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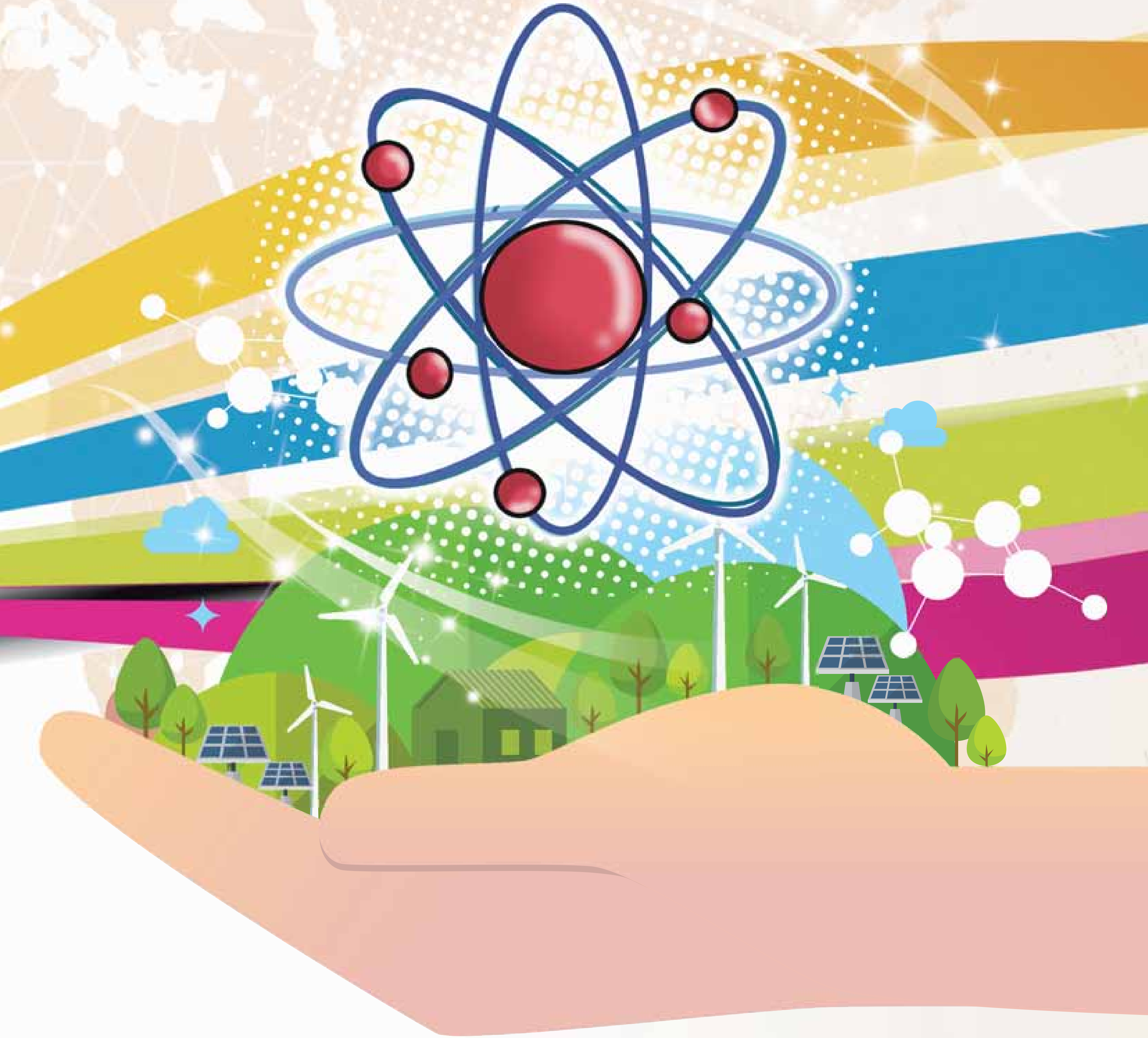
2022 Annual Report

Institute of Nuclear Energy Research
Atomic Energy Council, Executive Yuan



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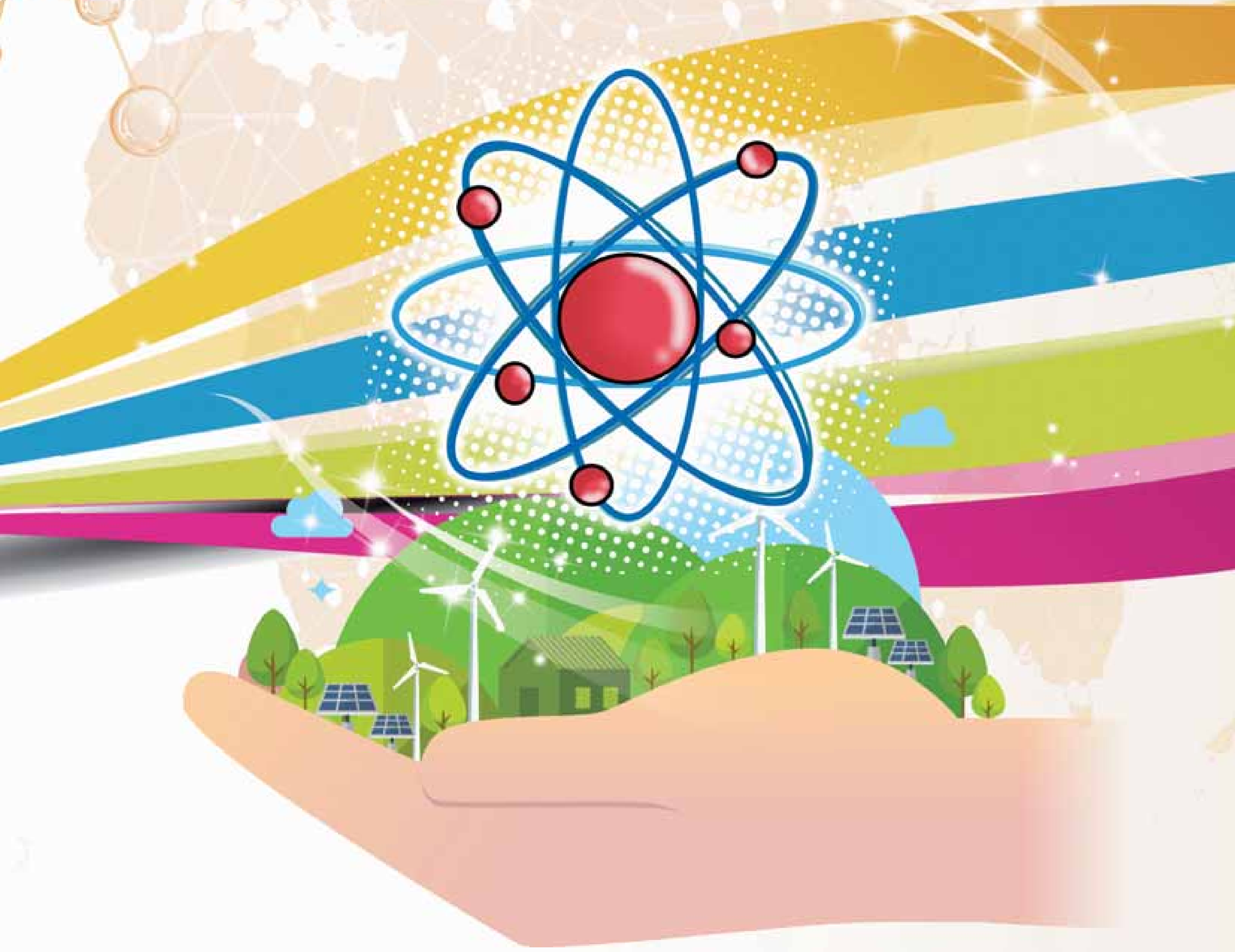

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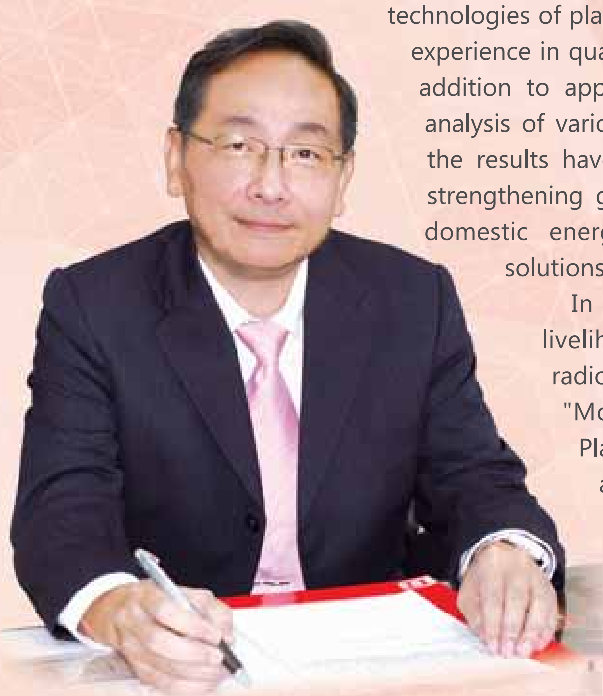
Contents

1.Preface

To become the most reliable atomic energy research institution in the country

The Institute of Nuclear Energy Research (INER), established in 1968, is the state level research and development (R&D) institute dedicated to atomic energy technologies. After 55 years of transformation and growth, nuclear safety, nuclear back-end, nuclear medicine and people's livelihood radiation application, new energy and system integration have become the main axes of development. In addition to being committed to forward-looking and innovative research, INER also actively promotes research and development results in people's livelihood and industrial applications. With the joint efforts of all colleagues in 2022, various Research and development have achieved fruitful results.

In terms of nuclear safety and nuclear back-end development, INER focuses on the safety analysis of nuclear power plants, the safe storage assessment of spent nuclear fuel, the decommissioning and cleaning of nuclear facilities, and the treatment and disposal of radioactive waste, and establishes key technologies to meet the needs of our country's nuclear power plant decommissioning. Regarding the issue of nuclear fusion, INER will cooperate with domestic plasma experts to complete the first domestic small-scale tokamak research device within 4 years to conduct researches on key technologies of plasma nuclear fusion. In addition, INER has 40 years of experience in quantitative risk assessment of nuclear power plants. In addition to applying its results to risk assessment and reliability analysis of various power supply and natural gas storage facilities, the results have also begun to be applied to the assessment of strengthening grid resilience. These technologies can be used for domestic energy utility operators to provide complementary solutions to help improve grid resilience.



In terms of radiation applications for people's livelihood, INER has successively established "14C-radiolabeled drug metabolism technologies platform", "Molecular Imaging and Radiation Pharmacology Platform" and "GLP Radiation Toxicology Laboratory", and developed "Long-acting targeted therapy for prostate cancer" , "Drugs for radioembolization of liver cancer" and "INER Dolacga Liver Imaging Agent", the first liver-targeting glycopeptide drug for liver function imaging in the world. INER will implement the "Establishment Plan of 70 MeV Medium-Sized Cyclotron" from 2023. After completion, it will serve as an important facility for the development of new drugs for nuclear medical diagnosis and treatment in my country, the expansion of the application of neutron and proton materials in my country, and the expansion of satellite and semiconductor detection technologies. In addition, in response to Japan's discharge of tritium-containing treated water from the Fukushima Daiichi Nuclear Power Plant into the ocean, INER established our country's first bio-tritium testing laboratory in August 2022 and built the "Ocean Radioactive Information System (TW-ORIS)". It can provide the public with information about radioactive substances in the surrounding sea areas of our country.

In terms of green energy and system integration, INER focuses on the development of energy creation, energy storage, energy saving and system integration technologies, with rich results and technology transfer to private manufacturers. From 2016 to 2022, 38 technology transfer projects have been signed, including technical projects such as liquid flow batteries, solar cells, solid oxide fuel cells, biomass biogas, smart grids, etc., with a total contract value of 130 million new Taiwan dollars. In addition, INER executes the "Green Energy Generation and Distribution Smart Management and Efficiency Improvement Technology Development Plan" and strive for the "Net Zero Emissions-Grid Resilience Analysis Plan (2023-2025)" forward-looking infrastructure construction plan to assist the government in developing my country's 2050 net zero emissions science and technology.

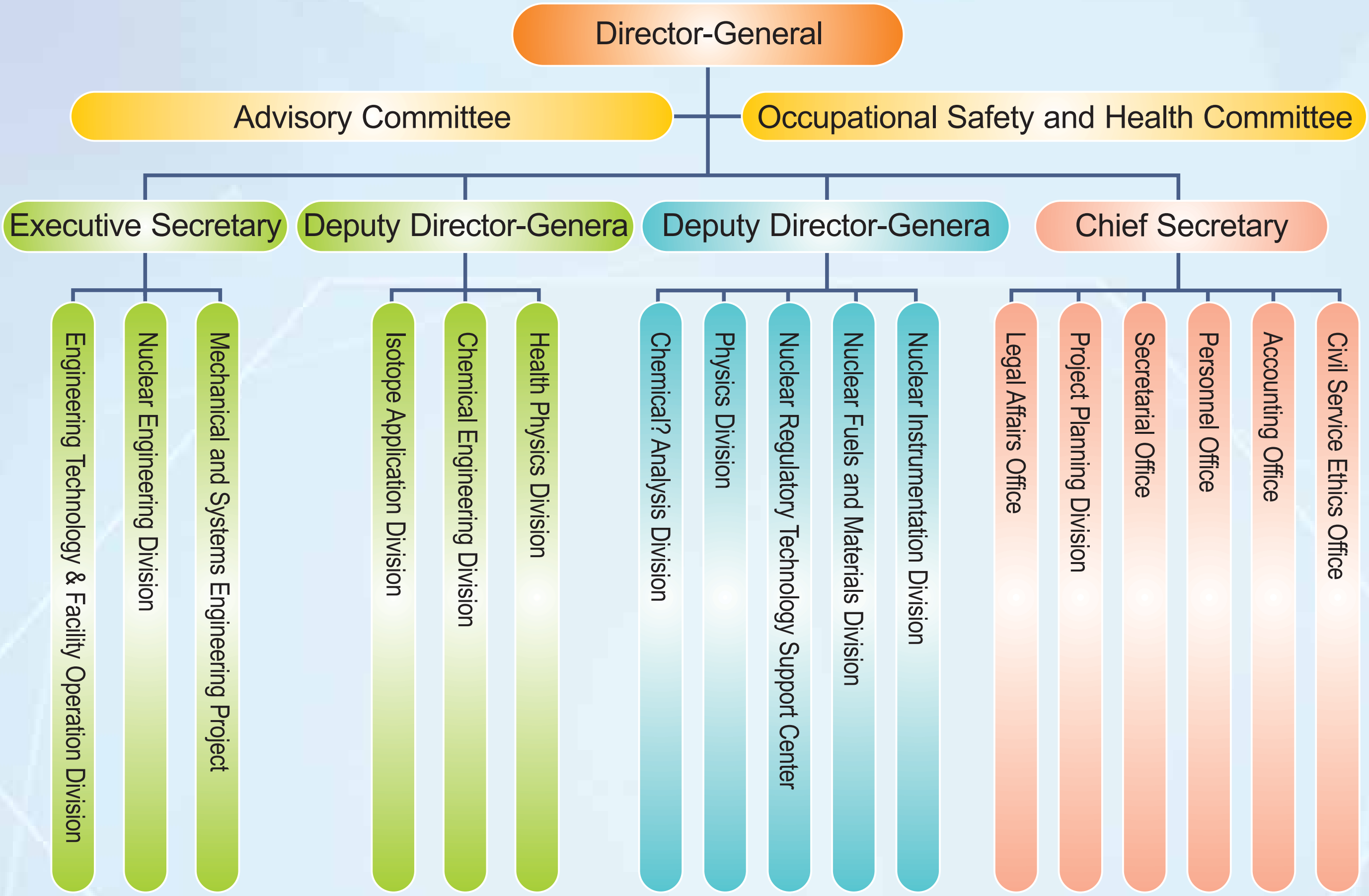
In order to enhance the visibility of patented technologies and opportunities for cooperation with the industry, INER actively participates in domestic and foreign innovative technology competitions and exhibitions. After winning the "2021 R&D 100 Awards" with "Intelligent Distribution Network Management System (iDNMS)" in 2021, INER received the "2022 R&D 100 Awards" with "Intelligent Distribution Network Management System (iDNMS)". In the "2022 Taiwan Innotech Expo", INER won 15 awards, including 2 platinum awards and 3 gold awards. It is the only unit that has won 2 platinum awards for 3 consecutive years.

In line with the organizational transformation of the Executive Yuan, INER will be transformed into an independent administrative institution. In response to the process of incorporation, INER will also focus on the management strategy. Looking forward to the future with the topics such as nuclear energy safety, radiation protection, nuclear back-end technology, the application of atomic energy to people's livelihood, and 2050 net-zero emissions, INER will take steady steps to face various challenges, embrace a new future, realize a low-carbon society and improve people's well-being to become the most trustworthy atomic energy research institution in the country.

Director General

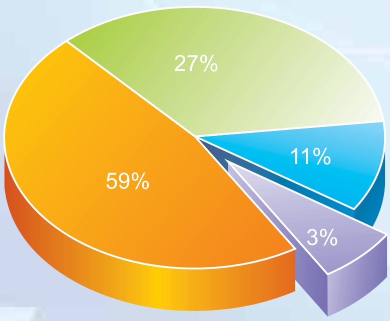
2.Organization Chart、Human Resources and Budgets

Organization Chart of INER



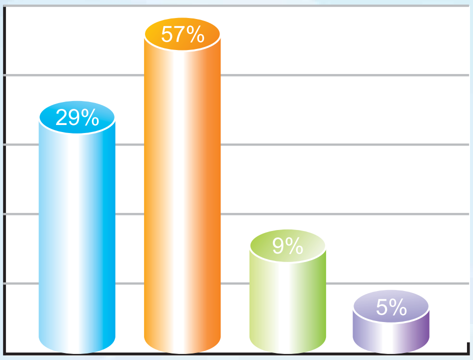
Human Resources and Budgets (Time of data: December, 2022)

Manpower Distribution of INER



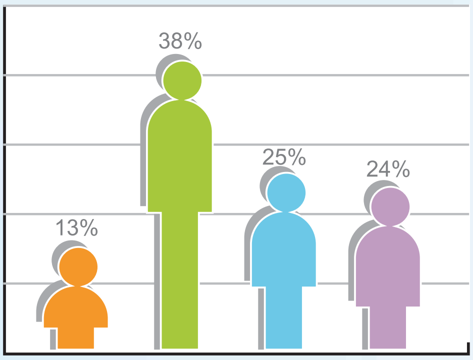
Research Staffs	486 Persons	(59%)
Technicians	219 Persons	(27%)
Administrative Staffs	93 Persons	(11%)
Other Staffs	25 Persons	(3%)
Official Staffs	823 Persons	

Statistics of Educational Background for Research Staffs



Ph.D.	140 Persons	(29%)
Master	277 Persons	(57%)
Vocational School	42 Persons	(9%)
Bachelor	27 Persons	(5%)
Research Staffs	486 Persons	

Statistics of Job Category for Organizational Research Staffs



Researcher level	63 Persons	(13%)
Associate Researcher level	184 Persons	(38%)
Assistant Researcher level	119 Persons	(25%)
Research Assistant	120 Persons	(24%)
Research Staffs	486 Persons	

2022 Annual Budget

Unit: Thousand NTD

Item	Number of Accounts	Percentage
Administration and Safety	1,150,873	72.30%
Management, Operation and Maintenance	216,130	13.58%
R&D Projects	221,843	13.94%
Construction and Equipment	3,057	0.19%
Total	1,591,903	100.00%

3.Current Major R&D Activities

3-1

Nuclear Safety & Nuclear Back-end Technologies

By the implementation of the national energy transition and nuclear-free homeland policies, all of the nuclear power plants in our country will enter decommissioning phase in 2025, after their operating licenses expire one after another. Now in compliance with the regulation, INER is also decommissioning and dismantling its research reactor and other nuclear facilities that were built in early years and operated with mission to promote applications of atomic energy technology. To meet the national need in the changing situation, INER currently focuses its research and development endeavor on the application of nuclear power plant safety analysis, storage safety evaluation of spent nuclear fuel, nuclear facility dismantling, radioactive waste management and disposal techniques. The purpose is to maintain the domestic nuclear safety and radiation safety, and aggressively apply the nuclear safety techniques to other inter-discipline systems. The following summarize the major outcomes in nuclear safety and nuclear back-end research of INER in 2022:

1.To ensure the safety of spent nuclear fuels during decommissioning, for the first time INER integrates the thermal hydraulic modeling and offsite dose analysis codes to calculate the consequence of a postulated severe accident in the PWR spent fuel pool (SFP). This research analyzes the thermo-hydraulic phenomena and source terms from the loss of coolant events happened at different locations on the SFP liner. The analysis has taken into account the population distribution of 16 directions around the plant site in the calculation of the latent public risk of fatalities due to cancers.

