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2021 Annual Report

Institute of Nuclear Energy Research
Atomic Energy Council, Executive Yuan

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Contents

1.Preface

For Realizing a Low-Carbon Society and Improving People's Well-being: An Application R&D Institution to Line up with the World

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. The research and development fields are roughly divided into (1) nuclear safety and nuclear back-end; (2) people's livelihood radiation application; (3) green energy and system integration. INER is committed to innovative research and development. With the existing system integration energy, it has accumulated considerable tradable technologies and patents. Through the promotional activities, including technology transfer, technical services, cooperative development, INER has assisted domestic enterprises in product development, innovative process and system improvements to achieve good results.

In terms of nuclear safety and nuclear back-end development, INER is not only committed to the research on the operation safety of nuclear energy facilities, but also to develop the technology of nuclear facilities decommissioning, radioactive waste treatment/disposal to obtain good performance in the operation, decommissioning, and waste management of nuclear facilities. INER has recently successfully developed a large-scale, low-cost and low-radioactive waste container and transferred the related technology to domestic manufacturers, and it is expected to be promoted and applied to the decommissioning work of domestic nuclear power plants in the future. Moreover, with the completion of the first domestic report focusing on the preliminary safety demonstration of the high-level radioactive waste disposal, Iner has been among the world's pioneers in the disposal technology.

In light of the Fukushima Nuclear Accident, INER has also completed the localized assessment technology for the earthquake resistance of nuclear power plants, which effectively improves the reliability of the safety system of nuclear power plants.

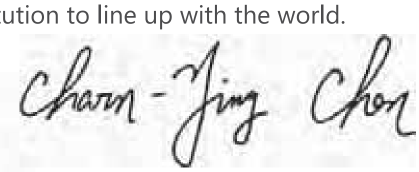
In terms of the application of radiation to people's livelihood, in response to the shortage of domestically imported nuclear medicines during the COVID-19 epidemic situation, INER had launched an emergency production of nuclear medicines such as "thallium chloride cardiac contrast agent" and "gallium citrate contrast agent for malignant tumors". To ensure people's right to medical treatment, the nuclear medicines were provided for more than 65,000 patients for imaging use in 2021, which showed an increase of 40,000 times compared with 2020. In addition, INER has also been approved by the Executive Yuan to implement the 70MeV medium-sized cyclotron construction project from 2023 onwards. The project's target is to continue the research on the development of

nuclear medicines for diagnosis and treatment, and to develop the neutron and proton science for the application on the domestic space and semiconductor industries. For the purpose of early warning of discharging the tritium-containing waste water from the Fukushima nuclear power plant into the ocean, INER has initiated "The Project on Environmental Radiation Monitoring and Safety Assessment of the Radioactive Substances in National Sea Area ", which will immediately establish an early warning system in the sea area of Taiwan, and develop the related monitoring technology in one and a half years. As for the radiation detection of food imported from Japan an issue of public concern, INER has established a dedicated food radiation detecting laboratory since 2016, and the food radiation detecting procedure has been recognized by the Taiwan Accreditation Foundation (TAF) and Taiwan Food and Drug Administration, Ministry of Health and Welfare (MOHW/TFDA). The total number of examinations is about 180,000 as of the end of 2021, ensuring the food safety for the public.

In terms of green energy and system integration, INER has not only achieved fruitful results in energy creation, energy storage, energy saving and system integration, but also actively promoted these achievements to industrial applications. In 2021, 9 technologies have been transferred to private manufacturers, including "Arc Plasma Specialized System Coating Large-area Tungsten Trioxide Thin Film Technology" and "All-solid-state Lithium Batteries", and the total contract money exceeded NTD 50 million. Cooperating with the Executive Yuan's "Smart Grid Master Plan", INER also actively participates in the forward-looking infrastructure project to accelerate the domestic development of smart dispatching, power generation, power grid management and other fields, and incorporates technologies related to net zero carbon emissions into the development plan to contribute more to the government's promotion of carbon reduction.

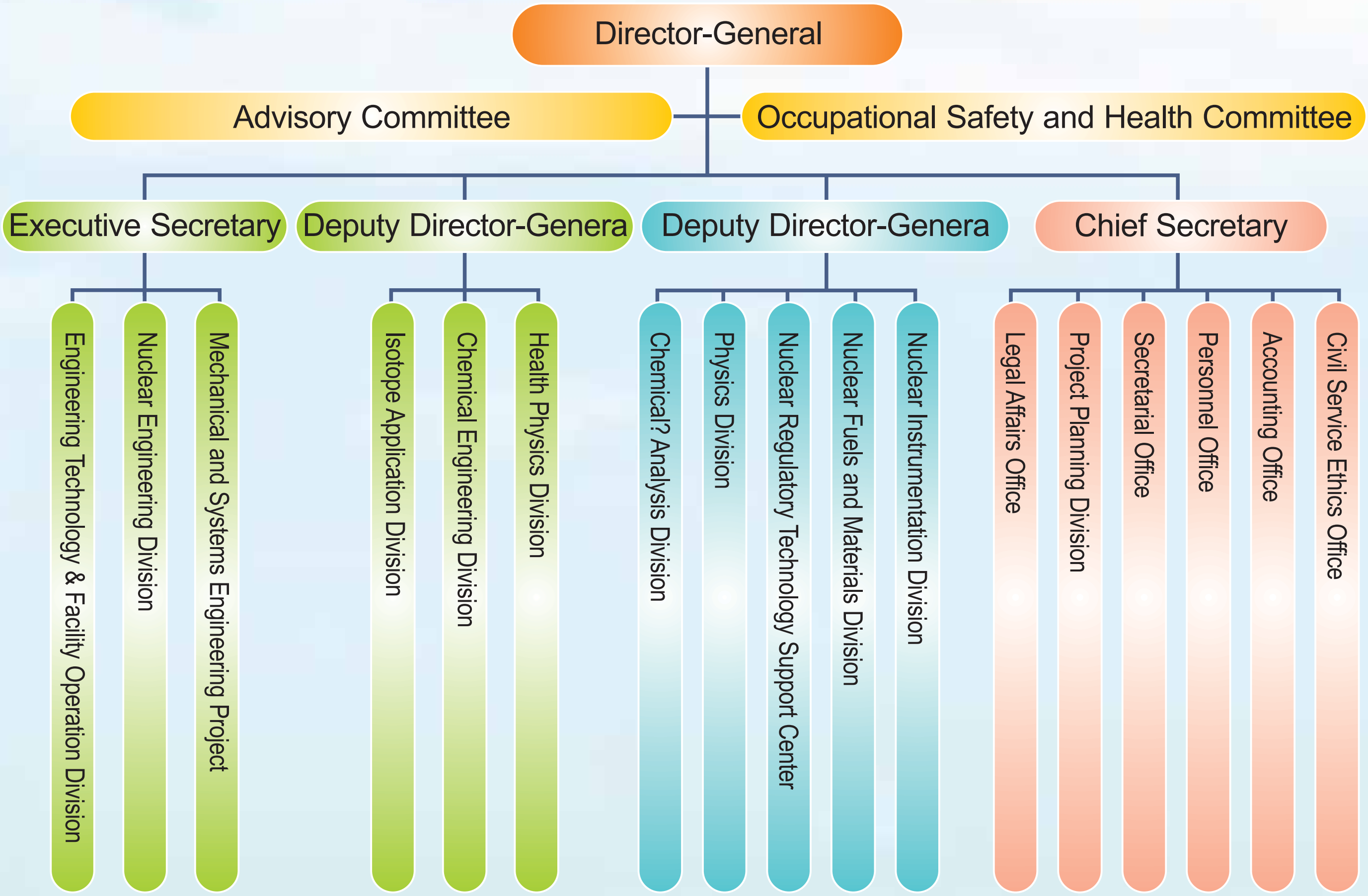
In order to promote as well as to demonstrate the R&D achievements, INER actively participates in international patent invention exhibitions and large-scale award-winning activities domestically and internationally. Among them, the patented technology "Intelligent Distribution Network Management System (iDNMS)" won the "2021 R&D 100 Awards", which is known as the Oscar of the global technology industry. At the Taiwan Innotech Expo (TIE) held in September 2021, 2 patented technologies of INER won the platinum award representing the highest honor, 3 gold medals, 2 silver medals and 3 bronze medals. The winning rate is about 77% which is much higher than the average winning rate (58%) of the conference.

In the future, 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 an application R&D institution to line up with the world.

Director General 

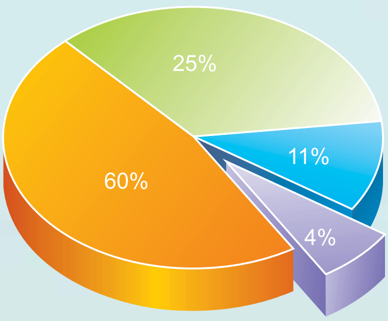
2.Organization Chart、Human Resources and Budgets

Organization Chart of INER



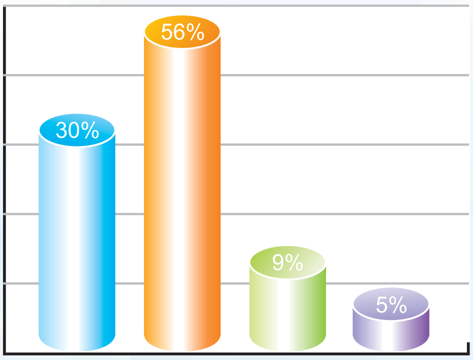
Human Resources and Budgets (Time of data: December, 2021)

Manpower Distribution of INER



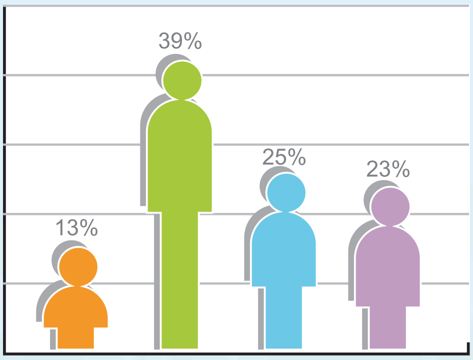
Research Staffs	486 Persons	(60%)
Technicians	204 Persons	(25%)
Administrative Staffs	89 Persons	(11%)
Other Staffs	29 Persons	(4%)
Official Staffs	808 Persons	

Statistics of Educational Background for Research Staffs



Ph.D.	145 Persons	(30%)
Master	274 Persons	(56%)
Vocational School	41 Persons	(9%)
Bachelor	26 Persons	(5%)
Research Staffs	486 Persons	

Statistics of Job Category for Organizational Research Staffs



Researcher level	66 Persons	(13%)
Associate Researcher level	189 Persons	(39%)
Assistant Researcher level	120 Persons	(25%)
Research Assistant	111 Persons	(23%)
Research Staffs	486 Persons	

2021 Annual Budget

Unit: Thousand NTD

Item	Number of Accounts	Percentage
Administration and Safety	1,166,812	66.21%
Management, Operation and Maintenance	181,634	10.31%
R&D Projects	281,464	15.97%
Technology Promotion and Service	132,474	7.52%
Total	1,762,384	100.00%

3.Current Major R&D Activities

3-1

2021 Research on Nuclear Safety and Nuclear Back-end Technologies

In line with the national energy transition and nuclear-free homeland policy, Taipower has planned to start decommissioning phase of the three nuclear power plants (NPP) in Taiwan after expiry of operating licenses from 2018 to 2025, respectively. The research nuclear facilities in INER are also being decommissioned and cleaned up in accordance with nuclear laws and regulations. Therefore, the R&D tasks of INER at this stage mainly focus on the application of nuclear safety analysis technology, the safety storage evaluation technology of spent nuclear fuel, the decommissioning and cleaning technology of nuclear facilities, and the radioactive waste treatment and disposal technology. Moreover, INER also actively promote the application of nuclear safety technology to other cross-disciplinary systems. Selected R&D achievements in the field of nuclear safety and nuclear back-end technologies in 2021 are as follows:

(1) In accordance with the safety enhancement measures of NPP after Fukushima nuclear accident in Japan, INER has established Seismic Margin Assessment (SMA) technology to verify whether the seismic margin of the original design of safety system is sufficient to cope with the Beyond Design Basis Seismic Event (BDBSE). Moreover, the reliability of safety related system could be effectively improved by implementing the corresponding retrofit of seismic inadequate items from the SMA insights.

(2) The possible blockage of Pressurized Water Reactor (PWR) containment internal recirculation sump by debris resulting from pipe-break jet transported to the sump strainer is a nuclear safety concerned issue. In order to respond to this regulatory mandate, INER has completed the improvement plan for Maanshan NPP, which include three working phases: Phase I for containment walkdowns and debris assessment, Phase II for new strainer installation, and Phase III for strainer downstream effects assessment.

(3) INER has established the Anticipated Transient Without Scram (ATWS) Integral Analysis Methodology and applied it to the safety assessment of Kuosheng NPP. The methodology combines five safety analysis technologies including system transient analysis, fuel rod failure evaluation, containment analysis, dose calculation, and stability analysis to verify the ability of the multibarrier safety design under the extreme strict postulated ATWS event.

(4) INER has developed a set of isolation tents with functions of detachable, mobile, automatic tracking and sensing constant negative pressure, and a nano-coating layer for efficient decontamination. It has already been applied during the decommissioning of INER underground storage of spent fuel casings, and proved effectively prevent the occurrence of radioactive material release events with an accuracy of 100%.

(5) The decommissioning of Taiwan Research Reactor (TRR) Facility is the current important mission of INER, and the dismantling of TRR furnace body is the most critical task. The dismantling process adopts top-down and inside-out strategy. INER has already successfully completed the dismantling of the upper biological shielding that is the uppermost component, and started the key TRR dismantling project.

(6) In order to improve the capacity and efficiency of the low-level radioactive waste storage facilities, INER planned the operating license change and reuse of the decommissioned facility. The original license of Building 012 was Nuclear (Fuel) Storage Facility Operation License. In order to reuse the site after decommissioning, the improvement measures for meeting regulations were completed, and successfully obtained the Radioactive Waste Storage Facility Operation License.

(7) INER has developed a software system for rapid image interpretation in the non-destructive testing (NDT) industry. It applies artificial intelligence (AI) and automation technology to establish a rapid, batch and accurate identification system for NDT eddy current detection signals, which greatly reduce safety maintenance labors during the detection period and increase the economic benefits.

(8) The dry storage of spent nuclear fuel (SNF) is the mid-term management strategy during decommissioning of NPP in Taiwan. INER established the integrity assessment and inspection technology for SNF of BWR plants, and successfully applied it to Chinshan and Kuosheng NPP. The integrity of all SNF rod claddings and assemblies are verified to ensure the safety for subsequent dry storage, and assure the nuclear safety during decommissioning.

(9) INER has completed the screening of potential radionuclides of concern for decommissioning of the three NPP in Taiwan to meet the needs of radiation safety for temporary storage and disposal of radioactive waste. INER used USNRC NUREG/CR-3474, IAEA NW-T-1.18 and TRS-389 and associated reports as initial data. Moreover, the Final Safety Analysis Reports (FSAR) and routine inspection data during the operation period, and calculation results from reactor core and biological shielding activation are also included to improve the integrity of the screening basis.

3-1-1

Ensuring the Reliability of Safety Related Systems – Assessment Technology for NPPs

In view of the Fukushima nuclear accident in Japan, capability to withstand Beyond Design Basis Seismic Event (BDBSE) of NPPs has become a serious issue worldwide in recent years. In general, seismic adequacy of the safety related equipment in NPPs is verified by Shake Table Test. Regarding BDBSE, directly performing Shake Table Test for all equipment again seems not be an efficient and economical approach because seismic design margin of some equipment is already sufficient to BDBSE. INER has established an applicable technology of Seismic Margin Assessment (SMA) for NPPs. In addition to verifying the seismic adequacy of safety related equipment in NPPs, the reliability of safety related system can be efficiently improved by implementing the corresponding retrofit of seismic inadequate items from the SMA insight.

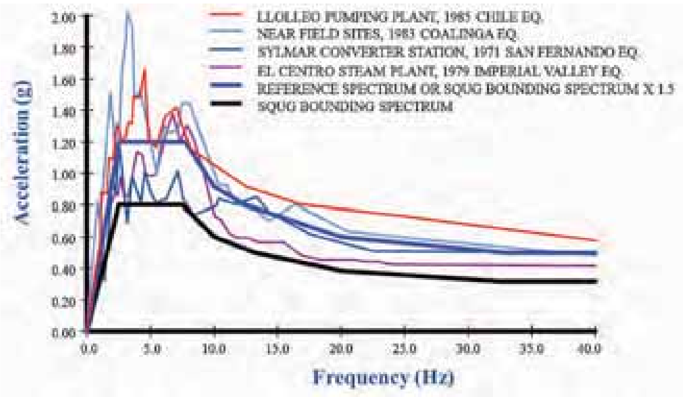


Fig.1. Databases of seismic response spectra (from : SQUG, GIP-3A, 2001)

INER integrates the existing seismic qualification data and experience database (Fig. 1) of the nuclear industry to develop SMA. Fig. 2 shows the flow diagram of SMA. By establishing a seismic equipment list and performing seismic walkdowns, the inherent rugged equipment can be identified and screened out from further evaluation. The corresponding retrofit only needs to be developed for equipment of which High Confidence of Low Probability of Failure (HCLPF) capacity is less than the required seismic demand of BDBSE.

