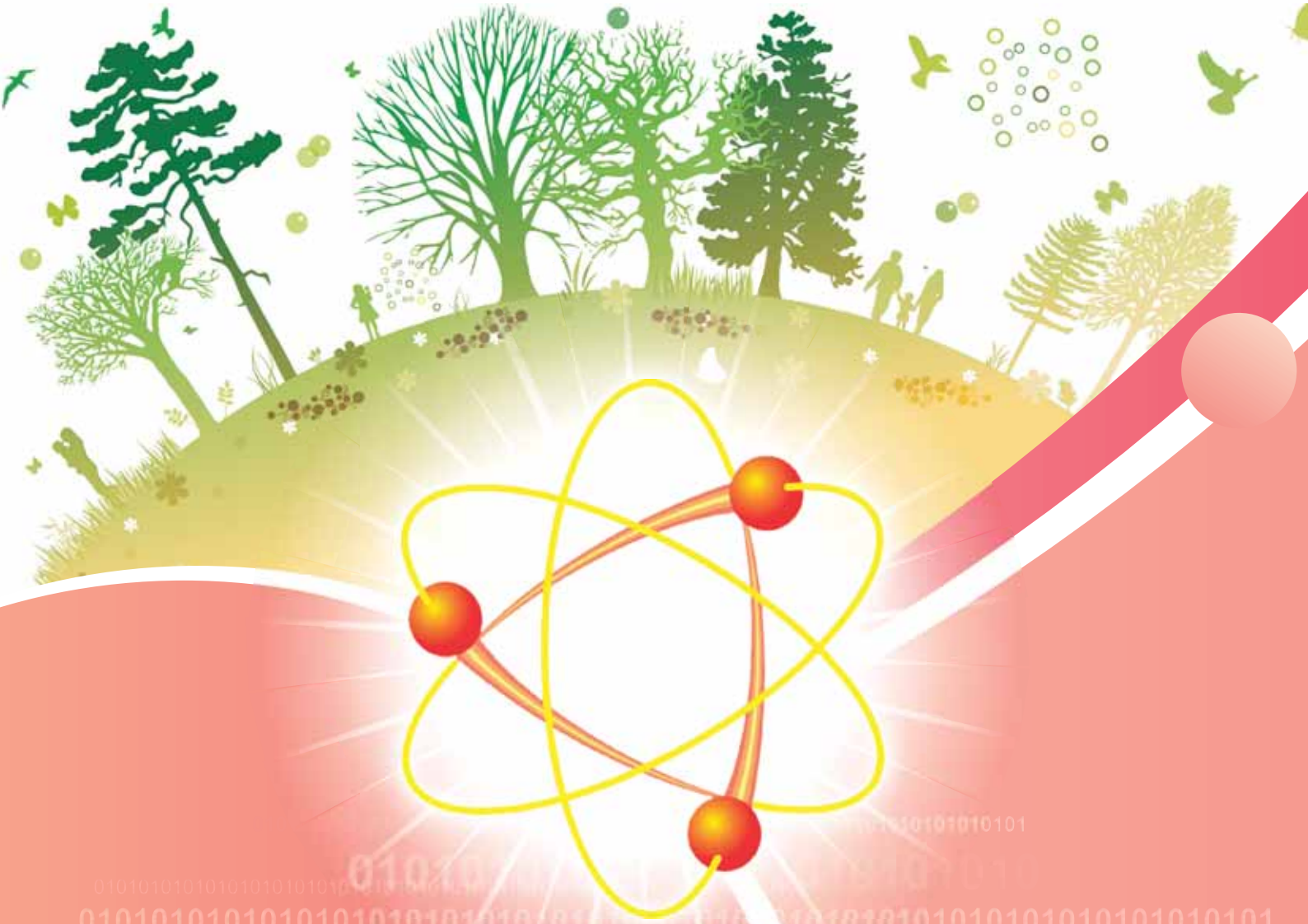
2019 Annual Report

Institute of Nuclear Energy Research
Atomic Energy Council, Executive Yuan



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Contents

1.Preface

To support nuclear safety, we are looking forward to continuous advancements towards green energy from the INER.

Founded in 1968, the Institute of Nuclear Energy Research (INER), is a national institute dedicated to research and development (R&D) on atomic energy technologies.Through half a century of transformations and advancements, INER has become the most established national laboratory in atomic energy research in Taiwan. INER is the sole domestic R&D institute that integrates atomic and green energy related technologies. INER attained impressive research achievements and many awards honored, both domestically and internationally.

In terms of nuclear technology application, we have devoted ourselves to study the equipment safety before and after an operational shutdown of nuclear facilities. Furthermore, in order to properly plan the decommissioning procedures of nuclear energy facilities and related technologies, we studied radioactive waste management strategies for intermediate storage and final disposal. We believe that the operation, decommissioning and waste management of nuclear facilities will demonstrate satisfactory execution results. Recently, INER has independently developed nuclear decommissioning related technologies and also completed the first phase of the Taiwan Research Reactor (TRR) cleaning operation. We have successfully cleaned and decontaminated the waste stored in the fuel pool. In August 2019, INER organized the "International Conference of Nuclear Facility Decommissioning Technology", and invited many professional experts to participate, such as, Taipower Company (TPC), engineering consultancy companies and international guests in the related domains. Uniting related industries to cooperate with decommissioning tasks not only enhances the localized decommissioning capabilities but also assists the decommissioning of domestic nuclear power plants.

When exploring how atomic energy applications can improve civilian lifestyle, INER continuously devotes itself to the research and development of nuclear medicine and advanced medical devices. During the period from March to May in 2019, to respond the drug shortage in Taiwan due to the underproduction of drugs from foreign

pharmaceutical factories, INER had mass-produced"INER Thallous Chloride (T1-201) injection" and "Gallium Citrate (GA-67) injection", the diagnostic radiopharmaceuticals for cardiography, and these pharmaceutical productions had been used for 18,000 patients in two months. Also in September 2019, the Ministry of Health and Welfare approved the use of Sodium Iodide(I-123), developed by INER, as an oral radiopharmaceutical diagnostic. It is developed for detecting neural crest-derived tumors such as Pheochromocytoma and Neuroblastoma. This medicine can be used by domestic hospitals and patients to replace imported drugs, at a lower price.

In terms of green energy technologies, our institute has been engaged in the R&D of related projects since 2002. In addition to obtaining abundant R&D results in solar photovoltaics, wind power, biomass, smart grids, and energy conservation, we are more actively promoting the industrial applications. For example, we considers that a large amount of renewable energy will be integrated into the distribution feeder in the future, which will cause problems such as power flow and failure to transfer power. Therefore, INER is cooperating with Taipower to develop an advanced distribution management system (ADMS) and geographic information system (GIS). Based on the initial test conducted at the TPC Yunlin Feeder Distribution Control Center (FDCC) in April 2019. The results showed that it can effectively improve the dispatch reliability of distribution feeders containing green energy.

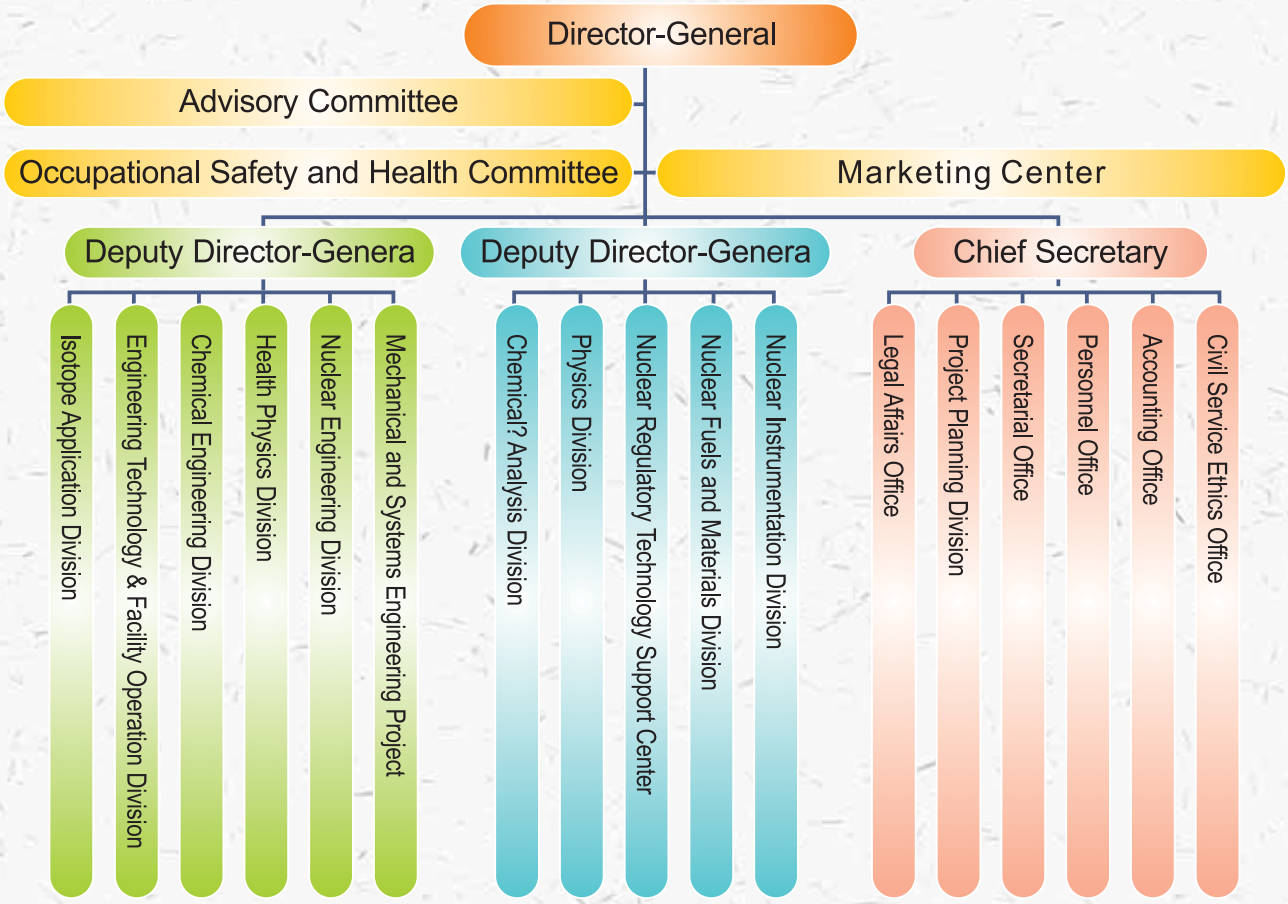
In order to raise awareness for atomic energy, INER cooperated with the Atomic Energy Council (AEC) to host three "Atomic Energy Science and Technology Exhibition" sessions in 2019. Each exhibition exhibited nearly 20 interactive R&D projects related to atomic energy and green energy for the public to learn and experience for themselves. The three sessions attracted 15,040 visitors, successfully cultivating public awareness of atomic energy-related technologies and generated great interest throughout the community.

In the past 50 years since the establishment of our institute, we have faced rapid changes in the external environment. There are still many competitors and challenges in the future. On the basis of inherent development, we will actively adjust the pace of organizational development so that atomic energy scientific research can strive for excellence, and strive to achieve the goals of improving national health, quality of life, and maintaining environmental safety.

Chern-Jing Chen

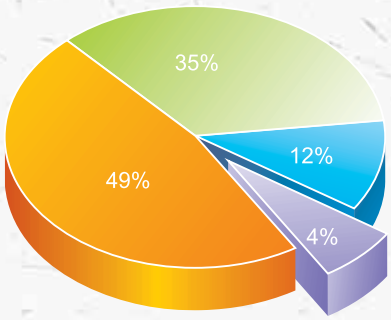
2.Organization Chart、Human Resources and Budgets

Organization Chart of INER



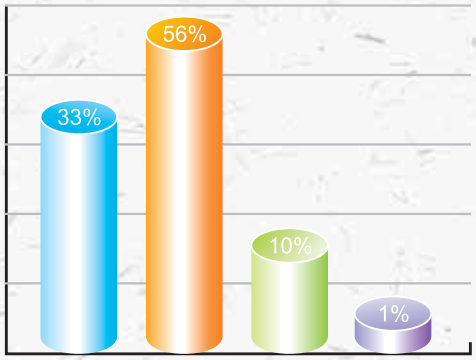
Human Resources and Budgets (Time of data: December, 2019)

Manpower Distribution of INER



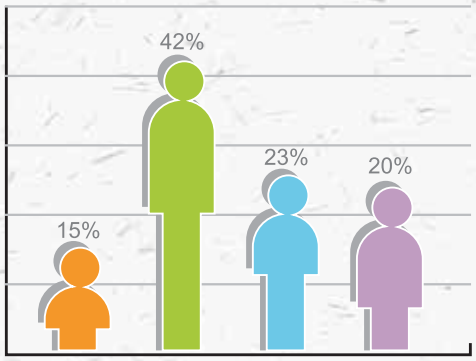
Research Staffs	370 Persons	(49%)
Technicians	264 Persons	(35%)
Administrative Staffs	92 Persons	(12%)
Other Staffs	34 Persons	(4%)
Official Staffs	760 Persons	

Statistics of Educational Background for Research Staffs



Ph.D.	121 Persons	(33%)
Master	208 Persons	(56%)
Vocational School	37 Persons	(10%)
Bachelor	4 Persons	(1%)
Research Staffs	370 Persons	

Statistics of Job Category for Organizational Research Staffs



Researcher	57 Persons	(15%)
Associate Researcher	155 Persons	(42%)
Assistant Researcher	85 Persons	(23%)
Research Assistant	73 Persons	(20%)
Research Staffs	370 Persons	

2019Annual Budget

Unit: Thousand NTD

Item	Number of Accounts	Percentage
Administration and Safety	1,184,974	67.10%
Management, Operation and Maintenance	150,936	8.55%
R&D Projects	330,516	18.72%
Technology Promotion and Service	99,620	5.64%
Total	1,766,046	100.00%

3.Current Major R&D Activities

3-1 R&D of Nuclear Back-end Technologies to Face Nuclear Power Plant Decommissioning and Radioactive Waste Safety Management

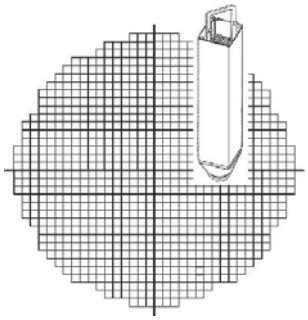
The year 2019 is the commence year of Taiwan nuclear power plant (NPP) decommission. For implementing 2025 nuclear-free homeland policy, NPP in Taiwan shall be permanent shutdown as soon as its 40-year operation license expired. The expired date of the unit 1 and unit 2 of the first nuclear power plant are on December 5, 2018 and July 15, 2019 respectively. The decommission plan has been accepted by the Atomic Energy Council, the safety authority on July 12, 2019.

To face the issues of nuclear power plant decommissioning and radioactive waste safe management positively, INER gradually revised its nuclear safety research area from reactor safety to back-end issues. In 2019, the research of nuclear safety in INER mainly focused on nuclear material management, spent nuclear fuel (SNP) pool cleaning in a decommissioning nuclear research reactor, engineering design and safety analysis of the radioactive waste disposal facility, advanced additive manufacturing process development and the applications of probabilistic fracture mechanics:

- Coupling with 3D power history, the improvement on estimation accuracy of SNF isotope inventories can enhance in-core fuel management, as well as SNF dry storage and final disposal applications.
- Measuring swelling pressure and hydraulic conductivity, bentonite showed its good structure and characteristics of buffer and backfill material for radioactive waste final disposal design.
- Cleaning TRR spent fuel pool, an underwater collection device with flexible bag was developed and the subsequent procedures were established such as dehydration, package, transportation, stabilization, and safe storage.
- Dismantling of TRR calandria, an underwater disc saw system was developed and a series of full size mockup cut tests were conducted. This can be applied to the tasks of the NPP dismantling in the future.
- Grouping a technical team, INER played an important role on engineering design and safety analysis for the Spent Nuclear Fuel Final Disposal Plan in Taiwan.
- Combining robotic arms and MIG automatic welding machines, Wire + Arc Additive Manufacturing (WAAM), a metal 3D printing technology is to manufacture various parts and products with highly complex shape. It saved costs, materials and leading time.
- Introducing the structure analysis modules, Probabilistic Fracture Mechanics (PFM) is to evaluate nuclear reactor pressure vessels. The results can be the basis for plant operation, maintenance, and safety regulation.

3-1-1

Improving the Estimated Accuracy of Spent Nuclear Fuel Isotopic Inventories – Advanced Analytical Technology for Spent Nuclear Fuel Coupling with a 3D Power History



Disposal facilities must be ensured and maintained for the long term safety of spent nuclear fuels. Nuclide inventories in spent nuclear fuels play an important role, because they could affect decay heat, criticality margin and the radiation activity which are important parameters in the safety design of disposal facilities. Due to the improvement of nuclear fuel design technology, there are a variety of different mechanical design, the uranium enrichment and fuel burnup have also been getting higher and higher and fuels have been irradiated under different operating power. All the above reasons could reflect the complexity of spent nuclear fuel, therefore it is necessary to accurately grasp the characteristics of spent nuclear fuels. ORIGEN, a program commonly used internationally, is limited in its ability to input limited information about spent nuclear fuel, making it less accurate. In order to accurately estimate the nuclide inventory, a Spent Nuclear Fuel (SNF) program which combines advanced nuclides analysis technology with a 3D power history is introduced by INER.

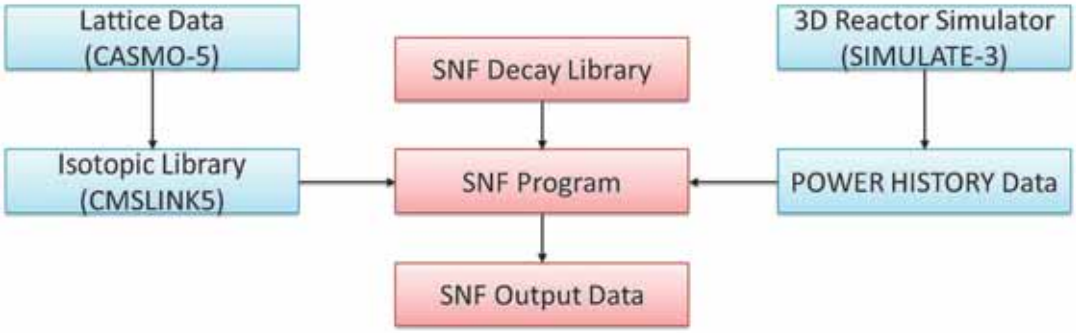


Fig. 1 Calculation flowchart and data flow of SNF

The SNF code can directly use the detail nodal information from core follow calculations performed by CASMO/SIMULATE (Fig.1), so as to achieve the consistency and accuracy of data. One of its features is that the 3D nodal power history is considered in the calculation process (Fig. 2), and even a single rod could be calculated in details. The SNF program is based on the "isotopic summation" calculation method, rather than the empirical formula to estimate the conservative values, to rebuild the initial nuclide concentration in each axial node based upon the discharged burnup of fuel, moderator density history, control rod history, fuel temperature history, boron history and nodal power history. It provides a very simple method for analyzing the spent nuclear.