2.INER develops the analysis technique for optimal design of spent nuclear fuel (SNF) storage configuration to meet the future needs of final disposal of the SNFs from the three domestic nuclear power plants. This technique would assist the Taipower when planning the SNF dry storage configuration, to take into account the specification of loading the SNFs into the disposal canister. It conducts optimal integrated design to determine the appropriate size of the disposal site under the premise of safety and economic benefits.

3.Due to high radiation, the dismantling activity of upper thermal shield is a critical and difficult task in the path to Taiwan Research Reactor (TRR) decommissioning. INER has independently developed a pneumatic reciprocating saw system that can be remotely controlled. Combined with hydraulic shearing equipment, the workers can remotely operate the saw system and dismantling equipment to minimize their exposure. INER has successfully completed the upper thermal shield dismantling in compliance with ALARA principle and met the decommissioning schedule.

4.Underwater cutting technology and methods play important roles in safely accomplishing high radiation nuclear facility decommissioning. To meet the need of the dismantling of TRR reactor, INER sequentially develops the design and manufacturing techniques of cutting tank, cutting operation platform, band saw, and disk saw system installation. INER expects to complete the cutting process of upper thermal shield, in order to meet the regulatory requirement on the end date of TRR decommissioning.

5.INER developed a monitoring system for boiler tubes of coal-fired plant called INER_BTHMS. The monitoring system focuses on tube failure caused by over-heating creep and establishes real-time database incorporating the maintenance data from tube inspection and replacement activities. INER_BTHMS calculates and evaluates the status of the health of boiler tube that is helpful to reduce the failure rate of unit and repair times after tube anomalies occur. The monitoring system is expected to effectively decrease the Equivalent Unavailability Factor (EUF) index of domestic power plant to stabilize the electricity supply.

6.In order to meet the management needs of large amount of radioactive waste generated from nuclear power plant decommissioning, since 2021 INER started integrating the domestic low- and medium-activity radiochemical laboratories, conducting inter-laboratory comparison on radionuclides difficult to measure. INER takes this endeavor with hope to help the domestic labs to establish the analysis ability for decommissioning-concerned radionuclides. In 2022, INER has accomplished the inter-laboratory comparison on radionuclides difficult to measure for two domestic radiochemical labs, significantly enhancing their radiochemical analysis techniques.

3-1-1

Ensuring the Safety of Nuclear Power Plant Shutdown and Decommissioning - Consequence Assessment of Spent Fuel Pool (SFP) Under Severe Accidents

The Fukushima disaster in Japan raised concerns about the safety of the spent fuel pool (SFP) in the nuclear industry. In response, the US Nuclear Regulatory Commission published the NUREG-2161 report in 2014 to investigate risks to public health from the structural integrity and potential loss of coolant in SFP during seismic events. This study has actually carried out the case application of the accident risk assessment of the spent fuel pool of the Maanshan nuclear power plant under a beyond-design-basis seismic event, and the result could help to clarify relative issues.

Fig. source：from Maanshan Nuclear power plant

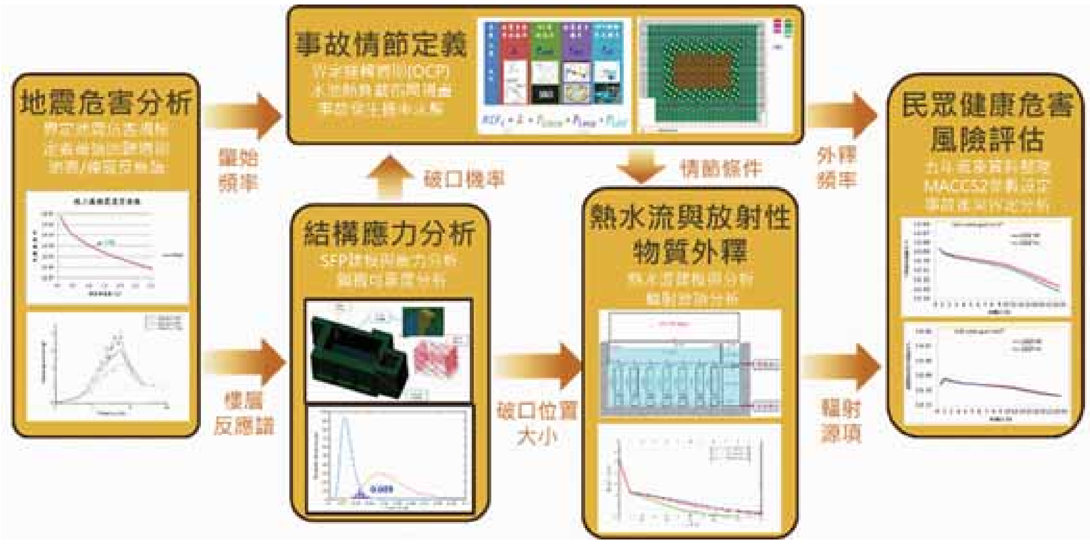


Fig.1. The Consequence Analysis Flowchart of the SFP Severe Accident

This study is the first to integrate MELCOR and MACCS2 codes for SFP analysis in Taiwan. This study develops a thermal-hydraulic model for the SFP of a pressurized water reactor (PWR), incorporating the decay heat, activity of spent fuel, SFP material characteristics, and loading. The SFP analysis includes water level variation, heat transfer mechanisms, zirconium-water reactions, component temperature rise, and source term. Health risk values were also calculated for the public based on population distribution and atmospheric conditions.

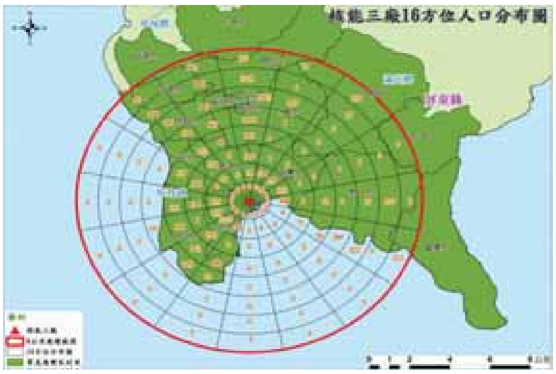


Fig.2. The Population Distribution of 16 Directions Around the Plant Site

Fig. source：from TPC report regarding the EPZ assessment

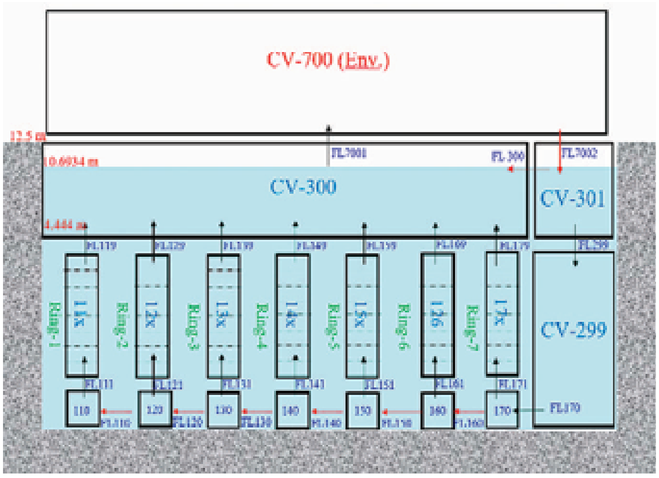


Fig.3. SFP Thermal-Hydraulic Model Diagram

INER has years of practical experience in the relevant technical requirements, primarily applied in operating nuclear power plants to improve efficiency and strengthen safety. As Taiwan's nuclear power plants gradually reach the end of their operational lifetimes, with spent fuel safety becoming a primary concern during the decommissioning stage, INER assists Taiwan Power Company in assessing related issues on the disposal of spent nuclear fuel as well as ensuring compliance with regulations and public safety.

This study developed a thermal-hydraulic analysis technique for the SFP of a PWR using MELCOR code and severe accident analysis program. In addition, the study also assessed the consequences of SFP accidents using the MACCS2 code for off-site dose calculations.

Conservatively assuming that the SFP steel liner cracks cause partial or total loss of the pool coolant without any mitigation, the results show that the potential individual cancer fatality risk within 8 kilometers boundary of EPZ is estimated to be about 1.0×10^{-8} per year, which is about 2 orders of magnitude lower than the quantitative health objective 2.0×10^{-6} (yr^{-1}) defined by USNRC

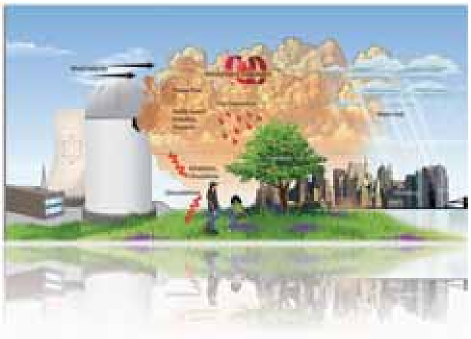


Fig.4. The Mechanism and Phenomena of Release and Propagation of Radioactive Nuclides

Fig. source：from US SNL Overview of MACCS2

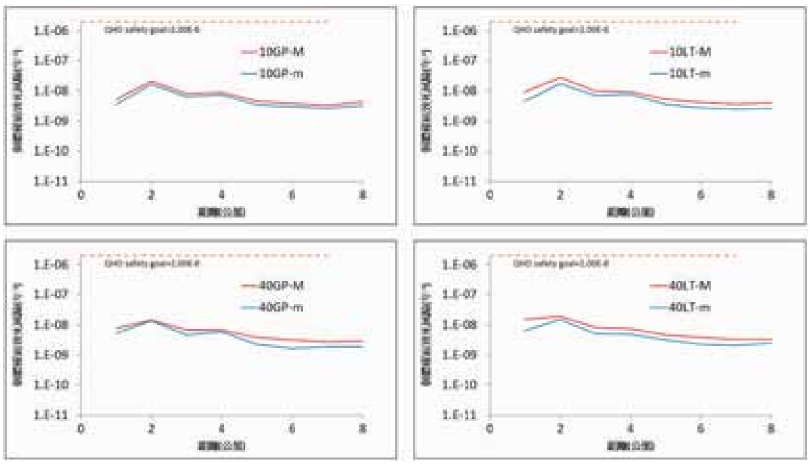


Fig.5. The Relationship between the Individual Cancer Fatality Risk and Distance.

As nuclear power plants in Taiwan go into the decommissioning phase, the government strictly requires that the operation and disposal of spent fuel in decommissioned units must comply with the "Radioactive Waste Management Policy". Currently, spent fuel is stored in SFP within the nuclear power plants in Taiwan, waiting for dry storage in the next stage. Therefore, the developed technical items in this project can provide an important basis for nuclear power companies in safety related evaluations regarding spent fuel storage management.

3-1-2

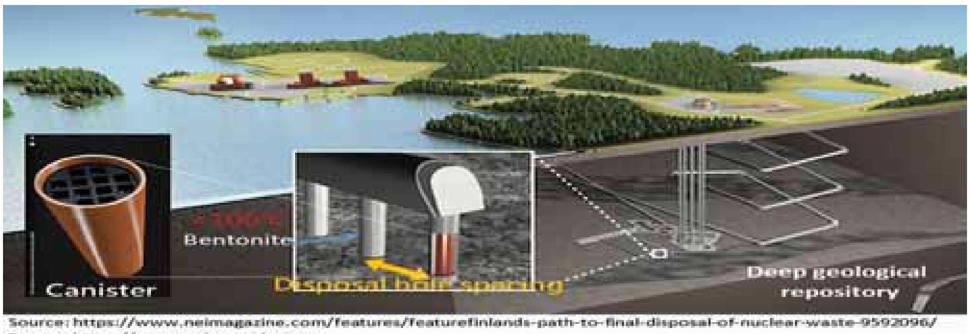
An Integrated Configuration Technology for Spent Nuclear Fuels Loading of Dry Storage Casks and Disposal Canisters

In Taiwan, spent nuclear fuels (SNFs) discharged from the nuclear reactor will be stored in the spent nuclear fuel pool in the power plant to cool down for some time. After that, they will be transferred to the dry storage casks for about 40 years of storage and then will be transferred to canisters for final disposal in AD 2055 if the underground facility construction is completed. As internationally recognized, "Deep geological repository" is the most feasible final disposal method. The SNFs and engineered barriers of canister, buffer, and backfill would be disposed of at approximately 500 m depth underground in a stable stratum (natural barrier). The release of radionuclides would be contained and the migration would be retarded by a multiple-barrier system to reduce the radiation influence on the human body.

As a buffer material, the temperature of bentonite should not exceed 100°C. When thousands of canisters are placed 500 m underground together to heat the stratum, the higher the initial ground temperature of the stratum is, the slower the heat dissipation will be, consequently the lower the heat load of the canisters can be withstood. Therefore, it is necessary to increase the disposal hole spacing, so that the temperature of bentonite will not exceed 100°C. The disposal hole spacing directly affects the length of the disposal tunnel and the size of the final disposal site. That means the larger the disposal hole spacing is, the higher cost it constructs at.

The stratum in Taiwan has the characteristics of high ground temperature and slower heat dissipation. Under such less desirable geological conditions, adjusting the heat loads of canisters to shorten the disposal hole spacing, while maintaining the containment and retardation functions of bentonite, is the most time-saving and effort-saving method that can be used to save huge construction costs. The way to control the heat load of a canister is achieved by designing the configuration of SNFs to be filled in it.

This technology is an integrated SNFs loading configuration technology for the two-stage storage containers, i.e. dry storage casks for interim storage and canisters for final disposal. It can set the SNFs configurations of the dry storage casks regarding how many dry storage casks are opened at a time and how many canisters are loaded per year. The simulated annealing method is used to search for possible SNFs configurations of canisters so the heat load of each canister is as close to each other as possible when the SNFs of each dry storage cask are transferred to the canisters.



Source: https://www.neimagazine.com/features/featurefinlands-path-to-final-disposal-of-nuclear-waste-9592096/
Source: https://www.neimagazine.com

Fig.1. Schematic Diagram of a Deep Geological Repository, Canister, Bentonite, and Disposal Hole Spacing.

Calculation of Decay Heat of SNF and Fuel Arrangement in Casks

Perform SNF decay heat power calculation according to the methodology of US Nuclear Regulatory Commission RG3.54 Revision 2, set the fuel configuration logic of the dry storage cask, and based on their resulting heat loads, estimate the heat load limit of canisters. The input data includes the operating cycle times, burnup, uranium weight, uranium-235 enrichment, and disposal time. The output data includes the fuel configuration of dry storage casks and the decay heat power of all SNFs.

SNF Configuration in Canister

Open a dry storage cask and put the stored SNFs into canisters one by one. If the heat load of the first canister exceeds the initially estimated limit, the second canister is placed, and so on. After completion of checking the canisters and if the number of not fully filled canisters exceeds 1, execute the simulated annealing algorithm to regenerate the fuel configuration of all canisters until only 1 or 0 canister is not fully filled. The input data is the fuel configuration of the opened dry storage cask. The output data is the fuel configuration of each canister.

Logical Judgement

Determine whether the following five process parameters have been achieved. (1) Has the opened dry storage cask completed its canisters' fuel configuration? (2) Is the opened dry storage tank the last one? (3) Can another unopened dry storage cask be replaced for canister fuel configuration? (4) Has the number of canisters loaded annually been reached? (5) Whether to end the search for the heat load limit of canisters?

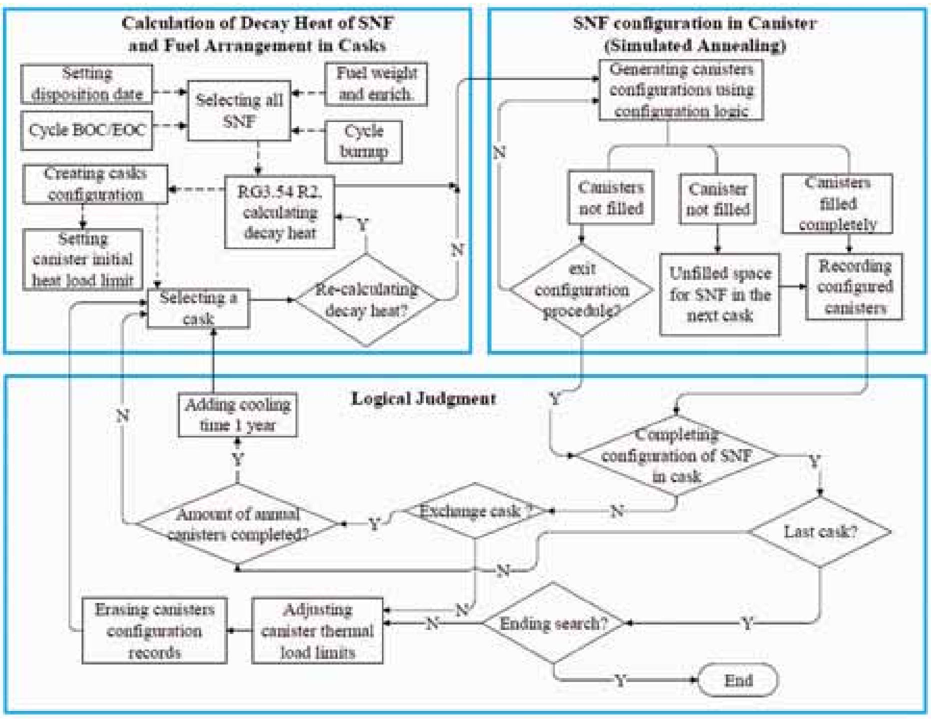
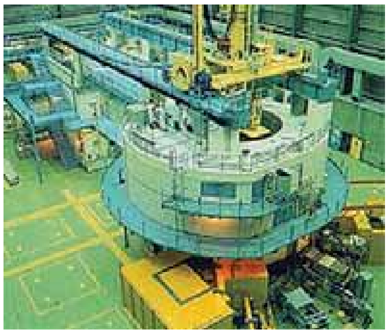


Fig.2. Flow Chart of Integrated SNFs Configurations of Two Storage Containers

The SNFs of the three domestic nuclear power plants will gradually enter the interim storage stage. This technology can assist Taipower in planning the fuel configuration of dry storage casks while taking into account the fuel loading needs of canisters at the final disposal stage, so as to avoid the problem that some canisters would not be fully filled with fuels in the future. The optimal integrated design of the fuel configurations of the two storage containers can determine the appropriate size of the disposal site under the premise of taking into account the safety function and economic benefits, and provide a reference for Taipower when selecting a repository site.

3-1-3

Overcome the Dilemma of TRR Decommissioning - Self-developed Cutting Technology for Thermal Shield through Pipe on TRR



The "Taiwan Research Reactor (TRR) Decommissioning Plan" was approved by the competent authority in April 2004. The decommissioning deadline is March 2029. The dismantling of TRR (as shown in Fig.1), the most critical work, was not yet completed. The main structure (as shown in Fig.2) includes movable components such as upper bio-shield, upper thermal shield, side thermal shield, graphite reflector, reaction tank and lower thermal shield , and peripheral bio-shield (including ring thermal shield). The strategy of disassembly will follow the principles of "top-down" and "inside-out". Therefore, it is necessary to disassemble and remove the movable components inside reactor first, then collaborate with peripheral bio-shield to disassemble reactor in layers, and carry out dismantling operation step by step. INER has completed the dismantling of the most upper component i.e. upper bio-shield of TRR in 2021. Because there is a through-pipe above thermal shield on the second layer component connected to bio-shield, it must be removed before the disassembly. However, the high radiation makes it not easy to dismantle, which is the key dilemma for TRR decommissioning.

Fig.1. TRR Reactor

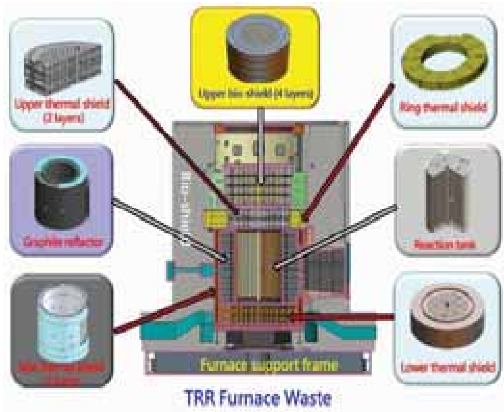


Fig.2. Main structures of TRR

The thermal shield passage tube on the TRR is connected to the upper thermal shield layer A and B, and partly extends into the bio-shield (as shown in Fig.3). Since it is located above the activated component (upper thermal shield), the on-site radiation intensity is relatively high. The radiation dose rate at the highest point is 50 mSv/h. Considering the radiation protection and dose control of personnel, staff cannot approach the cutting operation with the common cutting tools. Therefore, INER has self-developed pneumatic reciprocating saw that can be remotely controlled , combined with hydraulic shearing equipment, for workers to remotely operate dismantling equipment on furnace top 4 m away from the cutting position (radiation dose rate is about 40 μSv/h) , to overcome high radiation problem as well as other on-site problems. The removal of the upper thermal shield crossing pipe was successfully completed, so that the TRR decommissioning work can be executed under the planned schedule, also compling with the "ALARA" principle of the "Ionizing Radiation Protection Safety Standard".