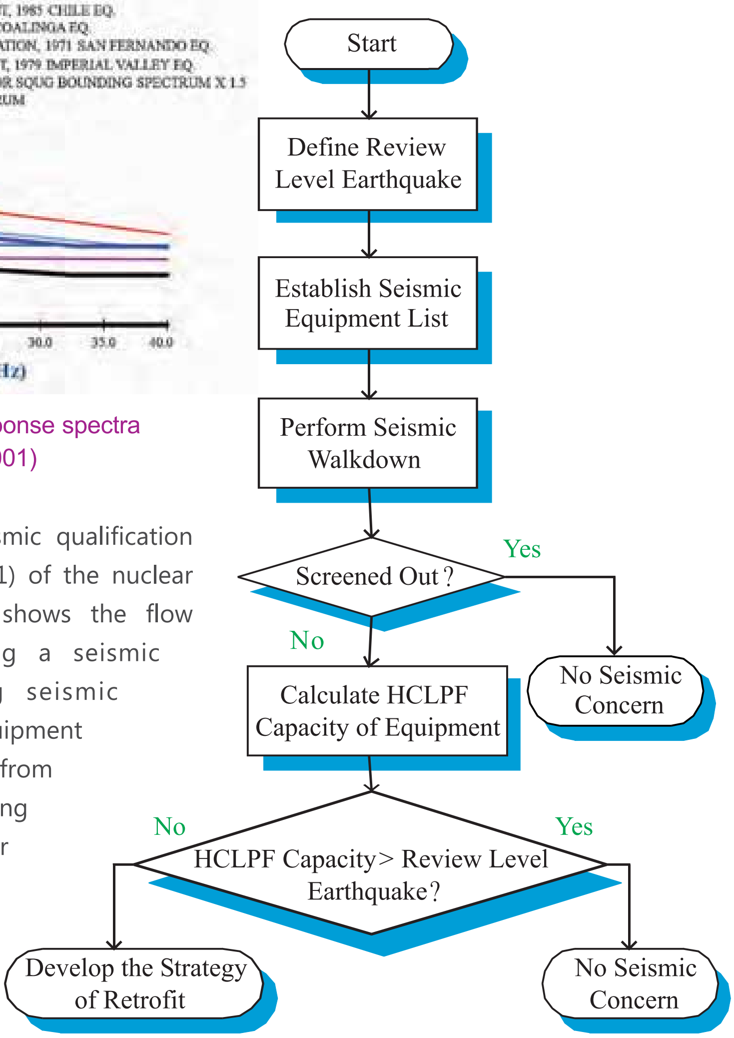


Fig.2. Flow diagram of SMA

Fig.3. Equipment related to backup power of the HIS system in Kuosheng NPP

Based on the accident of hydrogen explosion in Fukushima NPP, Atomic Energy Council in Taiwan regulates the nuclear utility to enhance the capability in order to prevent hydrogen explosions within the containment. The Hydrogen Ignition System (HIS) is a critical mitigation system to control flammable gases within the containment in Kuosheng NPP. However, the equipment related to backup power of the HIS system (Fig. 3) is not designed as seismic category 1, and it will affect reliability of the HIS system directly with regards to BDBSE.

SMA for backup power equipment of the HIS system in Kuosheng NPP has been performed by INER. Fig. 4 shows the example of screening evaluation for the batteries. The Battery, diesel generator, oil storage tank, and switch panel are also identified as equipment with potential inadequacy to seismic concerns. After the retrofit suggested by INER, all the equipment related to backup power of the HIS system has been verified as seismic adequacy for BDBSE. INER also assisted Kuosheng NPP to make resources for retrofitting the equipment more efficient in improving the reliability of the HIS system instead of repurchasing equipment that shall meet the requirement of BDBSE. Fig. 5 illustrates an example of seismic evaluation.

SCREENING EVALUATION WORK SHEET

Plant Name : Kuosheng NPP Unit : #1&#2

PART A. DESCRIPTION

Equip. ID. No. ______ Equip. Class Batteries and Racks

Equipment Description: HIS DG Batteries

Equipment Location: Bldg. DGB Floor El. 0.0 ft Room, Row/Col ______

Manufacturer, Model, Etc. Yuasa

Seismic Input Elevation DGB EL. 0.0 ft

PART B. BATTERIES EVALUATION

	Y	N	U	N/A
1. Are the batteries of good seismic design ? Lead-Antimony plates capacity Batteries mountings (restraint, spacers...) Side rails strength/stiffness	☐	☒	☐	☐
2. No other batteries concerns?	☒	☐	☐	☐
Are the batteries themselves screened out?	☐	☒	☐	

PART C. RACKS EVALUATION

	Y	N	U	N/A
1. Are the racks of good seismic design? Lateral load resistance Adjacent racks secured Wood racks adequacy	☒	☐	☐	☐
2. No other racks concerns?	☒	☐	☐	☐
Are the racks themselves screened out?	☒	☐	☐	

Fig.4. Screening evaluation of equipment

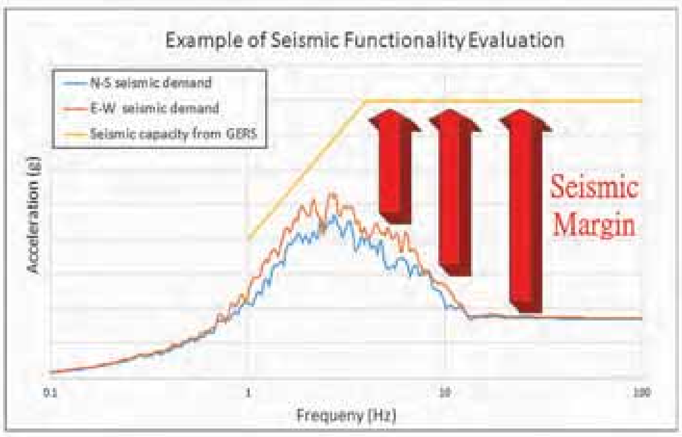


Fig.5. Illustration of seismic evaluation of equipment

INER has successfully assisted Kuosheng NPP to improve the reliability of the HIS system to withstand BDBSE. In addition to extending the application to safety systems of other NPPs in Taiwan, the application of SMA technology can also be used to verify the seismic adequacy of the required equipment with non-seismic design originally. This is necessary to be included in the safety system evaluation during the decommissioning phase in the future.

3-1-2

Enhancing the Operation Safety of Nuclear Power Plants - MNPP Containment Recirculation Sump Strainer Improvement

Generic Safety Issue, GSI-191, was established by the USNRC in September 1996 to determine whether further action was needed for debris and possible blockage of pressurized water reactor (PWR) sumps resulting from a pipe-break jet transported to the sump strainer (Fig. 1). In September 2004, the USNRC mandated that NRC licensed PWR plants address emergency sump strainer blockage with the issuance of Generic Letter, GL 2004-02. In Taiwan, Atomic Energy Council (AEC) has also requested Maanshan Nuclear Power Plant (MNPP) to evaluate the impact of debris loads on the sump strainer in response of GL 2004-02 as a regulatory mandate. Therefore, INER assists MNPP to perform the containment recirculation sump strainer improvement project in order to strengthen the safety of plant operation. The project is comprised of 3 phases: Phase I for containment walkdowns and debris assessment, Phase II for new strainer installation, and Phase III for strainer downstream effects assessment.

MNPP New Strainer

INER has assisted MNPP to complete the sump technical specifications on schedule and supervised the work of the new strainer installation. Two new strainers of each around 928 m^2 (9,988 ft^2) surface area have been installed above the sump (Fig. 2) in March 2014 and in April 2015 for Unit 2 and Unit 1, respectively. The MNPP strainer surface area exceeds the US Surry Unit 2 of 8,490 ft^2. Therefore, MNPP strainer design has reserved enough safety margins against any unexpected severe accident .

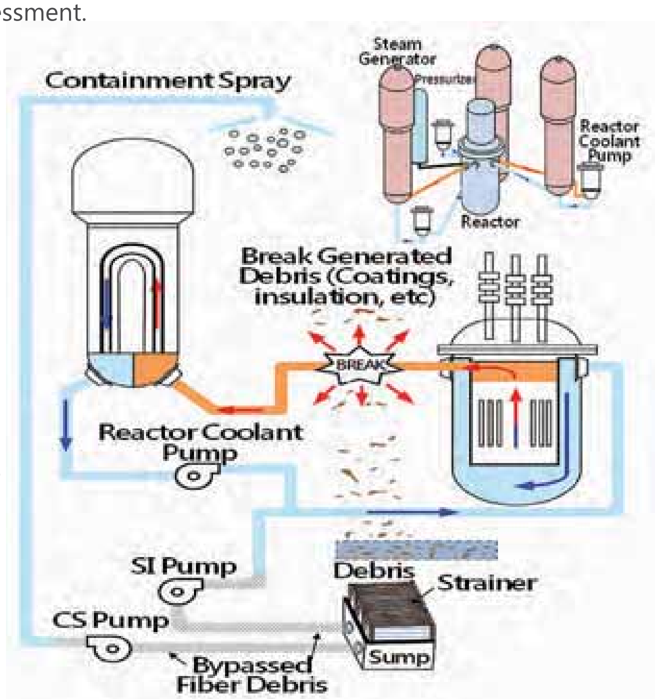


Fig.1. Strainer Blockage Schematic

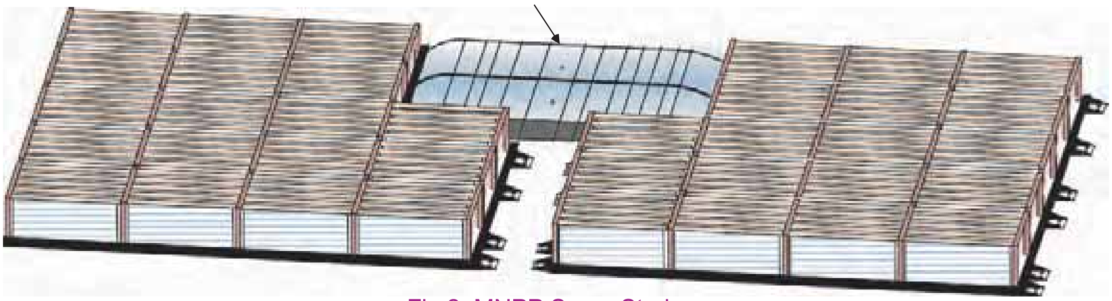


Fig.2. MNPP Sump Strainer

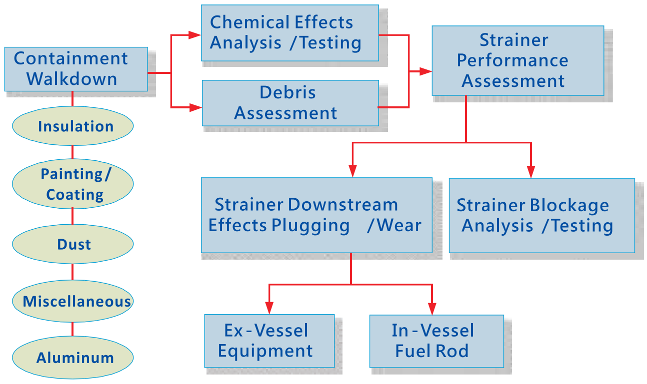


Fig.3. Work Items

Strainer Downstream Assessment

INER has performed MNPP sump strainer downstream effects assessment including in- and ex-vessel downstream effects. Safety injection throttle valves and equipment between the strainer and the vessel have been assessed for plugging and wear phenomena. In-vessel downstream effects calculation comprises the fiber debris amount, and the maximum temperature and debris deposition thickness on fuel cladding. However, the in-vessel fiber loading beyond the criterion may cause fuel blockage. The resolution path (Fig. 5) for the fuel blockage issue will follow the USNRC guidance ML19228A011.

Strainer Upstream Assessment

INER has assisted MNPP to finish the emergency sump strainer improvement of Phase I and Phase II (Fig. 3) including containment walkdowns, debris loads and chemical effects analysis, strainer technical specifications and performance assessment, strainer testing witness and manufacturing inspection, and strainer installation (Fig. 4) in order to satisfy the regulatory requirements, enhance the operation safety, reduce the plant risk, and ensure the strainer functioning well against any severe accident. In addition, MNPP final closure option for the strainer improvement has been prepared.

Fig.4. Strainer Onsite Installation

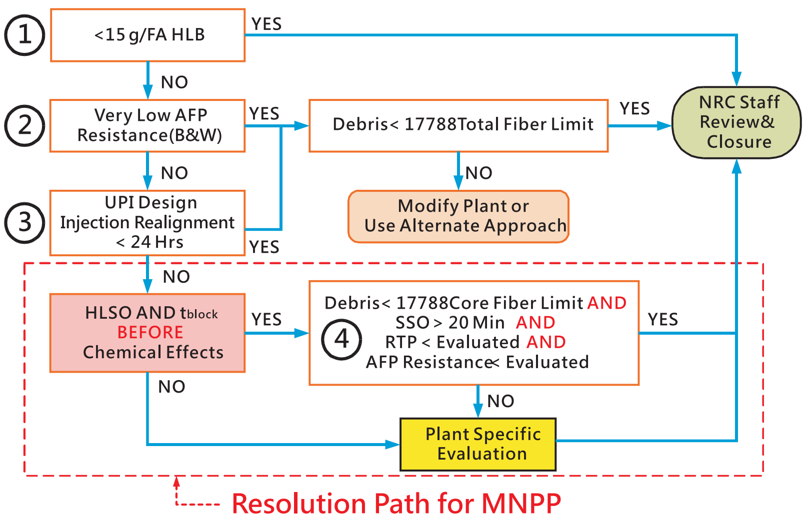


Fig.5. MNPP In-Vessel Fuel Blockage Resolution (USNRC ML19228A011)

INER has successfully assisted MNPP to respond the regulatory request. A new strainer has been installed in order to improve the safety of plant operation and ensure the reactor core integrity even in severe accidents. Additionally, INER is planning the resolution path of fuel blockage and the closure of the strainer improvement issue for MNPP to strengthen the nuclear power safety, protect public health, and guarantee stable power supply.

3-1-3

Ensuring the Ability of Multibarrier Protection - The ATWS Integral Analysis Methodology for Kuosheng NPP

To prevent radioactive materials release, the multibarrier concept was implemented to design Kuosheng nuclear power station. From inside out, the layers of barriers include ceramic fuel pellet, fuel cladding, 20 cm thick steel reactor pressure vessel, 1.2~2 m thick ferroconcrete primary containment, and secondary containment as shown in Fig. 1. " The ATWS Integral Analysis Methodology for Kuosheng Nuclear Power Station" developed by INER combines five safety analysis technologies including system transient analysis, fuel rod failure evaluation, containment analysis, dose calculation, and stability analysis to identify the ability of these barriers under the extreme strict postulated event, Anticipated Transient Without Scram (ATWS).

ATWS is control rod drive system fail to finish the scram function when an Anticipated Operational Occurrences (AOOs) happened. The AOOs are the events anticipated to happen once or twice during the life of nuclear power plant. For ATWS, Kuosheng configured Alternate Rod Insertion (ARI), Recirculation Pump Trip and Standby Liquid Control System (SLCS) to ensure the ability of handling this event. The integral analysis methodology combines technologies including the core thermal-hydraulic analysis, stability analysis, statistics analysis, containment analysis and radioactive dose evaluation. Therefore, under strict assumptions like the ATWS event, it can be used to evaluate fuel cladding peak temperature and oxidation, to calculate the probability of fuel cladding failure, to evaluate the integrity of coolant boundary and containment, and the radiation dose to personnel at control room, Exclusion Area Boundary (EAB) and Low Population Zone (LPZ), the relative position is shown in Fig. 2 .

Kuosheng nuclear power station(Wikipedia)

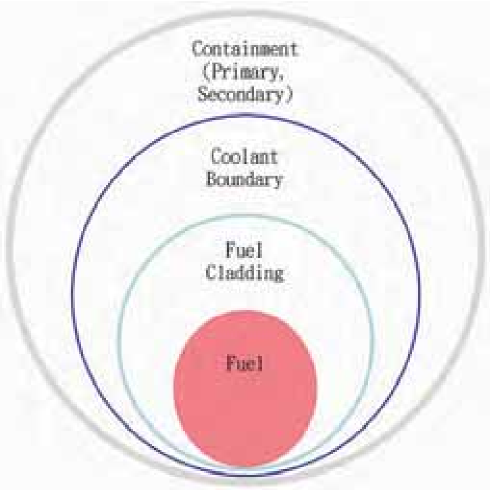


Fig.1. Schematic of multibarrier

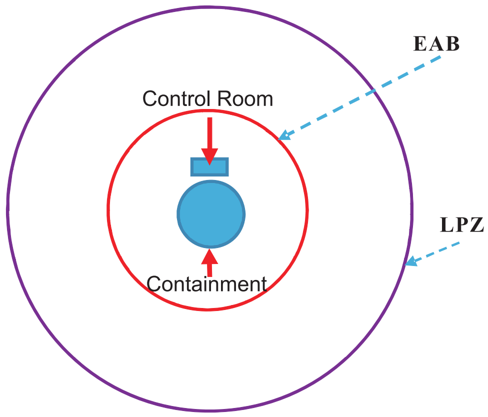


Fig.2. Schematic of the relative position of containment, control room, EAB and LPZ

The full analysis procedure consists of five parts as shown in Fig.3. The Thermal-Hydraulic code RETRAN-3D is used for System Transient Analysis, the results are then used for other parts. This is the first time in a domestic try to evaluate the failure number of fuel rod according to transient results, and following by dose calculation.

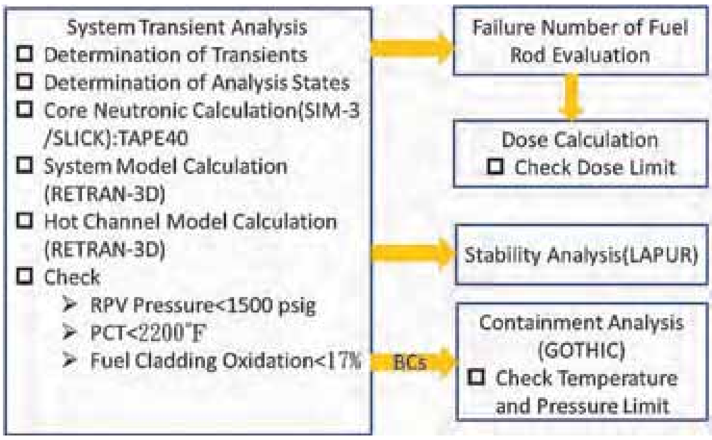


Fig.3. Kuosheng ATWS Integral Analysis Procedure

The purpose of stability analysis is to check if power oscillation occurs during ATWS events. This is done by checking Decay Ratio (DR). A small DR means that if oscillation occur, it will die out quickly and have no negative effects. Calculations show that under some conditions, DR can exceed 0.8. This means the power oscillation may occur during ATWS transients.

The primary purpose of system transient analysis is to verify the integrity of the Reactor Coolant Pressure Boundary (RCPB) and the fuel cladding. The most severe ATWS event of Kuosheng is Pressure REGulator failure Open (PREGO). Table 1 shows the integral analysis results. The peak pressure of Reactor Coolant System (RCS) is 1277 psig. The peak temperature of fuel cladding reaches 2042°F. And the fuel cladding oxidation is 4.4% of thickness. All of these are within the limits of the regulations. This means Kuosheng power plant can cope the ATWS events. Analysis based on these results shows that the pressure and temperature to which the containment is subjected are within limits, and means the containment can sustain anticipated functions. Also the resulted radiation doses are within limits.