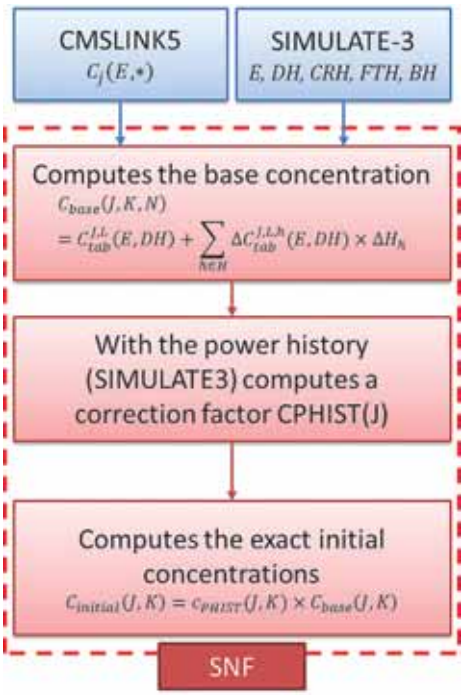


Fig. 2 Characteristics of SNF

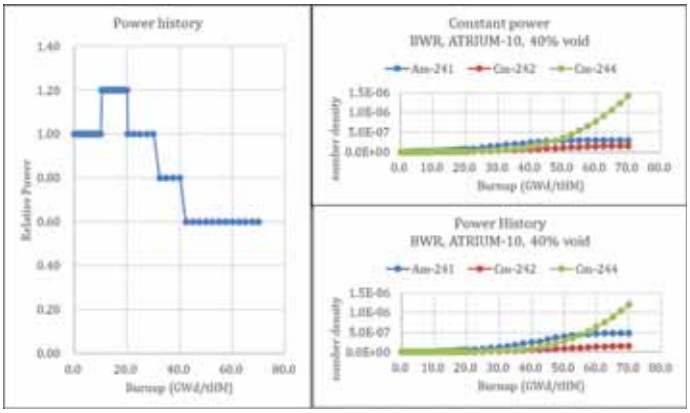


Fig. 3 Differences of Am-241 concentration at constant power and variable power

The number of nuclides in the spent nuclear fuel is very large, and it is impossible to determine their amounts by a single formula or parameter. In Fig. 3, under the condition of constant power and variable power, it can be observed that nuclides have difference at end burnup point. There are significant differences between the nuclide inventories of Am-241 and Cm-244 but Cm-242 is almost unchanged. Fig. 4 shows the results of using ORIGEN-ARP and SNF to estimate the Am-241 in spent nuclear fuels of NPP. There are significant differences of Am-241 in each fuel bundle. Fig. 5 shows the estimation of decay heat of spent nuclear fuels for NPP in 2055 by the SNF program and the NRC RG3.54 rev.1, which proves that RG3.54 rev.1 is relatively conservative.

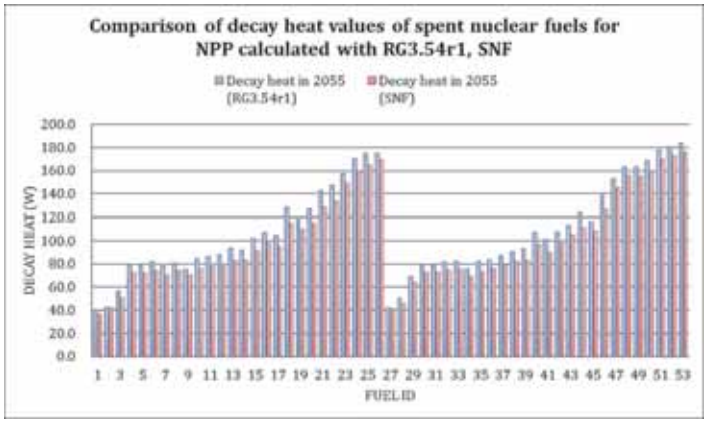


Fig. 5 Comparison of decay heat values of spent nuclear fuels for NPP calculated with RG3.54r1 and SNF

In the United States, Studsvik Scandpower has performed verification of the isotope summation method for SNF, including the decay heat measurements for extremely short cooling times (2 to 14,000 seconds) after irradiation of U-235 and Pu-239 samples, comparison with the ANS decay heat standards, and an experiment to measure BWR and PWR fuel decay heat at the CLAB facility in Sweden. Considering the measurement uncertainty at 2.5%, the difference between the calculated value of SNF and the measured value is generally within 2%, and the comparison results are quite consistent.

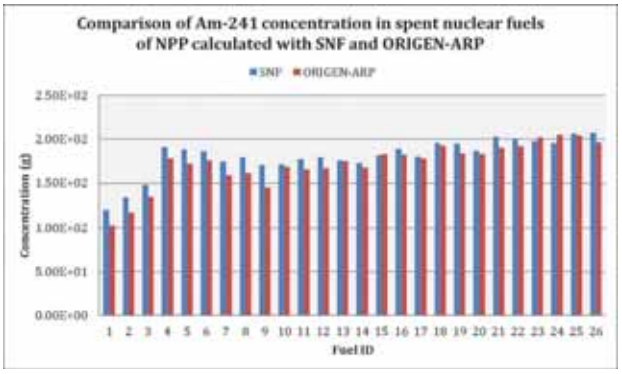
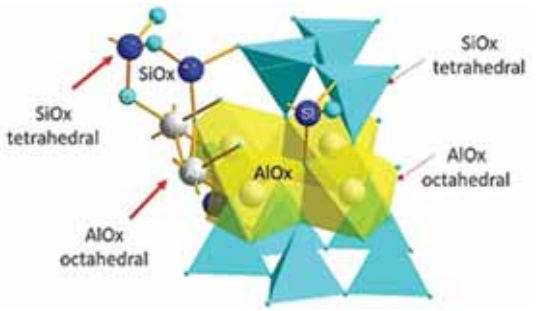


Fig. 4 Comparison of Am-241 concentration in spent nuclear fuels of NPP calculated by SNF and ORIGEN-ARP

The accurate estimation of SNF can provide a favorable demonstration to conservative analysis by ORIGEN. SNF can complement and cooperate with the SCALE/ORIGEN. In terms of disposal facility operation, SNF can provide accurate estimation values of every individual fuel, which will allow operators to know how much safety margin is. In the future, it will be used in the calculation of all spent nuclear fuels, and the development of a database to store the calculation data, providing a relevant application to the fuel management, the dry storage and the final disposal plan.

3-1-2 Bentonite Structure Study and Applications on Final Disposal

Bentonite mineral is composed of flake silicate with layered tetrahedral and octahedral crystal structures. Ions and water molecules can easily pass through the layers. Due to its good characters on clay plasticity, low permeability, high specific surface area, high reactivity, high adsorption and ion exchange capacity, high mechanical strength and high temperature resistance, et. al, It is used as buffer and backfill material for radiowaste final disposal design.



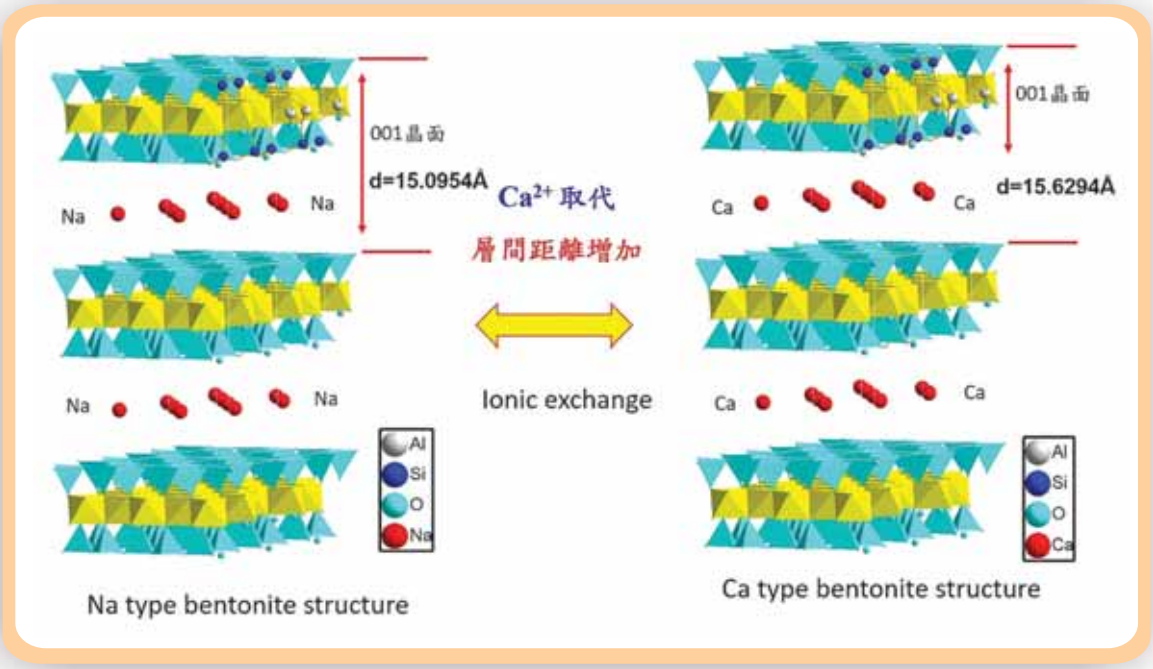


Fig 1. Structural changes of sodium bentonite and calcium bentonite

Fig 1 has shown the distance of bentonite [001] crystal plane change with the introduction of ions and water in the intermediate layer and cause expansion or contraction. When the Na^{+} replace by Ca^{2+} by leaching, the distance between the layers will increase from 15.0954Å to 15.6294Å. In Fig 2, the XRD small angle diffraction signal peak position moves forward to a small value 2θ position from 5.85 to 5.65.

Through the properties and characteristics of bentonite study, for the buffer quality control in future applications.

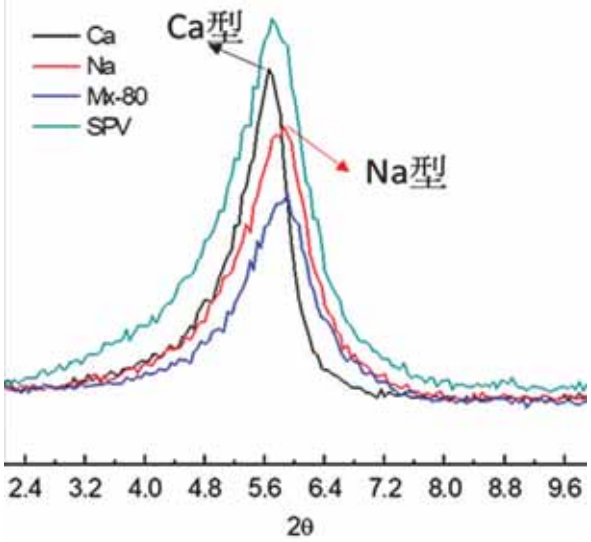
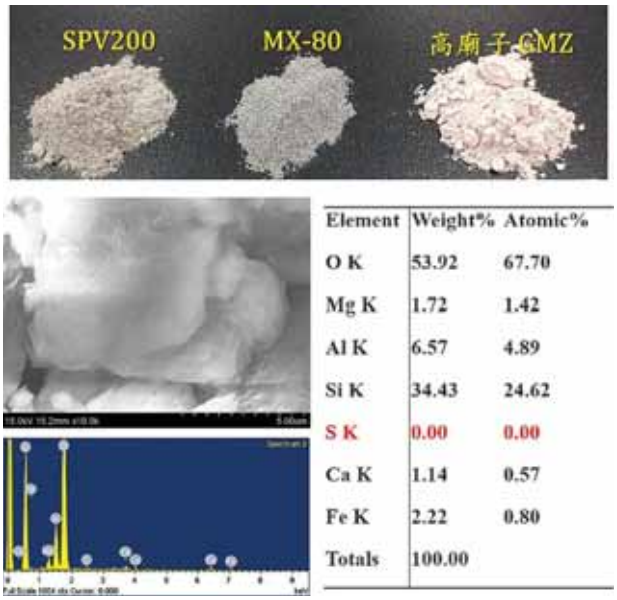


Fig 2. XRD small angle diffraction analysis of bentonite



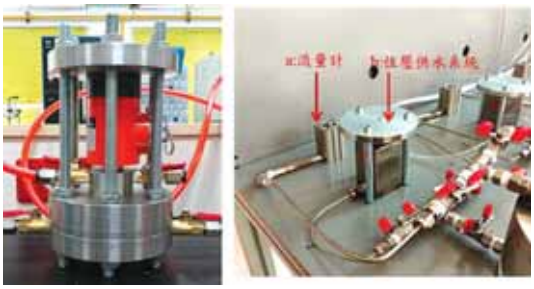
Element	Weight%	Atomic%
O K	53.92	67.70
Mg K	1.72	1.42
Al K	6.57	4.89
Si K	34.43	24.62
S K	0.00	0.00
Ca K	1.14	0.57
Fe K	2.22	0.80
Totals	100.00	

Fig 3. Bentonite SEM/EDS analysis result

The bentonites are analyzed by SEM/EDS. From the Fig 3. analytical results of EDS shows that the sulfur content is very low. The EDS detection limit can be used as a quality control tool for screening sulfur content in bentonite and reduce the corrosion effect of materials.

The research of bentonite is focused on measuring the expansion pressure and hydraulic conductivity.

To study swelling pressure and hydraulic conductivity, Figure 4 showed that the ionic strength in water greatly influenced on swelling pressure and hydraulic conductivity of the buffer material. The results provides the design specifications of the high radiowaste final disposal application, such as buffer material density and groundwater quality.



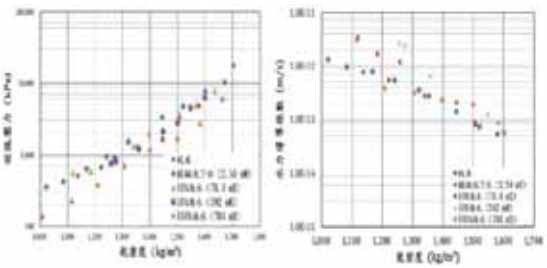


Fig 4. Measurement and analysis of swelling pressure and hydraulic conductivity

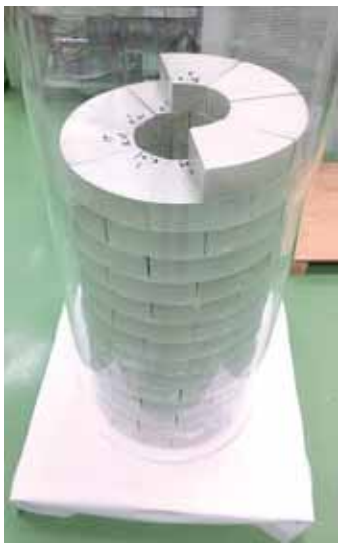


Fig 5. The ionic strength effect on the and the medium size model of bentonite.

Fig 5 showed the effects of different ionic strength water quality on the swelling of bentonite and the model of medium-sized bentonite blocks. The concentration of sodium chloride ion will greatly affect the swelling capacity of bentonite.

The further research works will on buffer design and numerical simulation calculations for a final disposal project.

3-1-3

Practical Experience and Technical Capability of Nuclear Material Processing - Removal of Uranium Powder from TRR Spent Fuel Pool

TRR spent fuel pool cleaning is the first stage work described in the Decommissioning Plan of Taiwan Research Reactor (TRR) approved by the Atomic Energy Council in 2004. Any radioactive substance has to be removed out of the spent fuel pool so as to relieve the potential risk of environmental contamination due to pool water leakage.

TRR spent fuel rods were stored in the spent fuel pool over the operational period. Uranium was washed out from damaged rods and became sludge form which deposited all over the bottom of the pool. An underwater device with flexible bag was used to scarify and collect the sludge into a sedimentation tank. Subsequent procedures were established in accordance with Defense in Depth and ALARA, such as: dehydration, package, transportation, stabilization, and safe storage, etc. In 2019, all of the sludge has been removed and been stabilized successfully. The pool water of the spent fuel pool keeps a lowest level.

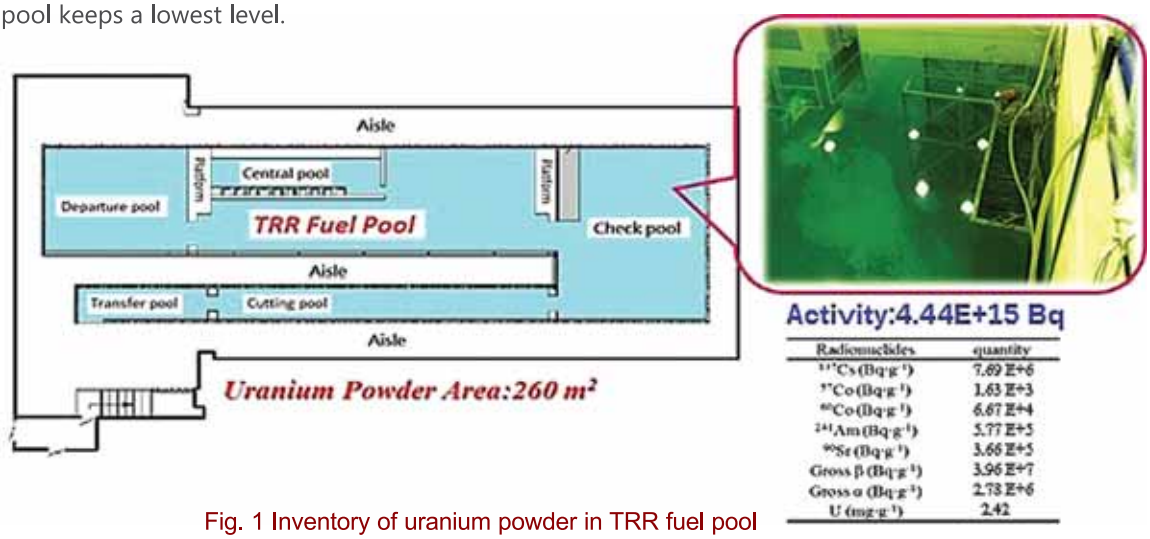


Fig. 1 Inventory of uranium powder in TRR fuel pool

Pool Cleaning

The sludge was difficult to removed due to its wide spread over the pool bottom and the deep pool water. INER surveyed technologies and built innovative systems, optimized operating conditions, integrated the subsequent high-radioactive waste treatment process, limited secondary waste production.

Patent obtain: "Collection Methods for High-level Radioactive Powders Underwater", "Material collection tanks and Operation method"

Fig. 2 Uranium powder Cleaning process in pool

Fig.3 Uranium powder transporting package

Stabilization and storage

Utilize the INER's hot room with shielding, negative pressure filtering and heating processing functions as the stabilization place for uranium powder, and jointly develop the stabilization processing technology with the U.S. National Laboratory. After equipment construction, test verification and actual operation, high temperature sintering stabilization and vacuum packaging procedures were adopted to successfully complete the stabilization of uranium powder. And design the transport lead cans with transportation and shielding functions, and temporary storage boxes with storage, shielding and re-removal functions, and package and transport the stabilized uranium powder products to the temporary storage boxes for safe storage in accordance with IAEA inventory verification needs.

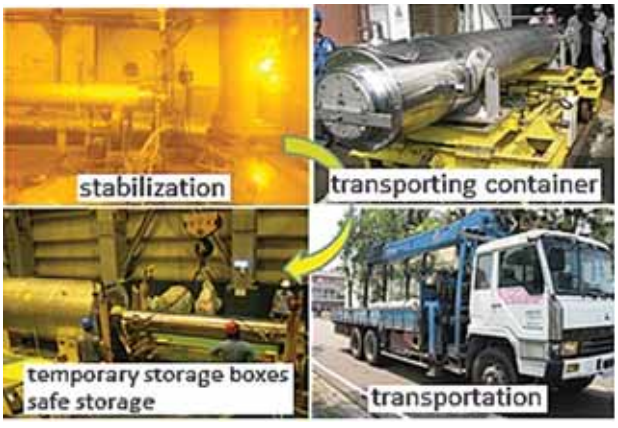


Fig.5 Transportation and storage of uranium powder stabilization products

Transporting package

Uranium powder has high radiation and high pollution radiation characteristics. For subsequent stabilization operations, the uranium powder can be transported in a "Deep Defense" design. The uranium powder cans are packaged in layers, and sealed and transported in lead bags, lead shielded containers, and sealed. Boxes and other packages, including a total of two layers of shielding and three layers of sealed filtration, meet the transportation standards and reduce the radiation dose of personnel, while minimizing the risk of harm. By transporting the packages by stacker, the uranium powder was successfully transferred to the stabilization operation Place to ensure environmental radiation safety.