Fig.3. The thermal shield through the tube on TRR

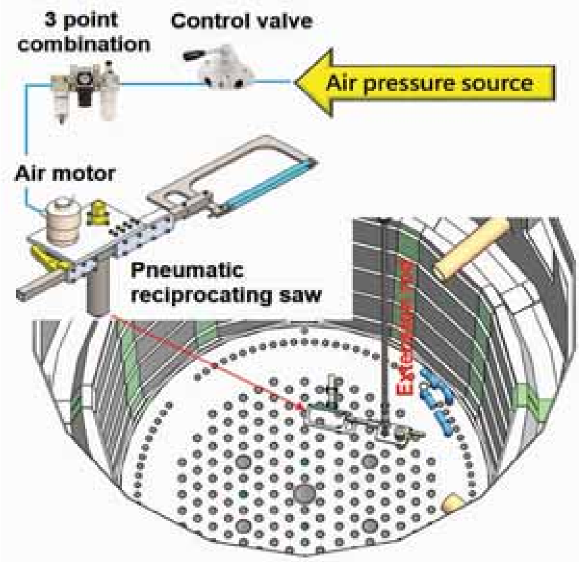


Fig.4. Pneumatic reciprocating saw cutting methodology

Technical Methodology and Plan

The upper thermal shield crossing 12-cm-diameter pipe is coiled between upper heat shield and bio-shield. In order to disassemble and remove subsequent furnace components, the obstacles in removal path must be cleared. Therefore, it is planned that the pipes in the circular space in furnace and pipelines in bio-shield are dismantled and removed together. The removal equipment by plan includes self-designed pneumatic reciprocating saw (as shown in Fig.4) and hydraulic shearing equipment. The pneumatic reciprocating saw is used to cut off most of the pipelines above upper thermal shield , then the hydraulic scissors are used to cut off remaining pipe heads protruding from the path of removal space, and directly grab and pack the dismantled waste. Staff operates remotely throughout all the above process to ensure radiation safety.

Operation Tools Manufacture

The hydraulic shearing equipment includes hydraulic shears and a hydraulic system, with a maximum shearing pressure of 500 bar and a maximum shearing diameter of 18 cm. The pneumatic reciprocating saw system operates with high-pressure gas to rotate and drive saw bow to reciprocate while the staff assists in applying rotational force. The range of the rotary resection is between 82 and 19 cm in diameter. The above tools are all designed to cooperate with extension rod to go deep into the furnace. After purchasing and manufacturing (as shown in Fig.5), the mock-up is carried out with samples, and the cutting or shearing operation is successfully completed, which meets the design functional requirements.

Fig.5. Operation Tools

Dismantling Operation

In the dismantling process, the staff is located on top of the furnace to perform dismantling work (as shown in Fig.6). The staff first installs the pneumatic reciprocating saw into the hole of original fuel rod and operates the rotary reciprocating saw to cut off surrounding upper bio-shield through pipe, then uses hydraulic shears to penetrate into upper thermal shield above and around the bio-shield, cuts off remaining pipe joints, and finally picks up the waste and packs it into a box , so as to complete all the dismantling operations (as shown in Fig.7) . There are three workers in total, and their collective dose is 25 μSv-man for six hours of work, greatly reducing dose received by personnel. The process has been inspected by competent authority and achieved zero deficiency in radiation safety.

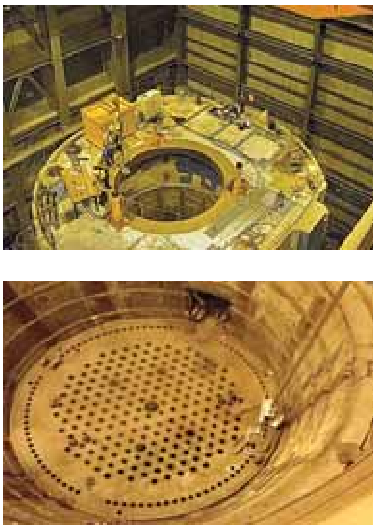


Fig.6. Cutting operation of upper bio-shield crossing pipe

Fig.7. Complete removal of upper bio-shield crossing pipe

3-1-4

Developing high-radiation nuclear facility decommission technology - independent research and development of underwater cutting technology and methods

Based on the decommission experience of nuclear facilities, many complex tasks will be involved in the dismantling of a nuclear reactor, such as the disassembling of reactor vessel, the underwater cutting of reactor vessel assemblies and the packing of radioactive waste. It is a major challenge in terms of technology, program management and radiation protection. Taiwan Research Reactor (TRR) reactor vessel was removed and stored in the disassembly workshop of Building 074 at INER in 2002. The decommissioning plan of TRR was approved by the competent authority in 2004 and put into execution form 2011. On the other hand, the operation licenses of the six domestic nuclear reactors were expired one after another. ChinShan Nuclear Power Plant was in the decommissioning stage. KuoSheng and MaanShan Nuclear Power Plant will execute the decommissioning plan in the future. It would be challenging to lift out, cut and finish packing the radioactive components from reactor vessel during the dismantling process. In order to reduce personnel dose during cutting process, the relevant operation will be performed underwater. Hence, it is an important issue to develop underwater cutting technology and methods for high-radiation nuclear facility decommissioning.

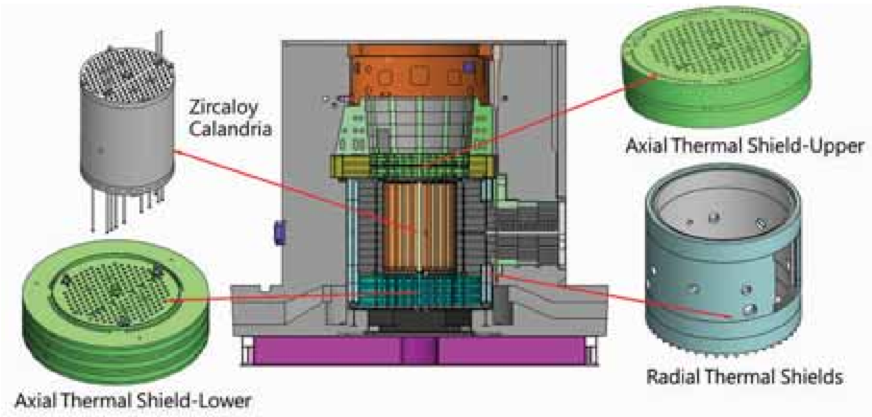


Fig.1. Main components of TRR reactor vessel

The underwater cutting operation methods can be classified into thermal and mechanical cutting. According to the foreign decommissioning experience, mechanical cutting is main stream to avoid the problem of secondary waste disposal. Those components of TRR reactor vessel are planed to be cut underwater after considering dose and structure conditions ,that include Axial Thermal Shield-Upper(ATSU), a Zircaloy Calandria, Radial Thermal Shields and Axial Thermal Shield-Lower(ATSL), as shown in Fig. 1 . After evaluating the size of those reactor vessel components , packing container and cutting workshop, some underwater cutting devices were developed to cut TRR reactor vessel components, such as cutting operation platform, band saw, and disk saw as shown in Fig. 2. Underwater band saw was applied to cut ATSU and ATSL, and underwater disk saw was used for Zircaloy Calandria and Radial Thermal Shields disassembling.

Fig.2. reactor vessel cutting device assessment

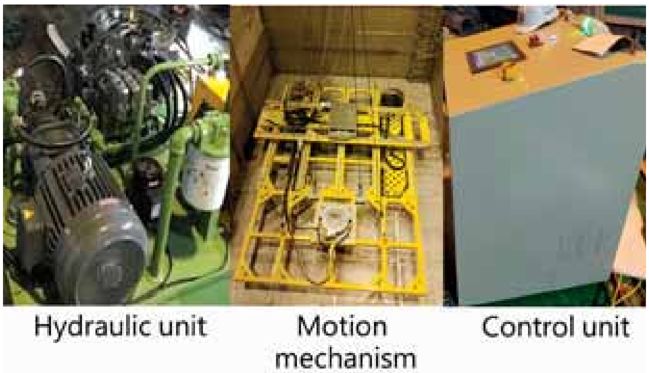


Fig.3. Composition of underwater cutting operation platform

After assessment, those reactor vessel components with cutting section thickness less than 0.18m, such as Radical Thermal Shields and Zircaloy Calandria, were suitable to be cut by disk saw. Based on 3D modeling and cutting process assessment, INER developed a disk saw suitable for used underwater and finished cutting cast iron samples with 0.15m thickness, as shown in Fig. 4. In order to avoid underwater manned maintenance activities during cutting process, a quick release mechanism between cutting machine and underwater cutting operation platform was designed to lift cutting device for daily machine maintenance (Fig. 4.)

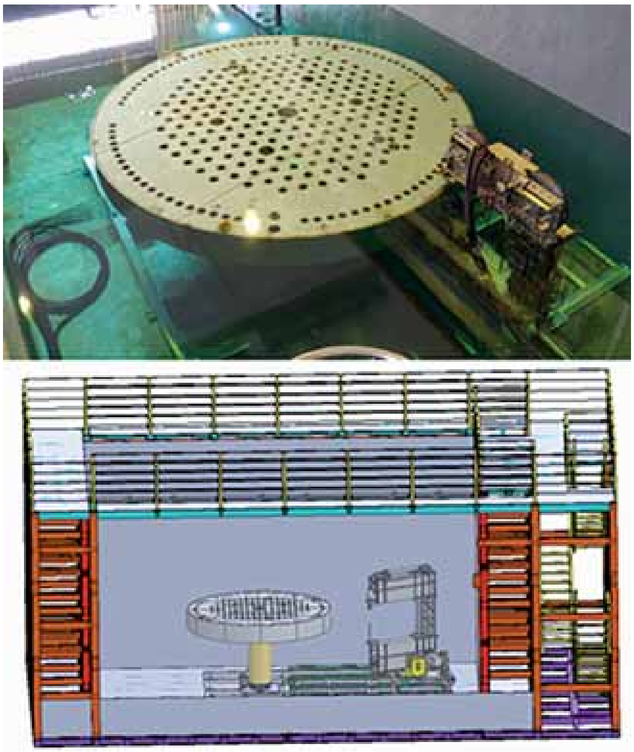


Fig.5. Integration of band saw and operation platform under water

Main functions of the underwater cutting operation platform are adjusting relative position between reactor vessel component and cutting machine, and controlling the cutting parameters of machine. It is composed of motion mechanism, control unit and hydraulic unit, as shown in Fig. 3. As a reactor vessel component is lifted out and moved to cutting workshop, the ATSU could be locked and rotated to reserved location by setting motion mechanism. The underwater cutting operation platform could be integrated with different cutting machine, such as disk saw or band saw. On the other hand, the parameters of cutting process, such as initial position, final position and feeding rate etc. , could be controlled by the control unit.

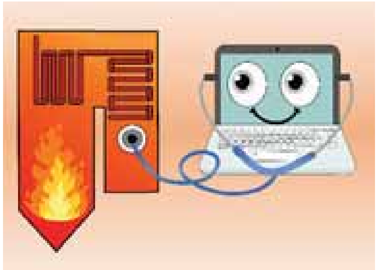
Fig.4. Underwater disk saw device test

As shown in Fig. 5, underwater band saw is designed to cut reactor vessel components, which's cutting section thickness is less than 0.6m. Maximum cutting section thickness of Axial Thermal Shield-Upper and Axial Thermal Shield-Lower is 0.43m, hence underwater band saw would be used to finish cutting process. It is expected to complete the model cutting test before mid 2023 and the actual cutting of Axial Thermal Shield-Upper in 2023 to meet the schedule of the TRR reactor vessel dismantling plan.

Underwater cutting technology and methods often play important roles on finishing nuclear facilities decommissioning. In order to meet regulatory deadline of the TRR reactor vessel dismantling plan, INER had developed wet cut workshop, underwater cutting operation platform, and try its best to improve the design of cutting machine suitable for used underwater continuously. In the future, It can be expected that the accumulated experience of TRR reactor vessel components cutting can be extended to the radioactive component dismantling of other domestic nuclear facilities, and enhance the capability of domestic nuclear dismantling industry.

3-1-5

Checking Health Any Time-
Health Monitoring and Assessment System for Boiled Tube of Fossil-Fuel Power Plant



Fossil-fuel power plant will be one of the main electricity generation sources after 2025 in Taiwan. How to operate the power plant efficiently and stably is a critical issue for the owner. It has been recognized that the boiler tube failure is the main initiator of unexpected shutdown of coal-fired power plants (about 80%) worldwide, and the key cause of the tube failure is regarded to be over-heating creep. In order to reduce the likelihood of creep-induced boiler tube failure, INER (Institute of Nuclear Energy Research) develops the monitoring system for boiler tubes of coal-fired plant called INER_BTHMS (INER Boiler Tube Health Monitoring System). The monitoring system could be considerably helpful to decrease the EUF (Equivalent Unavailability Factor) of plant based on the parameters of the real time operation, inspection of plant maintenance data and the frequency of tube replacements. It could be expected to elevate the confidence from people, owner and government on the electricity production using INER_BTHMS.

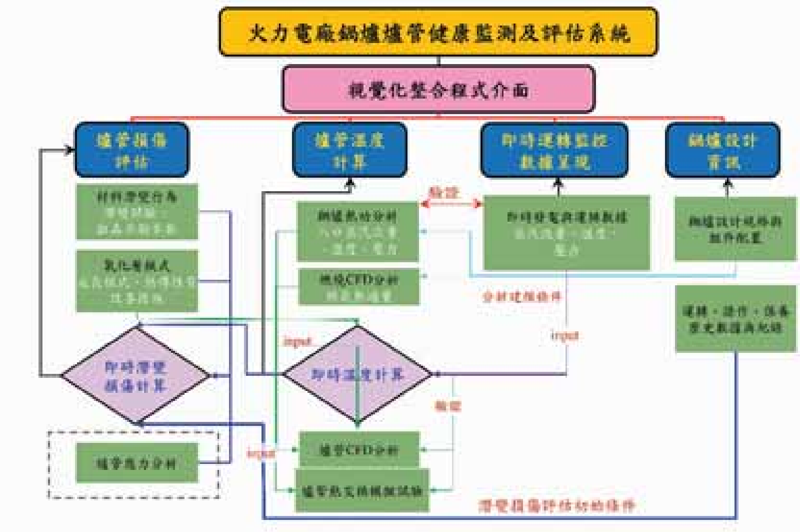


Fig1. Technical frame of tube failure monitoring system

The essential techniques used in the development of INER_BTHMS are shown in Fig. 1. There are four major aspects including specified tube modeling, real time database establishment, calculation codes for estimating temperature, pressure and lifetime of tube, and interface visualization. As the integration of all techniques in the monitoring system completes, it would make the monitoring system more user-friendly and provide information more directly for on-duty operators and senior engineers who can give prompt and precise judgements in any operation conditions.

The first part of the operation inside the furnace is to burn the coal powder to heat up the flue gas. The flue gas serves as the heat source in the superheater to turn the saturated steam into overheated steam (as shown in Fig. 2). The major challenge faced is that it is difficult to gain the real parameters (flow rate, temperature and heat energy) inside the furnace due to extremely high temperature environment. Consequently, the CFD (Computational fluid dynamics) technique is adopted for the simulations of combustion and heat transfer process to find out the critical parameters. The results from CFD simulation are the bases of verification and adjustment for the following numerical computer code development.

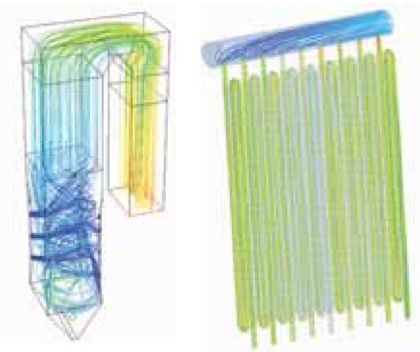


Fig2. Furnace combustion and fluid-structure interaction CFD analysis

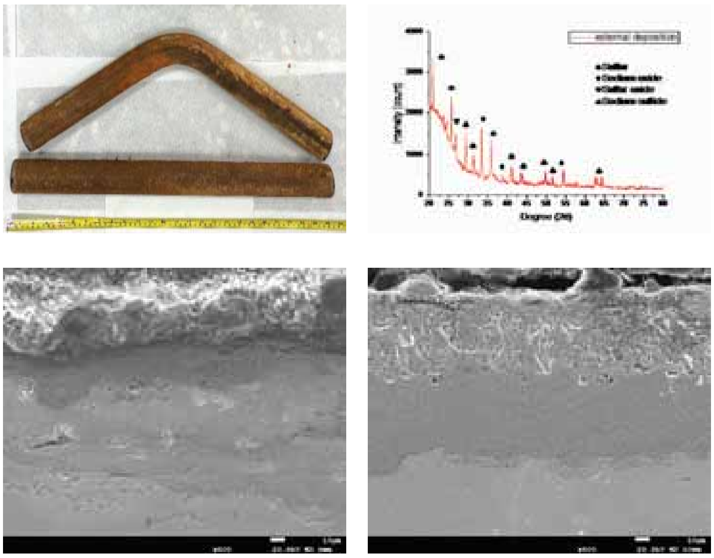


Fig 3. Metallographic and Thermogravimetric analysis on tube testing sample

The assessment of boiler tube is time consuming if distributions of temperature and pressure in the tube under online operation are obtained from CFD simulation. That would make the assessment impossible to obtain real-time results. The need of numerical computational code, therefore, is revealed in the progress of system development for covering the work from CFD simulation. Accordingly, the computational code which can rapidly and efficiently obtain the results in comparison to those from CFD is developed particularly for specific boiler tube model. The procedure of the numerical calculation has successfully acquired Taiwan patent No.I782765 in 2022 entitled "Method for Evaluating the Temperature Distribution of a Heat Exchange Tube" as shown in Fig. 4. The concept of the procedure is that some parameters are necessary input like the temperature from both inlet and outlet of tube, flow rate, and heat energy, when partitioning the whole model into several sub-models to get individual result. The last step is using iteration process to make the numerical results converge toward the real sensor data or simulation results.

Fig5. The prototype of INER_BTHMS

A piece of boiler tube removed from the boiler was investigated to evaluate the degradation on the real boiler tube as shown in Fig. 3. The metallographic analysis revealed the oxide layer has a thickness of 100μ on the both sides of the tubes as shown at the bottom of Fig 3. As the results of element analysis of the oxide layer, the compounds including sulfur, sodium and oxygen were revealed by thermogravimetric analysis (TGA) as shown at the upper right of Fig 3.


中華民國專利證書

I782765

洪淑敏

Fig4. Certificate of ROC patent "Method for Evaluating the Temperature Distribution of a Heat Exchange Tube"

The benefit of health monitoring and assessment system for boiler tube of fossil fuel power plant is to avoid the unexpected shutdown due to the creep-induced boiler tube failure and enable the stability of plant operation as shown in Fig. 5. It could also inform the annual plant maintenance decision making of the status of tube health, which could save a plenty of cost by replacing the unhealthy tubes for the further operation. The other feature of the system is that the system is completely developed by domestic institute. In a nutshell, there is no problem for the users on the communication of their requirements of getting customer support and service, and the further optimization of the system.

3-1-6

Radionuclide Analysis for Nuclear Power Plant Decommissioning - Inter-laboratory Comparison

Since the commence of domestic power plant decommissioning at the end of 2018, it was expected that a large amount of complex radioactive waste will be generated. During the decommissioning process, it is necessary to have the ability of determining various radionuclides in different types of radioactive waste (Fig. 1). The compositions and activities of radioactive wastes obtained from lab analysis can be the bases for the classification of radioactive waste and the decommissioning design of the radiation protection measures for workers. Currently, low- and medium-activity radiochemical analysis is facing the challenge of developing analytical protocols for those radionuclides difficult to measure and for the labs certified by professional institutions. Therefore, the Institute of Nuclear Energy Research has integrated three domestic radiochemical laboratories, conducting inter-laboratory comparison on radionuclides difficult to measure (Fig. 2). This plan will finally assist the domestic laboratories not only to become certified and also reinforce their abilities to determine the decommissioning concerned radionuclides.