Table 1. Kuosheng ATWS Analysis Results

Parameter		Analysis Results			Limit
		MSIVC	PREGO	TTWB	
RCS Pressure Peak(psig)		1,273.00	**1,276.96**	1,221.66	1,500
Fuel Cladding Peak Temperature(°F)		1877.44	**2041.92**	1682.39	2,200
Fuel Cladding Oxidation(%)		2.52	**4.41**	1.34	17
Suppression Pool Peak Temperature(°F)		164.7	164.2	**168.5**	200
Reactor Building Peak Pressure(psig)		3.58	2.88	**3.73**	15
Reactor Building Peak Temperature(°F)		148	139.5	**150.2**	200
Drywell Peak Temperature(°F)		166.8	160.1	**167.8**	330
Pressure Difference between Reactor Building and Drywell(psid)		0.50/-0.01	**0.53/-0.01**	0.5/-0.01	+21/-27.5
EAB Dose (mSv)	Thyroid Effective Dose	26.508	22.854	**31.136**	3,000
	Whole Body Dose	5.3044	4.5765	**6.2273**	250
LPZ Dose (mSv)	Thyroid Effective Dose	38.931	33.758	**45.566**	3,000
	Whole Body Dose	2.2989	1.9898	**2.6937**	250
Control Room Envelope Dose (mSv)	Thyroid Effective Dose	17.456	15.141	**20.428**	300
	Whole Body Dose	0.65656	0.56864	**0.76901**	50
	Skin Effective Dose	29.4791	25.5461	**34.5168**	300
	Total Effective Dose	1.541	1.3357	**1.804**	50

The integral analysis methodology can provide quantified evaluation of effects for ATWS events since it consists of complete assumptions, models, evaluation methods and up-down linked analysis process. On the other hand, present technology on stability analysis is still focus on qualitative analysis. It can be further developed according to the power instability suppression system set by the power plant to move towards the quantitative analysis technology.

3-1-4

Protective Cover for Decommissioning Operations-Isolation Tent with Automatic Tracking Perception and Constant Negative Pressure

Since the underground storage of spent fuel casings is not a confined space, the operation during the decommissioning period may cause air floatation, which may cause personnel to receive unnecessary radiation doses and pollute the on-site environment. INER has developed a set of isolation tents with functions of detachable, mobile, automatic tracking and sensing constant negative pressure, and a nano-coating layer for efficient decontamination.

It can be proved from the actual operation (Fig. 1) that this equipment can effectively prevent the occurrence of radioactive material release events with an accuracy of 100%. In addition, due to the high hydrophobicity and strong self-cleaning characteristics of this facility, there is no need to use too much water during decontamination, which can reduce subsequent radioactivity, wastewater generation and treatment costs. Each decontamination can save about 100 liters of wastewater.

Fig.1. On-site decontamination work

In order to ensure that the radioactive substances do not leak out during the decommissioning period, the tent is designed with negative pressure and is equipped with a differential pressure detector to track the pressure change in the tent and automatically link with the motor controlled by frequency conversion to keep the negative pressure constant and stable. In addition, a nano-coating layer is sprayed on the inner and outer layers to achieve the characteristics of high hydrophobicity and strong self-cleaning, so as to easily complete the decontamination process.

Fig.2. Functional Design Description

MEMO

Date . .

3-1-5

Initiate the Critical Work of Decommissioning the Taiwan Research Reactor (TRR) Facility -the Dismantling of the Biological Shield on the TRR Furnace Body

The "Taiwan Research Reactor (TRR) Facility Decommissioning Plan" has been approved by the competent authority in April 2004. The decommissioning period is until March 2029. The decommissioning scope (Fig. 1) includes (1) Ancillary facilities, (2) Fuel pool, (3) Dry Storage Pit (DSP), (4) TRR furnace body, (5) Auxiliary waste storage and treatment facilities, etc. INER has completed the dismantling of auxiliary facilities, fuel pool cleaning, and DSP cleaning is in progress. The dismantling of the TRR furnace body is the last and most critical task. The dismantling strategy will adopt the principles of top-down and inside-out. Therefore, the movable components inside the furnace body must be targeted first, which include upper biological shielding, upper thermal shielding, reaction tank and lower thermal shielding, etc. And then the outer biological shielding body of the furnace will be dismantled in layers, and gradually carry out the dismantling of the TRR furnace body. Since the upper biological shielding is the uppermost component of the furnace body, INER has completed the dismantling process of lifting, cutting and packing the component, and successfully started the TRR furnace body dismantling project which is the key work of decommissioning the TRR.

Fig.1. Scope of TRR decommissioning

TRR furnace body is stored in the disassembly workshop of Building 074. The upper part is cylindrical and the lower part is an octagonal body. The maximum width and total height are 14.2 m and 12.2 m respectively. The overall total weight is about 2,700 tons. The main components (Fig. 2) include (1) upper biological shield (four layers), (2) upper heat shield (two layers), (3) ring heat shield, (4) reaction tank, (5) side heat shield, (6) graphite reflector, (7) Lower heat shield (three layers), (8) biological shield, and (9) support frame. The upper biological shield is the first dismantling component of the TRR furnace body. The distance between it and the inner surface of the furnace body is very small. INER has developed lifting equipment and monitoring systems, and built cutting equipment and construction methods to overcome on-site environmental restrictions and problems. The dismantling of the upper biological shield and the disposal of waste are successfully completed, which is conducive to the subsequent dismantling of components.

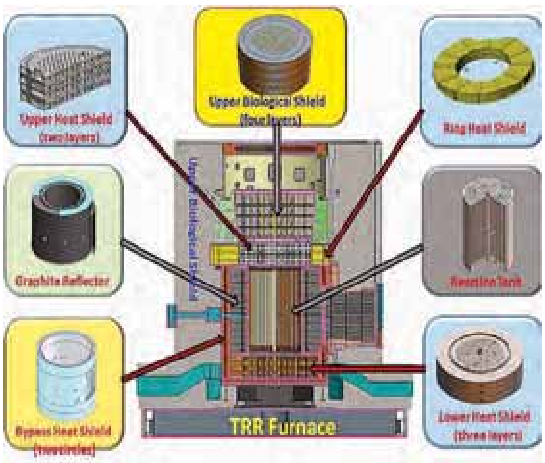


Fig.2. Main components of TRR furnace body

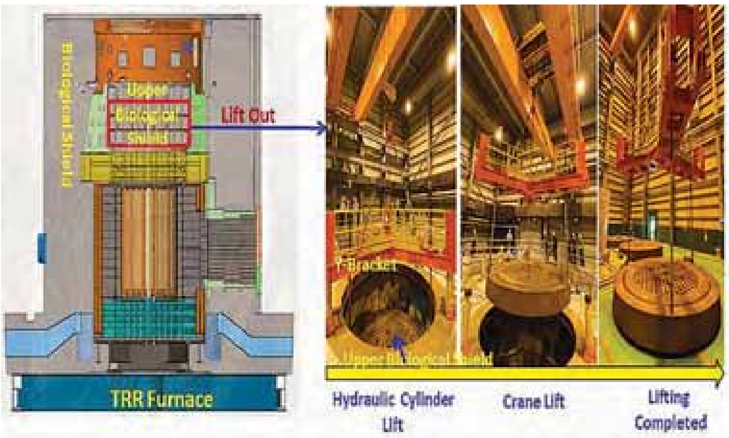


Fig.3. The upper biological shield is lifted out of the furnace cavity

Lift Out

The distance between the upper biological shield and the inner surface of the furnace is only 3.2 mm. INER designed the equipment and construction procedures according to the original drawings. The self-developed Y-type lifting equipment has been verified by simulation tests to meet the functional requirements, ensuring that the furnace is vertically lifted out of the cavity to avoid collision, and a monitoring system was installed to monitor the weight changes during the lifting and transporting process. The layers were lifted and transported out one by one. The radiation protection personnel measured the radiation changes throughout the whole engineering process, and successfully completed lifting and transporting the shield out of the furnace cavity (Fig. 3).

Cutting Operation

The upper biological shield is detected by pollution wiping, and there is residual non-fixed pollution found on the surface. In order to avoid airborne radioactive material release during the cutting process, a mobile isolation tent is built and an air monitor is installed. In order to avoid the spread of radioactive pollution, the cutting method adopts the biological shielding (three-layer) stacking method, the diamond cable saw cooperates with the guide wheel to control the direction, and according to the weight limit of the waste container, the cutting operation is carried out in six cutting lines, and the three-layer cutting operations are successfully completed (Fig. 4). Layer cutting decomposition (one layer is reserved for shielding), resulting in a total of 36 cutting blocks.

Fig.4. Upper biological shield cutting operation



Fig.5. Upper biological shielding packing operation

Packing Operation

The INER-LRW-C1 low-level radioactive waste container developed by INER is used for packaging operation of the biological shielding cutting parts (Fig. 5). The application of this container was approved by the competent authority in January 2020. It has the advantages of large size, low cost, and high storage volume. It can replace the existing 55-gallon barrel, greatly reduce the time of waste treatment operations, and improve the storage efficiency of the existing facility in INER. After the successful packaging operation, a total of 24 boxes have been transferred to the facility for safe storage.

3-1-6

Reuse of Decommissioned Nuclear Facility - The Operating License Renewal and Radiation Protection Enhancement of Building 012 at INER

The nuclear facilities at INER built in the early days are gradually entered the stage of decommissioning. With the successive implementation of Taiwan Research Reactor (TRR) decommissioning operations, including the ongoing work related to the dismantling of the TRR furnace body, the demand for radioactive waste storage capacity has increased significantly. In order to improve the storage capacity and storage efficiency of the low-level radioactive waste storage facilities of INER, the operating license change and reuse of the decommissioned facility are planned. The original operating license of Building 012 (including the delay tank) (Fig. 1) was the "Nuclear (Fuel) Storage Facility Operation License". After the nuclear material cleaning in the building is completed, there will be no subsequent nuclear material storage requirements. In order to reuse the site after decommissioning, the improvement measures for storage facilities were completed according to the "Radioactive Materials Management Law". The update version of the safety analysis report, facility operational technical specifications and accident contingency plans were prepared and apply to the competent authority for license change, and successfully obtain the "Radioactive Waste Storage Facility Operation License" (Fig. 2). The radioactive waste storage capacity of INER has been greatly increased, and the TRR decommissioned waste can be safely stored and complies with regulatory requirements.

Fig.1. Building 012 (including delay tank)

Fig.2. The original operating license of Building 012

There are three low-level radioactive waste storage facilities at INER. One of the facility is dedicated to the storage of Greater-than-Class C low-level radioactive waste. Except for the waste storage space required for the operation or cleaning of other facilities, there are still about 2,000 barrels of storage space. The total waste generated by the dismantling of the TRR furnace body is estimated 4,300 barrels. According to the TRR decommissioning plan, it will be stored in Building 012 and the delay tank. The statutory period of TRR decommissioning is March 2029, INER must implement decommissioning-related work on schedule. Therefore, in order to increase the storage capacity to meet the decommissioning needs of TRR, the license of Building 012 was changed to the "Radioactive Waste Storage Facility Operation License" in accordance with the "Radioactive Materials Management Law"(Fig. 3).

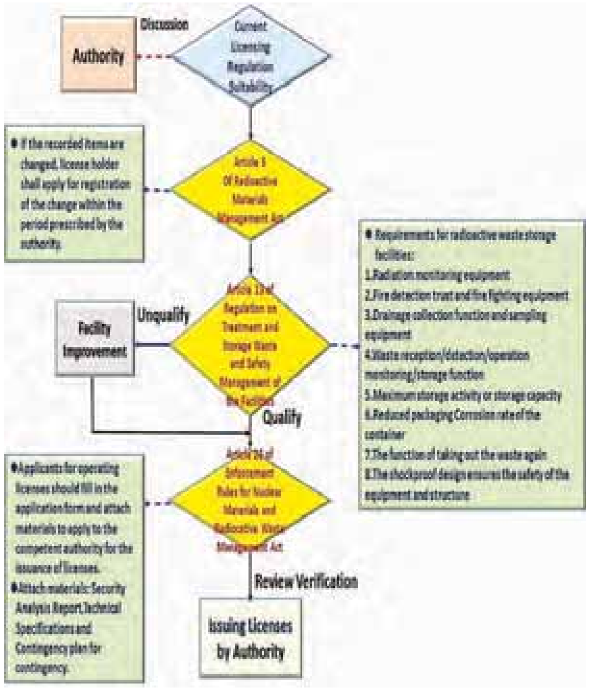


Fig.3. License renew process

For the research nuclear facilities in the decommissioning stage, INER shall plan temporary storage facilities in accordance with the storage requirements of radioactive waste generated from decommissioning. However, the construction of new radioactive waste storage facilities requires significant funds, and the progress of engineering and regulatory review is difficult to grasp. Therefore, after evaluation, it is proposed to reuse and apply for renewal of operating license of Building 012 (including the delay tank), instead of the construction of new facilities, which can save funds and meet the requirements of TRR decommissioning statutory schedule.

Fig.4. Improvements of radioactive waste storage facility

Fig.5. The additional stainless steel isolation plate in the fuel pool

Building 012 shall comply with the "Regulations for the safety management of radioactive waste treatment and storage and its facilities". Improvements have been made to the seismic design, radiation monitoring, operation monitoring and other items of the facility, and have been inspected by the competent authority to comply with the regulations (Fig. 4). In addition, in order to improve the radiation safety, the pool area is equipped with an isolation steel plate for the storage area that is still slightly polluted (Fig. 5). Those Improvement measures are implemented to meet the site reuse goals.

放射性廢棄物貯存設施運轉執照

執照號碼：物運字第32-05號
設施地址：桃園市龍潭區佳安里文化路1000號
設施經營者：行政院原子能委員會核能研究所
設施名稱：012館及延遲槽低放射性廢棄物貯存庫
有效期限：自發照日起至民國一百三十二年十二月三十一日止

上開放射性廢棄物貯存設施經審核與放射性物料管理法第十七條之規定相符合予發給本執照

行政院原子能委員會
主任委員
謝曉星

中華民國一〇九年

Fig.6. The new operating license of Building 012

Building 012 is the main site for TRR decommissioning. The decommissioned site can be reused as a storage facility for TRR furnace dismantling waste, which can effectively improve the storage efficiency of the existing facilities of INER, and the TRR decommissioning work can be successively performed on schedule. It is the first license renewal example of a radioactive material related facility in Taiwan (Fig. 6), and it can be referenced to facilities with the same operating license (Building 036A /K/ U, Building 020 , Building 016) if there is a need for radioactive waste storage in the future. INER can perform the same process to apply for license change and related improvement measures, which can enhance the operational efficiency of radioactive waste management.

3-1-7

Enhancing the NDT Performance – Applying AI for Image Interpretation

INER developed a software system for rapid image interpretation that is frequently used in the non-destructive testing (NDT) industry. The software can assist the inspection personnel in the interpretation of detection signals. It uses artificial intelligence (AI) and automation technology to establish a rapid, batch and accurate identification system for non-destructive detection signals, which can greatly reduce the labor costs required for safety maintenance during the detection period and increase the economic benefits.

Pipeline on-site inspection

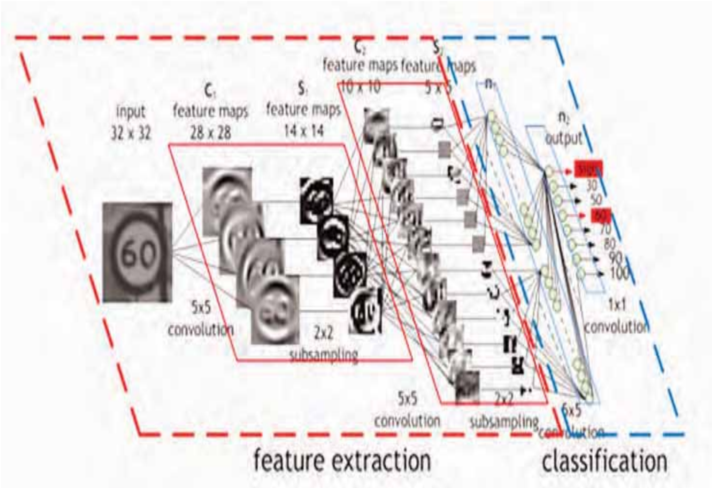
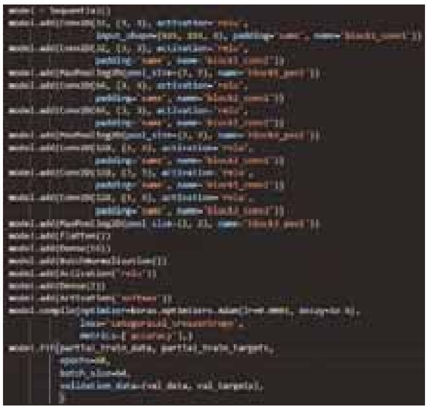


Fig.1. CNN Neural Network Architecture
(https://developer.nvidia.com/discover/convolutional-neural-network)



Programming with Python

The developed system interprets tens of thousands of test images, and completes the sorting and output of test results as CSV files (Fig. 1 and Fig. 2). This AI neural network system also has the ability to inherit the inspector's experiences and the ability to identify the signal map with deep learning model. The recognition rate for signal defects/non-defects reaches 99.9%.