Fig.4 Stabilization sites for uranium powder packaging and delivery

Comply with TRR decommissioning schedule

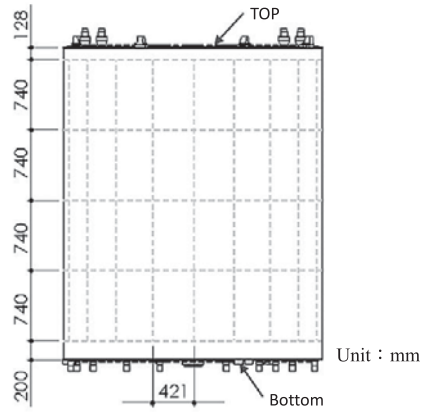
The uranium powder was leaked from the TRR defective fuel rod, and belongs to the nuclear material of the IAEA. In order to meet the declared quantity, overcome the high radiation intensity factor of uranium powder, complete the sampling of uranium powder and radiochemical analysis of the nuclear species, provide material-to-material comparison data of stabilizing products, understand the weight percentage of uranium and thorium contained, to accurately calculate the weight of uranium and thorium in uranium powder, and supporting materials of the material account inspection will be submitted to the IAEA to confirm that the entire nuclear material processing process complies with the nuclear material management requirements, and to enable TRR decommissioning to continue smoothly, in order to meet the legal timetable.

3-1-4

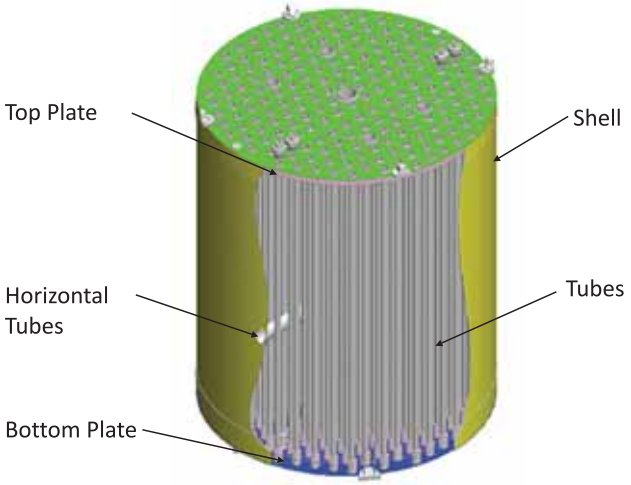
Dismantlement of TRR Calandria Development of An Underwater Disc Saw System

TRR calandria (reactor vessel) shall be dismantled in 2021 according to the Taiwan Research Reactor (TRR) Decommissioning Plan. Institute of Nuclear Energy Research (INER) collaborating with domestic vendors has been developing an underwater disc saw system for segmenting the shell of TRR calandria.

A series of simulation under water cutting tests onto a full size mockup calandria were conducted. The result showed that the disc saw cutting system can fulfilled the requirement of TRR calandria segmentation plan. The design can also be applied to the tasks of the nuclear power plant dismantling in the future.

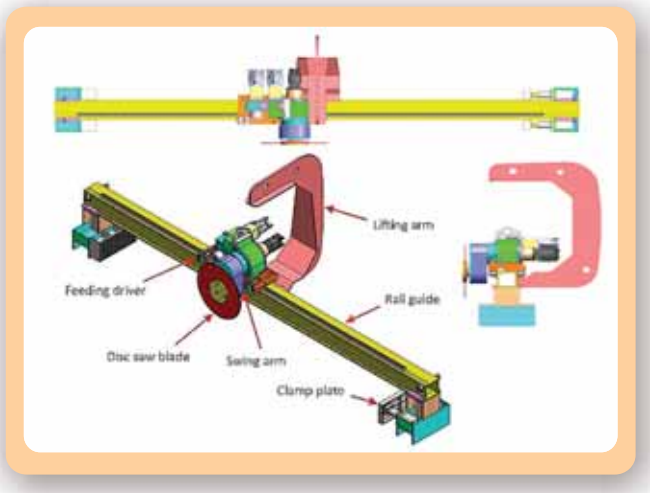


TRR calandria shell segmentation plan

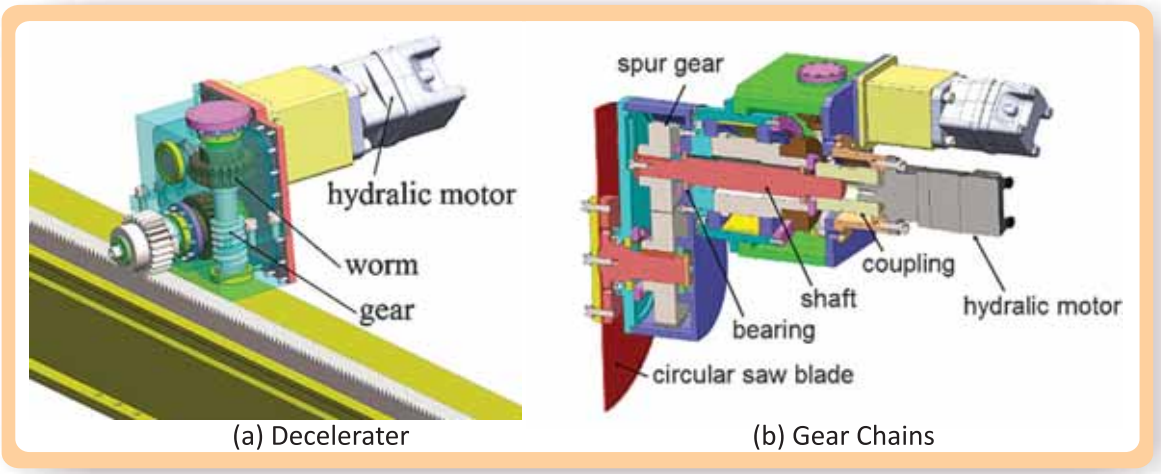


TRR calandria

The disc saw cutting system is divided into three units - the control unit, the hydraulic power unit, and the disc saw main body unit. The main body of the disc saw is composed of the rail guide, the swing arm, the feeding driver, the clamp plate, the lifting arm, and the saw blade. The main body of the disc saw is immersed into the water during operation. Thus, the structure parts are made of stainless steel 304. The portable control unit is used to control the blade moving and cutting. The driving power is provided by a hydraulic power unit. Water soluble ethanediol solution is used as the power transmission medium so as to avoid decontaminating the working pool.



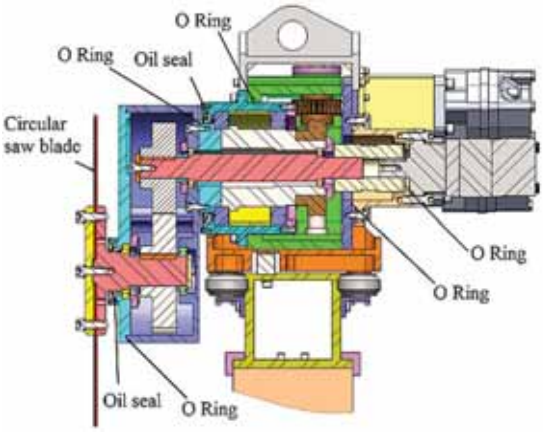
Main parts of the disc saw system



(a) Decelerater (b) Gear Chains

Driving Power transmission system

The developed underwater disc saw has been tested in the simulation pool. In these tests, the disc saw was installed on the simplified full size calandria mockup in the water, and cut the shell of this mockup successfully. The tests not only prove that the developed underwater disc saw can meet its design functions but also provide the chance to verify which portions can be improved and find out the better operation parameters.



Sealing

TRR Calandria Mockup

Simulation Cutting Test

The first disc saw cutting system can be used in a high radiation water environment. It will be applied for segmenting the shell of TRR calandria in the future. The application of a new design invention patent has been submitted to the Intellectual Property Office, MEAROC. The patent application number is 108137220.

3-1-5 Spent Nuclear Fuel Final Disposal - Engineering Design and Safety Analysis Technology

Main Focus of 2019 -Establishment of INER Technical Teams and Technical Plan

The planned schedule of the disposal program in Taiwan is from 2005 to 2055. INER has played an important part in the development of facility engineering design and safety analysis. The milestone of the first phase of the program is to propose a "Feasibility Assessment Report for the Spent Nuclear Fuel Final Disposal in Taiwan"(SNFD2017 report), which has been approved by the AEC in 2018. Meanwhile, INER has listed technical requirements for the second phase of the program, and has been preparing for the establishment of the basis of safety case since 2019. INER has already established the technical teams and technical plan for site selection of the program.

- The project is managed by the Deputy Director-General of INER, applying the matrix project management method. And the teams are organized by domestic and international organizations, and academic research organizations.
- The project is co-managed by 4 division directors of INER, and is participated by 7 divisions, more than 70 professionals. The teams are led by the mid-level supervisors, which form a cross generation management team, and facilitate the transferring of the technologies.
- Establishment of research teams organized by young investigators as the major force, continue to solve this national-level mission.

Development of unmanned vehicle aeromagnetic prospection technology

Site Characteristics Description-Indispensable to Engineering Design and Safety Analysis

In order to integrate site characteristics, engineering design, and safety analysis, INER has adopted the experience from SKB Sweden, and has preliminarily incorporated SDM (Site Descriptive Model) into the development.

The SDM investigation team has been set up to facilitate the improvement of the technologies and the sharing of the results, to develop site investigation technologies and the application of established model, and to hold and participate in domestic and international conferences and workshops, in order to enhance technical exchange and update information. According to the improvement item of the Regional Characteristics Investigation Technology of 108-109 plan (TPC), INER has been developing aeromagnetic prospection technology using unmanned vehicle.

Development of Engineering Design and Localization Needs

Introduction of the Swedish KBS-3 system, and establishment of design alteration capability in the localization process. The technical development in 2019 includes:

(1)Canister performance analysis: Establishment of proper criticality analysis technology, for the assurance of subcritical safety. Establishment of confining pressure-resistant analysis technology, for the maintenance of the space inside the canister. And establishment of shear force-resistant analysis technology. The canister should remain intact in the deposition hole under intersecting fracture conditions of all angles and positions.

(2)Buffer materials performance analysis: Improvement in design capability of buffer materials compacted density, for the maintenance of water-blocking. Establishment of canister performance analysis technology, for the maintenance of canister central position in the deposition hole. And establishment of buffer materials performance analysis technology, for the maintenance of buffer materials properties in the deposition hole.

(3)Development of disposal facility layout technology: Improvement of deposition spacing design, for the concerning heat issue and the maintenance of buffer materials properties. Intersecting fracture avoided design, for the reduction of hazard probability led by earthquakes. And improvement of deposition hole and tunnel stability design, and analysis of fracture infiltration.

Improvement of Safety Analysis and Development of Safety Case Methodology

Development of MeSA safety case methodology of OECD/NEA based on key elements of IAEA-SSG-23. A few important research items in 2019 include:

(1)Definition of FEPs influence: Establishment of FEPs database, for the long-term knowledge management. Expert meeting for interdisciplinary discussion of technologies and needs. And development of performance analysis and experimental verification for barrier system issue.

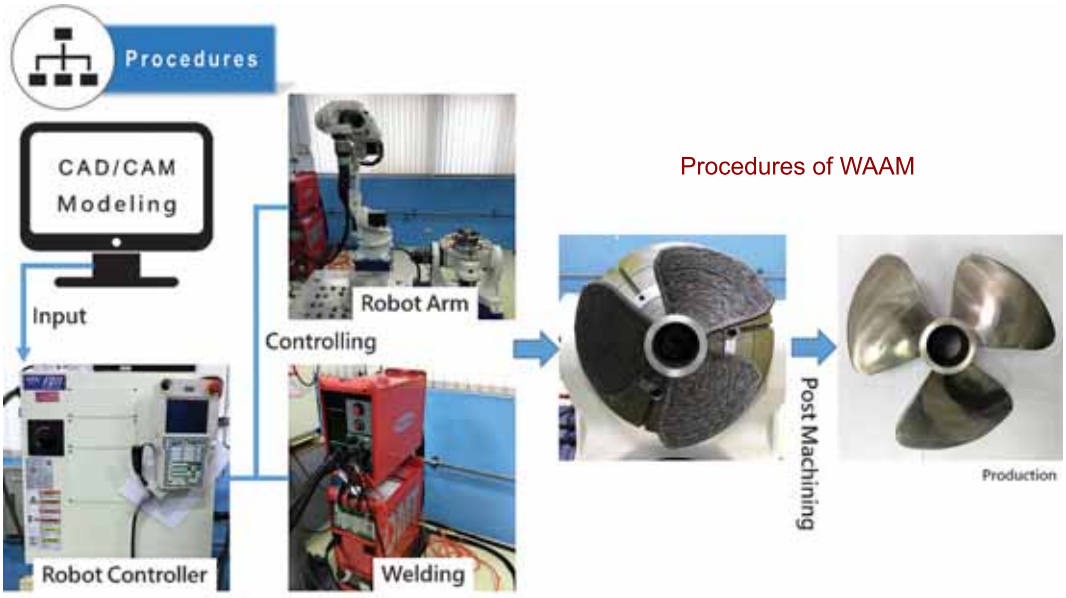
(2) Reference evolution and scenario development: Definition of scenarios and outcomes of nuclides release due to possible containment deterioration caused by external influence (plate movement and climate change) and internal influence (deterioration of barrier performance). And improvement of communication using story board.

(3) Development of safety analysis model chain: Establishment of quantitative model and data inventory based on FEPs and safety function scenario development, and establishment of model connection between upstream and downstream.

Reference evolution and scenario development story board of corrosion (up) and earthquake (down).

3-1-6 Technology of Wire+Arc Additive Manufacturing

Wire + Arc Additive Manufacturing (WAAM) is one of the 3D metal printing technologies. By combining robotic arms and MIG (Metal Inert Gas) automatic welding machines, the metal products with high strength and high geometry complexity could be manufactured. It provides benefits of cost-saving and shorter-time in preparation than the casting manufacturing. During the manufacturing, CAD / CAM software is used to achieve the 3D profile and the welding paths of the final product could be simulated before the manufacturing. The INER-developed welding parameters are used to make the laminated manufacturing layer by layer. At the same time, the relevant simulation software, Sysweld, can be used to evaluate the weldment. The monitoring for the distribution of stress and strain during the welding process is helpful to prevent weld defects. Based on these technologies, welding residual stress and weld defects caused by multi-layer welding can be reduced significantly. WAAM can produce the approximate geometry of the final product in a short time with the mechanical properties meeting the requirements of the relevant specifications and significantly reduce the manufacturing time and cost.



Procedures of WAAM

WAAM is a technology that integrates traditional arc welding equipment and weld metals on a robotic arm or CNC machine to perform layer-by-layer welding manufacturing. Its advantages are given below. 1. suitable for large components, 2. high efficiency, 3. reducing the manufacturing time compared to traditional CNC manufacturing, 4. decreasing labor costs and material scrap. At the same time, ASTM standards can be met to ensure product quality.

Manufacturing time for various parts

Properties

	Materials	Ultimate stress (MPa)	Yield Stress (MPa)	Elongation (%)
ASTM Specification	304 Plate (ASTM A240 304)	515	205	40
	304L Plate (ASTM A240 304L)	485	170	40
	304H Casting (ASTM A351 CF8)	485	205	40
	F304 (Forge Product)	515	205	30
WAAM Test	308L (Horizontal)	544±2	308±8.5	46±3.6
	308L (Vertical)	528±5.7	286±10.9	46±8.1

Mechanical properties of SS 308L by WAAM

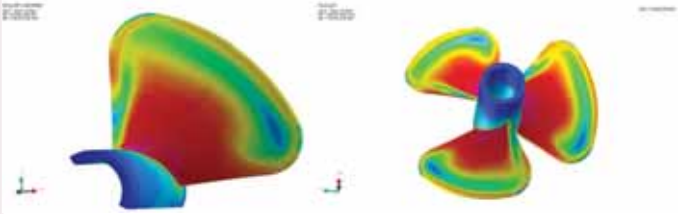
WAAM can directly manufacture 3D models with weld metal, which are designed by computer software. The mechanical strength and performance of the manufactured products can meet the industrial specifications, which are difficult to achieve by the other metal AM technologies.

This technology can easily combine with simulation software to analyze the welding residual stress and deformation of the product for the evaluation of product performance and remaining life. This facilitates subsequent product maintenance and monitoring.

Compared with the other additive manufacturing technologies, WAAM is more flexible in the manufacturing and can be operated in the atmosphere environment. It can also be used for test sample or mold manufacturing before the production stage, reducing a large amount of lead time and costs, and improving production efficiency. On manufacturing a small amount of diversified products, using this technology can reduce time and costs in the mold making and improve product competitiveness.

WAAM realize the 3D models to real parts

WAAM Simulation



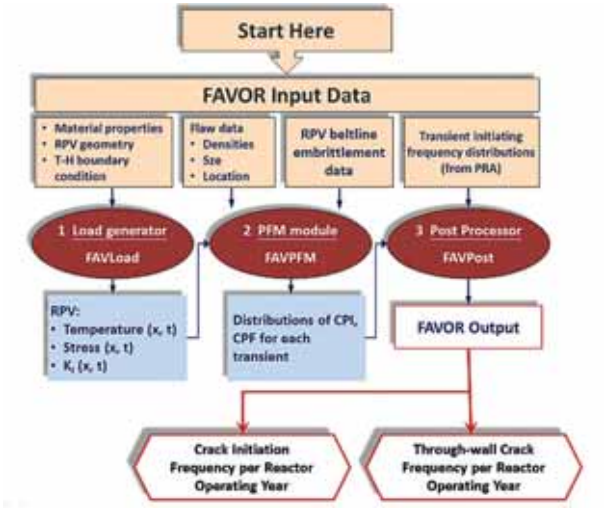
WAAM Simulation

WAAM is suitable for making large dimensions, small amount, and diversified products, in particular, precious metals.

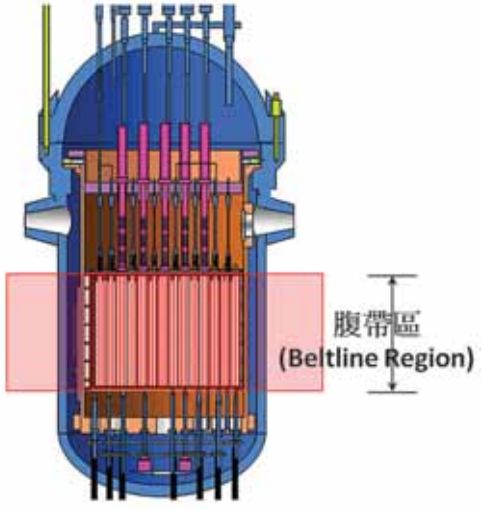
The mechanical strength of WAAM-manufactured products is similar to its base metal strength, which can meet the industrial standards, and has relevant specifications to follow, such as ASTM, which can ensure product quality.

3-1-7 Probabilistic Fracture Mechanics Evaluation for Nuclear Reactor Pressure Vessels

The reactor pressure vessel (RPV) is the most important pressure-boundary component of nuclear power plant. During the power generation, RPV has to withstand high temperature, high pressure and high radiation environment. Hence, the brittle fracture of RPV needs to be strictly prevented after long term operation. INER introduced the probabilistic fracture mechanics (PFM) technology that considers all parameters statistically and performs the fracture mechanics analysis iteratively to obtain more reasonable results. PFM analysis can provide more objective results by simulating any potential factors and therefore can be the basis for plant operation, maintenance, and safety regulation.