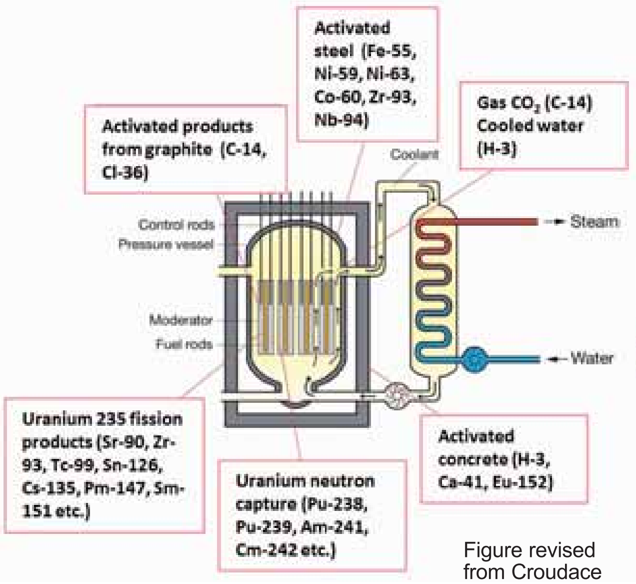


Fig.1. Formation of radionuclides in a nuclear power plant reactor

Fig.2. Process of executing inter-laboratory comparison

First Step of Inter-laboratory Comparison - Making test samples

The first step of inter-laboratory comparison is to prepare the test samples (Fig. 3). Four types of test sample were studied in this project include metal, resin, concrete and soil. According to their properties, appropriate pre-treatment methods were applied to make them homogeneous. Desired radionuclides were added to the homogenized matrix according to their characteristics and needs. I addition, test samples were also spiked with little amount of Co-60/Cs-137 activities to represent their uniformities in samples. The Co-60/Cs-137 activities, measured by a pure germanium detector in each sample were calculated through the one-way ANOVA statistical test (F/P values) to judge the uniformities of the test samples. The qualified test samples, well labeled and sealed, need to pass uniformity test before delivered to the tested laboratories.

Fig.3. Inter-laboratory comparison test samples preparation

Second Step of Inter-laboratory Comparison - Developing analytical techniques for DTM radionuclides

The analysis of radionuclides can be roughly divided into easy-to-measure and difficult-to-measure (DTM) categories. Radionuclides that are easy-to-measure do not need to go through pretreatment and are only measured for their activities with a gamma spectrometer directly. For difficult-to-measure radionuclides, pretreatment such as purification is needed and then the activities are measured by a gamma spectrometer, liquid scintillation counter, alpha spectrometer or mass spectrometer. In response to the demand of difficult-to-measure radionuclide analysis during nuclear power plant decommissioning, this laboratory comparison also developed analytical techniques of radionuclides, including Be-10, Cl-36, Ni-59, Nb-94/93m, Zr-93, Mo-93, Ru- 106, Ag-108m, Cd-113m, I-129, Cs-135 etc (Fig.4, Fig. 5, Fig. 6).

Fig.4. DTM radionuclide Ni-59 analysis

Fig.5. DTM radionuclide I-129 analysis

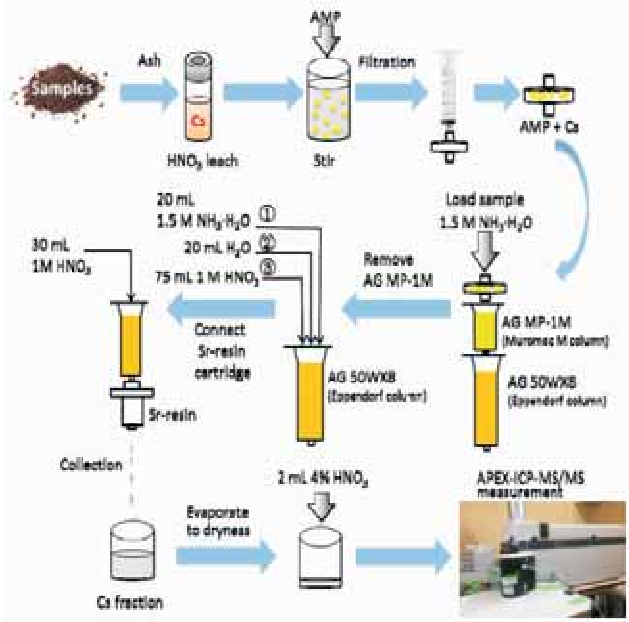


Fig.6. DTM radionuclide Cs-135 analysis

Third Step of Inter-laboratory Comparison Reported data evaluation

In this inter-laboratory comparison, the mean value of reported radionuclide activities from all attended laboratories is the reference value, A_s , and the standard uncertainty of the reference value is u_s. The reported activities of radionuclides from each attended laboratory is A_t, and the standard uncertainty is u_t. These calculated values , A_t/A_s and the ζ, will be evaluated for the performance of three different laboratories. For instance, A_t/A_s (ratios between 0.8 to 1.2) and the ζ(zeta score <3) are criteria to pass this comparison activity. (Fig. 7, Fig.8)

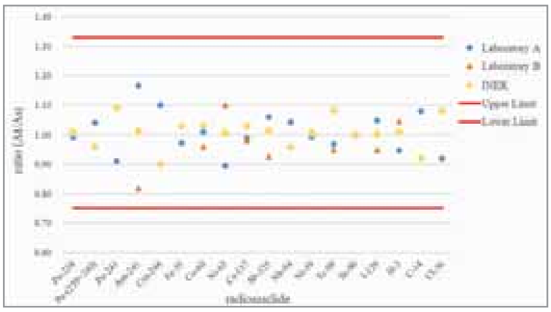


Fig.7. Evaluation result (ratio of , A_t/A_s)

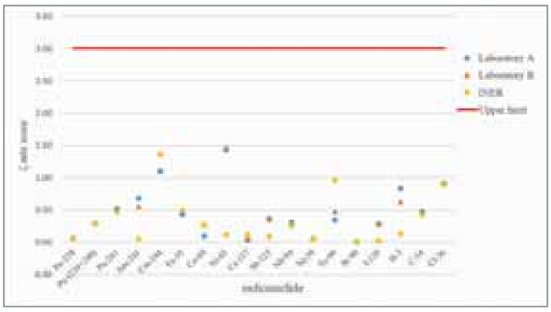


Fig.8. Evaluation result (zeta score, ζ)

Following the requirements of Proficiency Test (TAF-CNLA-R05(9)) and Technical Specifications for Medium and Low activities of Radionuclide Analysis (TAF-CNLA-T10(3)) issued by the Taiwan Accreditation Foundation, this inter-laboratory comparison was held by three domestic accredited laboratories. Laboratory A (Radiation Laboratory) and the Institute of Nuclear Energy Research (INER) participated with a total of 20 radionuclides: Pu-238, Pu-(239+240), Pu-241, Am-241, Cm-242, Cm -244, Fe-55, Co-60, Ni-63, Cs-137, Sb-125, Cs-134, Nb-94, Ni-59, Tc-99, Sr-90, I-129, H-3 , C-14, Cl-36. Laboratory B (Radionuclide analysis laboratory) took part with a total of 9 radionuclides of Am-241, Co-60, Ni-63, Cs-137, Sb-125, Cs-134, Tc-99, I-129, H-3. It is the first time that three domestic laboratories successfully passed the proficiency testing for radioassay about low and median Level of radioactivities in this inter-laboratory comparison campaign.

3-2 Civil Application of Radiation

(1)Develop radiopharmaceuticals and apply artificial intelligence to ensure the health of people

The Institute of Nuclear Energy Research (INER) is actively engaged in the application and research of atomic energy technology in the field of biomedicine in line with the mission of atomic energy technology to serve the people's livelihood. Its Taiwan's only 30 MeV medium-sized compacted cyclotron can produce a variety of medical radioisotopes, and it has a radiopharmaceutical production center that complies with PIC/S GMP specifications, and supplies radiopharmaceuticals for clinical diagnosis applications. In recent years, in response to the advent of an aging society and international development trends, INER has actively developed various radiopharmaceuticals that meet the needs of disease diagnosis.

"INER MIBG <I-123> Injection " has been provided to major domestic hospitals for clinical trial studies, and we further established "Innovative and automated development technology of INER MIBG <I-123> Injection; " INER Dolacga Liver Function Imaging Agent" is the world's first peptide-based contrast agent for liver function. It has a total of more than 20 patents in the global patent layout. It is currently in the second phase of clinical trials. It can see the range of liver cancer more accurately and distinguish between benign and malignant tumors, and can be used to quantify liver function, it is expected to become a single test for liver resection in the future. "AI artificial intelligence system" is aimed at chemical retrosynthesis analysis, applied to the production and development of radiopharmaceutical precursors and standards for comparison, and the process improvement will be able to provide high-quality radiopharmaceuticals in an all-round way, and can benefit for the health of the people in the country.

(2)Develop biological tritium detective technology and ocean current diffusion early warning system to protect sea area radiation safety

The Japanese government made a final decision to discharge tritium-containing treated water from Fukushima Daiichi Nuclear Power Plant into the Pacific Ocean in 2023. The INER prepared a project through cross-ministerial integration, and carried out from the perspective of active disaster protection. The achievements include: (1) Establish information integration platform Taiwan Ocean Radioactive Information System (TW-ORIS) for the public. This platform prevents the impact of fishing industry by social communication and information disclosure; (2) Establish a marine radiation early warning system based on ocean current prediction and ecological survey; (3) Develop biological tritium detective technology, conduct coastal ecological sampling and analysis, and obtain background base-line data. In the future, INER will continue to integrate inter-ministerial disciplines, develop advanced science and technology, solve public doubts, achieve stability in the hearts of the people, and protect sea area radiation safety.

3-2-1

Artificial intelligence guards the care of the elderly- Application of AI to improve the manufacturing process of nuclear pharmaceuticals precursors and standard products for the diagnosis of senile dementia

Chemical retrosynthesis analysis is a technique for planning the synthesis of target compound molecules. In this type of analysis, the target compound molecules are first analyzed through recursive analysis with a search tree, and the molecules are gradually disassembled into precursors with simpler structures until the obtained molecules are cheap available for purchase. For chemical retrosynthesis analysis, the AI artificial intelligence system uses a deep neural network (Deep neural network) model combined with Monte Carlo tree search (MCTS), referred to as 3N-MCTs.

The chemical reactions and The basic molecular database, which proposes a suggested scheme for the retrosynthesis of the target compound molecule, with several suggested reactions in each step of the stepwise synthesis of the target compound from the starting compound, each of which has a patent or literature basis, and has a certain degree of knowledge accuracy.

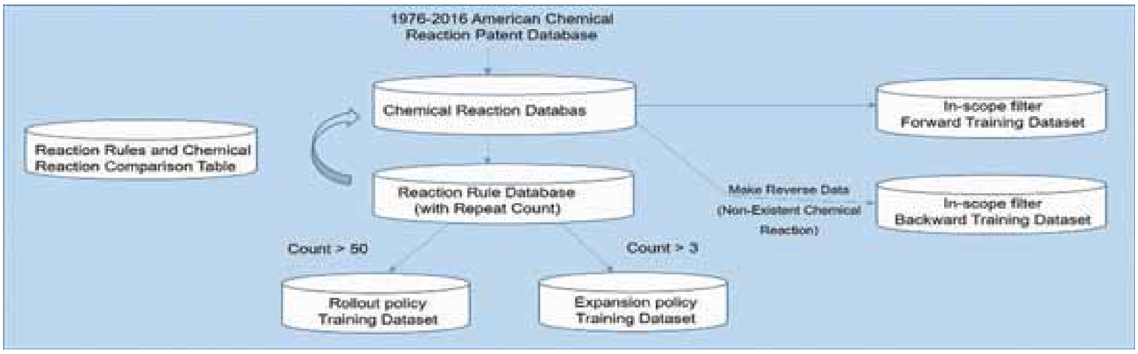


Fig.1. AI chemical retrosynthesis analysis deep learning model

The comprehensive results of AI retrosynthesis research are applied to the precursors and the standard products used for marker comparison. Using related 3N-MCTs neural network and chemical retrosynthesis technology derived from GCN model, the molecular structure of the target compound is disassembled in multiple directions, and each disassembly is accompanied by relative bonding or functional group conversion provided by the database. These reaction examples are all derived from the synthesis content of patents or academic journals in recent years. Previous examples that can be effectively solved include overcoming the bottleneck in the expansion process of neuroblastoma contrast agent marker precursor MIBGHS, finding the type of recrystallization solvent and optimizing conditions for renal function detection contrast agent marker precursor S-Bz-MAG3, and establishing cerebral blood flow New safety process for infusion contrast agent marker precursor ECD.

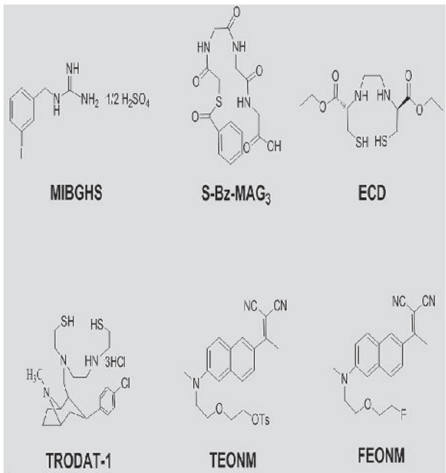


Fig.2. Precursors and standards produced and developed by INER

In response to the aging trend of the global society, Parkinson's disease and Alzheimer's disease are serious central nervous diseases for the elderly, and the development of related diagnostic drugs is very important for the health and well-being of the elderly . We also used the aforementioned AI retrosynthesis research experience to prepare the precursor TRODAT-1 (applied to the diagnosis of Parkinson's disease), the precursor TEONM and the standard FEONM (applied to the diagnosis of Alzheimer's disease) with high yield, efficiency and purity.), and the AI artificial intelligence application of chemical retrosynthesis in the process improvement will open up a new direction for INER in the research and development of nuclear pharmaceutics.

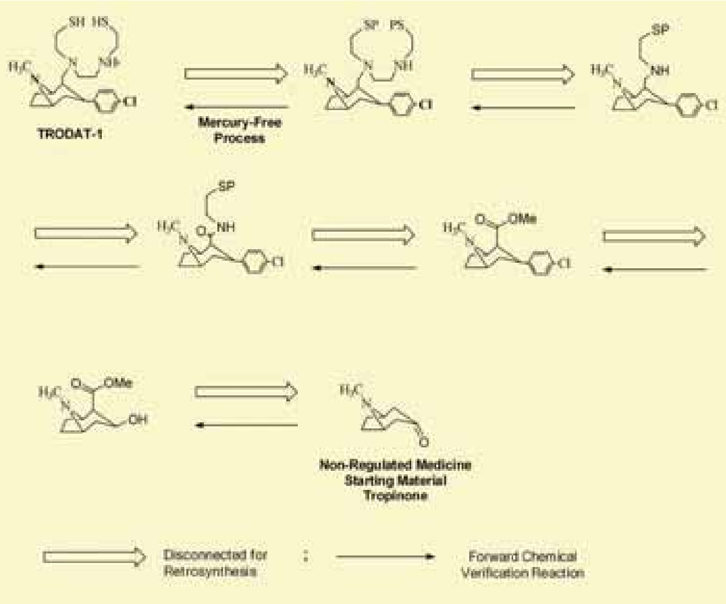


Fig.3. Analysis and verification reaction planning of AI chemical retrosynthesis of TRODAT-1

First of all, for TRODAT-1, a raw material drug for Parkinson's disease diagnosis contrast agent transferred by our institute in 2015, we tried to use AI chemical retrosynthesis to plan its new manufacturing process, and carried out chemical verification on the key steps of the new manufacturing process. The new process of TRODAT-1 proposed by AI has two highlights. First, it uses the non-controlled drug deketation instead of the controlled drug cocaine hydrochloride as the starting material of the process, and the price per gram of deketation is only three times that of cocaine hydrochloride. Next, the new process proposed by this AI also responds to the problem of mercury exceeding the standard in the finished products of the original process of TRODAT-1, and proposes the planning and chemical verification of the mercury-free process.

Then, AI chemical retrosynthesis is applied to the manufacturing process of TEONM, the precursor of the diagnostic contrast agent for Alzheimer?s disease, and the standard product FEONM. The TEONM and FEONM process proposed by AI chemical retrosynthesis has four characteristics. (1) The starting material is The compound that already contains the main double benzene ring structure can be purchased, (2) first introduce the lower left branched chain structure, (3) then introduce the upper right functional group, (4) the precursor and the standard can be synthesized in the fifth and sixth steps of the same process .

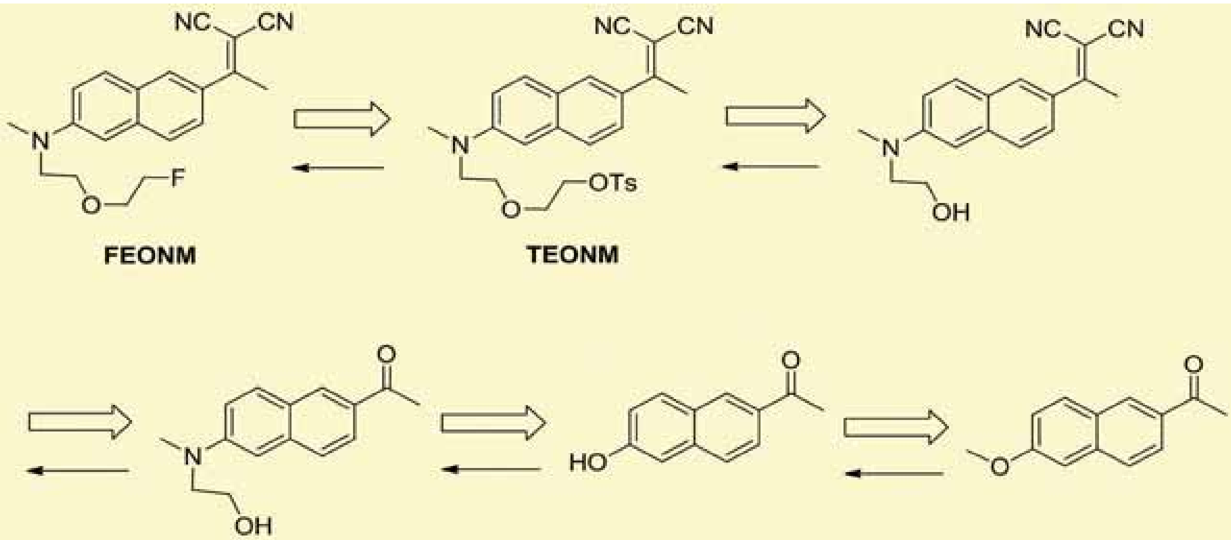


Fig.4. AI chemical retrosynthesis analysis and verification reaction planning of TEONM and FEONM

In response to the advent of an aging society and to prevent the risk of dementia in the elderly, INER has introduced AI methods to improve and develop precursors and standard products of related nuclear pharmaceuticals for the diagnosis of Parkinson's disease and Alzheimer's disease, and increase the synthesis yield , quality, and the sensitivity and accuracy of diagnostic imaging will contribute to the research on nuclear pharmaceuticals. In the future, we will establish a production and supply model for expansion, and provide technical service or technical transfer to external hospitals or pharmaceutical companies.

3-2-2

INER MIBG <I-123> Injection for Assessment of Sympathetic Nervous System Function

Introduction to the INER MIBG <I-123> Injection

The active ingredient in INER MIBG <I-123> Injection is meta-iodobenzylguanidine (MIBG), a compound that has a chemical structure similar to norepinephrine, a neurotransmitter in the sympathetic nervous system. MIBG is known to have a high uptake rate in tissues with sympathetic nerves, such as the heart, salivary glands, and tumors, particularly those that originate from neural crests or neuroendocrine cells. Iodine-labeled MIBG (I-123-MIBG) has been utilized to diagnose and evaluate the effectiveness of treatments for cancer patients with pheochromocytoma and neuroblastoma. In recent years, I-123-MIBG has been increasingly used for the diagnosis of sympathetic nervous system function in the heart, which can be used to predict potential arrhythmias and assess high-risk patients with heart failure, providing important information for clinical treatment decisions. Many studies have also indicated that I-123-MIBG provides clinical diagnostic information for brain neurodegenerative diseases such as Lewy body dementia and Parkinson's disease, serving as a useful tool for differential diagnosis.

Fig.1. Pharmaceutical permit obtained by INER MIBG <I-123> Injection (MOHW-PM-R00037).