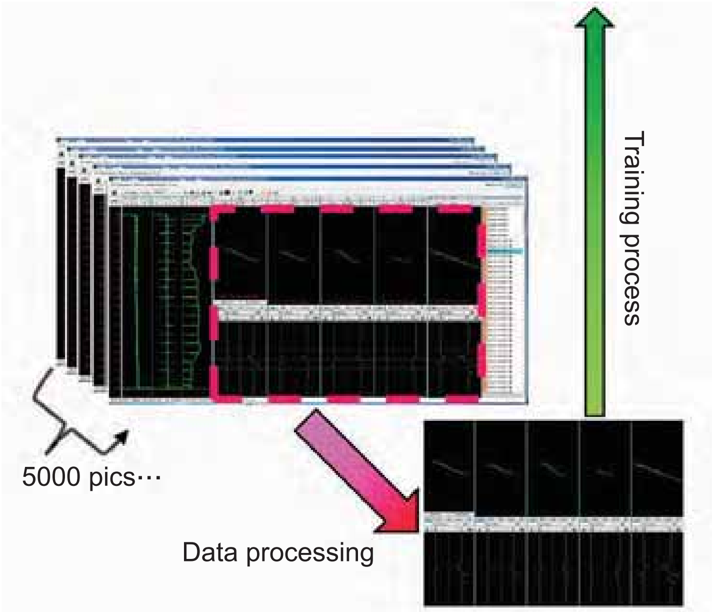


Fig.2. Collecting eddy current defect/non-defect signals for AI training

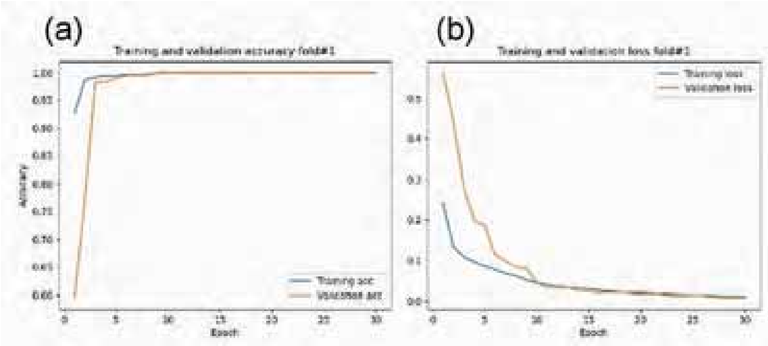


Fig.3. training and recognition results: (a)training 、(b) curves of loss function

System Demonstration:

- The best work in the R&D competition for the 53rd anniversary of INER.
- Oral Presentation at 20th NDT Technology Symposium in Taiwan, 2020.

System Features:

- Accuracy rate of 99.9% (Fig. 3 and Fig. 4)
- Fully automatic control analysis software (Fig. 5)
- Automated output identification test results
- Cost reduction

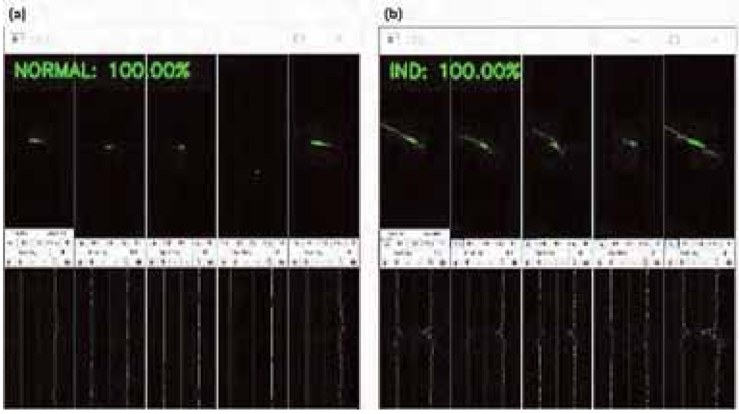


Fig.4. AI identification of defective/non-defective signal results

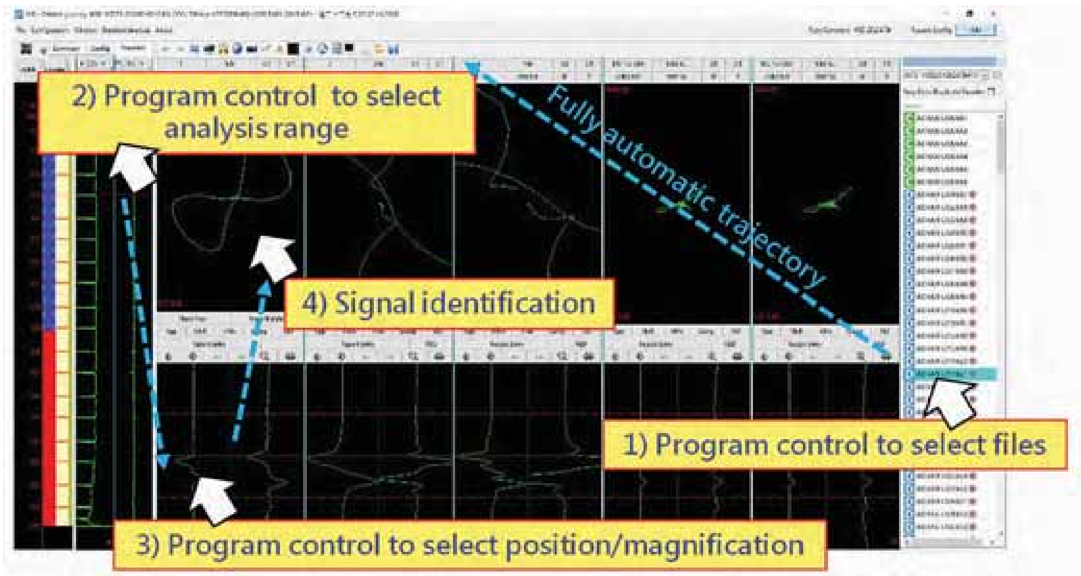


Fig.5. Schematic diagram of the combining application of AI with automation for signal interpretation

According to the test results, the system has been successfully developed with deep learning AI model. The system can potentially be applied to nuclear power plants in the decommissioning stage, thermal power plants in operation, wind power turbines, and even various engineering inspection systems.

3-1-8

Enhancing the Safety of Spent Nuclear Fuel - The Integrity Assessment and Inspection Technology for Used Nuclear Fuel

The used nuclear fuel management strategy in Taiwan adopts "short-term SFP (Spent Fuel Pool) storage (Fig. 1), medium-term on-site dry storage, and long-term final disposal". In line with the policy of nuclear-free homeland by 2025, the dry storage of spent fuel is one of the necessary measures for decommissioning of the domestic NPPs.

In order to ensure the safety operation of spent fuel in dry storage and to reduce the safety concerns after storage, INER has established the integrity assessment and inspection technology to confirm all fuels to be dry stored meet the basic requirements for the integrity of fuel rods and components.

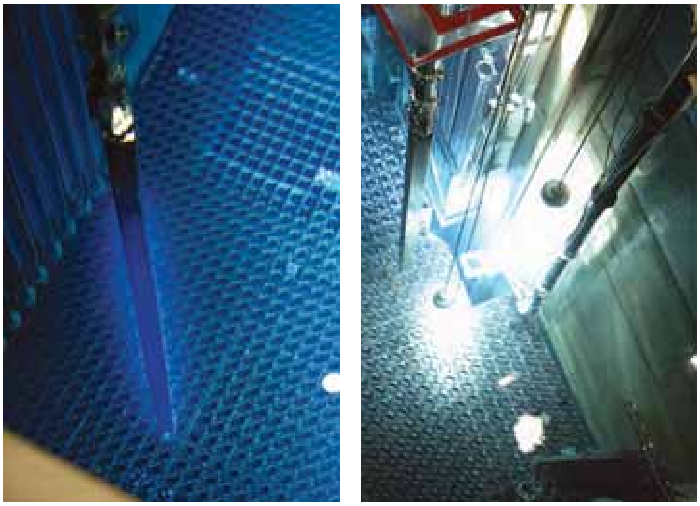


Fig.1. The Spent Fuel Pool (SFP) in Domestic BWR NPPs

The technology firstly established the spent fuel integrity identification procedure based on the international regulations and ISG-1 Rev.2 of NRC. The data analysis of fuel design, manufacturing, in-core operation, exhaust monitoring and handling records are completed for each stored fuel. The code simulation analysis of high burnup fuels are also carried out to ensure all the fuels meet the basic requirements of fuel integrity and retrievability.

The additional sampling inspections of spent fuels by vacuum sipping are executed to ensure the confidence of fuel integrity (Fig. 2).

Fig.2. The Spent Fuel Vacuum Sipping Inspection

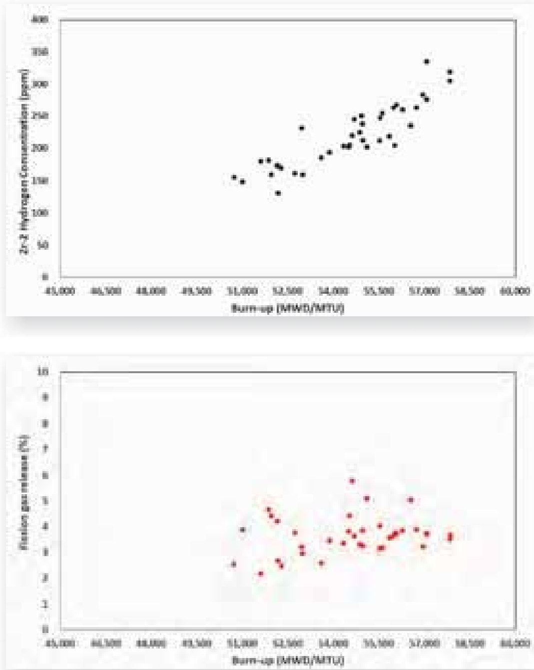


Fig.3. The Code Analysis Results of High Burnup Fuel in Domestic BWR NPPs

Due to the difference between the behavioral data of high burnup and low burnup spent fuel, the core simulation code and fuel behavior analysis code are applied to obtain the fuel characteristic data (Fig. 3).

The fuel behavior analysis among different fuel types, operation cycles and operational modes is used to understand the plant specific effects on fuel characteristics.

Most of the existing fuel vacuum sipping inspection equipment in domestic BWR NPPs are obsolete. INER has helped the domestic NPPs to update the vacuum sipping system, improve the main control unit and replace the fluid valves and pipes. The updated system has been used to execute fuel inspection in NPPs more efficiently (Fig. 4).

Fig.4. The Updated Control Unit of Fuel Vacuum Sipping Inspection System

INER has completed the fuel integrity assessment and inspection plans for the dry storage projects of CS NPP and phase 1 of KS NPP. Both plans have been approved by the regulatory authority.

In response to the plant specific issue, INER will continue to promote this technology to the phase 2 of KS NPP and MS NPP dry storage projects. The indigenous technology could be applied to the decommissioning work of NPPs and enhance the public's confidence on spent fuel management in Taiwan.

3-1-9

Ensure the Safety of Nuclear Power Plant Decommissioning -Radioactive Waste Classification and Potential Radionuclides of Concern Screening

Nuclear power generation flourished from the 1960s to the 1990s. However, after the Chernobyl and Fukushima accident, nuclear power generation undermine the public confidence, and many countries decided to shut down the nuclear power plants. The operating licenses of the three existing nuclear power plants in Taiwan expired from 2018 to 2025 (Table 1). According to nuclear-free homeland policy, Taipower company prefers not to extend the licenses and has submitted decommissioning plans. Nuclear power plants which are no longer in operation will generate huge wastes during the dismantling process after their licenses expiration. Their intricate systems and invisible radiation have greatly increased the difficulty of decommissioning. Temporary storage and disposal of radioactive waste is an important subject for decommissioning of nuclear power plants. Its planning relies heavily on radiation assessment, and the screening of radionuclides is one of the primary tasks. Since analysis and identification of each radionuclide requires a lot of manpower and time, how to reasonably incorporate potential radionuclides of concern to the greatest extent within limited resources for the decommissioning of nuclear power plants has become an important issue in various countries.

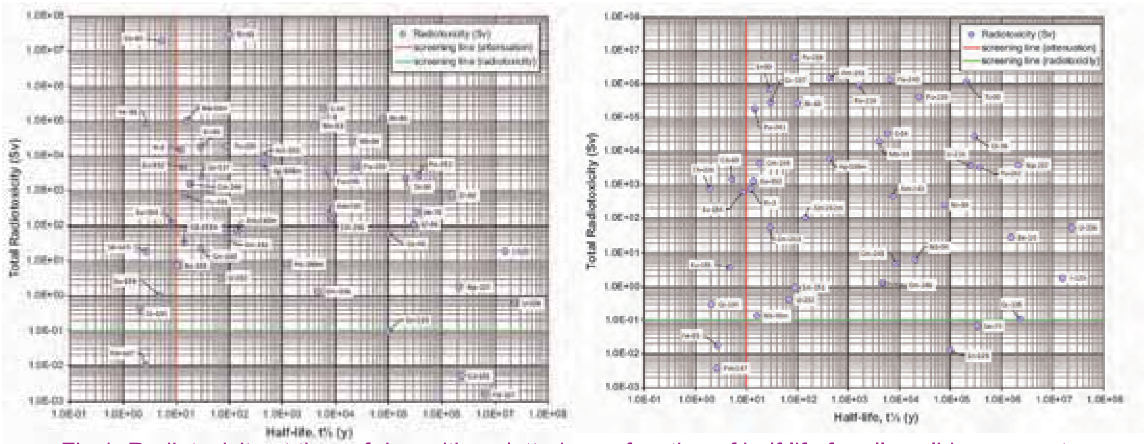


Fig.1. Radiotoxicity at time of deposition plotted as a function of half-life for all nuclides present in the waste inventory. （Left: reactor waste; Right: legacy waste）[*1]

Final disposal regulations for low-level radioactive waste in Taiwan are formulated with reference to U.S. regulations. Low-level radioactive wastes are classified into four levels, A, B, C and Greater-than-Class C（GTCC） from low to high according to the radionuclides and concentration of activities. Since radiotoxicity is proportional to the half-life (Fig. 1), the wastes with higher proportion of long-lived radionuclides are determined higher classification, which needs to meet higher standards on temporary storage or final disposal. In addition, clearance level are also formulated in accordance with the guidelines of the International Atomic Energy Agency (IAEA) to ensure that clearance wastes meet safety and environmental requirements. The related operations of wastes of nuclear power plant decommissioning need to meet the requirements of both regulations and the limits of both regulations must be taken into account for the screening of potential radionuclides of concern.

Table 1. License Expiration Date of Existing Nuclear Power Plants in Taiwan

Plant	Unit	License Expiration Date
Chinshan	1	2018/12/05
	2	2019/07/15
Kuosheng	1	2021/12/27
	2	2023/03/14
Maanshan	1	2024/07/27
	2	2025/05/17

[*1] Reference：SKB Report P-16-09, Screening of Radionuclides for Radionuclide and Dose Calculations, 2018

Reactor is the only source of radionuclides in nuclear power plants. The radionuclides involves two major types: activation products which the material of the reactor core and biological shielding are activated by neutron irradiation (Fig. 2), and the fission products generated from fuel leakage. There are mature activation evaluation programs for materials of reactor core and biological shielding exposed to neutron irradiation, which can calculate the radionuclides and activities of activation products. For fission products, data from reference reports are collected and summarized. To ensure the activity level conforms to the situation of nuclear power plants in Taiwan, the data will be corrected with the routine inspection data during the operation period of domestic plants. After normalizing the activity data from different sources and calculating the dose contribution, the relative activity or relative dose ratio, more than 1/1000 was used as the screening criteria to select key radionuclides (Fig. 4).

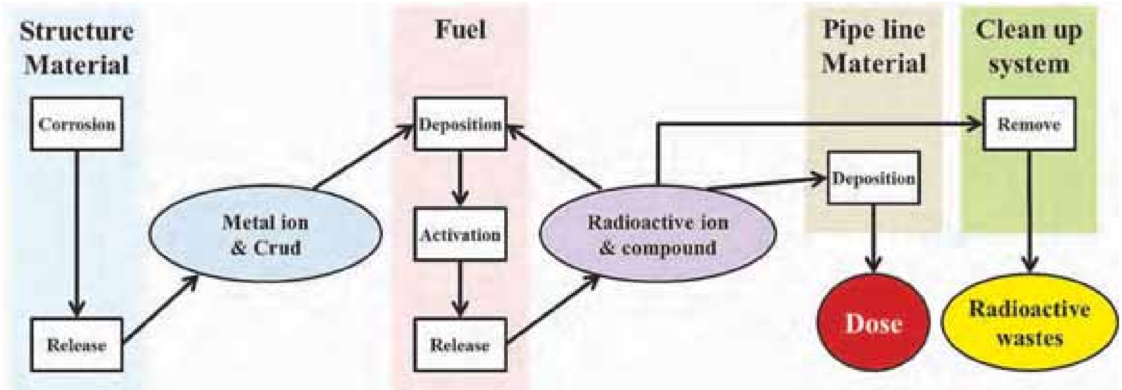


Fig.2. Production pathway of activation product

The three nuclear power plants in the US including the Zion Nuclear Power Station mainly used the NUREG/CR-3474 report issued by the USNRC, and 2 to 3 other reference reports as the starting data for screening. Finally, 20 to 27 potential radionuclides of concern were obtained respectively (Fig.3). This technology expands the scope of the initial data. In addition to the NUREG/CR-3474 report, 8 indicative reports such as IAEA NW-T-1.18 and TRS-389 reports issued by the IAEA are added. It also includes the Final Safety Analysis Reports (FSAR) and routine inspection data during the operation period of domestic plants. Other domestic data such as calculation results by INER from reactor core and biological shielding activation is also included to improve the integrity of the screening basis (Fig. 4).

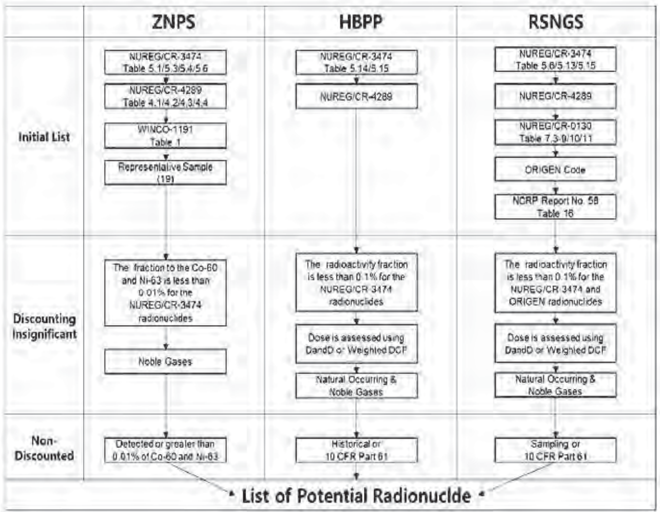


Fig.3. Summary of screening process for potential radionuclides of concern from reference.*2

Using this technology, the screening of potential radionuclides of concern for decommissioning of the three nuclear power plants in Taiwan has been completed. From the results, there are 32 radionuclides for the Chinshan nuclear power plant, 29 for the Kuosheng nuclear power plant, and 28 for the Maanshan nuclear power plant, respectively. The scope of application covers waste classification and clearance, which is reasonably conservative and feasible in operation. The results have been compiled and provided to Taipower company for reference, which has been preliminarily approved. The following adjustments will be made in accordance with different scenarios of decommissioning for nuclear power plants to meet the needs of practical operation and radiation safety.