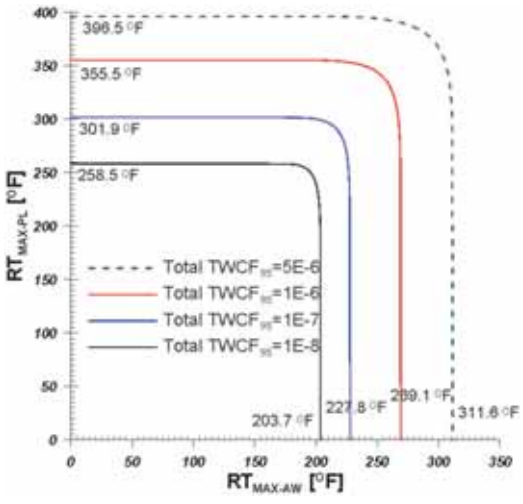


FAVOR data streams flow and analysis process



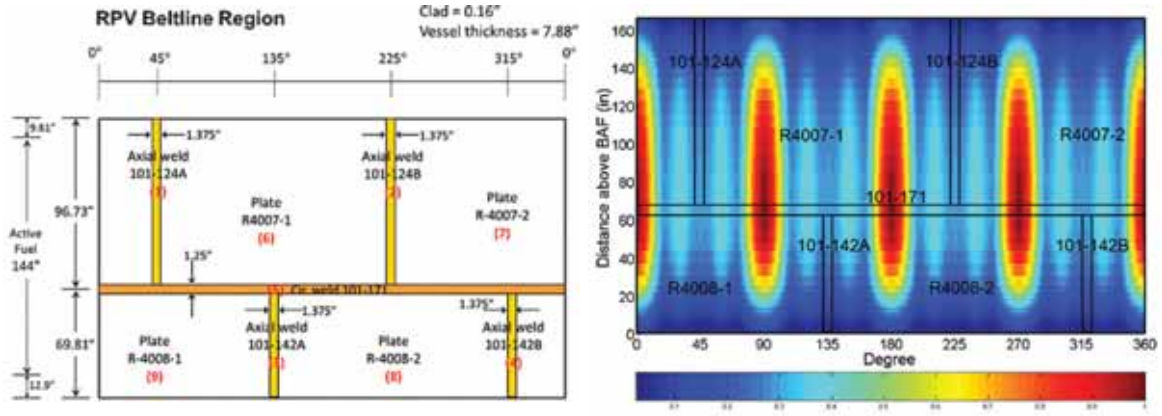
The beltline region of RPV

RPV is a large pressure-retaining container which is required more structural reliability. The regular inspection and evaluation should be performed to ensure the structural integrity. The PFM approach has been widely used for RPV integrity evaluation by international utilities and regulatory bodies. Based on the risk-informed concept, the U. S. Nuclear Regulatory Commission (NRC) made the PTS (Pressurized Thermal Shock, PTS) rule for Pressurized Water Reactors (PWRs), and decided the inservice inspection relief coverage of shell welds for Boiling Water Reactors (BWRs) according to PFM analysis results. Also, PFM approach has ever been applied to determine the operational limit and evaluate other potential degradation mechanism of RPVs. Collaborating with Oak Ridge National Laboratory (ORNL), INER introduced the PFM FAVOR code sponsored by U.S. NRC. FAVOR can simulate radiation embrittlement related properties, flaw distributions and hypothetical transients in the most appropriate way to analyze the potential fracture risk of RPV.



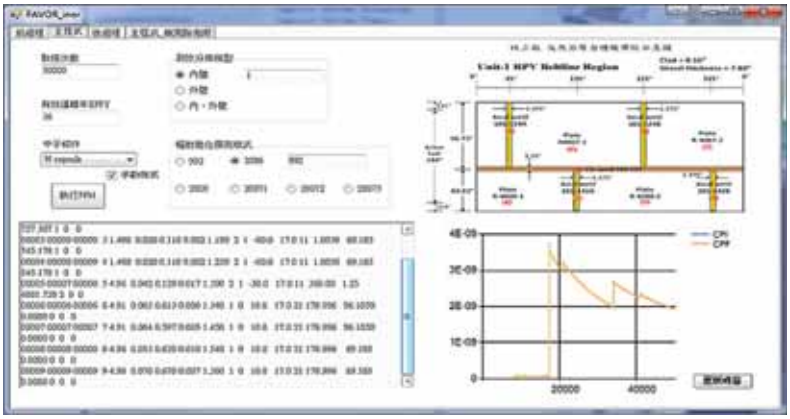
Determination of RT_{NDT} limits based on different acceptable risk

INER has established FAVOR PFM analysis models for domestic RPVs. Considering the most critical conditions, the low-temperature over pressure (LTOP) transient of BWR, and the PTSs of PWR, the PFM analyses have been performed. All analysis results meet U.S. NRC's safety goal and indicate that the domestic RPVs can provide sufficient structural reliability to ensure its structural safety.



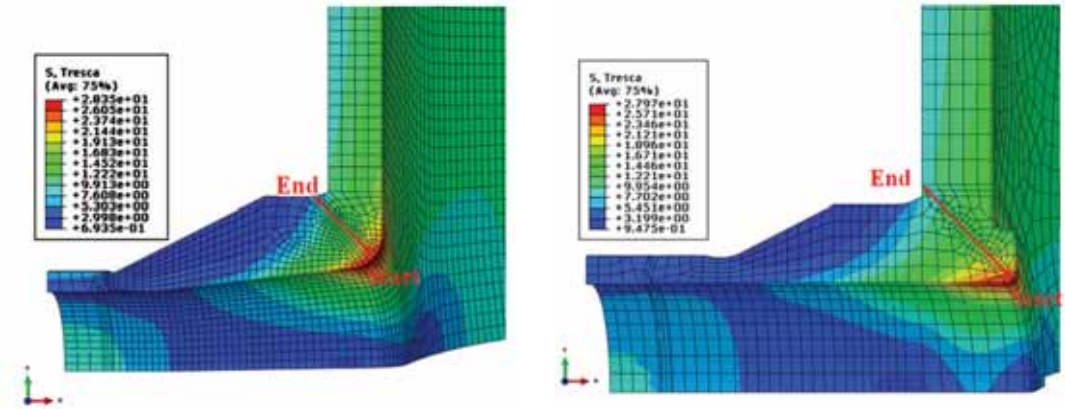
Analysis model of PWR RPV beltline region and the neutron fluence distribution

INER developed a graphic user interface which combines FAVOR code, domestic RPV models and parameters, as well as loading transients, to provide a convenient analysis tool for promptly evaluating Taiwan domestic nuclear power plants.



The graphic user interface of PFM analysis for domestic RPV developed by INER

INER will introduce the advanced version of FAVOR code, v 16.1 by continuously communicating with foreign research institute. Also, INER will enhance FAVOR to deal with RPV nozzle geometries and stress distributions. The enhanced version will be applied to evaluate essential inservice inspection coverage for nozzles and provide the operational limit of RPV. Present work could modify the operation and maintenance strategy to reduce the cost and person-rem exposure of nuclear power plants in Taiwan.



Stress analysis models of PWR inlet and outlet nozzles

3-2 2019 Research on Environmental and Energy Technologies

The government in Taiwan has launched the "Energy Transition" policy since 2016, which focuses on "green energy generation," "circular economy," and "low-carbon environment;" furthermore, the so-called "5 plus 2" flagship programs are incorporated to promote industrial development and realize the designated goal. The Institute of Nuclear Energy Research (INER), with the status as National Laboratories, supports strategic planning of national energy policy, aims to develop multiple energy technologies, and hopefully promotes industrial applications as well as competitive capability.

To comply with national policy, INER has been devoted to R&D on environmental and energy technologies, for which the major achievements in 2019 are categorized and summarized in the following sections.

1.Energy Saving: Implement plasma coating processes on smart energy-saving applications, and provide the future development direction of new green energy-saving industry, which promote energy conservation, carbon mitigation, and sustainable development. INER commissioned an arc-plasma coating system to plate electrochromic films for smart-window related industries. The superior characteristics of reducing energy consumption and expected significant cost reduction would be beneficial to promoting future applications. Furthermore, INER together with a domestic energy-saving film manufacturer successfully co-developed a unique roll-to-roll hybrid plasma modular coating system, to produce a series of top products of heat-reflective solar control film. The high-performance energy-saving film G50 was certified by the Industrial Bureau Nano Mark in 2019, and the application for the green building material label is currently under review by the authorities.

2.Energy Storage: Deploy diversified energy storage portfolio in electric grid, to enhance the penetration of renewable energy and improve the stability of power supply, in which vanadium redox flow battery (VRFB) is expected to be an important option in future grid-scale energy storage systems. INER has developed innovative low-cost membranes in the field of VRFB, e.g., the modified polybenzimidazole (PBI) membrane exhibits favorable characteristics compared to Nafion, with the energy efficiency only 2% less while the price barely about 20%. Through developing materials with high cost-performance ratio, INER may help domestic membrane industry to reduce VRFB system cost, enhance competitiveness and penetrate into international markets in the near future.

3.Clean Energy: High efficiency, low emission (HELE) energy technologies, including fuel cell, gasification, etc.

(1)Solid oxide fuel cell (SOFC): Develop SOFC power generating system, which features high energy efficiency, low pollutant emission, and abated carbon footprint, to provide a stable and flexible HELE energy option. INER assembled the first kW-level stack with self-made metal-supported cells (MSC) by plasma spray and indigenous components to execute further performance tests. In addition, more achievements are illustrated as follows: e.g., low-temperature MSC shows great power characteristics at the operation temperature lower than 600oC, the product from ceramic-based anode-supported cells (ASC) with novel geometry design has been realized via a small-scale production line, cell product with YSZ electrolyte will undergo kW-scale system pilot verification, and fuel reforming nano-catalyst demonstrated resistance to carbon deposition for longer lifetime. Through technology transfer and collaboration, INER assists domestic manufacturers to establish industrialization platform

imbedded with indigenous core fabrication technologies, for both industrial development and environmental protection.

(2)Gasification: Convert solid carbonaceous fuel via gasification to syngas and heat, which can be utilized to generate electricity as clean energy supply as well as to synthesize chemicals, to be complied with the mainstream of green energy generation and circular economy. INER adopts a design practice of dual fluidized-bed (DFB) gasification equipment that features near-zero nitrogen syngas composition with improved heating value through feeding pure steam as the gasifying agent. A pilot facility of a 100kW-class gasifier has been commissioned, and testing with biomass feedstock has been performed to verify continuous and stable operation of the DFB. INER develops gasification-based technology for energy supply systems, aiming at clean utilization of carbonaceous resources, abated carbon emission and resources recovery of waste; at the same time, it is pursued to achieve higher electrical efficiency, while preserve supply flexibility and system resilience.

4.Smart Grid: Apply energy information and communication technology (EICT) in district smart grid, and develop integrated power flow analysis program and feeders dispatching platform, to effectively increase the proportion of renewable energy on feeders, so as to achieve the goal of "smart integration." INER and Taiwan Power Company (TPC) joined force to develop the domestic Advanced Distribution Management System (ADMS) by integrating SCADA (Supervisory Control And Data Acquisition) and GIS (Geographic Information System). This system has been operating online in TPC Yunlin District since April 2019, and successfully reducing the duration of power outage. This outcome sets an important foundation for stabilizing the fluctuation in voltage, from which the proportion of renewable energy can be increased. Hopefully, the technical breakthrough will improve local industrial technology and applications of innovation industry as business opportunities for the power market in Southeast Asia.

5.Circular Economy: Reutilize resources through energy integration, and develop circular economy following global trend, to accomplish the vision of sustainable development and environment rehabilitation, in which application of bio-potential would be beneficial to enhancing the establishment of energy resources independence. INER commissioned the first domestic high-throughput automation platform, especially for strain development dedicated to industrial biotechnology, to accelerate the development of bio-tech. strains and master key technologies in industrial biochemical production processes. Taking poly-lactic acid (PLA) bioplastic as an example, within a short period the high-throughput facility successfully screened strains that greatly improved LA productivity. With the high-throughput strain screening platform, it is expected to improve the efficiency of product strain and reduce development cost, which would be dedicated to promoting biorefinery industry toward sustainable environmental development.

In summary, INER has been engaged for years in developing novel and renewable energy technologies, among which some fields catch up with international standard. Looking ahead, INER will comply with national policy of sustainable development, command indigenous key technologies, develop clean production and environmental protection technologies, while consolidate circulating network for energy and resources; ultimately, it is hoped to achieve the policy goal of clean environment with carbon abatement, and promote indigenous green energy industry.

3-2-1 Smart car-sunroof using arc plasma fast coating technology

In response to the global warming effect, countries attach importance to energy conservation and carbon reduction, in which intelligent electrochromic glass with adjusted visible light and blocked infrared heat source, can solve the problem of reducing power consumption for air conditioning and lighting. For the future green energy-saving market, such component is regarded as one of the most important new technologies, and is expected to have 5.6 billion U.S. dollars in 2025 business opportunities. In the traditional electrochromic components, magnetically controlled sputtering technology is the key process. Due to the slow deposition rate of magnetically controlled sputtering methods and the high cost of coating equipment, smart components such as car sunroofs and luxury cruise glass are still not widely used in the market today.

After cooperating with Taiwanese glass manufacturers for two to three years, the Institute of Nuclear Energy Research (INER) has utilized the new plasma technology from in-house research and development for plating color film, to break through the cost barrier of high-priced foreign electro-chromic elements. The results provide solutions to domestic smart-window related industries to enhance visibility internationally. The expected significant cost reduction would be beneficial to promote application of electrochromic window in green buildings and cars with high performance.

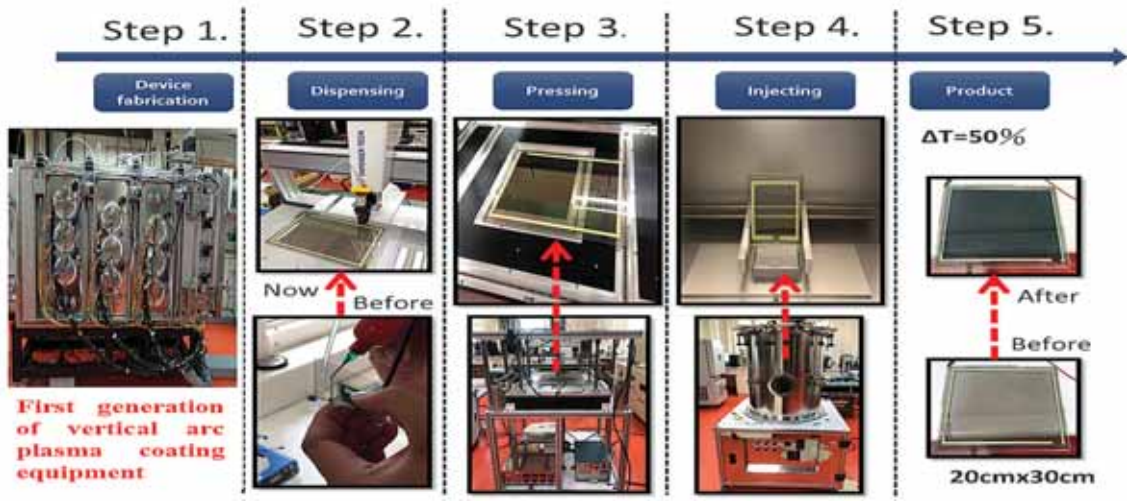


Fig. 1, Integration, electrochromic technology Product Development: from the upstream arc plasma source, midstream special process formulation and packaging system equipment integration and development to the downstream electrochromic product output.

The construction of a domestic original, large-scale low-cost arc plasma coating system results in 1/3-1/2 times the equipment cost to the traditional magnetically sputtering equipment, 3-5 times the coating rate, and 1/3 times the overall electrochromic film cost, which greatly improve the price advantage of the product.

Cooperation with domestic glass manufacturers to develop electrochromic components provides the characteristics of low-cost and rapid electrochromic color. The components can isolate 93.8% and 95.3% of the sun radiation heat and ultraviolet light, respectively; while block more than 62.3% of the thermal infrared, when turning back to transparent. So, it can significantly reduce the energy consumption of air conditioning expenditure, help to save the burden of air conditioning, while benefit energy saving and carbon reduction.

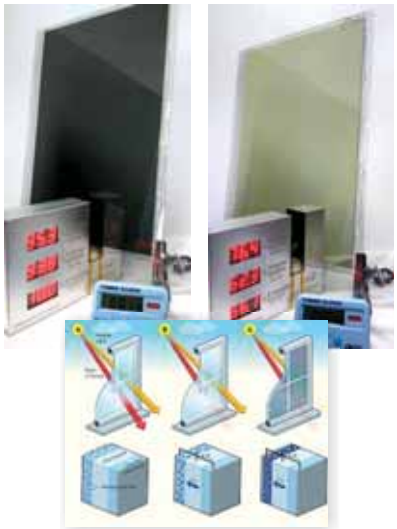


Fig. 2, left figure: self-group research and development of intelligent electrochromic film, right figure : principle of electrochromic components

Fig. 3, winning awards. From left to right are: Taipei 106 and 107 Invention Exhibition Silver Award in Taipei Invention Exhibition Silver Award

The high-density plasma source device utilized at INER exhibits excellent characteristics: (1) fast deposit rate, (2) the plasma with a high ionization rate, (3) good adhesion, and (4) advantage of broad process parameter conditions. The process conditions and stability techniques of the color-changing electrode film have been mastered. Its film properties feature a porous structure, which can increase the surface area ratio, and quickly change color

Fig. 5, Auto color sunroof

The opportunities of auto color sunroof (excluding after-market) are estimated, according to the following bases: production target of 30 millions vehicles a year, and actual production capacity to reach 80%. Assuming in the future 5% of which are the higher-level cars equipped with change-color sunroof, and the estimated average unit price of color sunroof to US $ 300; then, the potential opportunities = 30 million x 80% x 5% x US $ 300 = US $ 360 million / year.

During the R & D period, INER won Silver Awards in 2017 Taipei International Invention Show & Trading Technology Exhibition and 2018 Taiwan Innovation and Technology Expo. The said achievements promote honor for the institution.

A case of technology services to vendors from 2017 to 2019: "Preparation of Key Technology Assessment case of large commercial metal oxide electrochromic film electrode," contract value 1.3 million NT dollars (Hony glass and Licons Corporation), patent application 6 items. Efforts are being made to carry out technology transfer service for guiding domestic manufacturers, to commission large-scale electro-chromic film key production technology and equipment development.

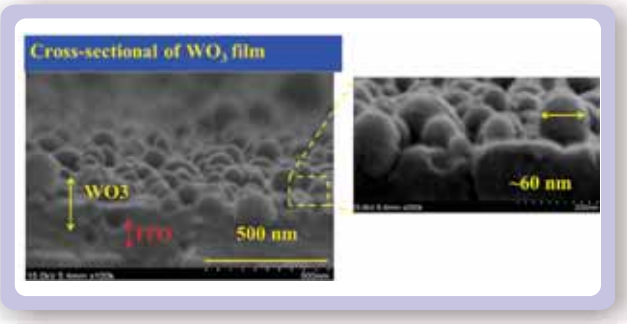
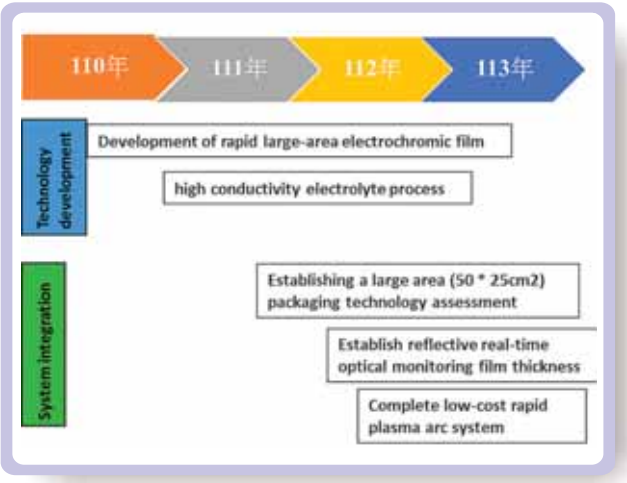


Fig. 4, the use of arc plasma deposition of microstructure (nanosphere about 60 nm-think), suitable for ion in and out of the structure



INER has developed plasma related fields for more than 30 years, and utilized arc technology in rapid manufacturing thin film with high energy efficiency, which is used in the assessment of commercial products. It is planned to implement small-scale production, to promote industrial early participation; hence, it can reduce the cost of initial investment by firms, and accelerate the time into a formal process for mass production.