Synthetic System and Operating Interface for the "INER MIBG <I-123> Injection"

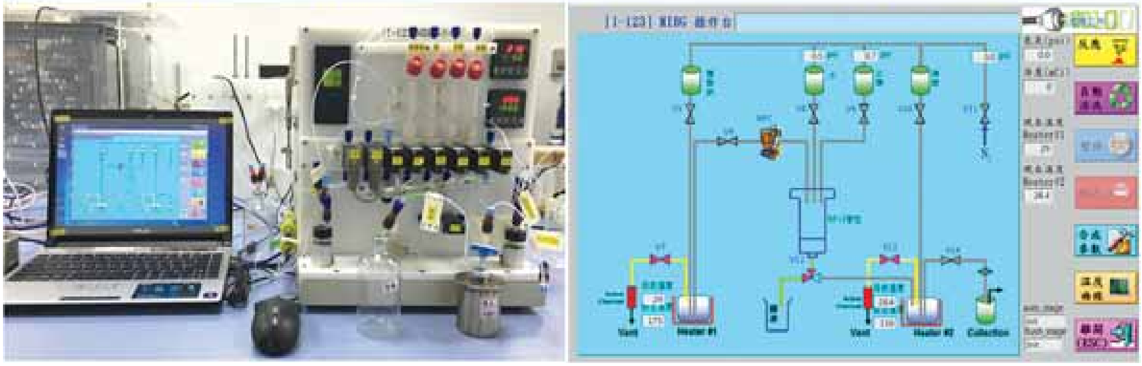


Fig.2. Synthetic system and operating interface for the "INER MIBG <I-123> Injection"

Introduction to the INER MIBG <I-123> Injection technology and its development

The INER operates the only 30 MeV medium-sized cyclotron capable of producing I-123 in Taiwan. The cyclotron can produce a variety of medical radioisotopes and the PIC/S GMP-certified Radiopharmaceutical Production Center develops and produces radiopharmaceuticals for clinical diagnosis and treatment use. Radioactive iodine labeling technology was developed by the INER to create Taiwan's the first I-123 MIBG injection. A computer-controlled synthesis system with automatic or semi-automatic control was also developed to improve the consistency of product quality and produce high-quality radiopharmaceuticals for clinical use (as shown in Fig. 2). This machine provides the consistency of product quality, and effectively reduces the radiation operation dose of personnel. This synthesis sysytem has obtained patents in the ROC, Japan and USA. We also used this synthetic system to establish the chemical, manufacturing and control (CMC) and other technical documents to apply for pharmaceutical registration. Pharmaceutical registration for the "INER MIBG <I-123> Injection" was approved in 2019 (MOHW-PM-R00037). To increase the shelf-life of drug to meet the needs of hospitals in central and southern Taiwan, restocking inspection, process testing, and personnel training were carried out before three consecutive batches of "INER MIBG <I-123> Injection" were produced and tested for efficacy/stability. All quality assurance requirements were met so the MOHW approved an extension of the shelf-life to 10 hours in 2022 and the injection is now routinely supplied to hospitals for clinical trials on request.

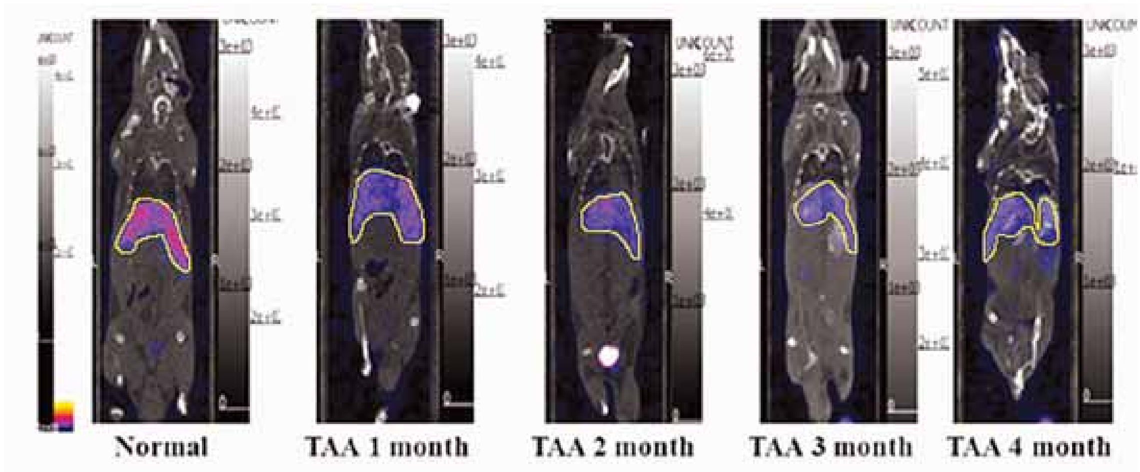
The R&D team of "INER MIBG <I-123> Injection" has won the Manufacturing Technology Bronze Award in the "2022 National Drug Technology Research and Development Award", jointly hosted by the Ministry of Health and Welfare and the Ministry of Economic Affairs. In addition, the "INER MIBG <I-123> Injection" as a diagnostic tool for sympathetic nerve function won the 19th National Innovation Award (Academic Research Innovation Award) organized by the Research Center for Biotechnology and Medicine Policy (RBMP) (as shown in Fig. 3). A stable supply of "INER MIBG <I-123> Injection" is now being provided to hospitals for academic and clinical trials in nuclear medicine for studying cardiac and central nerve function. Once the PIC/S GMP-compliant pilot sterile production line and pharmaceutical production facilities are completed and integrated with the new automated synthesis system for "INER MIBG <I-123> Injection", the INER will be able to supply high-quality radiopharmaceuticals for all applications and support more R&D.

Fig.3. Awards won by the "INER MIBG <I-123> Injection" in 2022.

3-2-3

New solution for reading liver severity: INER Dolacga Liver Function Imaging Agent was given gold award of the Pharmaceutical Technology & Research Development Award in pharmaceutical category

Based on the statistics of WHO Globocan in 2018, there is continuously 64% increasing liver cancer incidence from 2018 to 2040 worldwidely or in Asia. Besides, there is still 13,000 people died because of liver disease annually in Taiwan. The key for survival is to maintain enough functional mass of liver. However, there is no accurate and quantitative predictor for functional liver, until now. INER novel liver receptor imaging technique is a breakthrough for liver function assessment. First, Dolacga an the liver receptor imaging technique can sensitively detect changes in the severity of liver diseases, which is better than traditional serum transaminoferase assay. Second, both the asialoglycoprotein receptor histoimmunostaining and liver receptor imaging are superior to traditional fibrosis staining to reveal the fibrosis severity and hepatocyte regeneration and compensation. Third, the liver receptor imaging technique is advantaged over Indocyanine green to sensitively detect the chronic hepatitis severity. Although there are 13,000 people annually died for liver disease, there are people survival due to proper treatment, which indicates the best policy for liver disease management is accurate diagnosis and proper therapy. One tenth population have chronic hepatitis worldly, and one fifth of that have in Taiwan. If we can maintain enough liver function for survival when we suffer chronic hepatitis, it will be effectively not detrimental to late stage for liver surgery, and likewise, reduce the death risk and social cost.



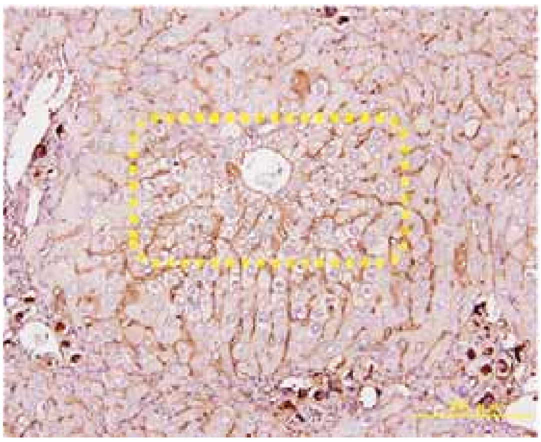


Fig.1. Left: Molecular images of normal and fibrotic livers from mice treated with thioacetamide (TAA). The normal mice and the mice that had been treated with TAA for 1, 2, 3, and 4 months were injected with Ga-68 Dolacga imaging agent, and asialoglycoprotein receptor (ASGPR) imaging was analyzed using nanoPET/CT(Mediso, Hungary). Right: Immunostaining of mouse liver tissues (5-7 μm) with an anti-asialoglycoprotein receptor antibody. The fluorescent yellow regular box shows many irregular, smaller hepatocytes regenerating around the central vein, which indicates ASGPR assessment might be a good indicator for measurement of real liver function. The bar scale indicates 200 μm. (More information please see Mol. Pharmaceutics 2018, 15, 4417-4425.)

Fig.2. INER Dolacga Liver Function Imaging Agent receives Gold Award of the 2022 Pharmaceutical Technology & Research Development Award in Pharmaceuticals Category jointly organized by Ministry of Economic Affairs and Ministry of Health and Welfare.

INER Dolacga Liver Function Imaging Agent is the first liver-targeted glycopeptide liver function test frozen crystal drug in the world. INER has more than 20 worldwide patent mapping. The benefit includes it can show more precise hepatoma scope, discrimate benignity from malignancy, and evaluate the liver function, which played an important role in the future residual liver function quantification and clinical diagnosis decision-making. Recent awards include Gold Award of the 2022 Pharmaceutical Technology & Research Development Award (Fig 2), Platinum Award of the 2021 Taiwan Innotech Expo, Silver Award of the 2020 National Invention and Creation Award, and three consecutive Excelsior Award for National Innovation Award during 2020-2022.

The ultrasound scan can diagnose liver cancer, but is hard to measure liver function. Besides, the diagnosis quality has a personal bias. Furthermore, the ultrasound is easier to affect by fatty liver and ascites interference and can not detect the deeper tissue. Likewise, the computer tomography technique can measure liver volume, but it is inaccurate when uneven liver function distribution in chronic hepatitis. Similarly, the indocyanine green (ICG) clearance test has little value in chronic hepatitis, because high bilirubin causes big interference in ICG absorption. It is known more than 90% of the liver cancer population have liver fibrosis, which is often the case of high bilirubin; therefore, the ICG test is limited to 10% liver cancer population only. In our mice study treated with thioacetamide and 2-acetamidofluorene, the Ga-68 Dolacga liver imaging agent is superior to ICG to discriminate the difference of liver function (Fig 3), which indicates liver receptor imaging technique has more sensitivity to detect chronic liver function change, which might be a helpful reference for nowadays liver cancer management.

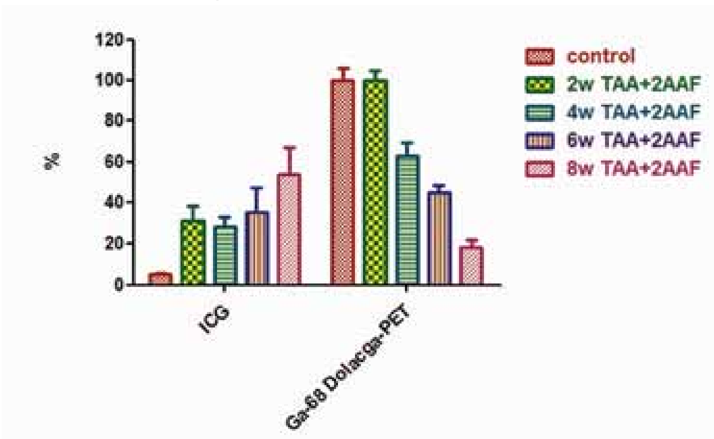


Fig.3. The Dolacga-PET is superior to the right ICG retention test to discriminate the chronic liver severity. The normal mice and the mice that had been treated with TAA and 2-AAF for 2, 4, 6, and 8 weeks.

INER Dolacga Liver Function Imaging Agent has passed the challenge of safety in phase 1 and 2 trials and 25 liver cancer subjects for hepatectomy have performed the Dolacga-PET imaging in the phase 2 study. The results showed clear hepatoma scope and liver function likewise we see in the preclinical study. In 2023, we will further evaluate the correlation of Dolacga-PET and chronic liver severity evaluated by tissue fibrosis staining to get the clinical evidence that the Dolacga-PET might be a new solution for reading liver severity.

3-2-4

Develop biological tritium detective technology and oceanic current diffusion early warning system

The Japanese government made a final decision to discharge the treated water containing tritium from Fukushima Daiichi Nuclear Power Plant into the Pacific Ocean in 2023. This issue has caused neighboring countries to be on the alert, especially concerned about the impact on the aquatic fishery. Therefore, the Institute of Nuclear Energy Research prepared technical issues through cross-ministerial integration. The achievements includes: (1) Establish information integration platform Taiwan Ocean Radioactive Information System (TW-ORIS) for the public, and it can simultaneously display the forecast of discharge events, aquatic product detection, seawater analysis, fishery impact, etc. This platform prevents reputation distrust of the fishing industry by social communication and Information disclosure; (2) Establish a marine radiation early warning system based on ocean current prediction and ecological survey, which can provide early warning and analysis of the impact of discharge of treated water from Fukushima Daiichi Nuclear Power Plant; (3) Develop biological tritium detective technology, conduct coastal ecological sampling and analysis, and obtain background base-line data.

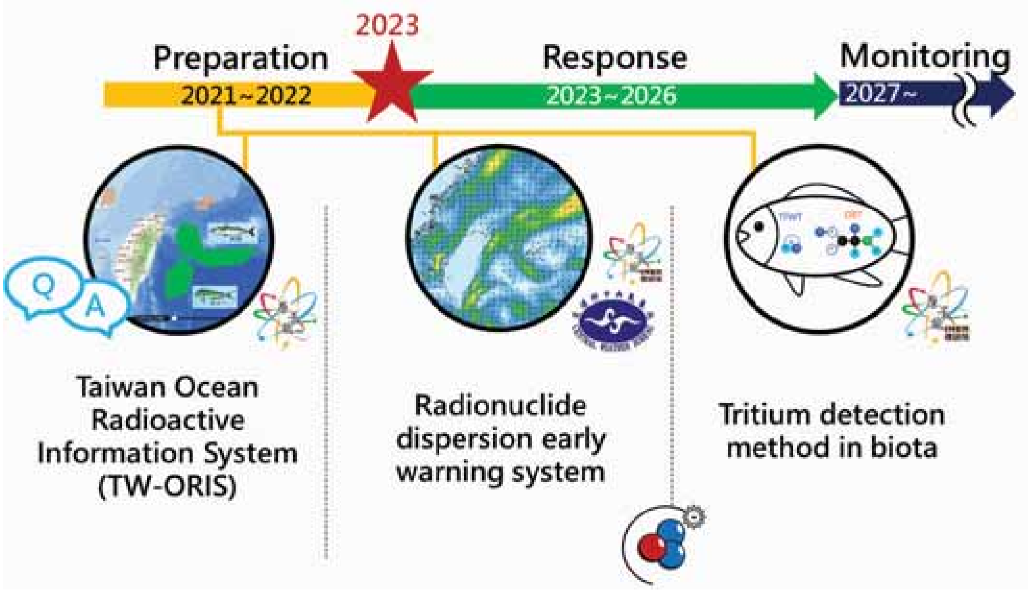


Fig.1. Technical preparation plan in response to the discharge of tritium water from Fukushima Daiichi Nuclear Power Plant.

The TW-ORIS presents the results of radiation monitoring and dispersion forecasts around Taiwan in graphical interface. The professional information disclosed on this platform has the following categories: (1)Base-line data about tritium of seawater; (2)Data about biological tritium of important economic fish; (3) Early warning about oceanic diffusion simulation; (4)Radiation database of international sea areas.

Fig.2. Taiwan Ocean Radioactive Information TW-ORIS (https://tworis.aec.gov.tw/)

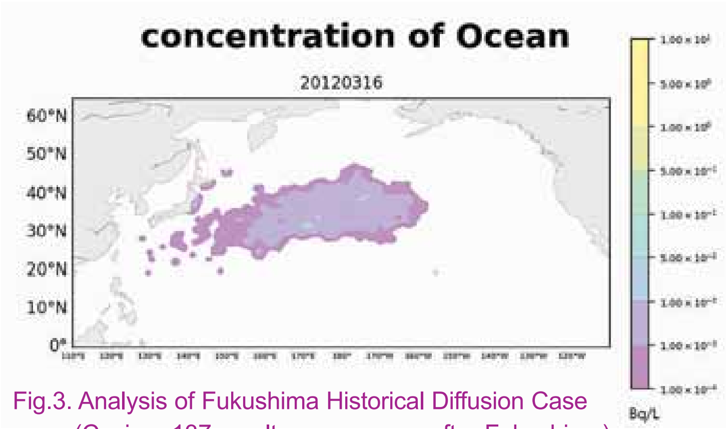


Fig.3. Analysis of Fukushima Historical Diffusion Case (Cesium-137 results as one year after Fukushima).

In cooperation with the Central Weather Bureau, INER has conducted analysis of Fukushima Nuclear event as a 10-Year historical diffusion case by adding important factors with regard to ocean currents, tides, and wind fields. Figure 3 shows the diffusion results about one year after the Fukushima event in 2011, it shows that the concentration of Cs-137 reached 0.05 Bq/L, and the location of treated water was in the central Pacific region.

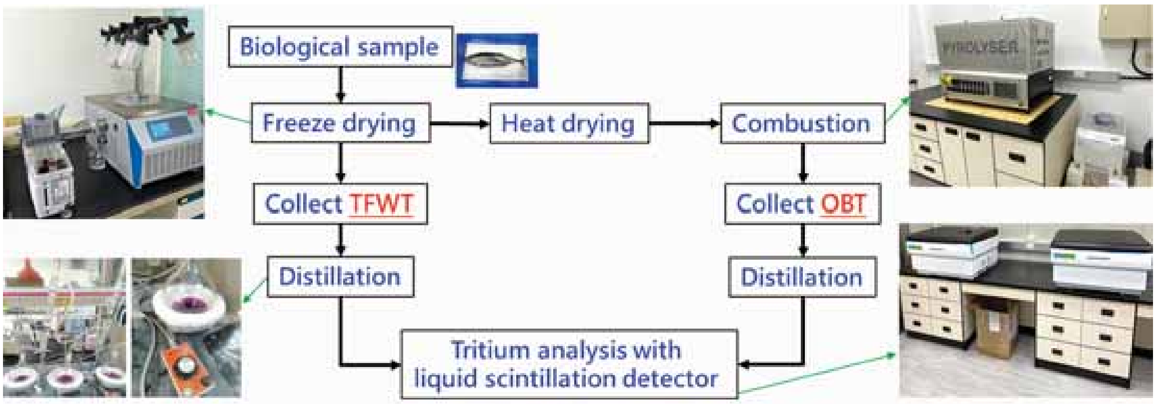


Fig.4. Biological tritium detective and analytic procedure established by INER.

INER has established Taiwan's first "Biological Tritium analysis Laboratory" in 2022. The lab can provide a baseline of ecological radiation background data, as an important reference for assessing the impact of radiation on marine ecology after discharges of treated water form Fukushima. Tritium in organisms is divided into two types. One is called Tissue Free Water Tritium (TFWT) , which can remove and collect water molecules in tissues through methods such as freeze-drying or evaporation; another Tritium-containing water molecules in the environment are metabolically ingested by organisms, and have covalent bonds with organic carbon or nitrogen atoms. This type of tritium is called Organically Bound Tritium (OBT), which needs to be passed through the high-temperature combustion, oxidizes and burns organic matter into carbon dioxide and water molecules for tritium activity analysis, as shown in Figure 4.

After completion of the first phase, INER has a further plan to improve all the response technology related to the treated water. This 4-year plan is to implement an oceanic radiation monitoring, develop a marine radiation release impact potential forecast system, conduct oceanic ecological impact assessment, establish a cross-ministerial response procedure, continue to develop advanced technology, and solve public concerns about treated water from Fukushima.

3-3

Green Energy Environmental & System Integration Technologies

In compliance with the national energy policy, the Institute of Nuclear Energy Research (INER) has committed to the research and development on the environmental and green energy technologies. Since 2016, the government has launched the "Energy Transition" policy and promoted the"5+2 Innovative Industries Program". The "Six Core Strategic Industries" was proclaimed in the presidential inauguration on May 20, 2020, with a high expectation that Taiwan will play an essential role in the global economy. At the end of Mach, 2022, in response to the issues on global warming and sustainable low-carbon society, Taiwan announced the pathways and strategies for the net zero emissions (NZE) by 2050. The perspective vision and the needs of energy transition as well as the key elements for decarbonizing power generation were delineated. As a national research institute, INER has been strategically demanding to support the national energy policy and aims to develop diverse energy technologies so as to facilitate the implementation of energy transition, promote the industrial applications and strengthen the national competitiveness. For the annual year of 2022, some remarkable achievements on the green energy and system integration technologies are briefly outlined as follows.

1. Innovative electrochromic glass: INER employs cutting-edge green manufacturing and low-carbon production methods to develop a unique high-density arc plasma source. It replaces the current sputtering process to produce novel nano-porous films, which are the main components of electrochromic (EC) energy-saving windows. In the top 100 global R&D revolutionary technology competition, INER was recognized and honored a Mechanical/Materials Award for the EC glass technology innovation.