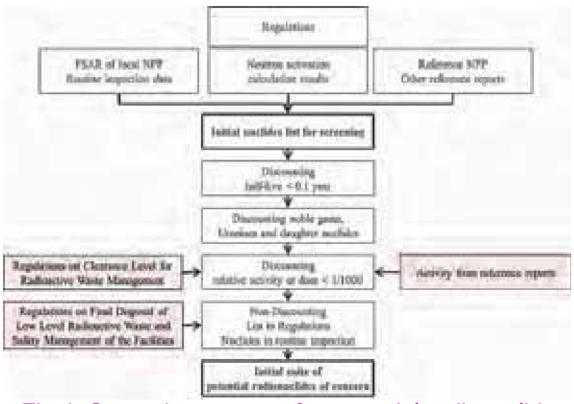


Fig.4. Screening process for potential radionuclides of concern by INER

*2 Reference：Proposal for the List of Potential Radionuclides of Interest During NPP Site Characterization or Final Status Surveys, Nuclear Engineering and Technology, Nuclear Engineering and Technology, 2021

3-2

Civil Application of Radiation

(1)Application of radiation technology for domestic needs: Institute of Nuclear Energy Research takes the health and well-being of compatriots in mind, and ensures a stable supply of domestic nuclear medicines; it invests in the development of atherosclerotic contrast agents, and the results of animal tests are better than those of foreign product.

Institute of Nuclear Energy Research (INER) owned the only 30 MeV cyclotron at Taiwan, which is not only used for the research and development of novel isotopes and radiopharmaceuticals, but also for the regular supply to meet the need of domestic nuclear medicine. In the past two years, due to the unstable international flights caused by the COVID-19 pandemic, there has been a shortage of imported nuclear medicines, especially the myocardial perfusion imaging agent thallium chloride [Thallium-201]. INER immediately expanded the production of radiopharmaceuticals to promptly address the gap in demand for thallium-201 radiopharmaceutical. The service volume for Thallium-201 provided by INER in 2021 was significantly increased by 40,000 people compared with that of 2020 (65,272 vs. 25,740). It can ensure patients to have the best diagnostic agent for clinical myocardial perfusion function test. We also take the social responsibility to stabilize the domestic supply of radiopharmaceuticals for the needs of nuclear medicine practices.

Atherosclerosis may lead to fatal diseases such as angina pectoris, myocardial infarction, sudden death, etc. For the needs of early diagnosis, INER is actively carrying out the optimal design of the compound structure targeting the CXCR4 receptor in vascular lesions. We also established radioisotope labeling technology to obtain the highly sensitive and specific nuclear medicine Gallium-68 APD. Based on the mouse disease model, the selectivity of Gallium-68 APD to arterial lesions is more than 5 times than that of the drug Gallium-68 Pentixafor currently undergoing clinical trials abroad. It also has the application potential to assist in the evaluation of the efficacy of new drug development.

(2)Develop key technologies for nuclear safety/nuclear back-end: establish the detection technology for difficult-to-measure nuclear species, with international consistency in accuracy and effectiveness. DEvelop a dose correction system for eye crystal dosimeters to protect the health of radiation workers; combine artificial intelligence with the development of radiation detection smart vehicles to reduce personnel exposure to hazardous environments.

In response to the recommendation of the International Commission on Radiological Protection to lower the occupational exposure limit of eye lens doses, the revision of the ionizing radiation safety standards in Taiwan, the National Ionizing Radiation Standard Laboratory at INER has established a dose correction system for eye lens dosimeters, and through the existing national dose traceability system to accurately assess the received dose of the eye lens. This calibration system can further improve radiation safety management and protect the health of radiation workers for the high-risk groups of eye lens doses of interventional physicians or cardiac catheterists who use fluoroscopic photography equipment.

In line with the 2025 non-nuclear homeland policy, the three domestic nuclear power plants will be decommissioned one after another. During the disassembly process of the units, it is necessary to conduct an assessment of the radiation source intensity of difficult-to-measure nuclear species to facilitate subsequent release operations. In response to demand, INER has actively established the measurement technologies for difficult-to-measure nuclear species such as H-3 and Sr-90, and conducted comparison and verification with the National Institute of Standards and Technology in the United States to compare the results. It shows that the accuracy and validity of our measurement results are consistent with NIST (INER/NIST=1.0008±0.55%). This technology can not only shorten the time and money required for testing abroad, but also support the government's radiation protection control actions to ensure the radiation safety of the public.

The issue of radiation safety of nuclear power plants has attracted media attention and the Chinese people. INER has integrated AI artificial intelligence, environmental sensing, machine vision and communication technologies to develop intelligent radiation detection vehicles. By carrying the suitable detection equipment, it can replace manpower to monitor the radiation detection. This intelligence vehicle could prevent personnel from being exposed to radiation hazards and ensure the safety of radiation operations; this vehicle can also be equipped with environmental sensors, which can be used in dangerous workshops or high-pollution areas to reduce personnel exposure in hazardous environments. It shows the potential for commercialization.

3-2-1

Maintenance of the 30MeV compact cyclotron in Taiwan and stabilization of supplies of radiopharmaceuticals during COVID-19 pandemic.

INER owns a 30 MeV compact cyclotron in Taiwan, which is 2 meters in height and 3 meters in width, and magnet weighs about 45tons, and is surrounded by a 2-meter-thick concrete barrier. The energy is 15-30 MeV with the maximum current of 200μA produce medical radio-isotopes such as I-123, Tl-201, Ga-67 and In-111, etc, which are provided to domestic research institutes and hospitals for clinical trials and medical diagnosis.

In Taiwan, this kind of short half-life radiopharmaceuticals mostly rely on imports. Due to COVID-19 pandemic, the international flights became unstable and resulted in the shortage of imported drugs since 2020. At this moment, INER working as an local drug manufacturer, immediately puts into drug production and solves the shortage of domestic thallium chloride[Tl-201] demand in time.

Production of INER Tl-201 injection

Tl^+ is similar to K^+, which can be uptake by myocyte and the intake is proportional to coronary blood flow. It can be used for functional diagnosis of myocardial infarction and hypoxia. The cyclotron provided Tl-201 to Radiopharmaceutical Production Center and produced "INER Tl-201 injection" via sterile clean room. The related process, facility, and critical device are shown in Fig.1 and Fig.2.

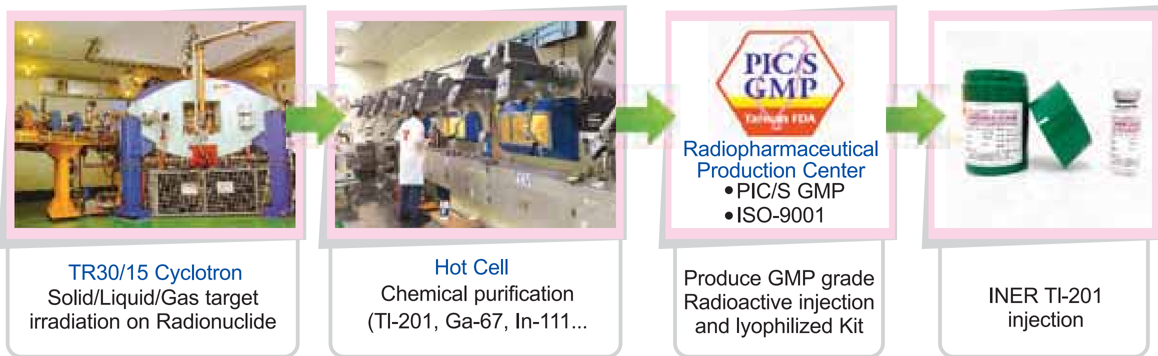


Fig.1. Manufacturing Process & Core Facility

Fig.2. Critical device for sterile medicinal production

Fulfilled domestic requirements, during COVID-19 pandemic.

INER Tl-201 injection was produced about 226,100 mCi from April 20, 2020 to Dec. 31, 2021 and provided about 90,400 services, and in which about 65,272 services were provided in 2021. INER has stabilized the supplying of Tl-201 injection in Taiwan and fulfilled domestic requirements during COVID-19 pandemic. The number of services and market share from 106 to 110 are shown in Fig.3.

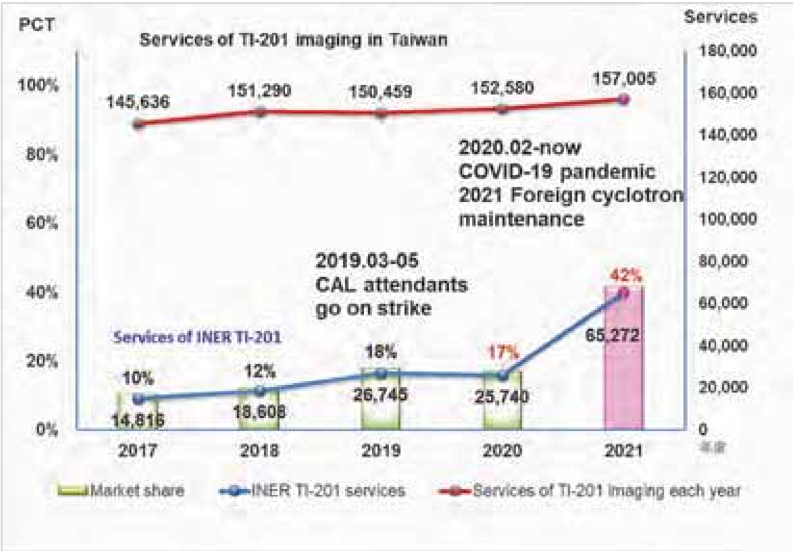


Fig.3. INER Tl-201 injection services and market share

Reduction of the crash rate by maintenance management

INER compact cyclotron started operations in 1993. Up to 2021, it has been over 28 years. INER enhanced the management and introduced Property Risk Assessment (PRA) into compact cyclotron by cooperation with Nuclear Engineering Division to improve the aging and reliability issues. During the period from Mar. 18 to April 12 in 2021, the center region of the upper liner maintenance was completed by INER. Then INER will align the budget year by year according to the results of PRA for the update and improvement of compact cyclotron. In 2021, the down time was 10.7%(down time= 935 hours of the total crash /365*24 hours of the whole year). Compared with the down time 22.7% in 2020, there was a significant improvement (Fig. 4).

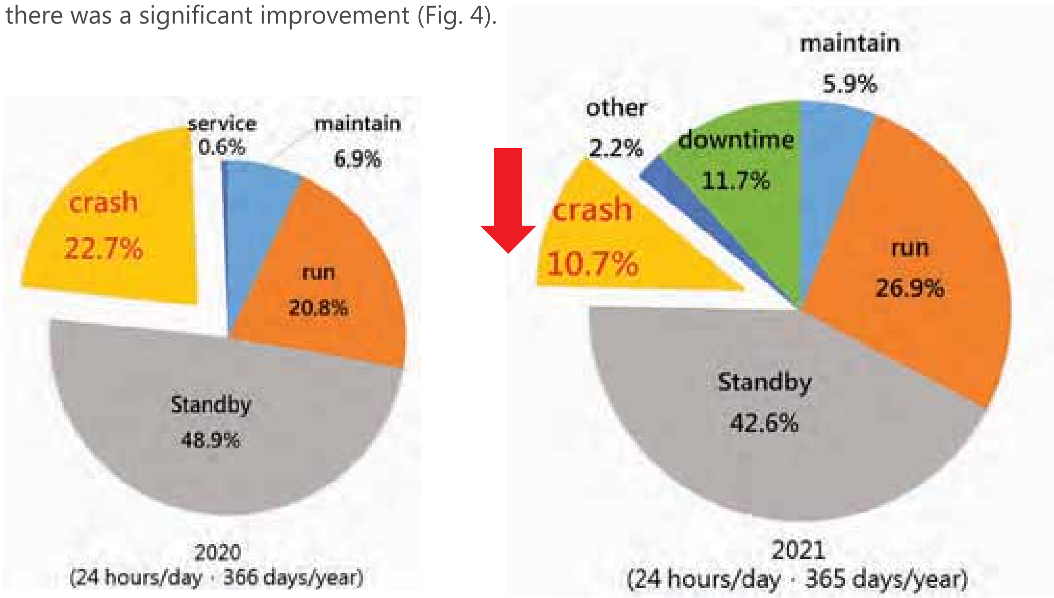


Fig.4. Cyclotron operating pie chart

Future prospection

INER plans to setup a 70MeV cyclotron for domestic requirements and to fill the energy gap of the cyclotrons in Taiwan. The 70MeV cyclotron may be applied to the measurement of space component radio-tolerance, development of proton and neutron material applications, new research of nuclear medicine, and also can backup with 30 MeV cyclotron to improve the supplying stability of local short half-life radiopharmaceuticals. This plan can drive domestic industries and enhance global competitiveness of Taiwan.

3-2-2

Early Diagnosis and Follow-up in Cardiovascular Disease—INER Atherosclerotic Agent

Metabolic syndrome(increased blood pressure, high blood sugar, excess body fat, cholesterol or triglyceride levels) induced chronic artery inflammation and atherosclerosis (Fig.1). Thrombosis induced ischemic heart disease and stroke are the top 1 and 2 leading causes of death in the world.

There is no clinical symptom in early Atherosclerosis. When patients feel chest pain, the artery has represent severe blockage. For the purpose to early non-invasive diagnosis and evaluate the therapeutic efficacy, good atherosclerotic imaging agent is needed for all of the people with cardiovascular diseases

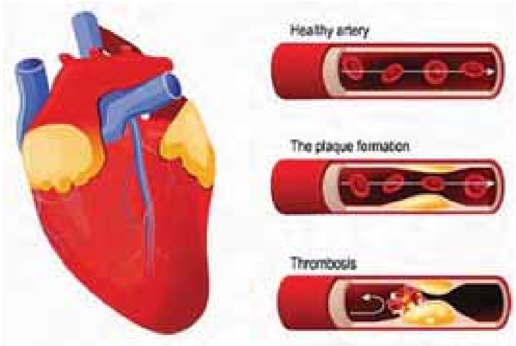


Fig.1. The process of atherosclerosis
(https://www.istockphoto.com/vector/atherosclerosis-stages-gm645060530-116966065)

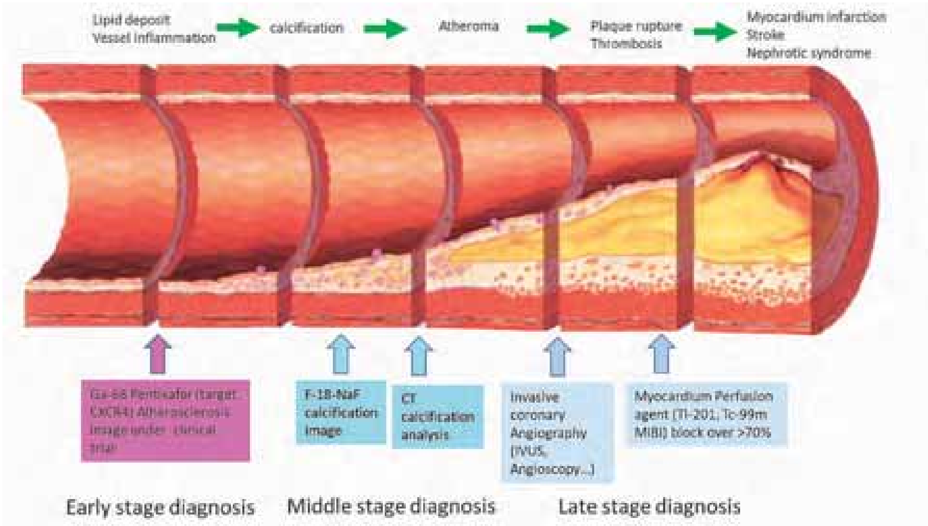


Fig.2. The detail progression of atherosclerosis and the update clinical application
(This figure is quoted from https://www.intechopen.com/chapters/61578 and modified by INER)

Pathogenesis and current status in clinical

Atherosclerosis is caused by chronic vessel inflammation. From the lipid deposit, calcification, Atheroma, thrombosis and lead to lethal ischemic heart disease and stroke (Fig.2). Till now, non-invasive image technology just can be diagnosis on middle to late stage of atherosclerosis. However, myocardium perfusion tracers (eg. Tl-201, ^{99m}Tc-MIBI) are just applied for the diagnosis of severe thrombosis on coronary artery and can not apply on the full body imaging.

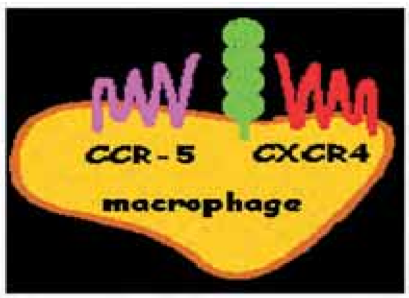


Fig.3. The surface of active macrophage can express CXCR4. From the development of tracer to target CXCR4, early non-invasive diagnosis of atherosclerosis can be done.
(https://www.thebodypro.com/article/hiv-1-env-chemokine-receptor-interactions-primary-human-macrophag)

Active macrophage will overexpression CXCR4 on the atherosclerotic lesions (Fig.3). By the good design of targeting CXCR4 chemical structure, we can get good sensitivity and specificity radiopharmaceutical for the diagnosis on the full body and improve all of the defaults on the currently used tracers, including Ga-68-Pentixafor.

Innovation concept

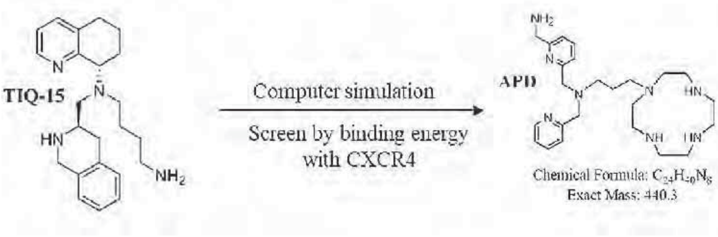


Fig.4. Novel CXCR4 atherosclerotic Ga-68-APD is designed from TIQ-15 on computer simulation approach International patent is pending.

INER Ga-68-APD atherosclerotic agent is designed from the structure of CXCR4 antagonist TIQ-15 by computer simulation approach (Fig.4). Patent is pending on Europe, American, Japan and Taiwan. The achievements of this basic research had win first prize in oral presentation on Society of Nuclear medicine annual meeting, Taiwan 2021.