The core values for energy policy, "green economy", "energy security", "environmental sustainability" and "social equity", are the four aspects to promote the energy development for sustainable society.

3-2-2 Mass production equipment of plasma coating for solar control film and top products

To promote sustainable environment, energy conservation and carbon reduction is one of the governmental key policies. Taiwan is located in the subtropical zone, where in summer air-conditioning power loads remain high. Effective shading, such as solar control films (also known as solar films), can help save electricity. The Institute of Nuclear Energy Research (INER) cooperated with Taiwan's largest energy-saving film manufacturer to develop a new type of top-level energy-saving film based on INER's plasma technology. By taking advantage of the reflection of heat radiation, the benefits of both shading and daylighting can be obtained, making up for Taiwan's long-term deficiencies in solar film technology, while improving the performance of the local solar film industry to international standards. After 4 years of cooperative research and development, the two parties successfully developed a unique roll-to-roll hybrid plasma modular coating system, and completed the delivery of the machine as well as the pilot production in August 2019. The cooperative manufacturer set up a factory for installation in Douliu. The coating system, which is expected to begin commercial operation in 2020, will produce the only heat-reflective solar control film series top products in Taiwan.

Fig.1 The cooperative manufacturer built the roll-to-roll hybrid plasma modular coating system in Douliu. Left: The machine is under construction. Right: Commissioning completed.

This roll-to-roll hybrid plasma modular coating system is from totally indigenous development, and the production cost is only one third of that of similar products abroad, which greatly improves the price advantage of the product.

The top heat-reflective solar control film is the main product of the roll-to-roll hybrid plasma modular coating system. It is characterized by the use of sunlight's wave nature and the use of silver-containing multilayer optical coating to control the transmission and reflection of sunlight on the solar film. This principle breaks through the shortcomings of the traditionally coated solar film, which is black and hot, and makes the film both transparent and heat-insulated. The film is suitable for vehicles and buildings, helping to save the burden of air conditioning and benefiting energy conservation and carbon reduction.

Fig. 2 Above: Top heat-reflective solar control film. Bottom: Principle for the heat-reflective solar control film

Fig. 3 Award certificate. From left to right: The 14th National Innovation Award, Bronze Medal at the Taipei AMPA, and the Create The Future Competition Award

During the cooperative development with the manufacturer, the INER won the 14th National Innovation Award in 2017, assisted the manufacturer to win the bronze medal at the Taipei AMPA in 2018, and won the automation award of the Create The Future competition held by NASA Tech Brief in 2018. The manufacturers and INER achieve affirmation of honors through endeavor.

The top heat-reflective solar control film employs the interference effect of light to reflect solar thermal radiation to the outdoors. The key is the nano-optical coating. This product was certified by the Industrial Bureau Nano Mark in 2019, affirming the nano-technology and unique performance of this product.

Furthermore, we designed and actually produced a solar film style G50 that can match high-performance glass green building materials. After testing by the Electronics Testing Center in 2018, its film-pasted glass fulfilled the performance specifications equal to the glass green building materials. In 2019, the cooperative manufacturer combined the G50 and glasses as a laminated glass to apply for the green building material label, which is currently under review by the authorities.

Promoting energy conservation and carbon reduction, developing green technologies, and assisting local companies in technological upgrading are the tenets of the INER. Hoping that we can promote more relevant technologies and create a better environment for people in the future.

Fig. 4 Nano-Certificate

Fig. 5 Specifications for glass green building materials

Fig. 6 Electronics Testing center confirms that G50 film performance meets the green building material specifications

3-2-3 Development of Innovative Membrane for Vanadium Redox Flow Battery

As a potential candidate of energy storage system used in power grid, vanadium redox flow battery (VRFB) carries the distinguishing features of high safety, long service life, recyclability of most component materials, environmental friendly, and independent power / energy designs. The cost is an important issue for VRFB. Membrane is one of the most costly materials in VRFB. Its function is to separate the positive and negative electrolytes to prevent the battery from self-discharging, and allow the charge carriers to transfer through freely. In substitute of the most popular and expensive Nafion membrane, we developed some innovative and low-cost membranes. Hopefully, these innovative membranes could help our domestic membranes industry and improve the competitiveness of domestic flow battery energy storage systems.

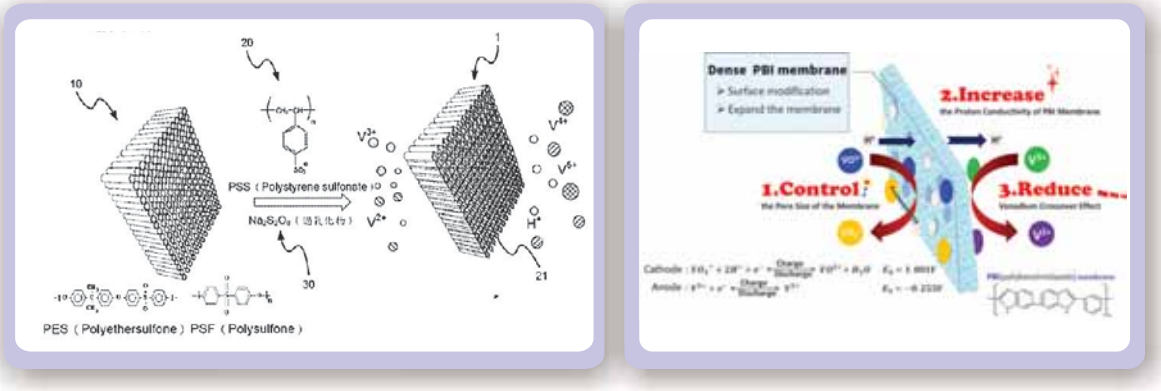


Figure 1. Modification Methods for Membranes

INER actively communicates with academics and the industries, researches in membranes for flow battery technology, and seeks for opportunities of cooperating with each other. By providing INER with various substrates and formulas of membranes, such as PBI, PSF, PES and PVDF, we analyze physical and chemical properties of them, modify surface membranes, and experiment on single cell performance for evaluating feasibility and durability of membranes for VRFB. The critical technology lies in the hydrophilic properties of the membrane surface, which can effectively improve the proton penetration rate; besides, controlling the optimal pore size can effectively block the penetration of vanadium ions to improve the single cell performance. It is expected that this technology can be applied to the performance test of large-area battery modules, replacing the expensive DuPont Nafion membrane, increasing the domestic production rate, and breaking through the development of key materials for VRFB.

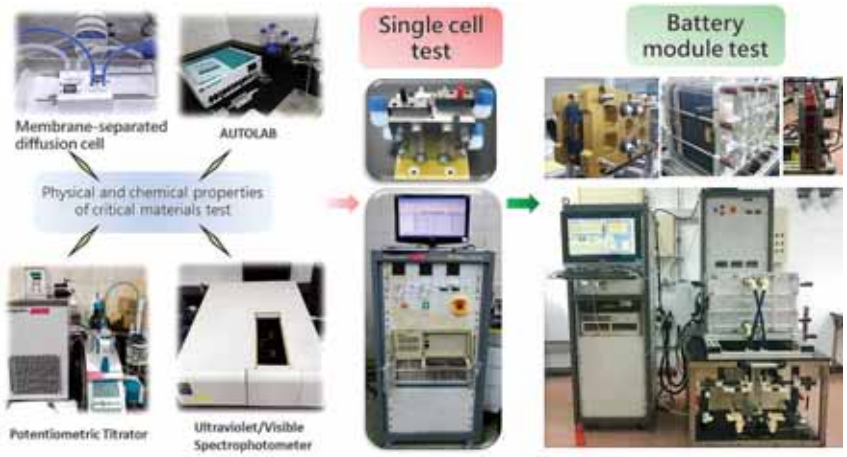


Figure 2. Device and Equipment of Characteristics and Performance Testing

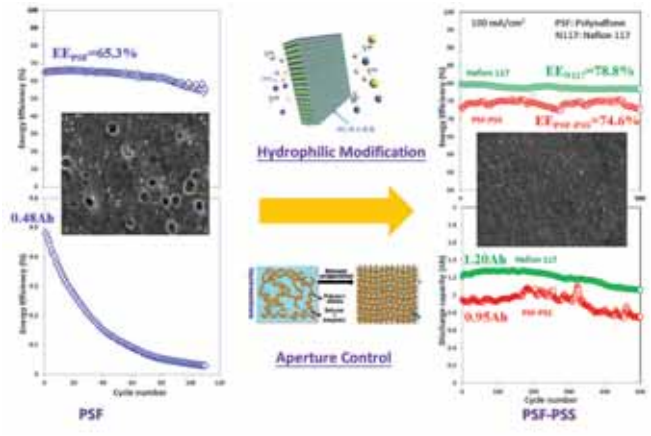
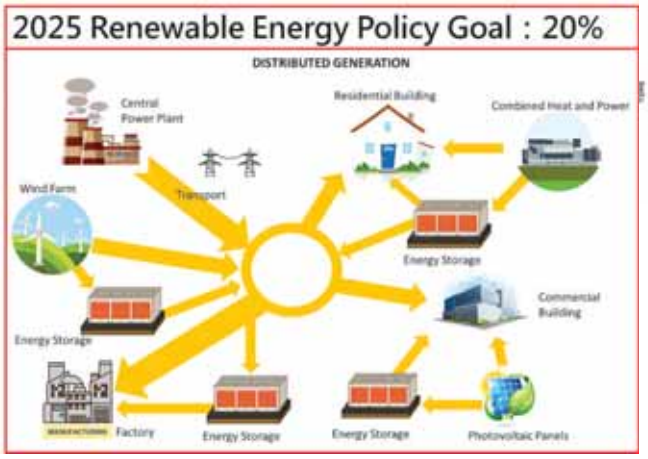


Figure 3. Efficiency and Stability of Low-cost Membranes

INER researches in the surface modification of PBI membranes with different properties and thicknesses to promote the performance of single cells, and compares them with DuPont Nafion membranes, the main international indicator. The price of invented PBI membranes produced by a domestic plant is only about 20%, compared to that of Nafion membranes; furthermore, the energy efficiency of the former is only 2% less than that of the latter. We believe that these indigenous PBI membranes will have a chance to penetrate into the international market in the near future.



Fugure 5. 2025 Renewable Energy Policy Goal

In the joint research and evaluation with a domestic fuel cell material R & D manufacturer, the evaluating membranes have been produced via existing plant equipment, with some modification and tuning suggested by INER . A joint-project of the "Southern Science Park R&D Advanced Industry-Academic Cooperation Plan" is approved under the condition of 50% of the total R&D funds being invested by the corresponding company . The patent entitled "Low-cost isolation membrane manufacturing method", was granted the bronze medal in the category of "inorganic chemistry, organic chemistry, and polymer chemistry" in the Taiwan Innovation Technology Expo Invention Competition.

Current density ($mA\text{-}cm^{-2}$)	Cut-off voltage(V) range	Active area (cm^2)	Nafion212 EE(%)	PBI(A1) EE(%)	PBI(A2) EE(%)	PBI(A3) EE(%)
120	0.7-1.60V	25	82.11	80.38	77.70	76.82

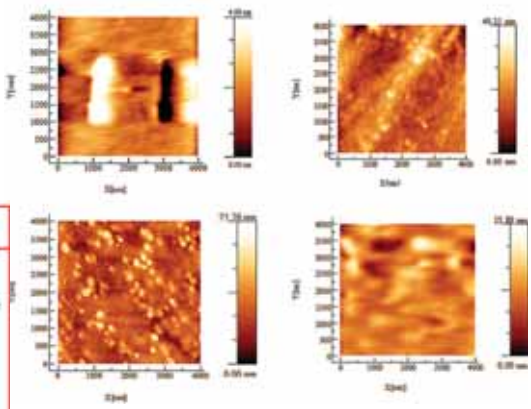


Figure4. Performance and Surface Structure of Invented Membranes

The energy storage system is important in energy regulation in grid systems. Therefor, as a potential candidate of future energy storage system, VRFB will be indispensable for large-scale application of renewable energy to meet the policy goal 2025. INER has developed innovative low-cost membranes, that may help our domestic membranes industry in the field of VRFB, and hopefully will have a chance to penetrate into international markets in the near future.

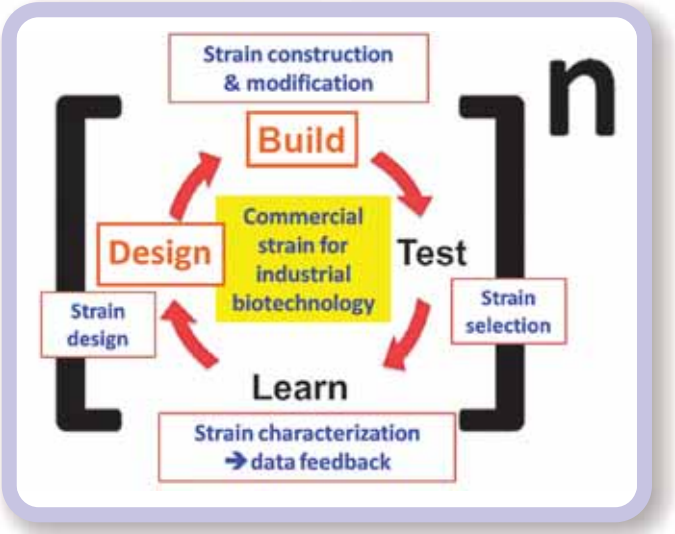
3-2-4

Microbiology Research Meets Robotic and AI -Introduction of High-throughput Microorganism Screening Technology

There are thousands of microbes in the environment, they cannot be seen with the naked eye, but are closely related to human life. Including yeast, bacteria, fungi, viruses, these microorganisms are widely used in various fields. For many products like foods, industrial chemicals, and pharmaceuticals, or even biofuels, their production must rely on microorganisms. This kind of cell factory is based on the microorganism's special metabolic pathway and its enzymes, to replace the complex chemical reaction process, and with the help of industrial fermentation to production specific product. It is called industrial biotechnology or biorefinery. Because of the process specificity and no harsh condition required such as high temperature or high pressure, it brings the advantage of reduction in process energy and the waste. nder the global commitment to sustainable environmental development, biorefinery will have great potential and pose an inevitable development direction.

High-throughput strain screening facility system at INER

Developing high-performance fermentation strains and enzymes is a key technology in industrial biochemical production processes. Recent advanced development in genomic has accelerated understanding of the physiological characteristics of microorganisms, and with the help of revolutionary gene editing methods, it is feasible to manipulate metabolic pathways in microorganisms for industrial process. Most important, introduction of high-throughput automated robotic facilities and artificial intelligence-assisted software for strain selection, significantly lower the overall strain development cost and broaden the range of product application. Furthermore, it is to promote development of bioeconomy.

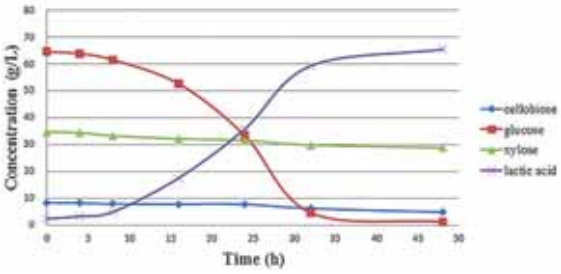


Concept of development strategy for industrial cell factory

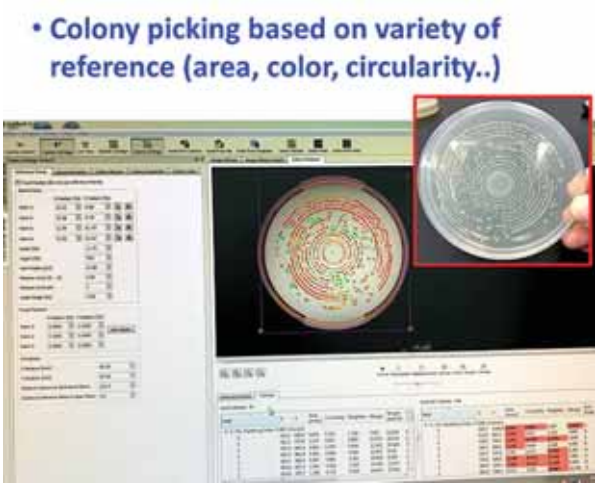
In view of this, the development process of recombinant strains in foreign biorefinery industries and research institutions has been taken into account at the Institute of Nuclear Energy Research (INER). Based on this, INER has established the first domestic high-throughput automation platform, especially for strain development dedicated to industrial biotechnology. The main functional equipment of this automation platform includes multi-channel robotic arms for a large number of liquid handing, artificial intelligence-assisted software as well as system facilities for colony selection and picking based on the colony properties, integration of the robotic arm and modules over the system, and the data storage for all the concatenation operations of system modules.

For example, it is often implemented to edit the strain gene or to cause strain mutation with physical or chemical methods, of which efficiency is compared for improving the product yield of the strain. After reaction and screening, 50 to 100 individual mutant strains can be selected and tested in a week, if the traditional manual selection method is used; in contrast, up to 300 colony strains can be selected per hour, if the high-throughput automation platform is applied. Not only is the workload increased dozens of times, but also manual handling error can be avoided during experiment.

Taking INER's industrial lactic acid (LA) production strain as example, LA is commonly used as materials for bioplastic polylactic acid (PLA), mostly using starch as a raw material to produce. INER's strain can use starch source to produce LA with more than 90% of production yield, 99% of optical purity; however, if using glucose-containing cellulosic hydrolysate for material, the yield is either unstable or even unable to ferment, because of many fermentative inhibitors existed in the hydrolysate. In order to improve the capability of hydrolysate utilization as well as to increase LA yield, high-throughput strain screening facility is utilized to conduct automated adaption of the strain in hydrolysate cultivation, that is expected to acquire a high-performance strain through the adaptation and selection process. After screening more than 500 colonies of strains, we successfully obtained strains that greatly improved in hydrolysate utilization and also increased LA productivity. Furthermore, the productivity of the selected strain was validated by scale-up fermentation in a desktop bioreactor.



Using cellulosic hydrolysate for industrial lactic acid production

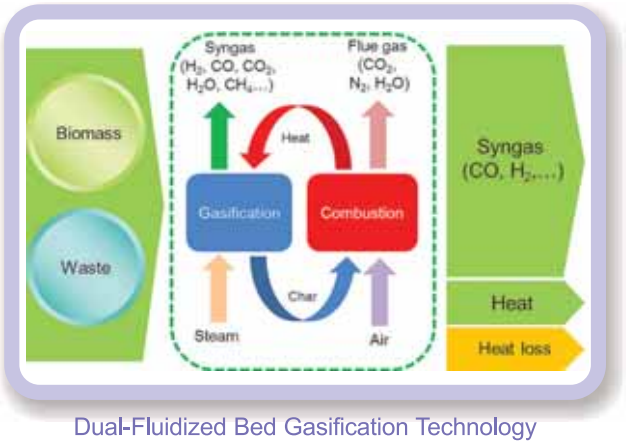


AI-assisted colony picking

In addition to the concrete progress in facility establishment and technology development, MOUs have also been signed among domestic industries and INER, that sought to have cooperation with industry intending to use high-throughput strain screening platform to develop strains for various bio-based chemicals production. As an important building block, bio-based chemicals can be widely used in textile industry, plastics, coatings, medicine, food, energy and versatile applications. With the high-throughput strain screening platform, it is expected to improve the efficiency of product strain, reduce development cost, and shorten the commercialization process. In the future, INER will continue to cooperate with industry and dedicate to promote biorefinery industry toward sustainable environmental development.