2. Recycling of photovoltaic modules: this study is aimed to develop a recycling technology for solar panel wastes to recover the valuable metal materials and avoid harmful environmental impact such as landfills. In this work, an inductively coupled plasma system is set up to pyrolysis ethylene vinyl acetate (EVA) in a solar photovoltaic module and to refine copper and silver metals from the disposed modules. Glass in the solar modules is melted to produce vitreous fiber by nozzle blowing method. This study is applicable for the end-stream treatment problem of optoelectronic technology as an aid to the circular economy, and as a good demonstration of sustainable development for the optoelectronic semiconductor industry.

3. Smart grids network management and diagnosis: this project is to strengthen the gird resiliency and to mitigate the likelihood of voltage fluctuations or three-phase unbalance due to the surge of renewable energy sources, which are inherently intermittent and may involve substantial variations. On the basis of INER's capability on the smart grid network management and diagnosis, we are continuously developing versatile techniques to enhance the operation stability of distribution network, distributed energy resources, and power transformation equipments. Currently, INER has set up the first domestic MW-level microgrid system certified by the energy trading platform of Taipower. An invention on the power restoration strategy was honored a Platinum Medal Award in the 2022 Taiwan Innotech Expo (TIE) Invention Competition.

4. Agrivoltaics - flexible organic photovoltaic: organic photovoltaics (OPVs) as a promising alternative green energy possess the advantages of low cost, ambient solution process, light weight, flexible, semitransparency, and easy large-area fabrication. Compared to traditional solar cells, transparency characteristic of semi-transparent PSC is beneficial to the wide applications for agricultures and green buildings. INER executed the industrial/academic cooperation project "Development of Commercial Organic Solar Cell Modules and Their Greenhouse Application and Field

Test Verification" to prove high stability and superior performance of semi-transparent flexible OPV modules. INER won the premium award of poster competition (category A), awarded by National Science and Technology Council. In addition, the invention "Packaging structure for flexible organic solar cell module and packaging method thereof?, received a Bronze Medal Award in the 2022 Taiwan Innotech Expo (TIE).

5. Preferential NZE technology—solid oxide cell: INER has committed to the development and applications of solid oxide cell (SOC) technologies, including cells, sealant, stacks, catalysts, components of balance of plant as well as integration of power generating systems. Through the linkage with domestic industries to improve technology and enhance energy efficiency, it is aimed to fulfill the national goals of energy savings and carbon reductions. Currently, satisfactory performance has been achieved for INER's intermediate-temperature stacks for both power-generation and electrolysis modes. The inventions on Glass-ceramic sealing strips and brazing material for sealing were honored a Gold and a Silver Medal Awards, respectively, in the 2022 Taiwan Innotech Expo.

6. CO_2 mineral carbonation and utilization technology: excessive greenhouse gas emissions have significantly accelerated global warming and caused incidents of extreme weather. The huge amount of carbon dioxide released from fossil fuels associated with chemical processes is contemporarily considered as the main contributor. In this project, we employ aqueous NaOH to capture carbon dioxide to form sodium bicarbonate as the mineralization product, which yields a lower CO_2 footprint than the conventional production processes. A bench scale CO_2 carbonation experiment is conducted to define the operating parameters as well as the capture efficiency. The results indicate the developed mineral carbonation processes would be applicable for carbon utilization and negative emissions. Currently, a cooperative program with Taiwan Sugar Corporation is under way to assess the feasibility regarding the cultivation of microalgae associated with the processing of carbon sources into both biofuels and valuable co-products. Ultimately, it is anticipated that applications for commercial-scale capture and mineralization of Co_2 can be implemented.

7. Construction and verification of floating wind turbine: in response to the development of offshore wind farms in the world towards large size, deep water and floating type, Taiwan has launched floating offshore wind power development project, in terms of regulations, technology, and infrastructure. To assist the domestic marine engineering teams to establish floating platform engineering technology, INER has built a scale model test platform providing developers test services for the floating platform model design and verification. The Software-in-the-loop (SIL) simulation scheme is utilized in the test platform up to 10-15 MW programmed wind turbine. The scale model test platform with an invention patent in Taiwan has been implemented in "DeltaFloat Test" conducted by the Ship and Ocean Industries R&D Center. It is beneficial to enhance design, testing and validation capability, shorten the wind farm development period as well as construct the supply chain for offshore wind turbine.

In overall, INER has devoted to developing novel and renewable energy technologies for years with remarkable progresses and reputation in the international communities. For the perspective vision towards "2050 Net-Zero Emissions", INER will continuously comply with the national energy policy, master indigenous key technologies, and pursue a sustainable prosperity carbon neutral society.

3-3-1

Institute of Nuclear Energy Research Honored a 2022 R&D 100 Award

The Institute of Nuclear Energy Research (INER) was honored a 2022 R&D 100 Award for its "Innovative, low-cost and low-carbon technology for mass-producing electrochromic glass". The R&D 100 award is often referred to "The Oscars of Innovation" and "The Noble Prize of Engineering". The award winners generally include the world's top research institutes such as Massachusetts Institute of Technology and Lincoln Laboratory, etc. In response to the "Net Zero Emission by 2050" policy, INER uses cutting-edge green manufacturing and low-carbon production methods to develop a unique high-density arc plasma source (Fig.1 left). It replaces the current sputtering process to produce novel nano-porous films (Fig.1 right), which are the main components of electrochromic (EC) energy-saving windows. The low power consumption of manufacturing can substantially reduce the production costs, which makes the product become more affordable and improve its market competitiveness. Additionally, by effectively isolating infrared heat, the energy-saving window can minimize the power consumption of air conditioners while reserving the indoor lighting. This innovation is environmentally-friendly and beneficial to accommodate the balance between its production and environmental sustainability.

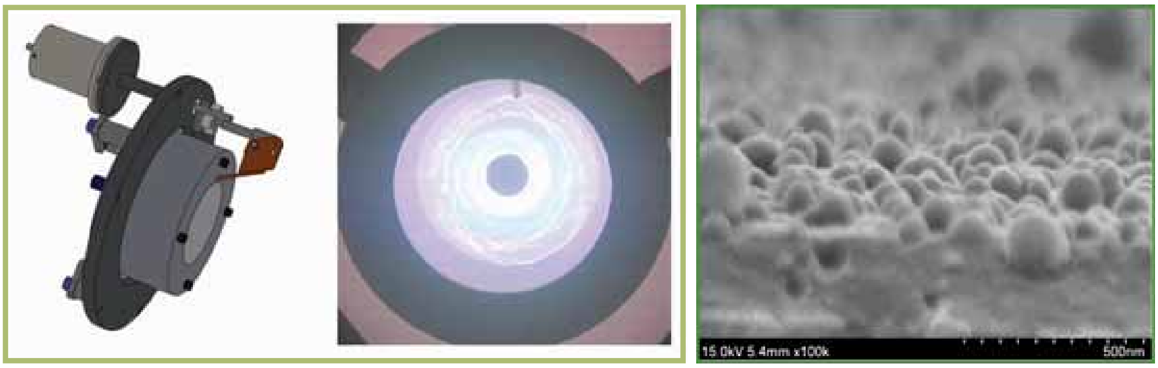


Fig.1. (Left) Innovative arc plasma source technology. (Right) Novel nano-porous film.

Using the unique high-density arc plasm source technology, INER has built the first mass production system for rapidly producing the EC thin film. Compared with the current commercial sputtering process, this technology increases the production rate by 5 to 10 times, and its product with nano-porous films is capable of maintaining the color retention of the EC window by more than 4 times. Currently, this technology has been successfully transferred to the domestic companies for local production of the EC window as well as the deployment of the product. It is expected that the product may tap into the multibillion-dollar global market in the future.

Fig. 2. Low-cost and fast mass production system for producing EC films.

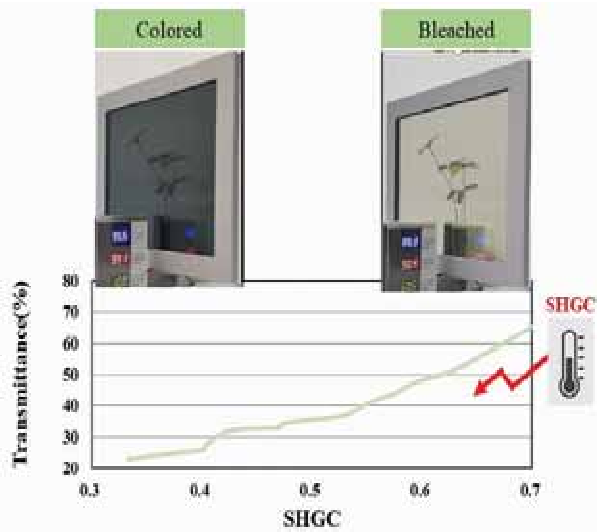


Fig.3. Electrochromic glass with adjustable SHGC value
*SHGC: Solar Heat Gain Coefficient

Compared with current technologies, our innovation adopts an environmentally-friendly green manufacturing process; it saves power usage in production process by 4 times. As it becomes generic practice, it will be equivalent to reducing 57,000 tons of carbon dioxide emissions per day. The product, EC energy-saving window, also reduces the energy consumption of air conditioners for 10 kWh per day for each room, corresponding to a reduction of carbon dioxide emissions 50,000 tons per day.

Reference:

1.Wang, N., et. al., Life cycle carbon emission modelling of coal-fired power, Energy, 2018, 12, 841-852.

2.Yao, J., Electricity Consumption and Temperature, IMF Working Paper, 2021.

Based on the technology, the EC energy-saving window has following noticeable properties:

1.Energy-saving: it only consumes energy while in operating, and its maximum power is less than 2.5 W.

2.Great memory effect: after removing the driving power for four days, the percentage of color changes is within 4%.

3.Good thermal isolation: it effectively isolates heat from IR and UV rays caused by the sunlight. The IR blocking rate of the colored state is 99.1%, and that of the bleached state is 67.3%.

4.High optical variation: the light transmittance of the colored state is 8%, and that of the bleached state is 60%. The optical modulation is 52% at wavelength of 633 nm

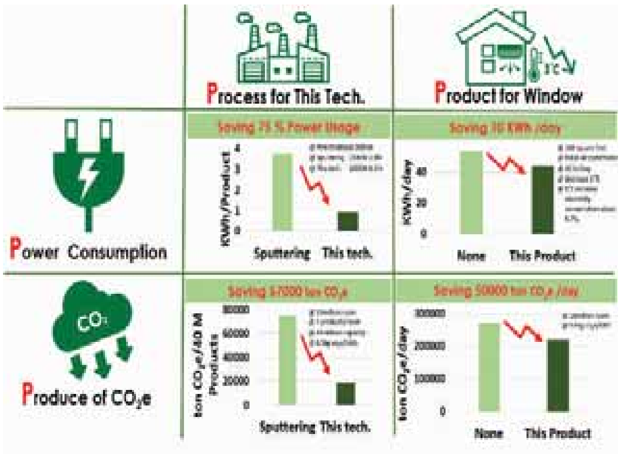


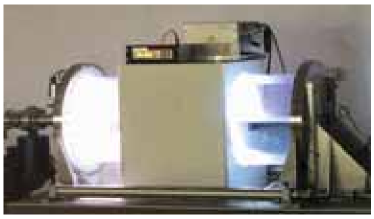
Fig.4. Schematic view of energy-saving and carbon reduction performance assessment of applying this technology in production

Annually, R&D 100 Awards recognize 100 works from lots of entries. The competition winners represent the top 100 revolutionary technologies of the year. Lists of awards cover many categories such as analytical, IT, materials, etc. In the competition, INER was honored a Mechanical/Materials Award for the EC glass technology innovation. INER's representative, Project Leader Dr. Po-Wen Chen, was invited to accept the award in the 2022 R&D Awards Banquet, which was held in San Diego (Coronado Island Marriott Resort & Spa) on November 17th, 2022 (Fig. 5).

Fig. 5. INER honored a 2022 R&D 100 Award .

3-3-2

Recycling of Photovoltaic Modules Using Inductively Coupled Plasma Technology



In compliance with the issues on global warming and sustainable low-carbon society, the government has set the perspective vision and a series of energy transition strategy. Of which, the renewable energy will play an essential role for the target. Under the promotion of policy and endeavors of industry sector, the installation of solar photovoltaic modules has grown rapidly. Consequently, it becomes a prerequisite issue to deal with those disposed solar panels, which cannot fulfill normal functions. According to the estimation of the Environmental Protection Agency of Executive Yuan, there will be more than 10,000 metric tons of solar panel wastes to be disposed in 2031, and ten times more in 2043. Considering circular economy, this study is aimed to develop a recycling technology for solar panel wastes to recover the valuable metal materials and avoid harmful environmental impact such as landfill. In this work, an inductively coupled plasma system is set up to pyrolysis ethylene vinyl acetate (EVA) in a solar photovoltaic module and to refine copper and silver metals from the disposed modules. Glass in the solar modules is melted to produce vitreous fiber by nozzle blowing method. This study is applicable for the end-stream treatment problem of optoelectronic technology as an aid to the circular economy, and as a good demonstration of sustainable development for the optoelectronic semiconductor industry.

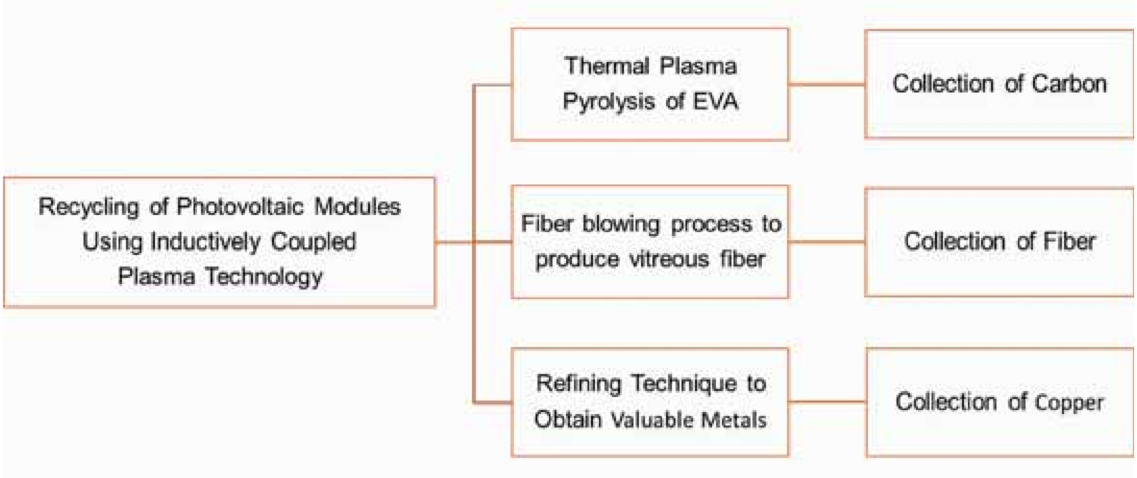


Fig.1. Research flowchart

The inductively coupled plasma system has been built to pyrolysis solar photovoltaic, module. In practice, the major components of module, such as EVA, glass, cell, and copper, can be properly separated for the follow-up reclamation without air and water pollution. The fiber blowing process is developed to produce vitreous fiber when the melted glass is broken with high velocity compressed air for recycling glass from a solar photovoltaic module. A refining technique is employed to melt solar cell ribbon to obtain copper from the wasted solar photovoltaic module.

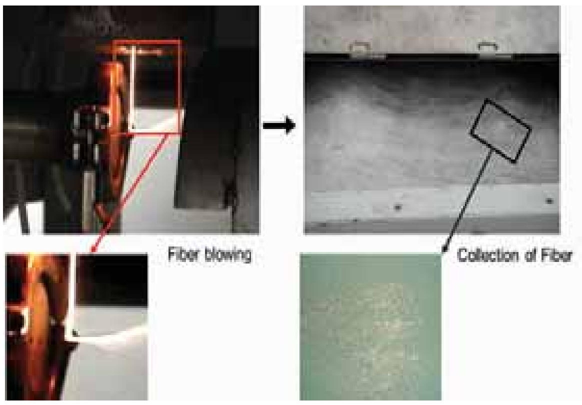


Fig.2. Fiber blowing process to produce vitreous fiber

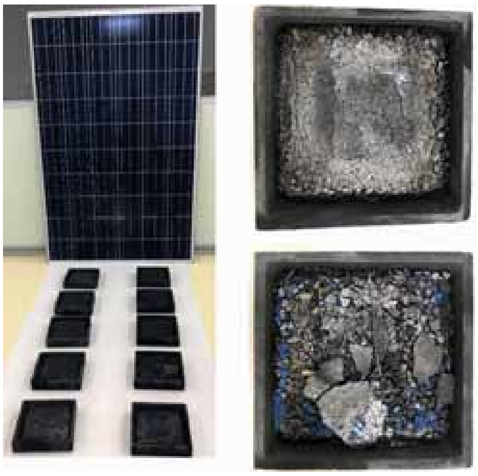


Fig.3. Solar photovoltaic modules after thermal pyrolysis treatment

In 2021 and 2022, we conducted technical services "Feasibility Assessment of Solar Photovoltaic Module Materials Full Cycle Application" and technical transfer "Plasma Thermal Cracking Solar Photovoltaic Module Materials Full Cycle Application Model Plant Construction Feasibility Evaluation" to Chang Yu Environmental Protection Corporation with a total amount of NT$1.5 million. Through the technical authorization and cooperative framework, it is beneficial to broaden the technical breadth, sustainability, circular economy, product diversity, and cross-field integration with industry partners. With a prosperous perspective, the company has invested NT $ 3 million to set up production equipment such as solar photovoltaic module dismantling, crushing and sorting equipment.

Table 1. Comparison of Disposal Technologies for Waste Solar Photovoltaic Modules

Processing Technique	Features	Limitations
Crushing & Sorting (Mechanical method)	●No patent concerns ●Low technical threshold ●Glass recovery rate of 95% ●Silicon recovery rate of 81% ●Silver recovery rate of 50%	●Low recovery rates ●Challenging to recover silver ●Generates a large amount of waste ●Recovered materials have limited uses
High-temperature thermal treatment (Thermal treatment method)	●Reduces waste volume ●Achieves a high glass recovery rate of 99% ●Battery cell and ribbon are separable, with complete removal of plastics	●Produces significant waste gas when burned ●Burning fluorine-containing back plates produce hydrofluoric acid ●Contaminated glass has limited use and requires manual sorting
Layer-by-layer separation method (Mechanical method)	●Physically separate all materials ●Achieve a high glass recovery rate of 99% ●Back plates can be removed individually	●Challenging to recover silicon and metals afterward ●Glass surface damage prohibits direct reuse
Wet recovery treatment method (chemical treatment method)	●Solvent treatment to dissolve EVA ●Strong acid treatment to recover valuable metals	●Solvent volatilization poses occupational and public safety risks ●Generates wastewater treatment issues
Inductively coupled plasma oxygen-free pyrolysis technology (Thermal treatment method)	●No air pollution issues with NOx and SOx ●No need to treat wastewater ●Collect and reuse reduced carbon materials ●Refine valuable metals and produce fiberglass raw materials ●High thermal efficiency with direct heating focused on the material being treated	●Construction cost is high compared to traditional heating methods ●The technology demands significant energy and requires skilled maintenance personnel ●Integrating and verifying the system is costly and time-consuming, and the plant cannot achieve full output immediately

Fig.4. Refining to obtain valuable metals

In this study, we will enlarge the effective area twice to the origin one, complete the advanced verification of system parameter optimization and the construction of inline automatic process of inductively coupled plasma pyrolysis to treat photovoltaic modules continuously. It is granted as a milestone for the full recycle of photovoltaic modules, realizing technology transfer, technical services and commercial operation tests. This technology can be employed to compensate for the end-stream treatment problems of optoelectronic technology, as an aid to the circular economy and as a good demonstration of sustainable development for the optoelectronic semiconductor industry.

3-3-3 Development of Intelligent Network Management and Big-Data Analysis

To comply with the policy, more and more renewable energy will be merged into the grid in the future. This leads to problems such as voltage fluctuation or three-phase unbalance caused by the instability and unpredictability of renewable energy. Due to the above-mentioned reason, a distribution feeder switch operating sequence strategy platform (Fig. 1) is developed by INER. Before switching the normal-closed breakers, the interconnection switch should be closed first, so as to avoid power outage, and the three-phase loads and the capacity of renewable energies can be calculated. This allows the dispatchers of power company to practice the procedure of switch status adjustment. Taking the substations of Taipower for example, the strategy proposed by the platform can decrease the maximum changing rate of three-phase load and ensure the reliability of switch operation and dispatch. Besides, with the patent "Divisional Section Transfer Power Restoration Strategy of Distribution Feeder", INER won the Platinum Award in 2022 Taiwan Innotech Expo (TIE) Invention Competition (Fig. 2).