Research results

From the PET image on the atherosclerotic ApoE$^{-/-}$ mice model, Ga-68-APD can apparently accumulation of tracer on atherosclerotic lesions within 1 hour and excrete from kidney, bladder. The highest Target/background ratio (TBR) =17.68±0.71 (n=3) and better than Ga-68-Pentixafor. F-18-FDG do not have good sensitivity and specificity owing to myocardium absorption. F-18-NaF imaging is just applicable on the severe lesion with (Fig.5).

Ga-68-APD can also evaluate the efficacy after health food (Bromelain) and clinical drug (SGLT2i) treatment (Fig.6)

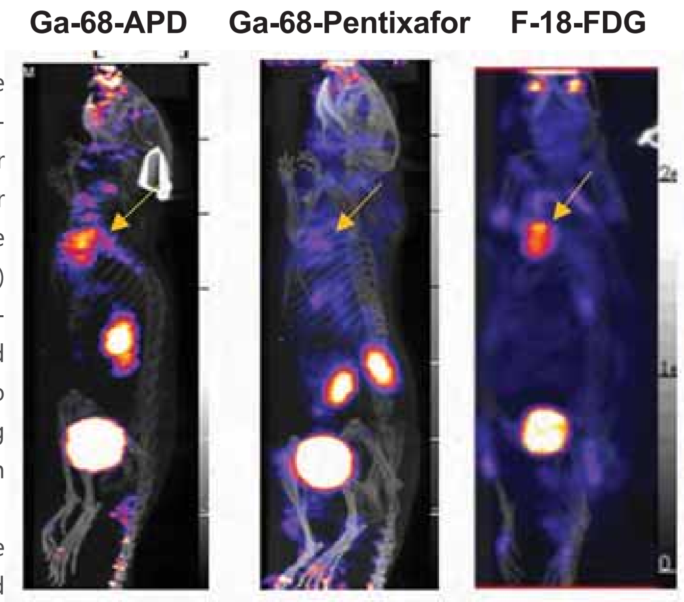


Fig.5. Ga-68-APD has better sensitivity and specificity on the imaging of atherosclerosis than Ga-68-Pentixafor and F-18-FDG.

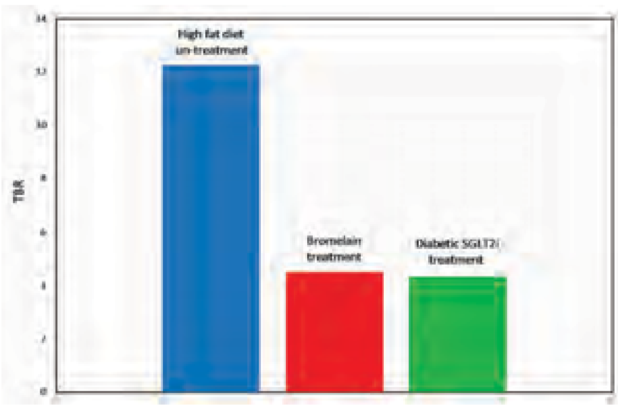


Fig.6. ^{68}Ga-APD can apply on the evaluation of efficacy of Health Supplement (Bromelain) and clinical diabetic drug (SGLT2i) . The results need for clinical requirement.

Future Development and expectations

Atheroma induced ischemic heart disease and stroke are the top 1 and 2 leading causes of death in the world. However, there are no techniques on non-invasive imaging on the early diagnosis. INER ^{68}Ga-APD atherosclerotic agent is designed on computer simulation approach and its efficacy of atherosclerotic imaging is better than ^{68}Ga-Pentixafor. Owing to its good hydrophilicity, ^{68}Ga-APD has low radiation on patient and suitable for the evaluation of efficacy on healthy food and clinical drug. It is believed to have very good potential for the application in clinical.

3-2-3

Development of Artificial Intelligence Vehicle Used in Radiation Detection

Since **Fukushima nuclear disaster** occurred in Japan, the safety issues of radiation were gravely concerned by the media and each individual. In the research, a vehicle with artificial intelligence(AI) capability was developed, on which radiation detector and monitoring devices were installed, in order to assist workers to perform the radiation detection with the hazards of excessive radiation exposure. On radiation safety concerns the system can also perform environmental detection in some special areas, reduce workers in dangerous regions and find out the safety retreat pathway.

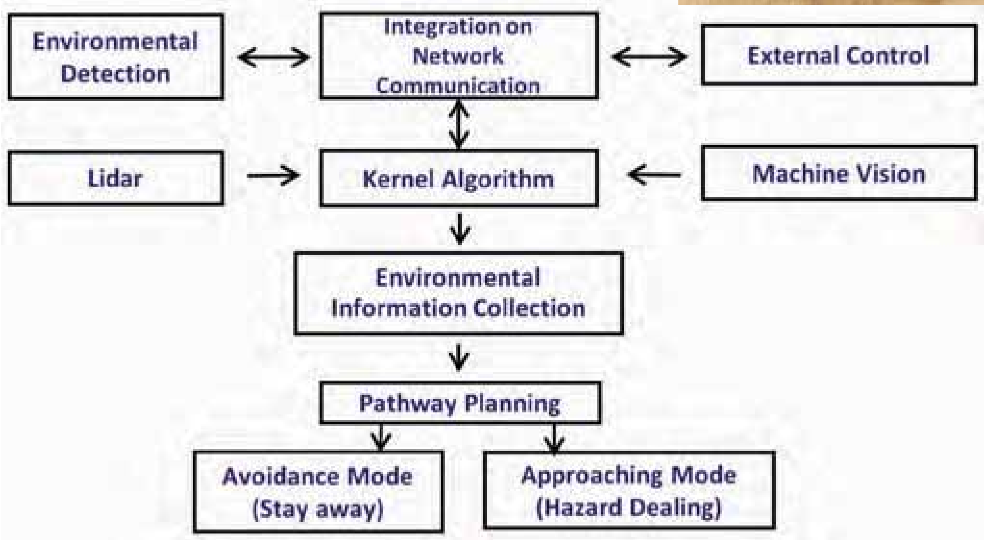


Fig.1. Systematic & Flow Diagram

The research has integrated technologies on AI, environmental detection, machine vision and communication technology etc. (as shown in Fig. 1), to effectively reduce the risk of workers being exposed in hazardous environments. Using the specific sensing modules and 3D geo-mapping features (as shown in Fig. 2) the system can work well to accommodate in each application scenario. The system can collect environmental parameters, demonstrated as spatial distribution patterns (i.e. in Radiation Levels, Temperature & Humidity, CO_2 & PM 2.5), transferred into a visualized overlaying images, to achieve a more precise and real-time decision making. Furthermore, with AI path planning function to investigate surrounding environment in advance, to guide the workers with the prior-collected area detection information, the best pathway to reach the contaminated region, such as emergent leakage incident. Generating a safe retreat pathway by AI algorithm is another highlight of the system.

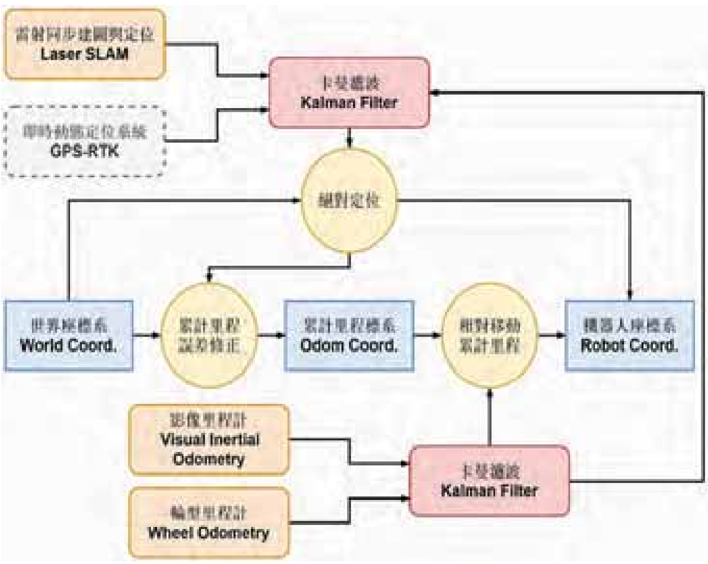


Fig.2. SLAM Architecture Diagram for the Multiple Positioning & Distance Measuring Systems

Fig.3. 2021 TIE bronze metal award

Event Participations and Exhibitions Attendance in 2021 Atomic Energy Science and Technology Exhibition (Taichung Venue), to promote nuclear technology application for civil use. In addition, attendance of Invention Competition on 2021 Taiwan Innotech Expo with the title " **a mobile system/method to detect regional radiative hazard**", won a bronze medal award. (as shown in Fig.3)

AI vehicle with radiation detection is remote-controllable, using the information of environmental detection to recognize the local hazard levels. The functions of moving, sensing and communicating in real time have been integrated in AI vehicle to benefit work in hazardous areas, e.g. environmental investigation in highly radiated areas, toxic gas detection or rescue mission etc.(as shown in Fig. 4). such various application scenarios are greatly enhancing the applicability of the multi-functional AI vehicle.

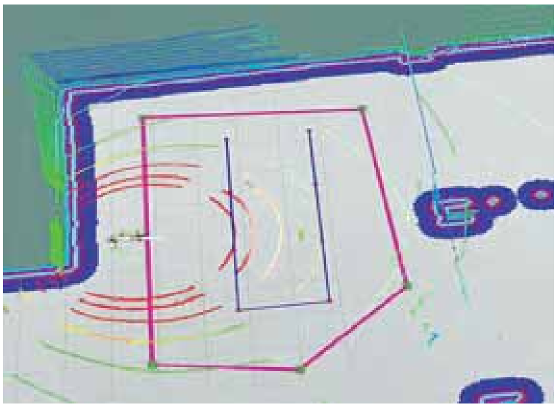


Fig.4. Auto-Planning of Environmental Information Collection & Detection


Fig.5. Nearby detection in low-level radwaste storage facility

The research has been patented in 2021, both well integrated with functions and installed in a AI vehicle, the system is now functionally working in the low-level radwaste storage facility(as shown in Fig. 5). Additionally, in touching with the nuclear power plant of Taipower to promote the research to radiative regions surveillance and nuclear plant dismantling processes. Further more, AI vehicle equipped with various environmental detectors will be more efficiently manipulated in areas with hazardous and high-contamination concerns. The research has potential to meet the market demand. Product commercialization could be achieved by promoting and seeking the opportunities of technology transfer or authorization.

3-2-4

The solution of measuring standards of difficult-to-measure nuclides traceability dilemma during nuclear power plants decommissioning—Establishment and Verification of measurement technology

In coordination with the government's 2025 nuclear-free homeland policy, three domestic nuclear power plants will be decommissioned one after another (Nuclear Plant #1: 2019, Nuclear Plant #2: 2023, and Nuclear Plant #3: 2025). Due to lacking of difficult-to-measure nuclides measurement technology and traceability standards, it is hard to evaluate the radiation intensity of those nuclides while establishing the derived concentration guideline level. The important thing is the standard radiation sources must be used in calibration, testing or verification of the instrument. At present, domestic industries purchase undetectable nuclides abroad and send them to foreign national laboratories for correction. That costs a good deal of money and time. Therefore, the establishment of measurement technology(Sr-90 has been completed) in this regard would save a lot of time and money and measurement accuracy could be improved. It is aimed to achieve the goal of supporting government's radiation protection regulations to ensure the nuclear safety of the public.

Fig.1. The liquid scintillation counter

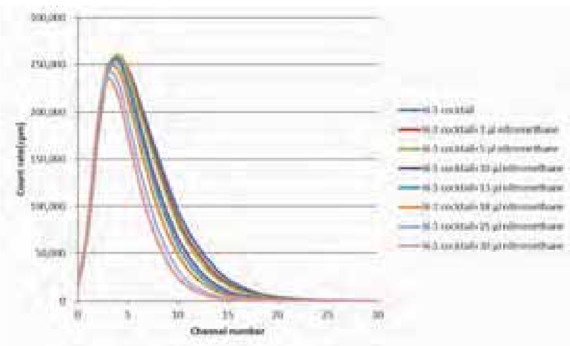


Fig.2. H-3 spectrum

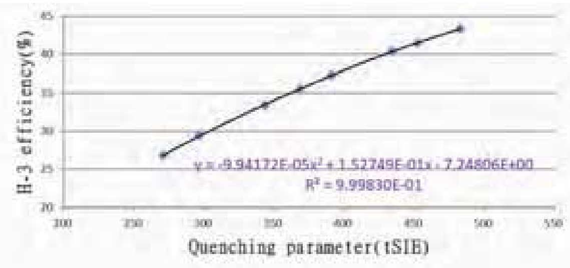


Fig.3. H-3 Quenching Curve

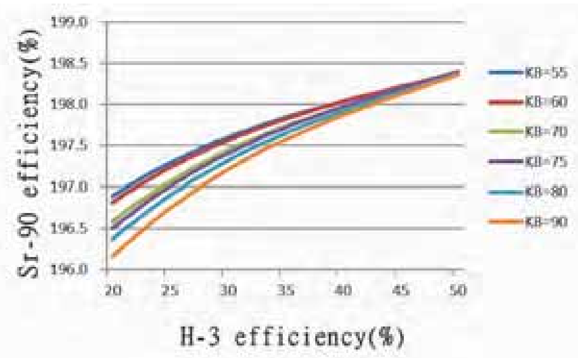


Fig.4. Efficiency relationship between H-3 and Sr-90

The liquid scintillation counter (Fig.1) primarily analyzes transuranic nuclides and nuclides which emit β(or α) particles. Such nuclides usually emit only low energy or a small amount of photons, and the sample usually needs to undergo complex chemical pretreatment. The target nuclides should be separated or purified before measurement and analysis during the processing procedure. Therefore, such nuclides are also called difficult-to-measure nuclides. The calibration or testing of these measuring instruments requires the standard nuclides or particles with the same energy and mass range to trace back to national standards well. The establishment of this radiation intensity standard is principally based on the liquid scintillation counter and the CIEMAT/NIST method (developed by the Spanish Standard Laboratory and the American Standard Laboratory, commonly used in the international standardization of nuclide activity) to evaluate the nuclides efficiency.

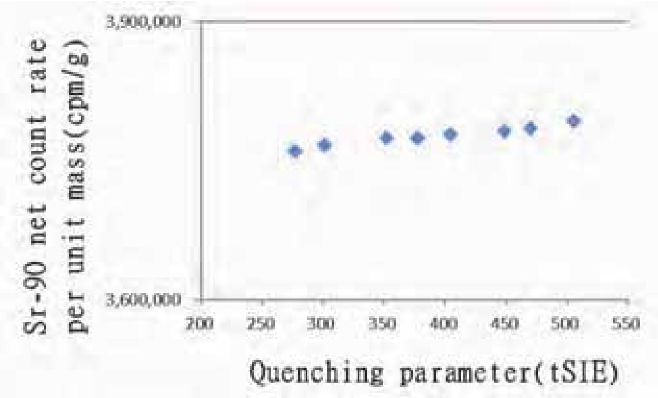


Fig.5. Sr-90 count rate

CIEMAT/NIST method: (1)H-3 is used as a tracer; Figure 2 is the change of its energy spectrum and its quenching curve under different quenching degrees (Fig.3). (2) Used Monte Carlo method to calculate the efficiency relationship between H-3 and the nuclides to be tested (Sr-90), as shown in Figure 4.(3) Figure 5 is the count rate obtained by adding different amounts of quenching agent to the Sr-90. (4) Through Figure 3 to Figure 5, the relationship between the Sr-90 source efficiency and the quenching parameter could be obtained (Fig.6). (5) Combined Sr-90 count rate and efficiency and evaluated the specific activity (31,815±158 Bq/g). Thus the measurement standard uncertainty was reduced from 3% to 0.5 and measurement accuracy was effectively improved. Considering domestic needs, the nuclides of the first priority and urgency will be activity-standardized so domestic industries have standards to follow. And at the same time, real-time calibration services can be provided for liquid radioactive activity measurement.

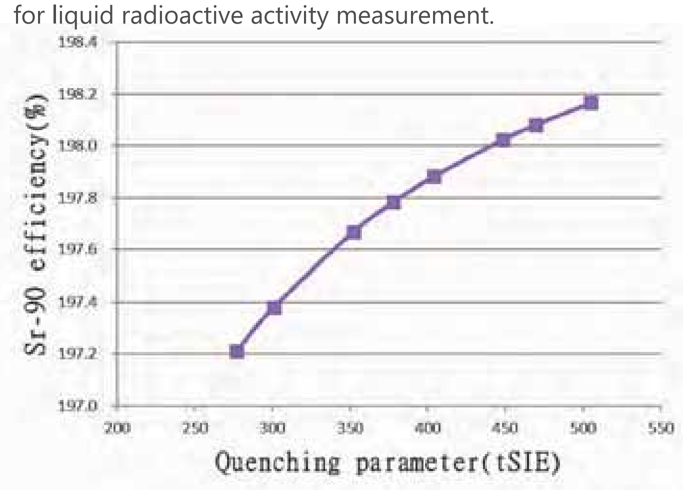


Fig.6. Evaluation of Sr-90 source efficiency

The uncertainty of this measurement standard is about 0.5% (the international trend is about 1.5%), and it is verified by the bilateral comparison with NIST to ensure the accuracy and validity of the measurement results: INER/NIST=1.0008±0.55%, as shown in Table 1. The comparison results are consistent, the difference is less than the uncertainty of the measurement standard, as the accuracy of activity measurement is greatly improved. Internationally, it is equivalent to the international standard and domestically it meets the domestic demand. It effectively reduces the cost of correction time and money, and lowers the public's fear for radiation.

Table 1. Measurement results and comparison verification

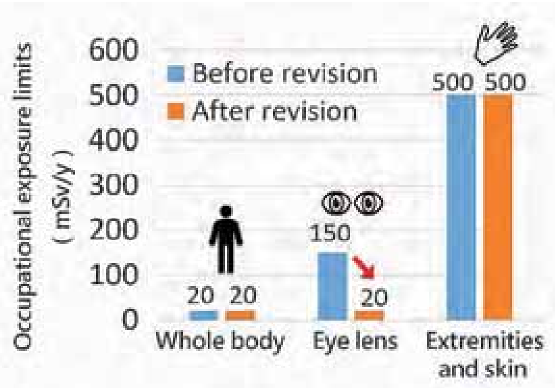
INER	31,815	Bq/g	±	158	Bq/g
NIST(U.S.)	31,790	Bq/g	±	73	Bq/g
INER/NIST	1.0008		±	0.55	%

Only the radiation measuring instrument with measurement traceability could assure high-quality and consistent results. However, when facing the calibration and traceability requirements for decommissioning, the current national standards of ionizing radiation is still insufficient. So, it is necessary to keep up with the latest standards to ensure the accuracy and consistency of various measurement results. With the establishment of the measurement technology for difficult-to-measure nuclides used in decommissioning in the R&D project, at he present stage,Sr-90 has been completed, and the nuclides will be gradually standardized, for instance,C-14,Ni-60,and Fe-55, calibration services and traceability standards will be provided as well to realize the nuclear-free homeland policy in 2025 and secure radiation safety of decommissioning and the public's living environment.