3-2-5 Development of Dual Fluidized-Bed Indirect Gasification Technology

In order to develop technologies based on green innovation and circular economy, an energy supply system based on gasification has been established at the Institute of Nuclear Energy Research (INER). Carbonaceous solid fuel (including coal, biomass, waste, etc.) is transformed into gas and thermal energy through a gasifier. The preliminarily generated gas is purified to obtain clean syngas, which can not only be supplied to generate heat and electricity as energy supply, but also can be used for producing chemicals. INER adopts a dual fluidized-bed gasification equipment design and completes the construction of a 100kW-class gasifier. The advantages of a dual fluidized-bed gasifier are the use of pure steam as the gasifying agent, so the syngas can reach zero nitrogen composition and the overall heating value can be improved. This technology can also be applied to waste recycle, achieving the purpose of circular economy.



Dual-Fluidized Bed Gasification Technology

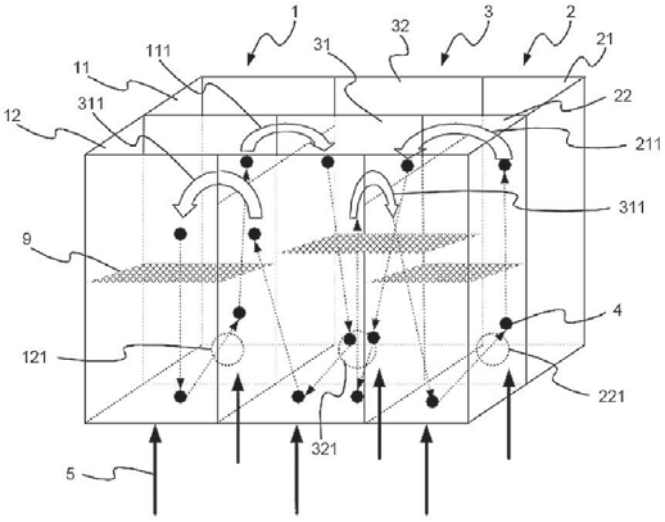
The dual fluidized-bed gasifier system consists of a gasification reactor and a combustion reactor. The carbon-containing fuels are fed into the gasification reactor and the gasification reaction occurs at high temperature to produce gas products containing syngas. The bed material (sand) in the gasifier forms a circulation loop between the two reactors. The heat generated by the combustion will be supplied to the gasification reaction.


The 100kW-class dual fluidized-bed gasifier


Wood pellets


Activated carbon


Agricultural waste

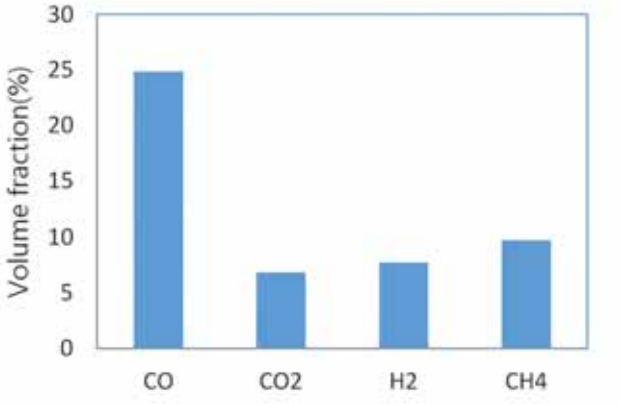


Schematic diagram of a patent for dual fluidized-bed indirect reactor

Invention patents:

1. Diameter varying fluidized bed reactor and regenerative reaction system, R.O.C. Pat. I669155.
2. Gasification Reactor with Shared Partial Reactor, patent pending (R.O.C. 107144843, US 16/561,151).
3. Chemical Looping Reactor with Shared Partial Reactor Vessels, R.O.C. Pat. I671492.
4. Chemical Looping Reactor with Shared Partial Reactor Vessels, patent granted, US 16/561,166.

Several tests of the pilot-scale dual fluidized-bed system for biomass gasification are performed. The gasification reactor behaves as a bubbling fluidized bed and the combustion reactor behaves as a fast fluidized bed. The effect of operating parameters on gasification process performance is investigated. The circulation of the bed material and the feasibility of the use of auxiliary fuel are also examined. Based on the test results, the dual fluidized-bed system is able to be operated continuously and stably.



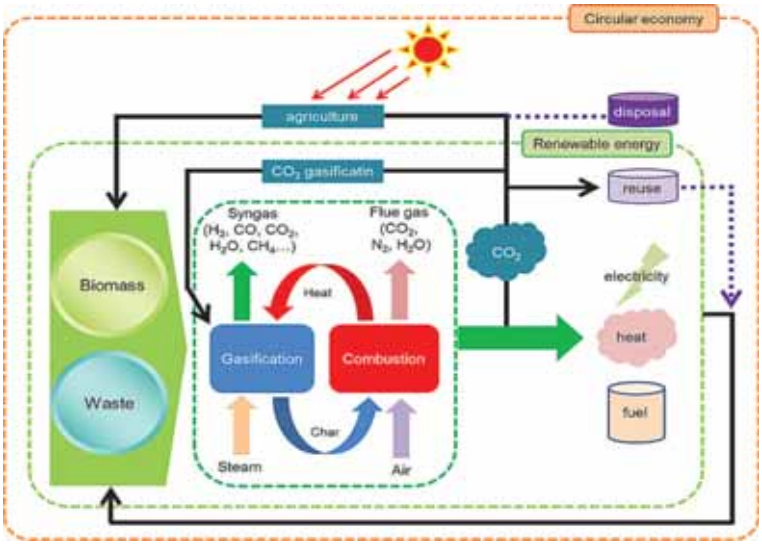
Gas product composition from gasification at 700 °C

INER develops gasification technology with flexible feed and multiple source applications.

(1)Continue to develop treatment applications for potential biomass and waste.

(2)Combined with a solid oxide fuel cell system to improve power generation efficiency.

(3)Produce multifunctional chemicals such as dimethyl ether from syngas, which can be used as a substitute for fossil fuels, and can also be used as an energy carrier to meet the peak / off-peak hours.



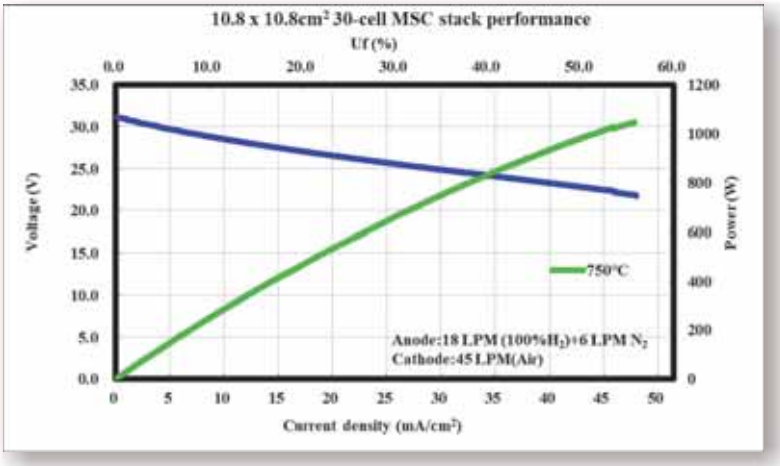
Development of multi-energy systems combining thermo-chemical and electrochemical technologies.

3-2-6

More energy, less carbon emission- the technology of solid oxide fuel cell

The Institute of Nuclear Energy Research (INER) has been devoting to the development of solid oxide fuel cell (SOFC) technology, and is now linked closely with local enterprise through technology transfer and cooperation to accelerate the application of domestic products. Under the frame of patent licensing, INER has assisted the licensee of anode-supported cell technology on the improvement of cell compositions and mass production processes. The output power of cells has been boosted significantly. INER has also cooperated with a local company to manufacture glass sealing tapes by tape casting for the following automatic stack assembling. After in-field stack testing, it is proved that the glass tapes and the sealing process can serve to the purpose. Through technology transfer and cooperation, INER has helped local businesses build up technical capacities, procure raw materials, and set up production lines, for the establishment of a domestic integral supply chain for the SOFC industry.

INER 30-cell MSC stack



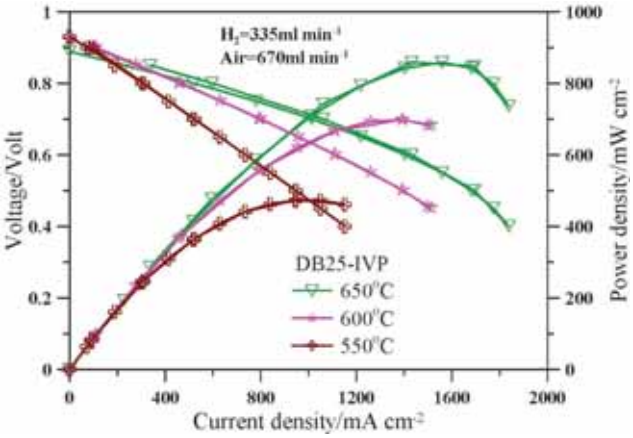
Stack performance test curves

kW-level new type stack

A stack assembled with 30 self-made metal-supported cells by plasma spray was tested. Tafel testing was conducted after pure hydrogen gas was fueled. The maximum power output was 1.046 kW at current intensity 48 A, with average power 34.8 W/cell. The corresponding electrical efficiency was 35.48% and fuel utilization rate 55.78%. This is the first kW-level stack fabricated completely with domestic components.

Low-temperature plasma sprayed metal-supported solid oxide fuel cell

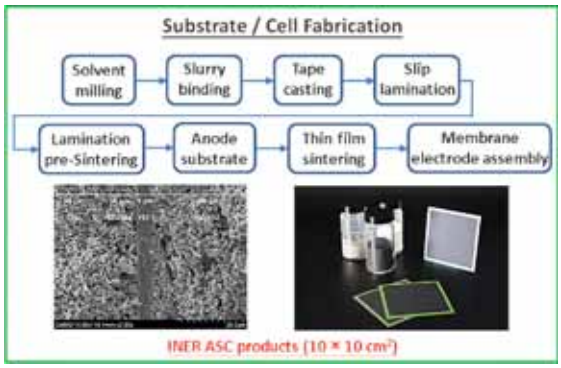
Metal-supported solid oxide fuel cells with 1.2 mm in thickness and 5x5 cm^2 in size are produced. The single cell can deliver about 842, 667 and 440 mW/cm^2 at 0.6 V and 650, 600 and 550°C, respectively. This cell shows a great power performance at the operation temperature lower than 600°C.

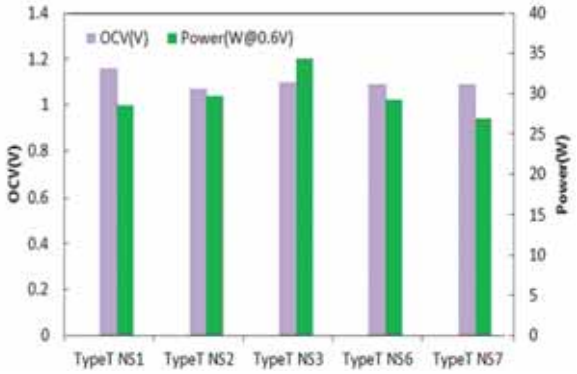


Performance of plasma-sprayed metal-supported SOFC

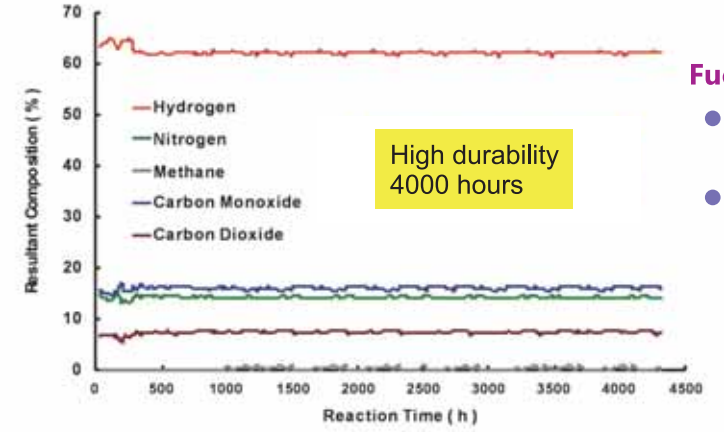
Ceramic based anode-supported solid oxide fuel cell

- INER-SOFC-MEA™ (thickness:~450μm) with novel geometry design have been realized via a small-scale production line. Cell product exhibits process and performance reproducibility for commercial available specs.
- The cell product with YSZ electrolyte exhibits power >25 W at 800°C (0.6 V) for kW-scale system application.





Ceramics-based anode supported solid oxide fuel cell technique and performance



Fuel reforming catalyst

- High activity over a range of reactions and temperatures
- Demonstrated resistance to carbon deposition for longer lifetime

Awards

- 2019 National Conference on Hydrogen Energy and Fuel Cell, Poster Paper Contest:
  Best poster award : 【Characteristics of plasma-sprayed contact and coating layers on interconnect in SOFC stacks】

3-2-7 Domestic Distribution Network Management System Incorporating Green Energy

It is expected that a large amount of renewable energy will be incorporated to distribution feeder, which can cause two-way power flow and set a new challenge of load transfer. In addition, the lack of integration of domestic Supervisory Control And Data Acquisition (SCADA) and geographic information system (GIS) used in power industry also significantly restrict the flexibility in application of renewable energy information. Therefore, the Institute of Nuclear Energy Research (INER) and Taiwan Power Company (TPC) joined force to develop the domestic Distribution Network Management System by integrating SCADA and GIS. This system has been operating online in TPC Yunlin District since April 2019, providing effective management of more than 300 distribution feeders and renewable power generation, as well as successfully reducing the duration of power outage.

Figure 1. Domestic Distribution Network Management System

A distribution map file conversion technology, with the ability to establish renewable energy information on distribution feeders, was developed to ensure the consistency between the Distribution Mapping Management System (DMMS) and the status of on-site equipment for the control of real-time renewable power generation. This conversion file was applied to TPC District practically. The DMMS automatically generates single-line diagrams of the distribution system and renewable energy information within 10 minutes. Now the frequency of files conversion is increased from twice per week to several times per day, effectively improving the reliability of feeders dispatching and operation. The SCADA is now capable of presenting renewable energy information, which assists dispatchers with better management for dispatching and operation of renewable energy and feeders. On the other hand, GIS visualizes geo-spatial information of feeders and features, and provides interactive positioning service to SCADA, achieving the development of technical integration of heterogeneous data.

Figure 2. Interactive positioning between SCADA and GIS

The power flow analysis program and feeders dispatching platform were integrated in the Distribution Network Management System. Taking the distribution feeders for example; when a fault occurs, the system is capable of performing fault detection, isolation, and restoration (FDIR) at upstream. The load transfer solutions for downstream are proposed, and the information of max./min. voltages, feeder line loss and capacity allowance are shown for the dispatchers' reference; hence, the distribution system fault restoring can be speed up. The verification and functional test of FDIR logics were performed for 171 feeders of 11 substations in TPC, and it shows that every function works as expected. In total, 35 successful identifications were made from April to December in 2019, along with the executions of fault detection, isolation and restoration of feeders.

Figure 3. Integration of distribution power flow calculation program and feeders dispatching platform

The online power flow calculation was developed for renewable energy. It assists the Distribution Network Management System in estimating the voltages at each bus, and keeps a track on the influence of renewable power generation on feeders. This outcome sets the important foundation for stabilizing the fluctuation in voltage, from which the proportion of renewable energy can be increased, and therefore facilitates the achievement of the goal aiming at 20% renewable power generation by 2025.

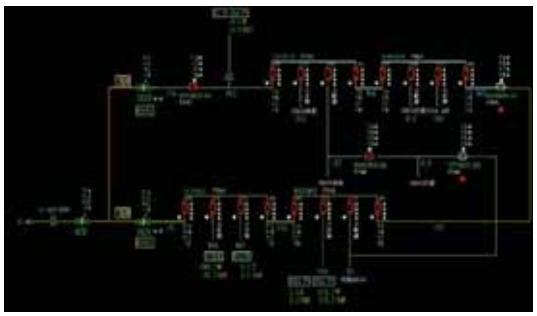


Figure 4. Topographic structure of Microgrid feeders for real-time distributed energy information

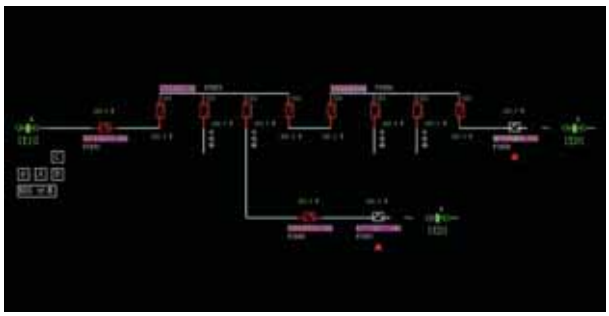


Figure 5. Microgrid feeders structure with online power flow calculation

It is expected that a large amount of renewable energy will be connected to power distribution system and feeder in the future. INER will continue the development of multi-section feeder restoration, 3-phase reconfiguration, dynamic protection coordination settings, fault detection and isolation, and restoration of the outage sections on Distribution Network Management System. Hopefully, the technical breakthrough will improve local industrial technology and applications of innovation industry as business opportunities for the power market in Southeast Asia.

3-3 Value the quality of life; promote the application of atomic energy in livelihood

Along with the industrial revolution and the development of science and technology in the late 19th century, from macroscopic view to microscopic exploration, the atomic energy science has rapid developed to be a unique manifestation. Till now, it has combined with modern science and technology such as information science, biotechnology, nanotechnology, new materials technology and environmental technology to truly implement in the fields of medicine, agriculture, industry and environmental protection, etc., to develop various innovative technologies and high-quality products. This kind of high-value technology or product is just like air and water, which is tightly integrated in your daily life.

In 2018, the research results were mainly displayed on important topics of new drug research, public health and environmental exploration.

There are two new self-innovative chemical entities. First, "dual-target tumor hypoxic imaging agent", INER has designed the CA9-binding peptide to conjugate with carbonic anhydrase IX (CA9)-binding compound (sulfonamide derivative, and labeled with the indium-111 to become a tumor hypoxia imaging agent (^{111}In-DOTA-CA9-AAZ) in order to improve the affinity to the target (eg, hypoxic location). The results showed that the dual-target tumor hypoxia imaging agent was significantly accumulated at the tumor site in tumor hypoxic animal model, and also highly concentrated in the tumor site relative to that of liver, muscle, blood, and large intestine in biodistribution assay. In addition, the target effect of the dual-target probe was significantly better than that of the single target probe.

Second "INER Dolacga imaging agent", INER has cooperated with National Taiwan University Hospital to conduct Phase I clinical trial, mainly for healthy subjects to evaluate the safety of drug, from Feb.to Aug. 2019, a total of twelve healthy subjects were included in trials. According to the results of those subjects, all the biochemical test data were within the range of health reference values, Dolacga were highly specific to liver receptors and no adverse event reported that is an evidence of drug safety. INER Dolacga imaging agent is a small peptide-like agent with only 3,000 MW, which is easy to purify and characterize, and has a low background value to improve diagnostic sensitivity. "INER Dolacga imaging agent" is the world's first peptide-like liver function imaging agent.

There is an important outcome of public health issue, in Aug. 2018, cooperating with the AEC in addressing public concerns about radon released from negative ion mattresses, INER had immediately completed the establishment of radon gas measurement laboratories, standard procedures for radiation measurement of negative ion products, radiation measurement and dose assessment models for various commodities, and technical service contact window. A research project was conducted by

joint inspection of AEC, TFDA and BSI, the result shown radon concentration of many skin-friendly products exceeds the exposure limit of 1 mSv/year. Based on this point, the dose assessment of commodities must be considered. In the future, investigations on raw material sales of negative ion powders and control of raw material source will be conducted to ensure that the public can use consumer products containing negative ions with relieves.