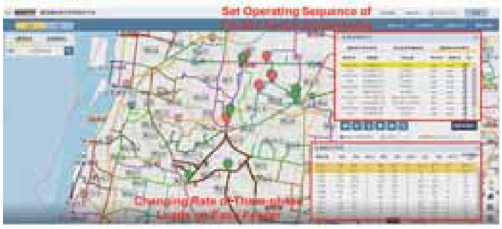


Fig.1. Distribution Feeder Switch Operating Sequence Strategy Platform

Fig.2. Certificate and Trophy of the Platinum Award in 2022 TIE Invention Competition

With more and more Distributed Energy Resources (DERs) connected to the network, if a fault occurs in the network, the fault currents are from multiple sources, instead of single one, which leads to challenges for design of protection coordination. A program of fault current calculation considering DERs is proposed. After the fault location and fault type are determined by user, the fault voltage and fault current each node are calculated, and the results are shown in the Geographic Information System (GIS), which can be the basis for design of protection coordination.

Fig.3. Illustration of fault area shrinking

INER integrated graphical structure and bi-direction tracking technique to track the data of the geographical space database, so as to calculate the length of each line based on the coordinate information at each node. As well, the data of distribution network database can be referred and cross-validated, and the data of parameter database is therefore established. With the connectivity tracking technique, the operation data of Fault Current Indicator (FCI) is analyzed, then the fault area is therefore shrunk. Taking Fig. 3 for example, the fault area is shrunk from "pink and yellow area" to "yellow area".

Fig.4. MW-level microgrid demonstration

As the large amount of intermittent renewable energy is integrated into the grid, the stability of grid will become more challenging in the future. The microgrid can work together with distribution network by providing power ancillary service to the grid for assisting in achieving demand balance and power stability. Therefore, INER constructs the first domestic MW-level microgrid (Fig. 4) composed of 100kW PV, three 65kW micro-turbines, 750kW diesel generator, 500kW battery energy system and 250kW active and reactive power regulation system, and develops energy distribution technique for enhancing the real-time dispatching capability of microgrid and renewable energy.

INER developed energy distribution technique (Fig. 5) according to the characteristics of response and duration for the distributed generation sets in MW microgrid, and cooperated with dispatch center of Taipower to fulfill providing spinning reserve by demand response. Unlike providing power ancillary service by traditional uni-generation set, the microgrid effectively integrates distributed generation within 1 minute as receiving dispatching demand to output active power above 1MW (about 33% of INER's peak loads) at least for 1 hour to reduce the electric energy consumption (Fig. 6). In addition, the microgrid of INER is the first MW-level microgrid system and certified by the energy trading platform of Taipower.

Fig.5. Platform of energy distribution technique

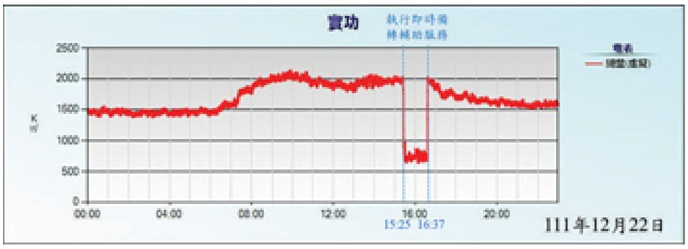


Fig.6. Electric energy consumption of INER while microgrid providing spinning reserve (15:25 to 16:37)

After a significant number of variable renewables are connected to grids, their intermittency and uncertainty will cause power flow fluctuations. As a result, the power transmission and distribution equipment in the substation have to frequently response the change all the time, which would increase the potential risks of unexpected power outages. Therefore, INER devotes a great attention to developing 6 baseline models of the power transformer for online condition monitoring and fault diagnosis based on big data analysis and artificial intelligence; which includes hot-spot temperature, cooling system, ground current, partial discharge, core and winding vibration, On-Load Tap Changer (OLTC), and Dissolved Gas Analysis (DGA). All the developments have been applied to a 200MVA power transformer in a substation of TPC to execute its on-line degradation evaluation and early fault warning (Fig. 7), so as to reduce the chance of unplanned outage.

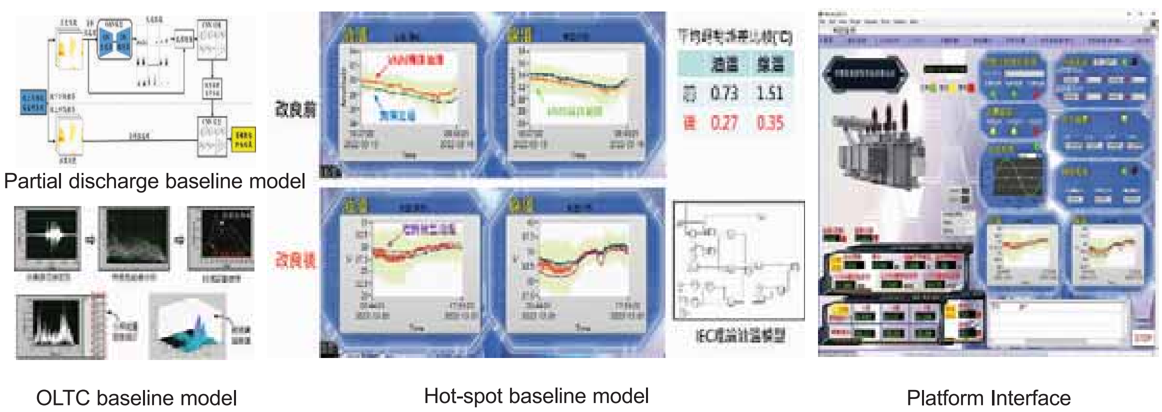


Fig.7. The integrated platform of condition monitoring and smart diagnosis for a 200MVA power transformer

To procure the goal of strengthening the resilience of domestic grid, INER will keep developing techniques such as operation sequence of feeder switch, dynamic protection coordination, emergency ancillary decision-making system of microgrid, and fault diagnosis and prediction of substation asset management to enhance the operation stability of distribution network, distributed energy resources, and power transformation equipment.

3-3-4

Perfect Interpretation of Agrivoltaics: Semi-transparent Flexible Organic Photovoltaic Modules

Organic photovoltaics (OPVs) as a promising alternative green energy possess the advantages of low cost, ambient solution process, light weight, flexible, semitransparency, and easy large-area fabrication. The development of non-fullerene acceptor (NFA) incorporated into the so-called bulk-heterojunction (BHJ) OPVs enables the rapid progress of power conversion efficiency (PCE), achieving 18.22% to date. However, the reduction in PCE due to the upscaling from small-area device to large-area module has still been the critical issue toward commercialization. Another factor causing the reduction in PCE toward commercial applications is the transfer of opaque OPV to semitransparent OPV. The declined PCE (light-harvesting loss) increases with increasing the transparency degree, being a trade-off effect. Optimum development of semitransparent large-area OPV module suffers the complex problems caused by both upscale and semitransparency, which have been still under investigation and a challenging issue.

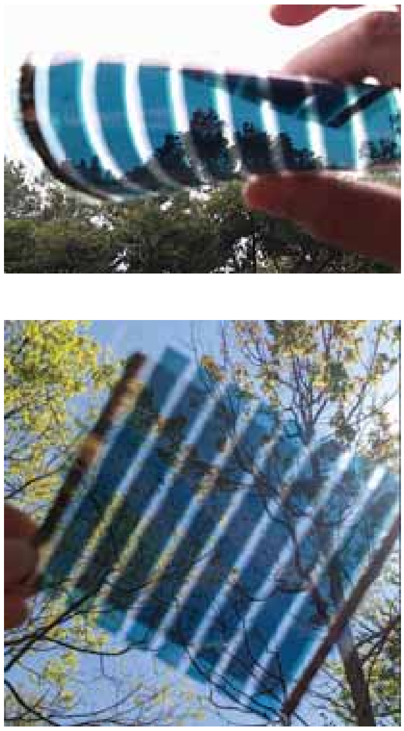


Fig.1. Flexible organic photovoltaic module shows transparent behavior.

Compared to traditional solar cells, transparency characteristic of semi-transparent PSC is beneficial to the wide applications for agricultures and buildings. Semitransparent PSC can be widely used in our daily life, including building - integrated photovoltaics (BIPV), smart windows and greenhouses, etc. To assess the outdoor stability and electric behavior of these OPV modules on a curved roof of greenhouse as field test, a tunnel greenhouse was built by Taiwan Agriculture Research Institute in Taichung. Two ends of the tunnel greenhouse are straightly in the north and south directions. The panels were mounted on the curved roof (inside face) of the tunnel greenhouse from the top to side (radial distribution with ~70 degree) toward the eastern direction. According to the experimental results, The semitransparent flexible OPV modules INER made have achieved excellent results of T_{80} life > 200 days. To our knowledge, the outdoor stability with T_{80} lifetime > 200 days for these flexible OPV modules (the initial PCE > 4%) are the longest or most stable compared to all the reported flexible modules or cells with similarly high PCE.

Fig.2. (a) Tunnel greenhouse with one end toward north direction, (b) All modules mounted on the curved roof, (c) Serially-connected modules via metal fasteners as terminal contact for each panel, and (d) Daily energy output per active area of OPV and Si-PV panels.

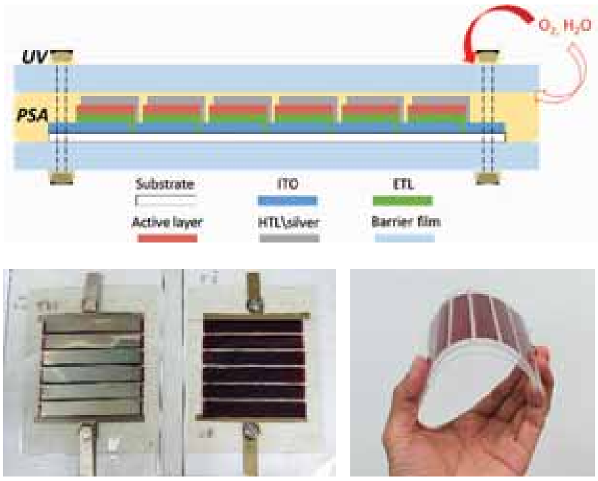


Fig.3. Cross section and photographic images of the flexible encapsulated modules.

A statistical review based on the recent literature on the large-area flexible OPV modules (active area ⩾5 cm^2) reveals the roughly inverse relationship between PCE and module area. Almost all the semitransparent slot-die-coated modules have PCE values almost below 5%. The PCE of INER's semitransparent module is the highest among the flexible semitransparent OPV modules. According to our experience, the PCE of our module will have a slight decline with increasing the module area (number of series-connected cells or cell length) to 100 cm^2 or up to hundreds of cm^2. It can be predicted that the modules for further size extension (> 1000 cm^2) can have high opportunity to reach better performance after adopting the industrial R2R coating machine and improving the temperature/humidity control of Lab (crystallization quality control) in the future.

In 2022, INER participated in the Taiwan Innotech Expo, and won the Bronze Medal Award by the invention of "Packaging structure for flexible organic solar cell module and packaging method thereof". The encapsulation method can apply to semitransparent flexible OPV module for field test at Taiwan Agriculture Research Institute. Besides, it is also suitable for the flexible OPV module used for indoor application, which can supply electricity indoors. In addition, INER executed the industrial/academic cooperation project "Development of Commercial Organic Solar Cell Modules and Their Greenhouse Application and Field Test Verification" to prove high stability and superior performance of semi-transparent flexible OPV modules. INER received the premium award of poster competition (category A), awarded by National Science and Technology Council.

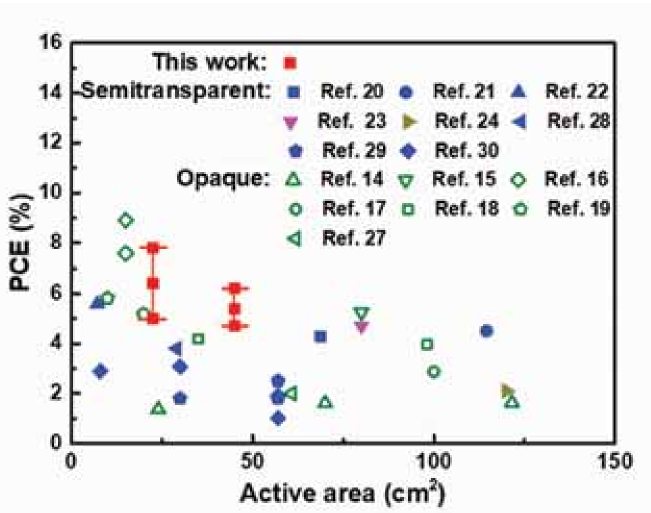


Fig.4. Relationship between PCE values and module area for all the flexible together with our results.

INER has pioneered ambient solution-printing technologies for the mass production of the large-area flexible semitransparent OPV. The key technologies of module mass production with highly commercial competitiveness developed by INER include: (1) continuous R2R mass production of flexible modules, (2) innovative semi-transparent module technology, (3) low-cost effective flexible encapsulation technology of modules, (4) use of non-toxic eco-friendly solvent in ambient air, (5) high stability and durability of module, and (6) reliable and integrated life tests comprising the accelerated test and outdoor field test to ensure PSC quality. INER will be a backstage driving force to accelerate the advent of PSC module-based products, and link up the academic community with industry to form an PSC industry chain. The development of PSC industry chain would build the foundation of localized industry and increase the industry domestic competitiveness.

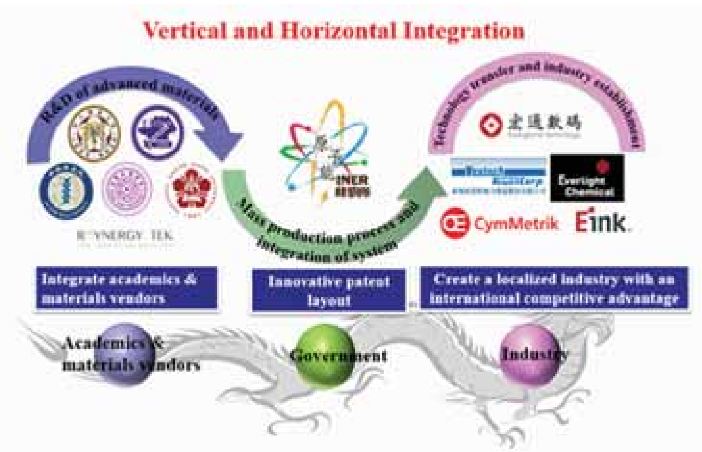


Fig.5. The Whole Integration Chain Comprised of Upstream Research, Midstream INER and Industries.

3-3-5

Choice technology for net-zero emission : solid oxide electrolysis cell to produce green hydrogen

The institute of nuclear energy research (INER) has committed to the development and applications of solid oxide cell (SOC) technologies, including cells, sealant, stacks, catalysts, components of balance of plant as well as integration of power generating systems. Through the linkage with domestic industries to improve technology and enhance energy efficiency, it is aimed to fulfill the national goals of energy saving and carbon reductions. Currently, INER has developed all self-made innovative stacks with metal-supported cells (MSC). In compliance with the global trend of carbon reductions and net zero emissions, it is demanded to increase the weighting of renewable energy. Meanwhile, the adoption of energy storage devices becomes a prerequisite to attain the target of energy transition. Solid oxide electrolysis cell (SOEC) features a high energy conversion efficiency, which can effectively convert the electricity into gas to store off-peak power as chemical energy. MSC stacks with brazing alloy filler as sealant are tested and improved. Efforts on the R & D of SOC technologies and applications will be continually devoted for the emergence of a new green energy industry.

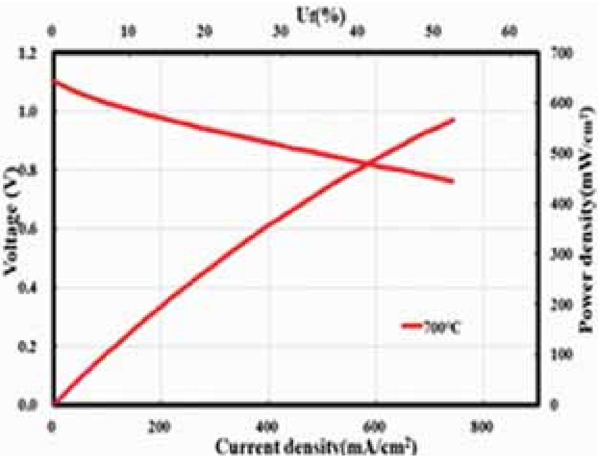


Fig.1. Performance of MSC

Intermediate temperature plasma sprayed MSC

The electric power and hydrogen-producing efficiency of MSC were improved. The single cell (10×10 cm^2) could deliver 41.6 Watts (513.58 mW/cm^2) at 0.8 V and 700°C (OCV=1.103 V). At 750°C and current 40 A for water electrolysis, the hydrogen producing rate was 0.3 L/min with efficiency of 74%. The results revealed excellent power performance for the MSCs.

Novel solid oxide electrolysis stack

Under the frame of patent licensing for manufacturing cells, INER has assisted the licensee to mass produce anode substrate tapes and to manufacture commercialized cells with performance evaluation. INER also cooperated with domestic companies for interconnect manufacture and protective coating spray, applied in newly designed MSC stacks, and set up a SOEC testing platform. A 5-cell MSC stack was assembled. This self-developed stack can be operated in both SOFC and SOEC modes, and potentially extended to kW scale for hydrogen production.

Fig.2. The 5-cell MSC stack

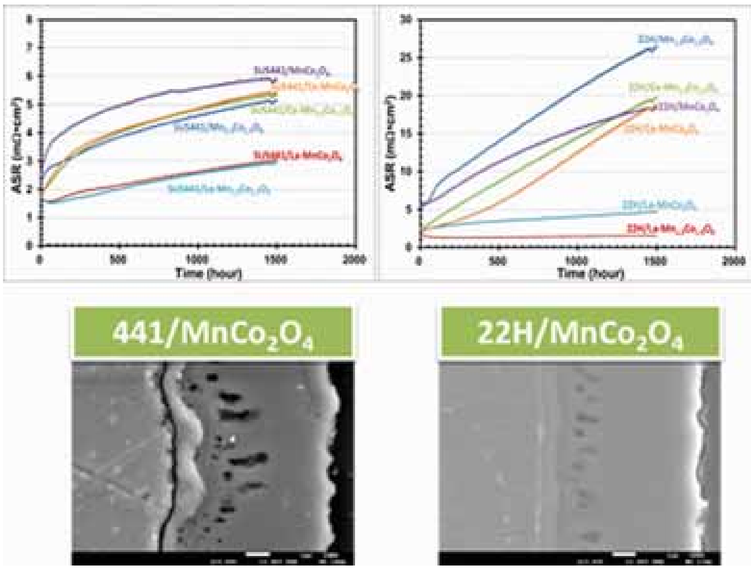


Fig.3. High temperature ASR evolution and cross sectional microstructure

Conductive protective coating for preventing metallic oxidation

INER has developed patented Mn-Co oxides for metallic protective coating, and co-operated with China Steel Corporation to study the application of coated metallic interconnect in SOFC. With La and Ce doped ceramic coating deposited on Fe-Cr based metallic interconnect in SOC stacks, testing on oxidation resistance and area-specific resistance (ASR) measurement was conducted. It was proved that the protective coating could be applied on low-cost steels to gain high oxidation resistance with good electric conductivity and promote durability.

Brazing material for sealing

The self-developed Ag-Ge-Si ternary alloy was successfully used as hermetical sealant in MSC SOFC stacks through compositional adjustment that the coefficient of thermal expansion falls between 7.4 and 18.5 ppm/°C. With stably sealed interfaces, the stacks can be operated in a reverse reaction mode for producing hydrogen through water electrolysis. Thus the stacks can serve as hydrogen energy storage devices for power modulation. Other applications include homo or hetero junctions in heat exchangers, reaction chambers, engine parts, electronic sealing components, cooling substrates in electronic devices, molds, cutting tools, and so on. The relevant patent has received a silver medal award in 2022 Taiwan Innotech Expo.