3-2-5

Establishment of Dose Calibration System for the Lens of the Eye

The International Commission on Radiological Protection (ICRP) reviewed recent epidemiological investigations and recommended to revise down the occupational exposure limits for eye lens doses (Fig.1(a)). Domestic regulations will be amended to conform to the international trend, and accurate measurement equipment of eye lens dose will be developed. The National Radiation Standard Laboratory (NRSL) (Fig.1(b)) of INER has established a dose calibration system for the eye lens dosimeters to achieve accurate dose evaluation. The system can be used as a technical support for new regulations (Fig.1(c)(d)), providing traceability for dose evaluation laboratories , improving the quality and accuracy, achieving further radiation safety management, and protecting health of radiation workers.



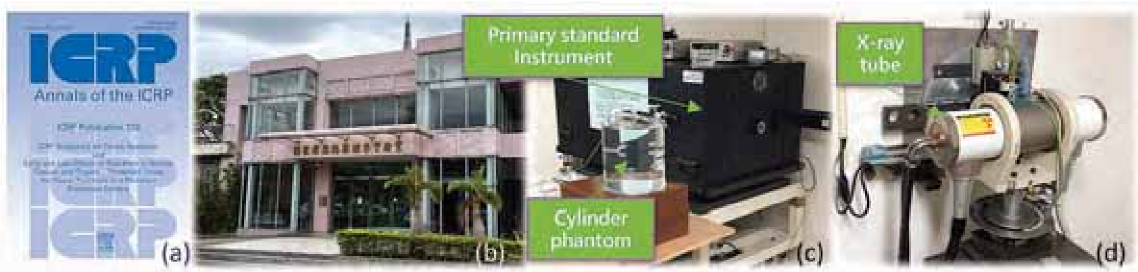


Fig.1. (a) ICRP Publication 118, (b) National Radiation Standard Laboratory (NRSL), and (c) (d) device of dose calibration system for the lens of the eye.

Domestic radiation workers have used radiation monitoring badges worn on the body for dose evaluation. However, for groups that receive high doses to the eye, the use of specialized lens dosimeters (Fig.2) can effectively evaluate the dose received, and the function of the dose calibration system is to ensure that the measured dose is accurate and meaningful. Dose evaluation laboratories can send dosimeters to NRSL to be irradiated with standard doses. Then the irradiation results will be sent back to the laboratories and compared with the laboratories' data to achieve accurate dose evaluation.

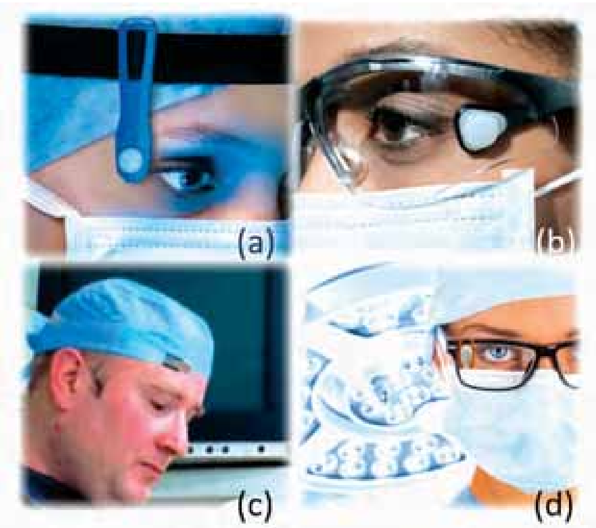


Fig.2. International commercial lens dosimeters (a) EYE-D, (b) DOSIRIS, (c) Harshaw and (d) LANDAUER. Data source: Official websites of each brand.

Radiation Quality	Additional filtration			HVL		Differences from ISO	Standard dose rate at 3m
	mm Sn	mm Cu	mm Al	mm Al	mm Cu	%	(Gy/s)
N-40		0.21	3.92	2.76		4.98	1.838E-06
N-60		0.6	3.92		0.24	1.19	1.613E-06
N-80		2.04	3.92		0.57	-2.04	9.653E-07
N-100		5.1	3.92		1.10	0.73	4.425E-07
N-120	1.04	5.1	3.92		1.72	2.99	4.886E-07
N-150	2.55		3.92		2.36	2.62	3.927E-06

Fig.3. Parameters and results of ISO radiation qualities selected.

In order to establish the dose calibration system for the lens of the eye, NRSL set up the radiation qualities used in the calibration system by measuring the half-value layer (HVL) according to the ISO 4037. NRSL also completed the standard dose rate measurement at a distance of 3 meters from the X-ray machine (Fig.3), so as to accurately estimate the value of dosimeters given by irradiation.

The above experiment used air kerma as the measurement unit, which should be converted into the personal equivalent dose of H_p (3) by the conversion coefficient of the ISO 4037, that is, physical quantities are converted into operational quantities to estimate protection quantities stated in the regulations (Fig.4). The uncertainty of the HVL of radiation qualities established and the standard dose rate all meet the tolerance range accepted by international standards. In addition, we did some research on the characteristics of the dosimeters to learn the effect of different experimental conditions on the dosimeter readings for future proficiency testing (Fig.5).

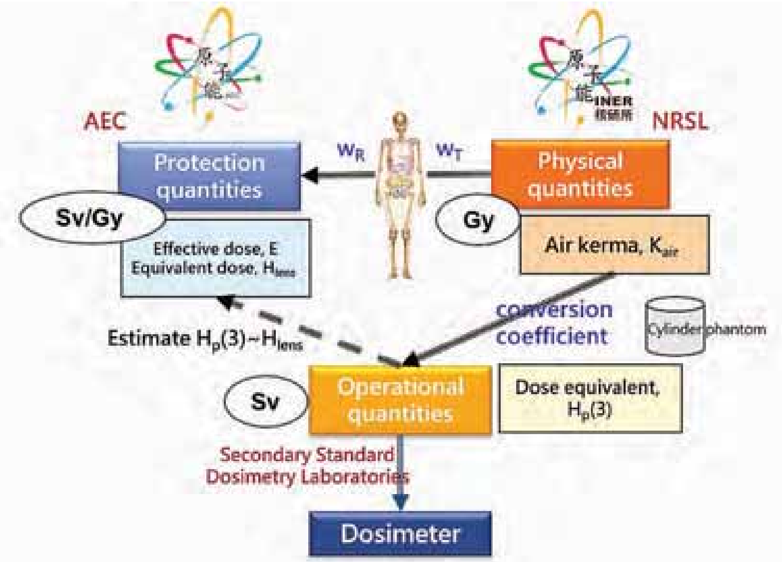


Fig.4. The relationship among physical quantities, protection quantities, and operational quantities.

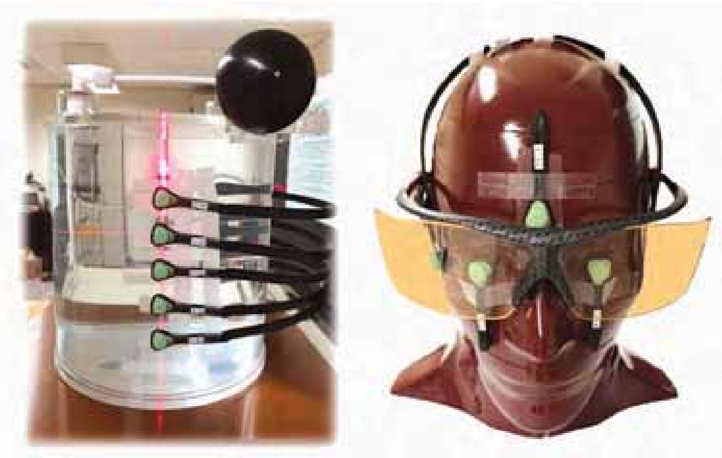


Fig.5. Characteristic study on the effect towards irradiation results with different dosimeter intervals and using lead glasses.

In the future, the dose calibration system can provide irradiation services for at least 5 domestic dose evaluation laboratories, play a pivotal role in the eye lens dosimeters proficiency testing that are to be held in the coming years. And the system can effectively improve the evaluation dose accuracy of eye lens and ensure the safety of radiation workers.

3-3

Green Energy & System Integration Technologies

The Institute of Nuclear Energy Research (INER) has been devoted to R&D on environmental and energy technologies, to comply with national policy. The Government has launched the "Energy Transition" policy and the "5+2 Innovative Industries Program" since 2016, while the promotion of "Six Core Strategic Industries" was announced in the presidential inauguration on May 20, 2020, with a hope that Taiwan will play a key role in future global economy. With the status as National Laboratories, INER supports strategic planning of national energy policy, aims to develop multiple energy technologies, and hopefully promotes industrial applications as well as competitive capability.

The major R&D activities in 2021 are categorized into five fields, and the current achievements are summarized in the following sections.

1.Energy Saving: Electrochromic glass can actively control and isolate lights, providing effective means to mitigate greenhouse effect, while innovative low-cost mass production technology can promote products to enter the global market.

Arc plasma has been successfully applied to electrochromic film technology at INER. With electrolytes from manufacturers, a product that can reduce the energy consumption of air conditioning and increase the effect of indoor lighting has been developed, with characteristics surpassing the commercial standard. The future cooperation will be focused on the layout of core electrochromic products (for mobile vehicles, green building, etc.), lead to products popularization, and help link the industrial chain to expand the development space.

2.Leading-Edge Research: With R&D experience in concentrator solar cells, INER engages in the development of high-efficiency space solar cell, aiming to enhance indigenous capability in the space industry, and assists in achieving the goals of national long-term space technology development.

Based on the manufacturing technology of concentrator III-V multi-junction solar cells, INER steps into the development of space solar cell with early achievements. The in-house developed solar cell exhibits maximum energy conversion efficiency of more than 29%, while INER is continuously improving the average efficiency in mass production to over 28%. Concurrently, the cells undergo the environment tests in accordance with the international standard; after passing the verifications, they will be installed in the power supply system of domestic satellites.

3.Renewable Energy: Offshore wind power is one of the important items among the "Six Core Strategic Industries." However, extreme environmental conditions are not included in current international standards; hence, INER assists MOEA to establish domestic technical specifications, to improve the structural reliability.

INER conducts the comparison of differences with domestic and international offshore wind turbine (OWT) standards, and sets up the specific OWT design load cases; then, the performance and safety requirements for OWT plants have been proposed, according to local environment in Taiwan. Implementing the design load cases in compliance with the requirement of IEC 61400-3-1, the design evaluation technique of giant OWT can be established. INER, together with other members, has assisted the certification review for domestic offshore wind farm projects, and promoted the OWT technology in Taiwan.

4.Smart Grids: With a large amount of renewable energy incorporated into the existing distribution system, its intermittency will cause grid instability. INER has developed "Visualized Feeder Dispatch Management Platform" and "Pre-diagnosis Technologies for Equipment," which help the power company respond early and select adaptive strategy.

The "intelligent Distribution Network Management System (iDNMS)" developed at INER, which assists Taipower to perform fast power restoration, has won the 2021 R&D 100 Awards and Public Servant Outstanding Contribution Award. In addition, the "Voltage Control System and Method for Microgrid" could prevent power system blackout, and won the Platinum Award in the 2021 Taiwan Innotech Expo (TIE) honorably. Furthermore, an AI big-data monitoring and pre-diagnosis system is developed and actually installed in Taipower substations, where a fault in the driving device is indeed detected, and will assist Taipower Company in strengthening the safe operation and maintenance management.

5.Circular Economy: INER has developed production technology of marine-degradable plastics, which can mitigate micro-plastic pollution and provide convenient low-carbon life, as well as create a novel blue-ocean market, beneficial to environmental sustainability.

Petro-plastics have become almost indispensable in human life and caused severe burden to the environment. Bio-plastics, e.g., Polyhydroxyalkanoates (PHAs), feature good biodegradability; so, they could be possible green alternatives to petroleum-based plastics, and suitable for solution in pollution issues posed by plastic wastes. Through technology improvement, INER establishes key facilities and protocol for high-yield PHAs production, strengthens collaborative industry/university/government partnerships, and promotes potential industrial applications.

In summary, INER has been engaged for years in developing novel and renewable energy technologies, among which some fields catch up with international standard, and receive domestic as well as international recognition. Looking ahead, INER will comply with national policy of sustainable development, command indigenous key technologies, and push toward "2050 Net-Zero Emissions" scenario; ultimately, it is hoped to achieve the policy goal of clean and low-carbon environment, and promote sustainable development with carbon neutrality.

3-3-1

Innovative low-cost technology for electrochromic glass mass production

At present, the world is facing the crisis of global warming and energy shortage. People spend most of their time in buildings or vehicles. In residential and commercial buildings, the energy consumption is mainly air conditioning and heating, in which the energy required accounts for about 30% of the total energy. Among them, electrochromic glass can actively control to isolation infrared light sources, which can solve the deteriorating greenhouse effect to achieve the effect of indoor temperature control.

The Institute of Nuclear Energy Research (INER) developed a fast electrochromic film using arc plasma technology for a new environmentally friendly process. INER collaborated with Technologies Inc. , Taiwan's largest electrochromic rearview mirror manufacturer and distributor. After 5 years of collaboration with INER, we have successfully developed a machine equipped with a unique high-density plasma deposition system capable of mass-producing electrochromic glass. Electrochromic glass products with active dimming - adjusting the amount of light and blocking infrared heat sources - were developed, and a technology authorization case was signed in 2011. It is expected to be transferred to the mass production equipment of partner manufacturers this year. The production and distribution speeds of electrochromic products in Taiwan can be accelerated, and the related products can enter the global market of tens of billions of dollars.

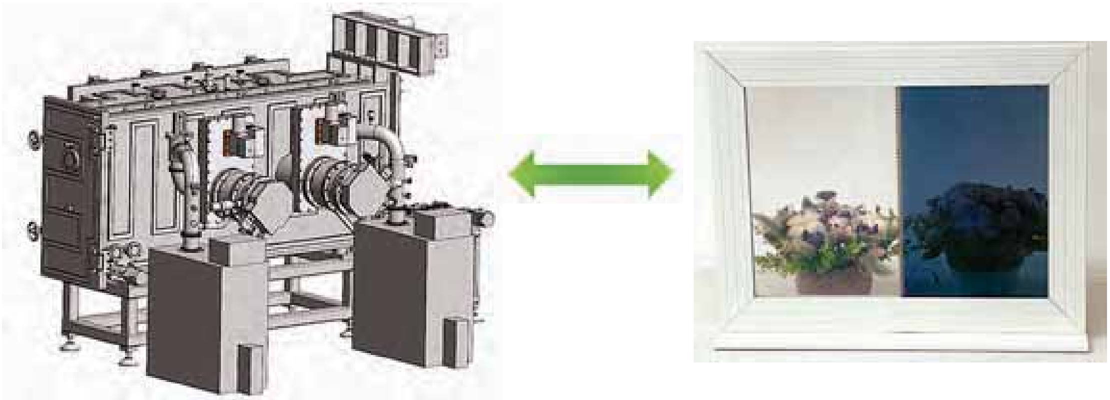


Fig.1. Fast electrochromic coating machine of INER was successfully prepared Energy-Saving Window (Area: about 400x300 mm^2)

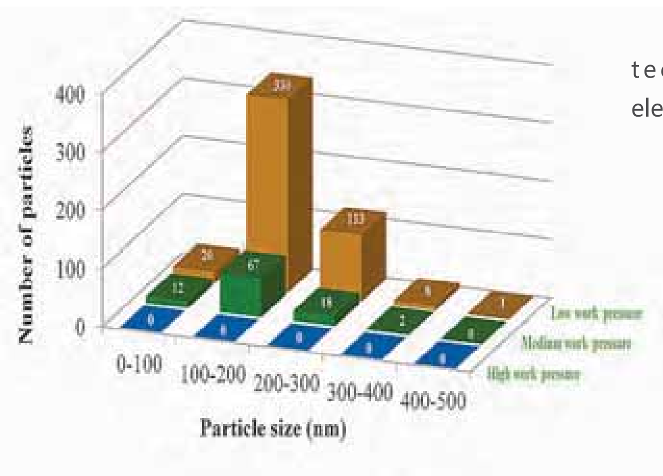


Fig.2. The particle size on the surface of the electrochromic film.

For the first time, using arc plasma technology successfully applied to electrochromic film technology in Taiwan:

1.The key feature of the improved arc plasma source established by the INER team was to fully control the discharge mechanism of the high arc current (at least 400 amps) and precisely control the arc point movement (at least 200 m/s).

2.Macro-particles generation was reduced the particle size to the nano level and was controlled between 100~200 nm.

During the development period, we received the "Taiwan Innotech Expo 2021 Virtual" Gold Award and the "Certificate of the 18th National Innovation Award 2021", which earned us recognition.

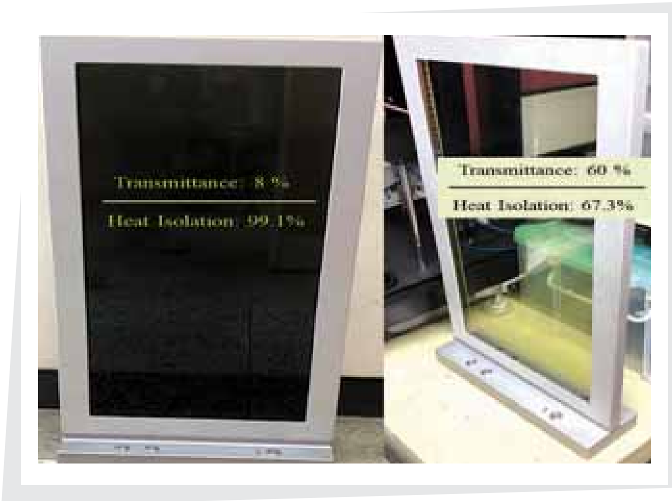


Fig.3. INER and electrolytes from manufacturers developed electrochromic skylight test (area 260×550 mm^2)

The electrochromic films are made by the team of INER with arc plasma equipment and electrolytes from manufacturers. We have developed a product that can adjust the transmittance and infrared ray rejection rate, according to different voltage values. The product can reduce the energy consumption of air conditioning and increase the effect of indoor lighting at the same time.