There is an important outcome of environmental safety issue. Under the policy of non-nuclear homeland in 2025, whether it is a power plant in operation or after decommissioning, it has used nuclear fuel "deep geological disposal" and used "multiple barriers" to effectively contain or delay the release and migration of nuclear species to a negligible level, and it is an internationally recognized feasible way currently. Understanding geochemistry and nuclear species migration can provide complete hydrochemical data, and more importantly, protect our living environment. INER has established the only one radionuclides migration laboratory to simulate nuclides migration parameters by geochemical reactions (radionuclides diffuse and migrate underground). Now, it is in the early stages of development and strengthening confidence in safety assessment can be seen in the future.

This year, INER have demonstrated fruitful results and attained one great achievement. Over the years, INER has played a leading role in many fields through the microscopic research of atomic energy technology. However, due to the rapid changes in the environment, we face a lot of competition and challenges. How to make the atomic energy research keep improving and reach its peak again to improve people's health and quality of life and maintain environmental safety that is the goal and ideal of every research talent, and it is also the core value pursued by INER, vision for sustainable business and eternal promise of INER.

3-3-1 Development of dual-target tumor hypoxic imaging agent

Unmet medical need

At present, surgery, chemotherapy and radiation therapy are the major methods for tumor treatment. The local hypoxia occurs in many tumor tissues tumor which are resistant to chemotherapy and radiation therapy, increasing the risk of tumor metastasis and reducing the chance of successful surgery. Therefore, accurate diagnosis of the location and levels in hypoxic tumor can provide physicians to choice the correct treatment method and evaluate the treatment efficacy for improving the success rate of treatment. At present, many tumor hypoxia diagnostic drugs are still in clinical trials such as ^{89}Zr-girentuximab and ^{124}I-cG250. They mostly belong to single-target antibody drugs which have a slow clearance rate in normal tissues and interfere with the image interpretation. Therefore, the institute of nuclear energy research's innovative development of dual-target tumor hypoxic imaging agents not only reaches the tumor hypoxia site quickly, but also reduces the image signal of normal tissues for making accurate interpretations by physicians and reducing the risk of wrong decision in treatment methods.

Drug design concept

Target drugs usually use antibodies, peptide fragments and small molecule inhibitors as probes to carry drugs to tumor sites for diagnosis or treatment. Peptide or small molecule substances can clear blood from animals faster than antibodies, and can effectively reduce background interference of images. In addition, literature reports indicate that carbonic anhydrase IX (CA9) is involved in various physiological processes, including pH adjustment, cell attachment, proliferation, and metastasis, which are manifested in large amounts in tumor hypoxia sites and is considered the best tumor hypoxia biomarker. Therefore, the institute of nuclear energy research's innovatively designed of tumor hypoxic imaging agent which combined with a CA9-binding peptide and a CA9-binding compound (sulfonamide derivative) as a dual-target probe, and labeled with the indium-111 (^{111}In-DOTA-CA9-AAZ) (Figure 1). This multi-targeted drug can improve the affinity to the target location (such as: hypoxic location) (Figure 2).

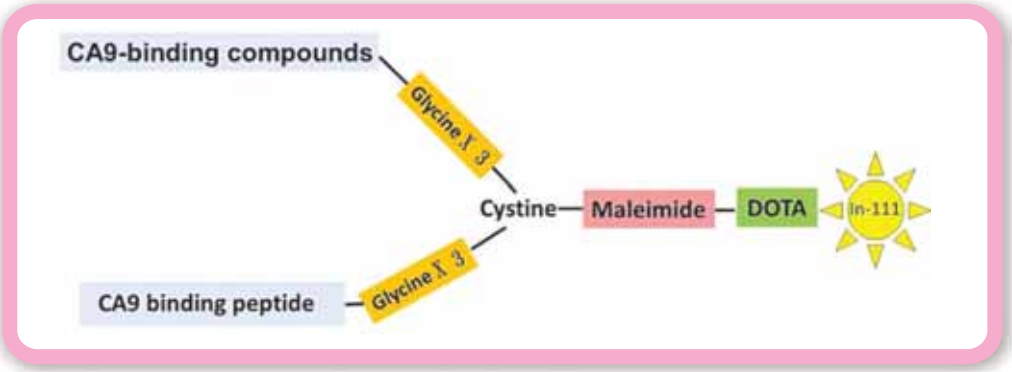


Figure 1：The structure of dual-targeted tumor hypoxic imaging agent

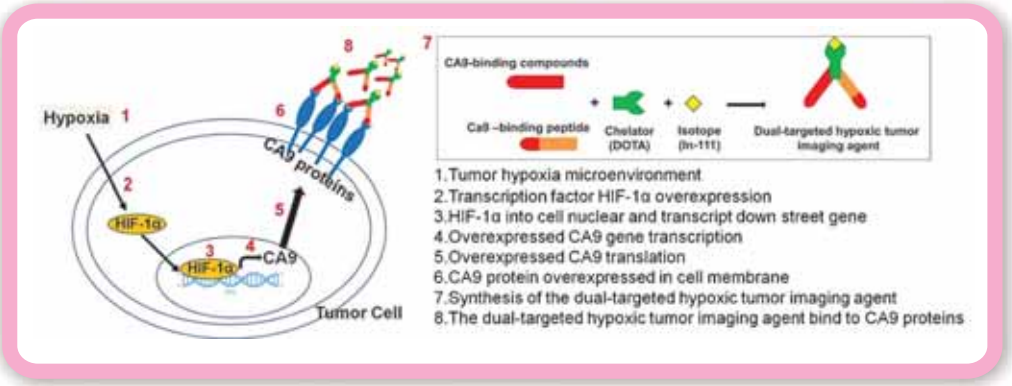


Figure 2：The targeting flowchart of dual-targeted tumor hypoxic imaging agent

Biological Verification and competition analysis

The results showed that the dual-target tumor hypoxic imaging agent (^{111}In-DOTA-CA9-AAZ) was highly stable in serum and still has a radiochemical purity of more than 90% after 144 hours (Figure 3). ^{111}In-DOTA-CA9-AAZ significantly accumulated at the tumor site in tumor hypoxic animal model (Figure 4) and also highly concentrated in the tumor site compared with that of liver, muscle, blood, and large intestine in bio-distribution assay. In addition, the dual-target probe is significantly better than the single-target probe (Figure 5), like ^{18}F-FMISO (gold standard), the dual-target drug is better at targeting, specificity, biodistribution (Figure 6) and stability et al (Table 1). Besides, the resolution of single-photon tomography technology has been improved and close to imaging quality of positron tomography in recent years.

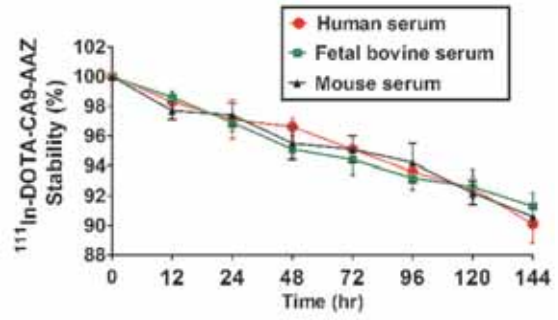


Figure 3: Stability of Dual-target tumor hypoxic imaging agent

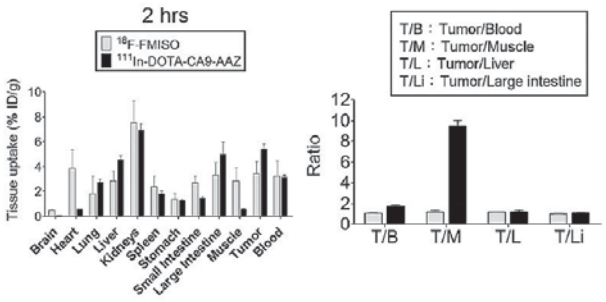


Figure 6: Comparison of bio distribution of ^{111}In-DOTA-CA9-AAZ and ^{18}F-MISO

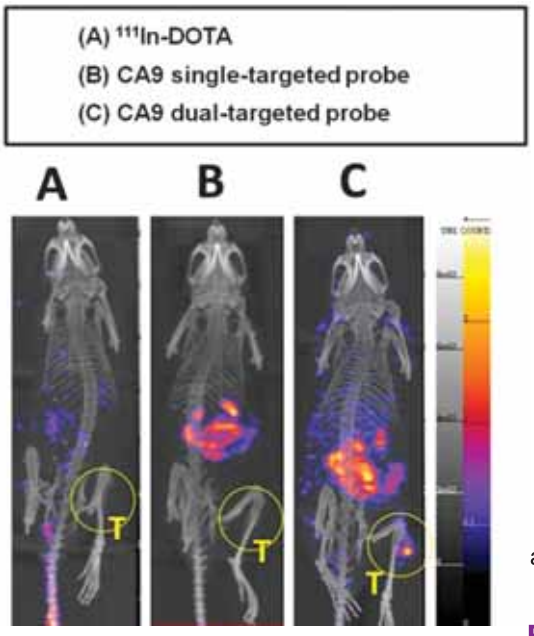


Figure 4: NanoSPECT/CT imaging

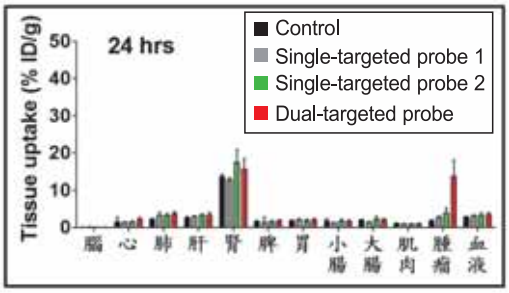


Figure 5: biodistribution of Dual-target tumor hypoxic imaging agent

Table 1: Dual-target tumor hypoxic imaging agent vs. ^{18}F-FMISO

	^{111}In-DOTA-CA9-AAZ	^{18}F-FMISO
Signal/noise ratio	High	Low
Targeting	High	Passable
Specificity	High (No cluster in normal tissue)	Low (cluster in normal tissue)
Biological distribution	High (2 hr: >5%ID/g) (24 hr: >12%ID/g)	Low (2 hr: <3%ID/g)
Probe stability	High (freeze drying for storage)	Low (use immediately)
Probe application	High (Diagnosis and Therapy)	Low (Diagnosis)
Image of resolution	Passable	High
Instrument number[a]	131 (SPECT/CT)	56 (PET/CT)
Price	Low	High

a：Ministry of Health and Welfare, Taiwan. Statistics and analysis of medical institutions in 2018.

Future development and outlook

The in vivo and in vitro test results confirmed that the novel dual-target tumor hypoxia imaging agent can be applied to the evaluation of various tumor hypoxia levels and locations, and has potential for clinical application. In the future, pre-clinical assay of drug, including the pharmacokinetic tests and animal toxicity tests, will be conducted to provide information for human clinical trials. In addition, the concept of dual-target probe can be used to label therapeutic nucleus (such as: Lu-177) and extend the development of dual-target tumor hypoxia therapeutic agent.

3-3-2 Dolacga: A Revolutionary pharmaceutical Imaging Agent for Liver Reserve Function

Unmet medical need

The liver is like a factory. The factory requires workers to operate. The liver also needs a certain number of liver parenchymal cells to perform liver functions. If too many liver cells are absent, the liver will be out of function due to failure. Liver cancer is one of the top ten leading causes of cancer death in the world (ranked fourth), the United States (ranked eighth), and Taiwan (ranked third). Treatment strategies of liver cancer include liver resection, liver transplantation, radiofrequency ablation, transcatheter arterial embolization, radiotherapy, systemic chemotherapy and best supportive care. However, no matter which treatment strategy is chosen, it is necessary to evaluate the possibility of liver failure caused by liver treatment in advance. Therefore, Only by giving the correct diagnostic information on liver function can provide the appropriate treatment to ensure individual survival after treatment, which is the most important task in the development of treatment strategies.

Drug design concept

Asialoglycoprotein receptors (ASGPR) are surface receptors on hepatocyte membranes, responsible for the homeostatsis of blood glycoproteins, and have functions such as absorption, metabolism, and elimination, so the number of receptors can reflect liver cell function. INER has the advantage of its molecular imaging platform, and completed the development of liver function imaging agents through the innovative liver receptor-targeted technology. After six years of in vitro and in vivo testing, we have demonstrated that non-invasive liver receptor imaging can actually reflect the receptors changes on liver tissue (Mol Pharmaceutics 2018;15:4417-4425)

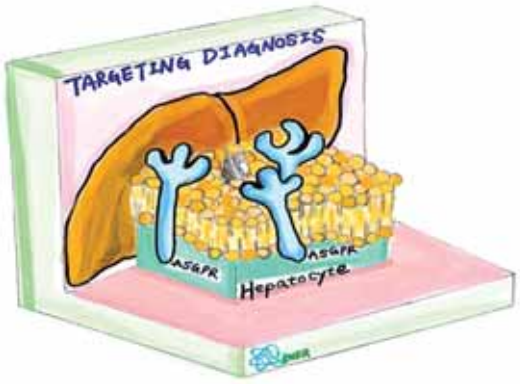


Figure 1. Asialoglycoprotein receptors are located on hepatocyte membranes.

Development of liver imaging agent

After confirming the effectiveness of liver function imaging agents in vivo. The formulation of imaging agent was optimized and stability and animal studies were conducted for preparation of clinical trial. Lyophilized preparation and radioisotope Ga-68 were used for the radiolabelling. The strategy is easy for usage, sale, promotion and for hospitals without cyclotron.

Our result shows that radiolabeling of lyophilized was achieved with >95% yield and at least 12 months of stability, it has high specific accumulation in the liver of normal mice (Figure 2).

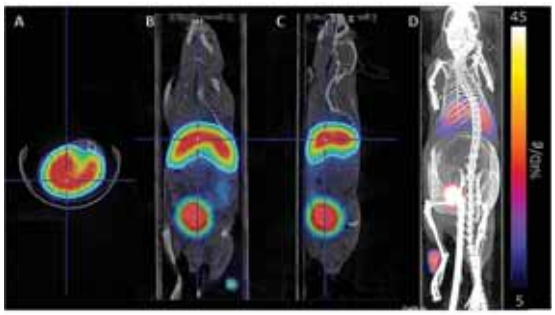


Figure 2. PET/CT images of normal mice after injection of Ga-68-NOTA-HL (J Label Compd Radiopharm. 2018;61:885-894).

Phase I clinical trial of liver imaging agent

The INER Dolacga liver imaging agent (Table 1) was approved to perform phase I clinical trial at National Taiwan University Hospital. It can be used for the evaluation of liver residual function as the basis for the selection of clinical liver resection and liver replacement therapy. Twelve subjects were evaluated in Feb-Aug. 2019. All subjects were screened before they could enter the clinical trial. They had to undergo a series of biochemical and laboratory examinations on the day of imaging and at two weeks after imaging. The results of clinical trial showed that all biochemical test data are within the range of health reference values and no adverse event reported. Dolacga are highly specific to liver receptors and have been proven to be a highly safe drug, which is the first peptide-like liver imaging agent used in humans (Figure 3).

Table 1. Specification of INER Dolacga product and reconstituted ^{68}Ga-Dolacga solution.

Sample	Items	Acceptance criteria
Lyophilized Dolacga	Appearance	White powder
	Container Closure Integrity test	No leak
	Sterility	No bacteria growth
	Bacterial endotoxin	< 87.5 EU/mL
Reconstituted Ga68-Dolacga solution	Clarity and color	Colorless liquid
	pH	4~5
	Radiochemical purity	≥ 90%
	Sterility	No bacteria growth
	Bacterial endotoxin	< 87.5 EU/ mL

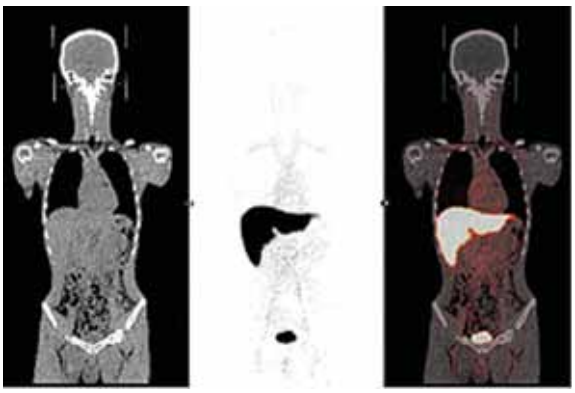


Figure 3. The representative images of clinical phase I study by INER liver imaging agent.

Competitive advantage

At present, there is only a protein-based liver imaging agent (galactosyl serum albumin, GSA) developed by Nihon Medi-Physics Co., Ltd., The imaging agent is a biological agent, but its disadvantages are high background, complicated pharmaceutical regulations, inconsistent production per batch, and difficult quality control.

Compare to previously product, INER Dolacga imaging agent is a small peptide-like agent with only 3,000 molecular weight. It is easy to purify and characterize. Dolacga has the advantage of low background value which helps improve diagnostic sensitivity that is more competitive.

INER Dolacga imaging agent had won the 10th National Innovation Award in 2013. Due to continuous innovation and development process, it won the Excelsior Award in 2019 (Figure 4).

Figure 4. The Excelsior Award 2019.

Future development and outlook

After complete of phase I clinical trial, the liver specific-targeting and drug safety of INER Dolacga imaging agent were confirmed in healthy subjects. We expect to submit an application for phase II clinical trial for patient subject who need to liver transplantation in order to prove the effectiveness of the drug for liver function estimation. The ultimate goal is to confirm the diagnostic value of INER Dolacga imaging agent through more studies of liver disease, such as chronic liver disease, and to clearly define the indications of INER Dolacga imaging agent .

3-3-3 Establishment of radiation dose assessment methods and models for commercial products containing negative ions

Public health Issue

In May 2018, South Korean NSSC revealed that mattresses made by Daijin Bed Co. contained unsafe radiation levels with dose rate of > 1 mSv/yr, it caused people fearing.

So INER has started to establish a radon measurement laboratory, analysis procedures of radon and dose assessment methods and models immediately in Aug. 2018. We setup a technical service window for radon detection of NORM-contained products to offer services and answer public doubts. An investigation had been carried out by the cooperation of INER,TFDA and BSI subsequently, we hope that the general public can use consumer products containing negative ions with relieves.

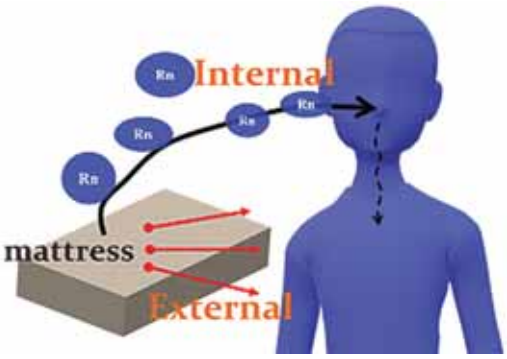


Fig. 1 The pathways of radon inhalation and dose exposure

What's radon?

Radon is a naturally occurring radioactive gas formed by slow decay of uranium and thorium found in the earth's crust, naturally occurring radioactive material which ionizes the air on the surface of the commercial products and generates negative ions. The danger posed by radon is primarily due to the alpha radiation emitted by its daughter nuclides that damages DNA in the lungs. Radon is stipulated as the second leading cause of lung cancer after smoking by the World Health Organization. The pathways of radon inhalation and dose exposure are shown as Fig 1.

Radioactivity concentration detection of radon and its daughter nuclides

INER external technical service flow chart was shown as Fig. 2. Surface dose rate (measured with ATOMEX AT-1121) means the external dose, radon concentration (measured with Durridge RAD7) means the internal dose. The internal radiation dose resulted from the progeny of radon gas was evaluated by using the internal dose conversion factors (DCFs) reported in ICRP Publication 115 shown as Eq., and to simulate the use of related products. The evaluation based on the dose conversion factors, the equilibrium factor, the respiratory rate and daily exposure time. The concentration of radon gas (including 220Rn and 222Rn) was determined, and the internal radiation dose was also evaluated and compared to the dose limit (1 mSv/yr) of the public in Taiwan. The radiation dose evaluation for NORM-contained products is shown as Fig. 3 .