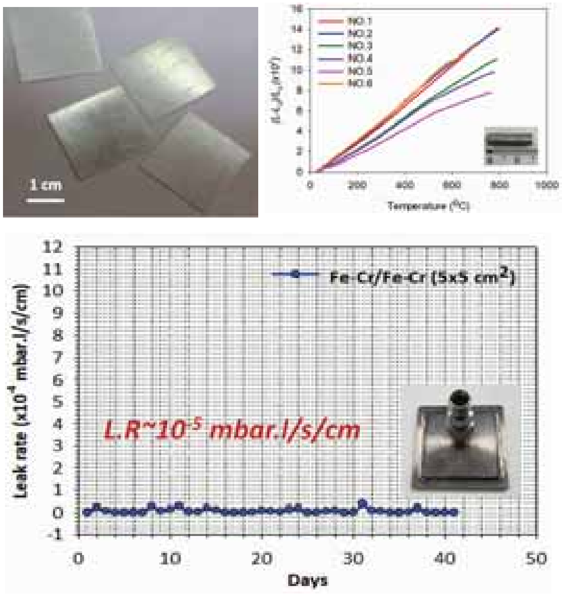


Fig.4. Curves of coefficients of thermal expansion and leakage testing of brazing material for sealing

Fig.5. Glass-ceramic sealing strips as stack sealant

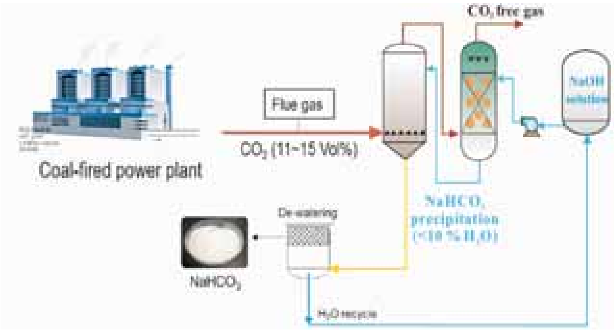
Glass-ceramic sealing strips

INER has successfully employed the tape-casting technique to manufacture glass ceramic thin strips with proprietary formula. The strips were adopted as sealant in SOFC stacks to effectively promote the yield ratio of sealing and reduce the risk of leakage. Mass production of the strips is advantageous for commercial applications. The relevant patent "A method of preparation and application for glass ceramic sealing thin strips" has received a gold medal award in 2022 Taiwan Innotech Expo.

3-3-6

CO_2 mineral carbonation and utilization technology development and demonstration system establishment

Excessive greenhouse gases in the atmosphere are responsible for various environmental problems, such as the increasing number of ocean storms and rising sea levels. Carbon dioxide (CO_2) is the major contributor to global warming. The proposed project design, which makes use of aqueous NaOH to capture CO_2 to form sodium bicarbonate ($NaHCO_3$) as the mineralization product, yields a lower CO_2 footprint than the conventional production processes. This approach is environmentally friendly, eliminates the cost associated with pre-treatment, as well as requires milder process parameters than other major competing carbon capture processes.



A bench scale CO_2 carbonation was designed to determine the effect of the operating parameters (pH of column, flowrate of CO_2 and NaOH concentration) on the CO_2 capture efficiency (refer to Fig. 1). The simulated flue gas (CO_2:14 vol%) was fed into packed columns and bubble column in series, where a NaOH solution reacts counter-currently with the CO_2 to form $NaHCO_3$. Accordingly, the optimum operation conditions of the CO_2 carbonation could be determined. The experimental data showed the purity of produced $NaHCO_3$ was above 80% and the overall CO_2 conversion rate was over 90%. The $NaHCO_3$ slurry produced from the operation of the carbonation test unit was subjected to XRD analysis after dewatering and drying. The X-ray diffraction pattern indicated the product is closely relevant to pure sodium bicarbonate (refer to Fig. 2(c)). The test results will serve as the design bases for the construction and operation of a pilot-scale plant.

Fig.1. Bench-scale CO_2 carbonation test unit

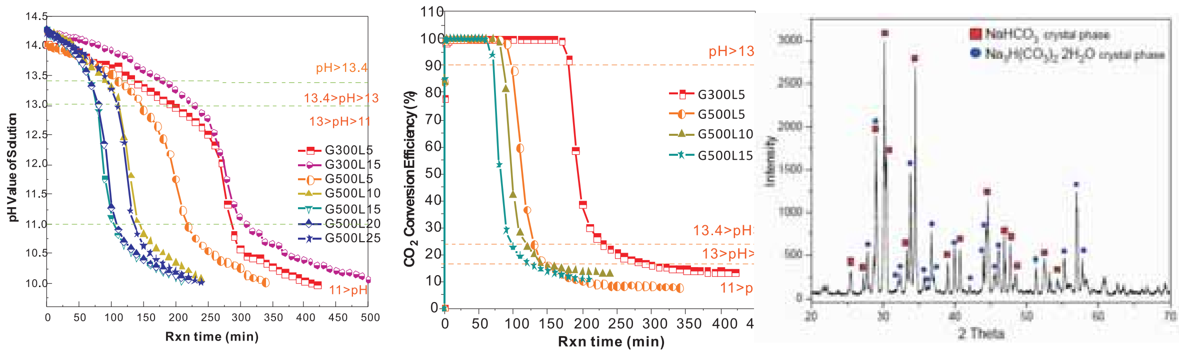


Fig.2. Bench scale CO_2 carbonation test results (a) pH curve of the carbonation column (b) Co_2 conversion rate (c) X-ray diffraction pattern of sodium bicarbonate produced.

Fig.3. Field test site : Flue-gas stack of steam boiler plant at the sugar factory

To help characterize and optimize the processes, a cooperative program with Taiwan Sugar Corporation is under way to evaluated the possibility of carbon capture for steam boiler plants at the sugar factory in Shanhua, Tainan (refer to Fig. 3). A slipstream of gas from the gas-fired steam boiler process equipment onsite will provide a carbon source for the cultivation of microalgae that can be processed into both biofuels and valuable co-products to reduce environmental impact. With this facility test, additional field data will be collected to further characterize the emitted flue gases associated with various process conditions and to suffice the need of model corroboration. Furthermore, these efforts will be used to refine process simulation, and ultimately extend the applications for commercial-scale capture and mineralization of Co_2.

Regarding the potential CO_2 reduction of CO_2 carbonation process, a study of life cycle analysis on CO_2 utilization technologies was conducted. Through a comparison of footprint for two sodium bicarbonate production processes (CO_2 carbonation vs. Solvay process), it emits 1.69 tons of CO_2 per ton of $NaHCO_3$ produced in the Solvay process, while it will capture 0.52 tons of CO_2 in the carbonation process. A net difference of 2.2 tons is observed for these two processes. Apparently, the CO_2 mineral carbonation process is beneficial to reduce the carbon footprint and possesses the potential for practical applications.

Tab.1. Exhaust flue gas composition from different point sources

Composition	Incinerator	Taisugar boiler	INER boiler
Temperature (℃)	145	135	133
CO_2(%)	5~15	14.3	13.8
O_2(%)	9~15	8.5	6.7
NO_X(ppm)	---	130	40.2
SO_X(ppm)	---	24	1.2
H_2O(%)	20	18.2	11.79
Particulate (mg/Nm³)	4~30	25	2.3

The pilot-scale of carbonation process can be skid mounted for easy mobilization and setup at field test sites, and will provide the field test with the capability to test and characterize the formation of bicarbonate crystals from CO_2 emissions from various sources and fuel types(refer to Tab. 1). Through the field test, the pilot plant is capable of capturing 90% of the CO_2 from a slipstream of the heavy oil steam boiler, which is equivalent to capture around 9.5 kg/day of CO_2 or to produce 15.5 kg/day of $NaHCO_3$ as the mineralization product. It is anticipated that the carbonation process for CO_2 capture and utilization will be validated to illustrate its readiness of the technology and its feasibility for commercial-scale demonstration (refer to Fig. 4).

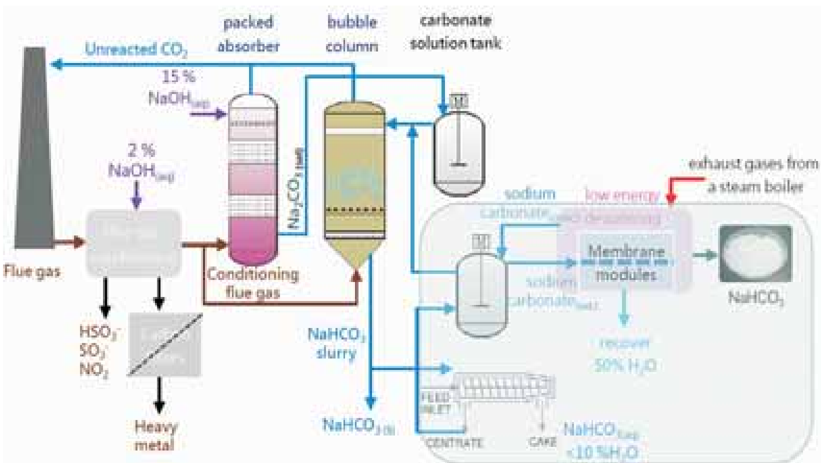


Fig.4. Process configuration of the CO_2 utilization process

3-3-7

Construction and Verification of DTU 10 MW Floating Wind Turbine Scaling Model test

The development of offshore wind farms in the world trends towards large size, deep water and floating type. In August 2022, Bureau of Energy (BOE), Ministry of Economic Affairs (MOEA), held the "Explanatory Meeting for Floating Wind Demonstration Project" for Taiwan's floating offshore wind power development, in terms of regulations, technology, and infrastructure. In order to assist the domestic marine engineering teams to establish floating platform engineering technology, the Institute of Nuclear Energy Research (INER) has built a scale model test platform providing developers test services for the floating platform model design and verification (as shown in Fig. 1).

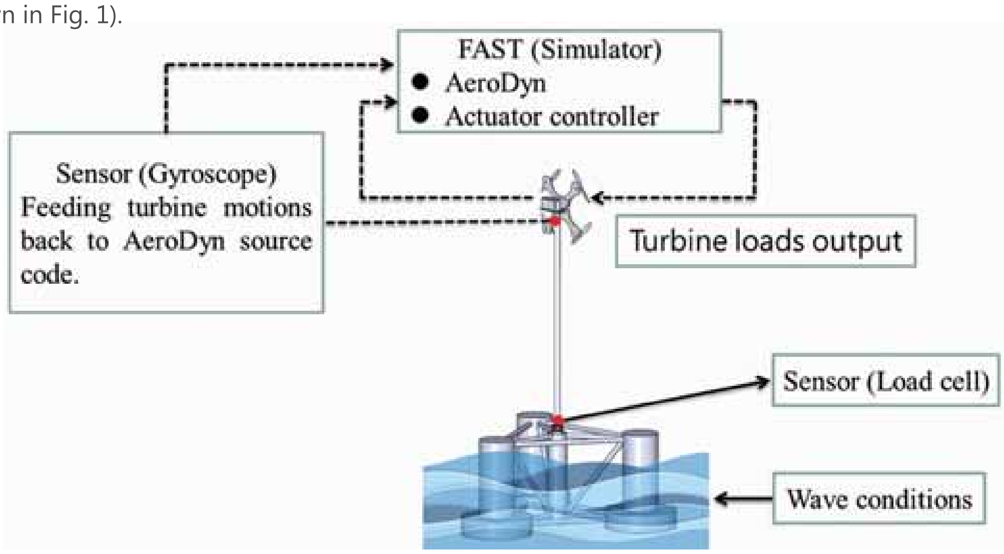
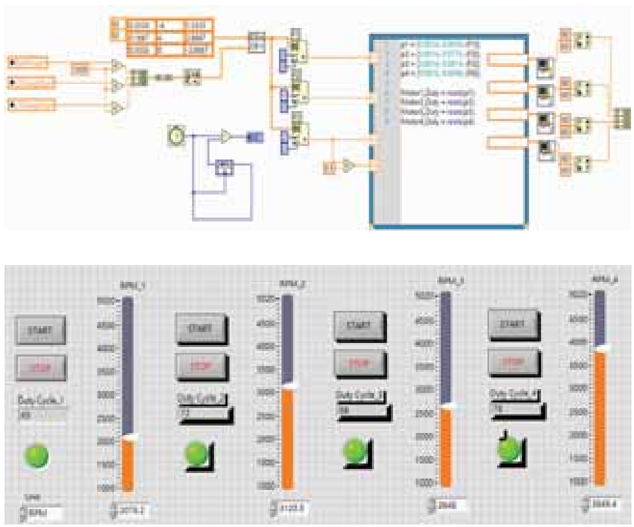


Fig.1. Framework of scale-down test platform for floating wind turbine

The scale model test platform with Software-in-the-loop (SIL) technology which can perform 10 to 15 MW programed wind turbine makes the experiment design flexible and reduces the model manufacture cost. According to the wind turbine attitude and wave conditions in the test, the wind incident angle can be updated in real time and the aerodynamic force will be recalculated. Meanwhile, the aerodynamic and hydrodynamic loads of the offshore wind turbine (OWT) can be simulated.



The system containing National Instrument (NI) embedded controller and LabVIEW software (as shown in Fig. 2), and integrating the gyroscope and the thrust controller into NREL FAST dynamic load software can realize the function tests under the normal operation and shutdown scenarios.

Fig.2. LabVIEW human-machine interface

Fig.3. Scaling tank test for DTU 10 MW floating wind turbine

The offshore wind turbine simulation device has been granted a patent (I718554) by Taiwan Intellectual Property Office. It also has been used in the "DeltaFloat Floater Tank Scale Model Test" conducted by the Ship and Ocean Industries R&D Center (as shown in Fig. 3).

The scale model is designed following the Froude scaling law. Comparisons of the experiment and simulation in the motions (heave, pitch, and roll) of the floating platform are performed to verify the scale model (as shown in Fig. 4).

The comparison results show that the motion characteristics are quite consistent and errors of the free decay periods are all within 5% (as shown in table 1).

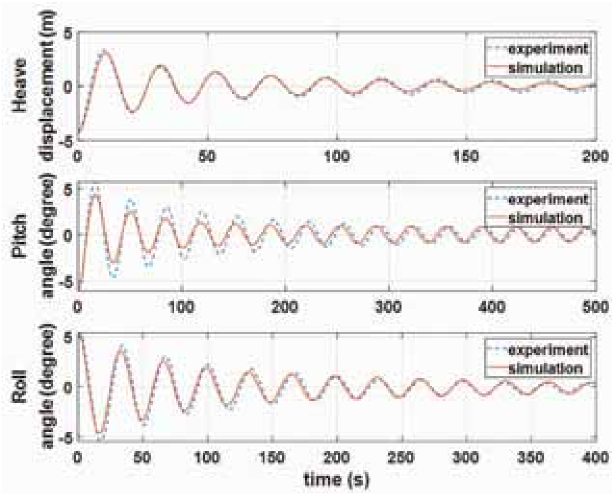


Fig.4. Comparisons of free decay for DTU 10 MW

Table.1. Comparisons of free decay period

DOFs	Experimental period (s)	Simulation period (s)	Difference (%)
Heave	22.021	21.057	4.38
Pitch	34.905	34.524	1.09
Roll	33.466	33.333	0.4

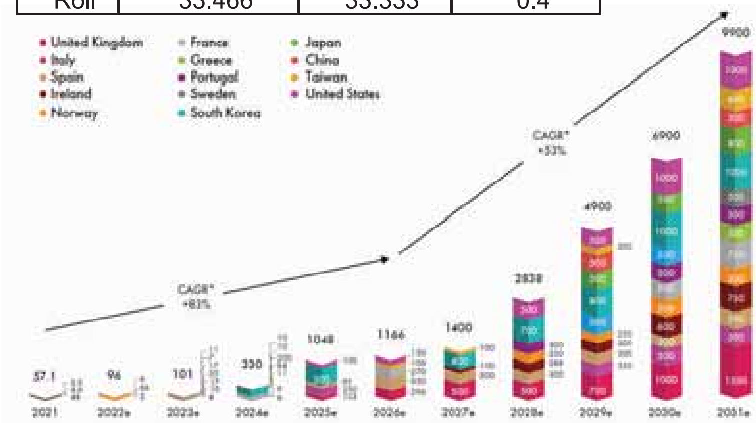


Fig.5. New floating wind installations, Global (MW) (Source: GWEC, 29 June 2022)

According to the "Floating Wind Farm Demonstration Plan" planned by Bureau of Energy in 2022, which includes 6 to 12 floaters and no more than three demonstration wind farms in total. The scale model test platform can be used for design and evaluation of the floating platform with the increase of the new large-scale floating OWT plans in the future (as shown in Fig. 5). Also the offshore wind turbine simulation device will be helpful for shortening the wind farm development period.

4. 2022 highlighted events

4-1

2022 highlighted events

1. *2022/01/01-12/31* Emergency production of "INER THALLOUS CHLORIDE (T1-201) INJECTION" and "INER GALLIUM CITRATE (GA-67) INJECTION" was implemented by the INER in response to the shortage of imported radiopharmaceuticals during the COVID-19 pandemic. Approximately 75,800 scans were supplied in 2022.

2. *2022/02/11* Premier Su inspected the Radionuclides in Foods Testing Laboratory at INER.

3. *2022/03/23-03/27* INER Deputy Director-General Hsu traveled to Japan with the "ALPS Treated Water Discharge Observer Group" and engaged in technical discussions with Japanese experts. The group visited the ALPS treated water discharge and storage facilities at Fukushima to obtain critical information on ALPS treated water and their discharge for domestic reference.

4. *2022/04/07* INER signed a tripartite memorandum of understanding with the Punjab Energy Development Agency (PEDA) and Punjab State Council for Science and Technology (PSCST). Under the agreement, INER agrees to help Punjab solve its air pollution problem through the industrialization of biorefinery technology. Clean energy and green products will be developed as well.

5. *2022/04/18-05/06* The INER commissioned physical examinations for employees. In addition to the employees of the AEC, INER, and FCMA, the head of the neighborhood arranged for local residents to participate in the examinations as well.

6. *2022/06/12* The "2022 Symposium on the Developmen of Nuclear Medicine and Molecular Imaging Applications" was held at GIS NTU by the INER. The event was held concurrently as an on-site and online conference, with a total attendance of 680 participants.

7. *2022/06/23、06/27-07/01* The INER organized a video conference to present the results of the "2021 Research Project Under Commission of the Atomic Energy Council, Executive Yuan". A total of 289 persons from industry, university, and institute partners were invited to participate over eight sessions.

8. *2022/08/03* Academician Dr. Chen Chien-jen, former Vice President and current Director of the Genomics Research Center, Academia Sinica, was invited by the INER Ji-Peng Lectures to give a speech on "COVID-19 Pandemic and Post-Pandemic Reform for Resilience". Dr. Chen then visited the INER Radiopharmaceutical Production Center and gallery of green energy R&D projects after the speech.

9. *2022/08/22* The winners of the 2022 Global Top 100 R&D Awards were announced, and the INER participated in the competition and won a prize with its "Innovative, low-cost, and low-carbon technology for mass-producing electrochromic glass ".

10. *2022/08/25* The "International Symposium on Radiation Dispersion Simulation and Measurement Technology for Discharge of Tritium-contaminated Wastewater From the Fukushima Daiichi Nuclear Power Plant" was held by the INER at GIS NTU. The symposium was conducted in parallel both online and in-person, and 122 people from 11 organizations attended this symposium.

11. *2022/08/26* The INER organized the "2022 International Workshop of Nuclear Facility Decommissioning Technologies"and invited experts from the TPC, academia, and industries for the workshop in order to form the teams for supporting the future decommissioning activities of the nuclear power plants in Taiwan.

12. *2022/08/31* The Tritium in Organisms Testing Laboratory at INER was formally established with a capacity for testing up to 500 samples each year.

13. *2022/10/14* The winner list of the "2022 Taiwan Innotech Expo" competition was announced, and INER won two platinum awards, three gold medals, five silver medals, and five bronze medals in the competition.

14. *2022/10/21* Director Mohamed Lamari and three other officials from the International Atomic Energy Agency (IAEA) visited the Institute of Nuclear Energy Research Institute. The locations visited included the TWC- (Hot Cells in Building 020), TWL- (Central storage facility in Building 036A/K/U), and the surrounding areas.

15. *2022/10/27* Political Representative Mark Pearson, Commerce Representative Tina Wilson, and others from the New Zealand Commerce and Industry Office Taipei along with representatives of the New Zealand companies BioForestry and X company visited to the INER. The visit served to lay the foundations for further Taiwan-NZ collaboration to accelerate the development of the wood chip circular economy industry.

16. *2022/11/02* The INER entered the MOEA Intellectual Property Office "2022 Competition for Patent Portfolio Analysis" and won first prize with its "Hydrogen Fuel Cell Car" project.

17. *2022/11/10* The Research Center for Biotechnology and Medicine Policy announced the winner list of the 19th National Innovation Award and the INER won two "Research and Innovation Awards"

18. *2022/11/29* INER Dolacga Liver Imaging Agent won the gold award in pharmaceuticals categogy of the Pharmaceutical Technology & Research Development Award (PTRD) jointly hosted by the Ministry of Health and Welfare and the Ministry of Economic Affairs in accordance with the Regulations Governing Incentive Rewards for Research and Development of Pharmaceutical Technology.

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