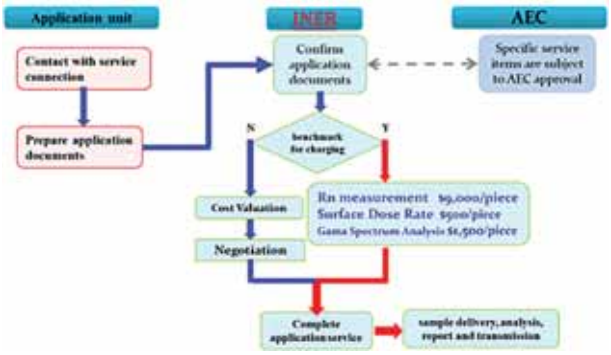
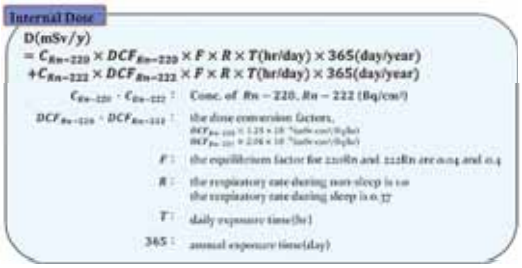


Fig. 2 INER external technical service flow chart



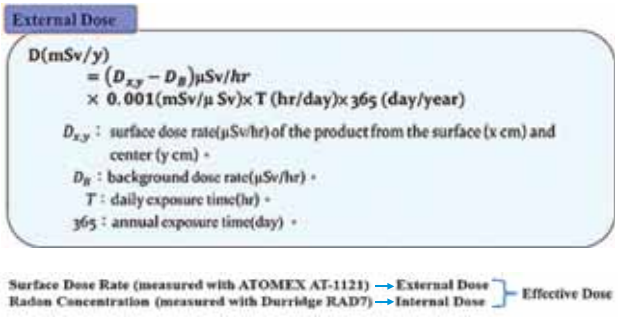


Fig. 3 The radiation dose evaluation for NORM-contained products

Research result (1):

INER analyzed the samples from the joint inspection of AEC, TFDA and BSI. A total of 11 products have been analyzed including beddings (mattresses, quilts and pillows) and other non-bedding products (facial masks, water cups, protective gear, kettle). The situation of mattress measurement and evaluation mode and setup for those products are shown as Fig. 4 & Fig. 5. The result shown that many skin-friendly products exceeded the exposure limit of 1 mSv / year (Table 1).

Table 1 Inspected quantities and dose evaluation results for the 11 kinds of products

Product type	Number of inspection sample	Number of annual effective dose exceeding 1 mSv	^{220}Rn Conc. (Bq/m^3)	^{222}Rn Conc. (Bq/m^3)	Internal dose (mSv/yr)	External dose (mSv/yr)
Mattress	20	8	0-11550	18-215	0-78	0-0.5
Quilt	14	3	4-986	7-60	0.01-7	0-1
Pillow	9	4	9-21760	7-89	0.07-144	0-0.1
Mask	4	3	11-19140	25-258	0.01-9	0-0.002
Eye mask	2	2	100-2860	34-122	11-20	0.03-0.04
Scarf	1	1	175	17	4	0.11
Carpet	1	1	93	11	2	0.5
Shawl	1	1	372	21	10	0.2
Protective gear	2	0	13-19	6-11	0.006-0.4	0-0.02
Water cup	4	0	10-27	3-16	0-0.4	0-0.04
Kettle	1	0	14	10	0.02	0

Research result (2):

In addition to the analysis and dose evaluation for commercial products containing natural radioactive materials, INER also grasps the international trends on this topic and published relevant research in the 5th International Conference on Environmental Radioactivity in the Czech. Most importantly, INER will cooperate with AEC to survey the companies sold "negative ion powder" raw material to insure the safety of source that consists of justification of a practice, optimization of radiation protection, limitation of individual risk.

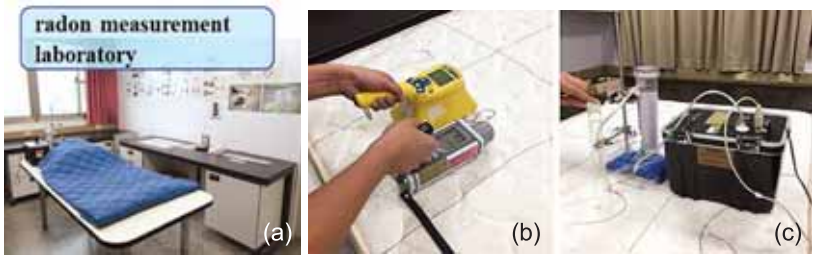


Fig. 4 The situation of measuring a mattress, (a) INER radon measurement laboratory, (b) measured with ATOMEX AT-1121, (c) measured with Durridge RAD7

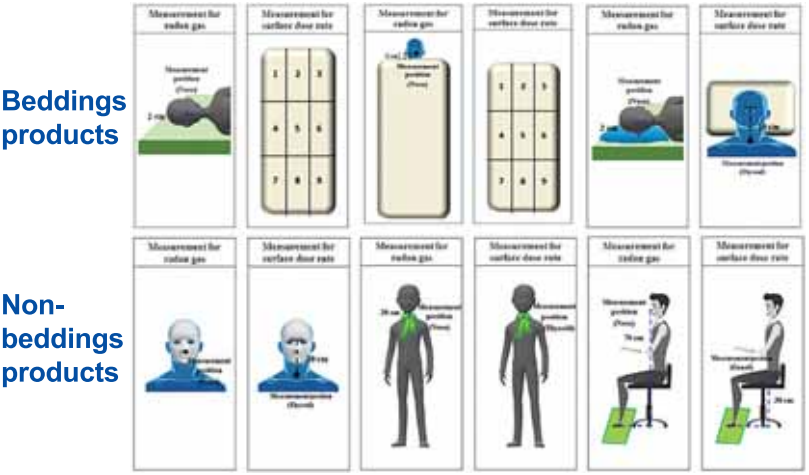


Fig. 5 Evaluation mode and setup for those products

Future development and outlook

We will continue to provide technical support for industries and government inspections, and ensuring the health and safety of people through the real-time commercial radiation dose control immediately. Future plans will be conducted. (1) Continue to detect radiation and dose assessment for commercial products containing natural radioactive materials. (2) Collect the latest dose assessment parameters of radon to establish and update radon measurement technology and standard operating procedures for NORM-contained products. (3) Establish a radon standard calibration system and equipment. (4) Setup a integration webpage of natural radioactive material information to facilitate to query for public .

3-3-4

Weather the storm, using geochemical reactions to explore the effects of radionuclide migration

Environmental safety issues

Under the policy of non-nuclear homeland in 2025, the disposal of spent nuclear fuel (SNF) for nuclear power plants in operation or after decommissioning, is a difficult issue. Deep geological disposal is an internationally recognized feasible method for the disposal of SNF. The so-called "deep geological disposal" is to use the containment and isolation characteristics of the host rock and adopt the "multi-barriers" concept to bury the nuclear wastes in underground strata at a depth of about 300 m to 1,000 m. This is done together with the utilization of engineering facilities, e.g., encapsulated canister, buffer and backfill material, to form a multi-barrier system composed of both natural and engineered barriers, which effectively confines and retards the release and migration of radionuclides, so as to secure a long enough time for the radiation intensity of nuclear wastes to decay to a negligible degree before it affects the current living environment of human beings. The public's biggest doubt about the spent nuclear fuel final disposal (SNFD) is the issue of radionuclide release. Preventing the radionuclide release is the most important task of SNFD.

Since 2015, INER has set up the only and domestic laboratory for radionuclides migration of SNFD program to establish key nuclides transport technologies. However, due to changes in the global environment during the 100,000 years of disposal, it is not possible to fully perform various conditions through experiments. Therefore, the use of geochemical reactions to simulate radionuclides migration parameters (diffusion and migration of radioactive species in the ground) is required. In addition to establishing relevant core technologies for the decommissioning phase of nuclear power plants. Further complete hydrochemical data needs to be constructed to protect our living environment and to enhance the confidence level of safety assessment.

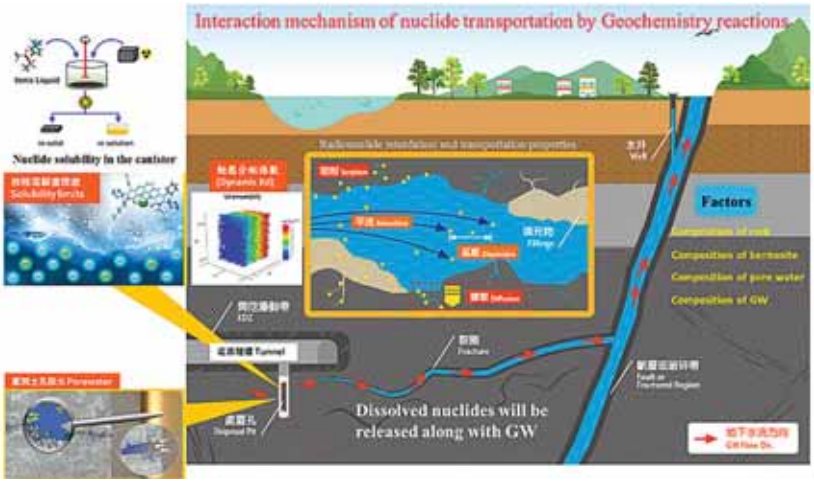


Figure 1. Transport property of reference evolution factors and interaction mechanism

Basic theory and characteristics of radionuclides migration

Fig.1 shows the release path of radionuclides, including SNF interacting with groundwater when groundwater invades the waste pack, and radionuclides such as U, Np, Pu, Am and Pd may be dissolved in the groundwater. The solubility of radionuclides affects radionuclides migration which impacts on radiation safety of the surface environment. Therefore, the solubility limits of radionuclides used to calculate the dose contribution is one of the important tasks for performance/ safety assessment of disposal facilities. Among them, the solubility of radionuclides and the sensitivity test of the distribution coefficient of nuclides sorbed on the geological materials are the key parameters that affect the radiation dose assessment. Figure 2 shows that groundwater decomposes due to exposure to radiation sources and produces hydrogen peroxide (H_2O_2), free radicals (H-,HO-,HO_2-),OH^- and H_3O^+ and other oxides. Radioactive species are the main source of radiative pollution for final disposal.

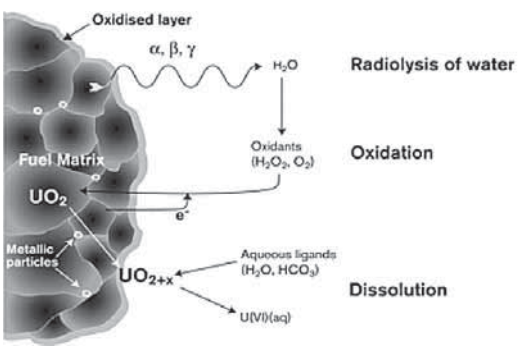


Figure 2. Radiation induced fuel dissolution mechanism

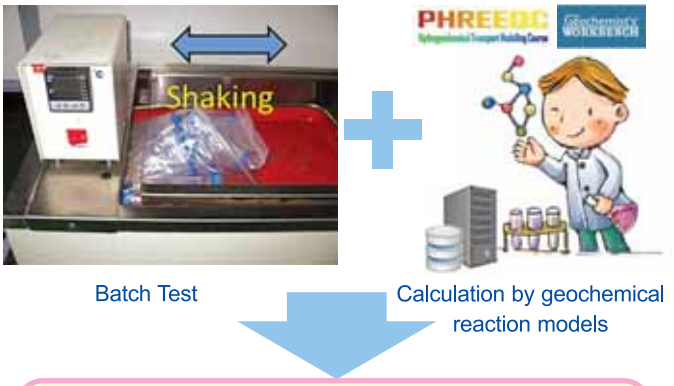


Figure 3. Schematic diagram of establishing radionuclide distribution coefficients

Research results (2): Nucleus species redox potential / pH assessment

Based on the site reference case and evolutionary conditions, the radionuclides redox potential/pH diagram was plotted, solubility was calculated, and they were compared with international literature, as shown in Fig.4, the surface complexation and ion exchange between radionuclides and geological materials were established. Thermodynamic database of local geochemical reactions. As shown in Figure 5, the solubility calculation of the radionuclides is based on the local water conditions, and then the radionuclides diffusion (retardation) under different water chemical environments is simulated.

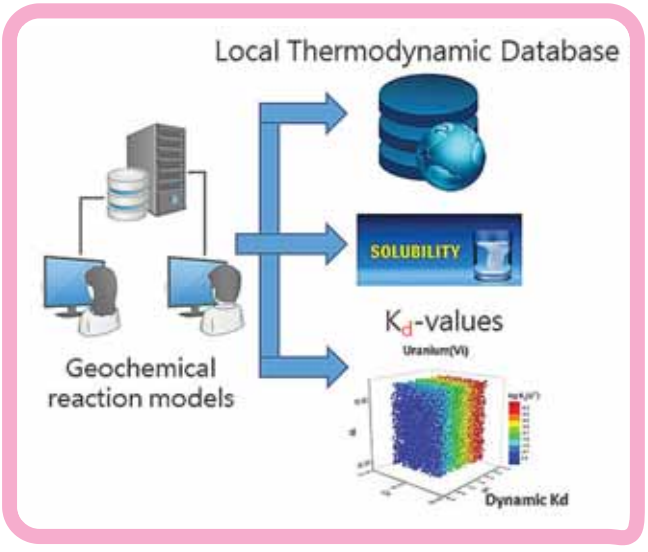


Figure 5. Establishment of nuclides migration parameters

Future development and outlook

At present, the geochemical model is under development. In the future, the modelling verification and experimental validation for distribution coefficient in the rock fractures and engineered barrier will be carried out with the goal of establishing the core technology for high-level radwaste final disposal. In addition, the hydro-chemical coupling processes and solute transport at SNF repository will be established to provide a reference for subsequent safety analysis, canister design and overall assessment of final disposal.

Research results (1): Evaluation of distribution coefficient of radionuclides

When the radionuclides release to the deep geological repository, they will flow through the fractures of the potential host rock. When the radionuclides dissolved in water pass through the fracture surface, they diffuse into the rock. The deep geological disposal of SNF requires a safety assessment period of up to 1 million years, and its environmental conditions change over time, which may affect the adsorption of radioactive species . The adsorption of site-specific characteristics of radionuclides are related to the conditions of the groundwater quality. As shown in Figure 3, the key parameters, distribution coefficients (K_d-values) for radionuclide sorbed on the geological materials can be calculated and evaluated by way of batch sorption experiments and geochemical modelling. The international adsorption data of key radionuclides on the buffer material and the host rock (e.g., granite) are continuously collected based on the surface complexation models and ion exchange reactions. After referencing the case studies of international literature, the distribution coefficients (K_d values) using the geochemical computer modelling are estimated and then verified by batch sorption experiments.

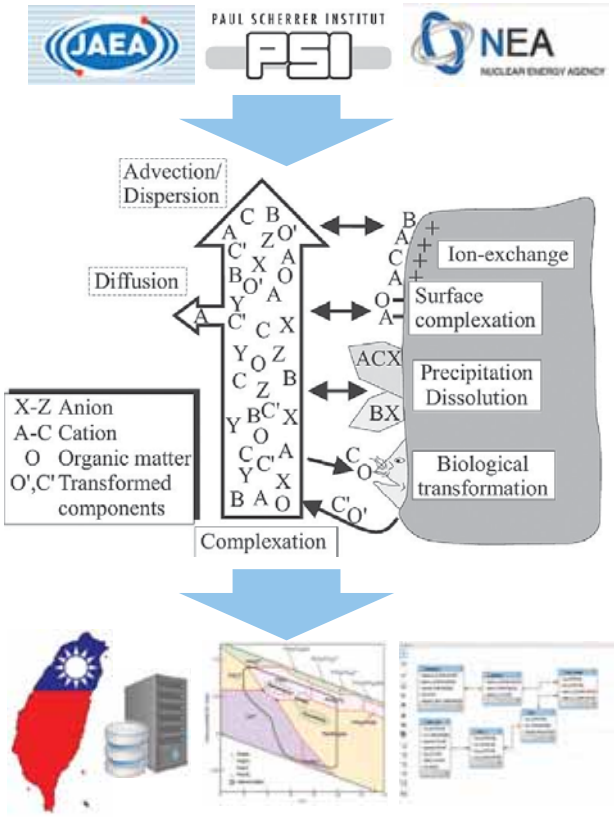


Figure 4. Establishment of local thermodynamic database

4. 2019 highlighted events and memorabilia

4-1 2019 highlighted events and memorabilia

1. ***03/06~03/08*** Four IAEA safeguards officers conducted the regular 2019 nuclear safeguards inspection at the INER. The inspection showed no abnormalities.

2. ***03/15~05/17*** The INER went into full production for the nuclear medicine diagnostic drugs, "INER Thallous Chloride (T1-201) Injection" and "Gallium Citrate Ga-67 Injection", because overseas drug plants could not produce them fast enough, causing a shortage in Taiwan. In two months, the INER produced enough injections for the imaging use of 18,000 patients.

3. ***04/10~04/11*** The INER assigned personnel to Tokyo to participate in the "15th Japan-Taiwan Joint Seminar on Energy Cooperation" to report on cooperation items, such as the "development of key materials and system setup for high efficiency recombinant hydrogen production", while arranging a meeting with representatives of the Taiyo Nippon Sanso Corporation to exchange opinions on hydrogen energy-related technology.

4. ***04/19*** The INER developed an indigenous advanced distribution management system (ADMS) and geographic information system (GIS), and conducted initial testing at the TPC Yunlin Feeder Distribution Control Center (FDCC). The test results show that the ADMS and GIS effectively improved the operation reliability of green energy distribution feeders.

5. ***05/16*** The INER organized the 2018 Presentation of "Results from Research Projects Commissioned by the AEC." Partners from industry, academia, and research institutes were invited to attend the event; there were 331 participants.

6. ***05/27~05/30*** Five experts from the IAEA, the U.S. National Nuclear Security Administration (NNSA), Los Alamos National Laboratory (LANL), and the Argonne National Laboratory (ANL) visited the INER to inspect the WBR fuel and discuss follow-up stabilization procedures.

7. ***07/24~07/26*** The INER assisted in the organization of the "3rd Taiwan-Japan Nuclear Expert Conference." The Japanese delegation included 26 members; approximately 100 people participated in the conference. After the conference, participants visited the Chinshan Nuclear Power Plant and the INER.

8. ***08/17*** The INER organized the "International Conference on Nuclear Decommissioning" and invited TPC, engineering consulting firms, foreign power plant decommissioning companies, and related equipment field experts to participate. The goal is to form a team needed for Taiwan's future nuclear power plant decommissioning.

9. ***08/28*** The INER invited the President of the Japan Health Physics Society, Professor Michiaki Kai, to give a speech. Legislator Dr. Wu Kuen-Yuh and Control Yuan member Dr. Chang Wu-Shou were invited to provide guidance. After the speech ended, the VIPs visited the INER's Food Radioactive Inspection and Measuring Laboratory.

10. ***09/04*** The INER Sodium Iodide (I-123) Oral Solution developed by the INER used for radioactive diagnosis obtained the Ministry of Health and Welfare's permit.

11. ***09/26~09/28*** The INER won five medals at the "2019 Taiwan Innotech Expo", including a platinum, a gold, a silver, and two bronze medals.

12. ***11/08*** The INER completed the fuel pool uranium powder stabilization work for the Taiwan Research Reactor (TRR). The entire stabilized product (12 sets of storage containers) were transported via the hot room to be placed in the temporarily storage box.

13. ***11/20*** The INER and the National Space Organization signed a memorandum of understanding (MOU) to become a partner in the development of Taiwan's space program.

14. ***12/06*** The INER won a "research and innovation award" and three "2019 renewal awards" in the 16th National Innovation Award organized by the Research Center for Biotechnology and Medicine Policy. The awards were presented at the Taipei Nangang Exhibition Center.

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Institute of Nuclear Energy Research

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