1.During coloring, the light transmission rate is 8%, and the infrared blocking rate is 99.1%.
2.During bleaching, the light transmission rate is 60%, and the infrared blocking rate is 67.3%.
3.In the visible wavelength, the transmittance changes to 52% (≥ 50% is the commercial standard).

Through the rapid electrochromic coating machine of INER, electrochromic products can be introduced, and the advantages can be analyzed from the five forces aspect:

1.Cost: low cost of machine and equipment
2.Production: the production rate of the machine is fast
3.Cooperation: good cooperation with Licon company
4.Promotion: new process machines, strong promotion
5.Consumption: replace the current problem of high unit price

In the future, electrochromic products will be popularized.

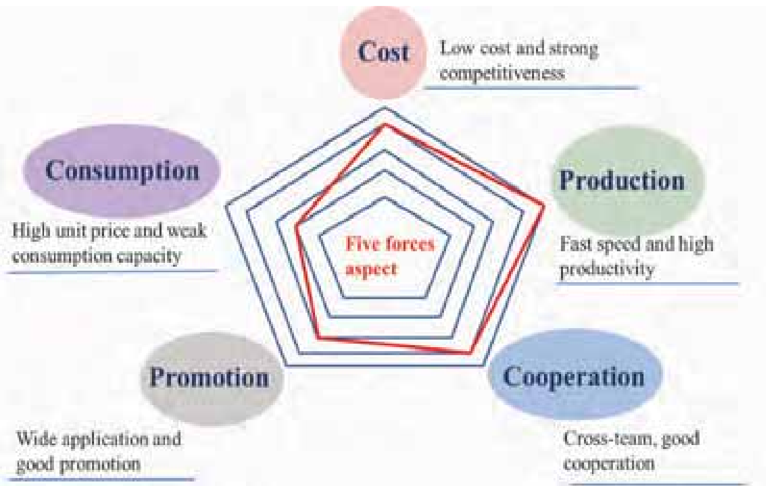


Fig.4. Analyzing products from five forces

3-3-2

High-Efficiency Space Solar Cells
The critical power components for national long-term space technology development projects

Image: The official website of Compound Semiconductor

INER has been engaged in the research on the manufacturing technology of concentrator III-V multi-junction solar cells since 2003, and our technology has been applied to high-concentration solar power generation systems. In 2009, the first MW-level concentrator solar farm in Asia was established. In addition, the developed cell chip with a light-receiving area of 0.3025 cm^2 has reached an energy conversion efficiency of 40.6% under AM1.5G (131 times of sun concentrations/intensity) condition. After finishing the first and second national energy technology projects, our focus of research in recent years has veered to the development of space solar cell technology.

In the early years, space solar cells are dominated by silicon solar cell modules. However, due to the limitations of inherent material properties, the efficiency of silicon modules cannot be sufficiently improved, and they suffer from serious degradation after long-term operation in the high-radiation environment of space. III-V multi-junction solar cells can overcome the problems of silicon solar cells. INER possesses many years of experience in III-V device development, and therefore we are one of the first national research laboratories in Taiwan to develop space solar cell technology with this material.

Fig.1. AIX2800 G4 epitaxial system for solar cells

The main materials of INER's high-efficiency space solar cells are III-V compounds. In the epitaxial technology of III-V materials, the most sophisticated and common manufacturing method is Metal-organic Chemical Vapor Deposition (MOCVD). Our MOCVD system is the AIX2800 G4 commercial mass production system designed by Aixtron. The capacity of its reactor is 5 wafers with diameter of 8 inches or 15 wafers with diameter of 4 inches or 60 wafers with diameter of 2 inches. The system was shown in Fig.1.

In accordance with user commands, the system controls the introduction of III-V group elements to the reactor at different times, different compositions and different flow rates, and adjusts parameters such as temperature, carrier gas flow rate and time interval to sequentially finish each epitaxial layer required by space solar cell epi-wafers.

Then, the surface metal electrodes are made by photolithography. After 4-inch wafer cutting, two solar cell chips with a light-receiving area of 30.18cm^2 can be obtained, which is the most common cell size currently used in satellites.

(a) (b)

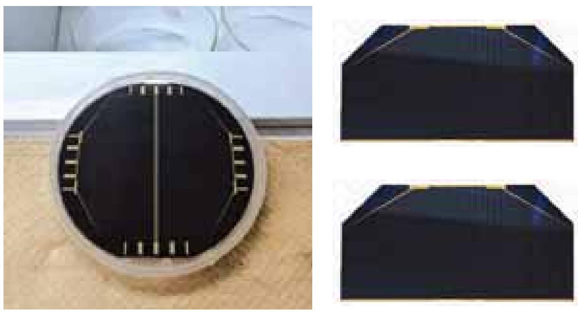


Fig.2.
(a) A 4-inch solar cell wafer
(a) Solar cell chips with a light-receiving area of 30.18 cm^2 after cutting

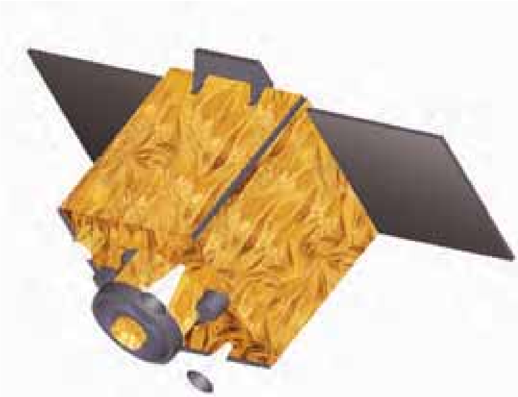


Fig.3. FORMOSAT-8(The program is planned to launch one satellite per year from 2023 to 2026)
Image: The official website of NSPO

Recent technological status

A space solar cell with a light-receiving area of $30.18 cm^2$ and a maximum energy conversion efficiency of more than 29% under the extraterrestrial (AM0) solar spectrum has been obtained, as shown in Fig.4. At the same time, the developed solar cells are also subjected to the environment tests in accordance with the international test standard ECSS-E-ST-20-08C. The objective is to verify the reliability of the cells and ensure that they have sufficient strength to survive the long-term operation in the space environment.

In addition, INER's research team is continuously improving the average efficiency of space solar cells, which is over 28% in mass production , to meet the requirements of power supply systems for satellites.

High-efficiency space solar cell is a cutting-edge technology, and therefore the development of the related domestic industry is still in the beginning stage. As national research and development laboratories, INER is devoted to the development of high-efficiency space solar cell technology. Because of the synergy between space solar cell and concentrator solar cell, with our more than 10 years of research and development experience of solar cell epitaxy and electrode fabrication, several achievements have already been obtained at INER. The developed space solar cells can be used in the satellites designed by The National Space Organization (NSPO), and they will be the first batch of space solar cells made in Taiwan.

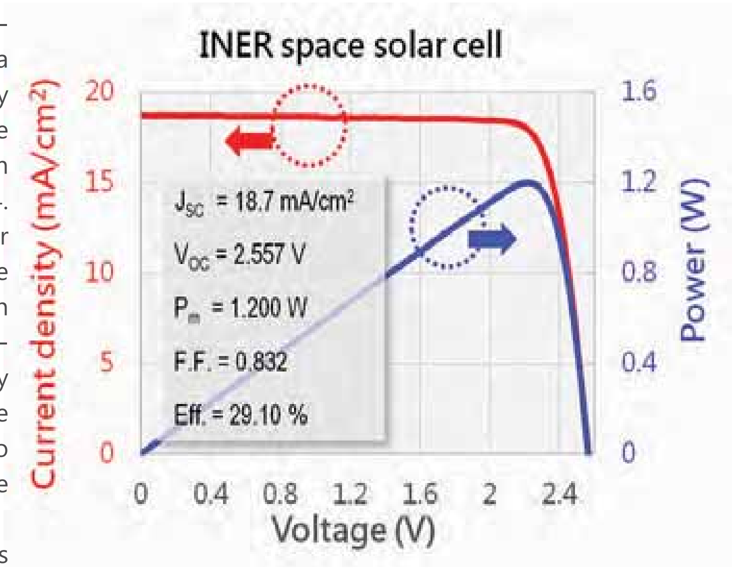


Fig.4. The I-V and P-V curves of the space solar cell

Prospects

INER's high-efficiency space solar cells will be installed in the power supply system of domestic satellites, after passing the environmental tests and verifications. In addition, the III-V semiconductor epitaxy technology will continue to expand. This technology can not only be applied to space solar cells, but can also be used in satellites' communication (Comm.) and power devices, due to its high radiation resistance, high electron mobility, high breakdown voltage, etc. It can help to prolong the lifetime of key electronic components of satellites.

INER aims to apply our technology to the development of solar cells and electronic components for satellites, increase the market share of domestic key components in the space industry, and achieve the goal of technological independence.

3-3-3

"Novel Blue Ocean Strategy" of Biomass — The Production Technology of Marine-Degradable Plastics

Say goodbye to petrochemical plastics - the first step to low-carbon life

(Plastic iceberg in the sea. Source : https://autoclean.tw/blog)

Plastic products have gained universal use on the market. More than 80% goods are petroleum products, which are light, resilient, supple, versatile and convenient to consumers. It has become an indispensable part of human life. The more plastics are used, the more wastes will be produced. Plastic pollution has entered the fossil record with steady increase of plastic contamination since 1945. In the future, historians and archaeologists may name periods of human life as the "Plastic Age" with greatest impact on human society after Bronze and Iron Age. Plastic pollution has become a significant threat to human health as these plastics are consumed globally without restrictions. Microplastics with particle size smaller than 5 mm are ubiquitously present in the aquatic food chain or water cycle. In fact, little evidence shows that plastic will ever fully break down in the environment. It will become the biggest burden on the earth. In view of this, the Institute of Nuclear Energy Research (INER) has developed production technology of marine-degradable bioplastics, which can relieve the problem of microplastic pollution and make life more convenient for consumers.

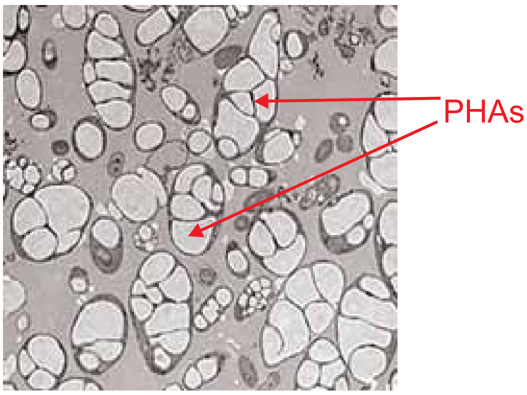


Fig.1. PHAs produced by microorganism
(Source : Elhadi et al.,2016)

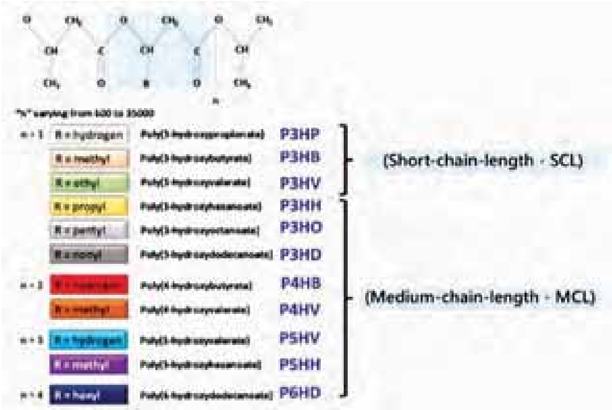


Fig.2. Different monomer compositions of PHAs
(Source : Pagliano et al.,2017)

Welcome to the new generation of marine-degradable plastic PHAs

1.Among the biodegradable plastics, Polyhydroxyalkanoates (PHAs) are particularly promising because of their good marine biodegradability. PHAs are synthesized and stored as water-insoluble inclusions in the microorganism (Fig.1) and accumulated inside cells under nutrient limitation and excess of carbon source as storage energy granules.

2.It has a variety of types and can be composed of more than 150 different PHA monomers (Fig.2).

3.These features have diverse PHA properties which can be tailored for different applications. Because PHAs exhibit good biodegradability (Fig.3), the disintegration rate must reach 90% under controlled composting conditions within 84 days.

4.Because it contains high biocompatibility, gas barrier and mechanical processing properties similar to traditional plastics, they can be used for packaging materials and medical application. It's a green alternative to petroleum-based plastics, which make them suitable for solution in pollution issue posed by plastic wastes.

Fig.3. Biodegradable PHAs - the disintegration rate reach 90% under controlled composting conditions within 84 days.
(Source : Rawa G.Yousuf thesis of 2017)

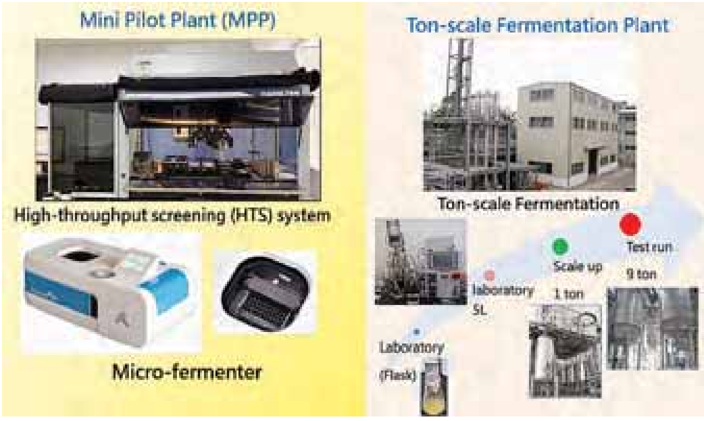


Fig.4. Equipment for mini pilot plant and ton-scale fermentation test plant

Improving industrial biotechnology platform

INER is the top research organization, which has both mini pilot plant and ton-scale fermentation plant (Fig.4). The mini pilot plant (MPP) was established in 2020, which includes high-throughput screening system and micro-fermenter. High-throughput screening is an automated machine, which can speed up the schedule of research development. The micro-fermenter can automatically provide the function of real-time monitoring for growth of microbes. Based on the platform, INER aims at accelerating the research progress of PHAs production technology and reducing the cost of fermentation. Meanwhile, with the ton-scale fermentation plant built in 2007, scaling up of fermentation technology can also be performed into commercialization. The platform integrates the research results from laboratory and mass production of industry, leading to commercialized marine degradable plastic PHAs.

Establishing high-yield PHAs producing microbes

PHAs producing microbes were screened and isolated from diverse sources in Taiwan. Some PHA producing strains such as *Cupriavidus necator, Haloferax mediterranei, Bacillus sp, Pseudomonas sp* and other bacteria have different features of growth, fermentation conditions and PHA types. Taking *Cupriavidus necator* as an example, cells were grown to the results of cell dry weight (CDW) of 65.2 g/L with stable PHA content of 43.2%. The crude PHA concentration is 28.16 g/L, which is higher than yields that reported in other literature (Fig.5). The improvement for higher yield will be optimized and the research results create new possibilities for potential industrial applications.

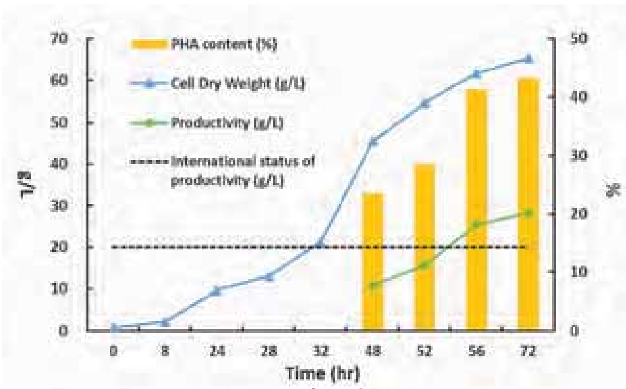


Fig.5. Fermentation results of PHAs production by ***Cupriavidus necator***

Creating a blue ocean market for marine-degradable plastic PHAs

Owing to the limited experiences in PHAs research and product application, INER cooperated with a domestic petrochemical company to develop and screen the potential strains of PHAs for special carbon source. On the other hand, PHAs materials with 90% purity are tested for prototype of PHA product. The injection or extrusion methods were tested to make some PHA products, including 3D printing wires, cosmetic boxes, vases and other applications (Fig.6).The higher purity and more special PHA is, the higher value application PHA can be. According to the different characteristics of PHAs, the diversified products will be developed to enhance the investors' interests from industry and strengthen collaborative partnerships among industry, university and government to create a novel blue-ocean market, moving towards environmental sustainability in the future.

Fig.6. Development and application of PHAs products

3-3-4

The Development of Intelligent Distribution Network Management and Pre-diagnosis Technologies for Power Transformation Equipment

In recent years, with a large amount of renewable energy incorporated into the existing distribution system, the intermittency of renewable energy will cause voltage fluctuation and three-phase imbalance. When fault occurs in a feeder, the electricity supply of renewable energy devices will temporarily suspend, which makes a feeder more difficult to perform power restoration when the load in the downstream area is too heavy. Due to this reason, INER has developed the "Distribution Feeder Normally-open Switch Optimum Allocation Platform", so as to balance the load in each feeder by adjusting the on/off state of switches on the feeders. Taking the substation of Yunlin Branch, Taipower for example, the load factor of each feeder can be balanced from the simulation result made by this platform. This prevents the problem that part of the feeders of a substation have heavier load in its downstream area when fault occurs, and further makes the process of power restoration more successful.

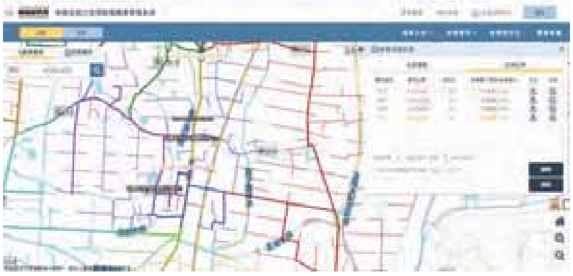


Fig.1. User Interface of the State Estimation Platform

Fig.2. Visualized Feeder Dispatch Management Platform

There are many nodes in the primary main and branch lines in complicated distribution systems. Therefore, lots of measuring equipment should be built to obtain precise information of each node. Not only is it the high cost of building equipment, but it is difficult to deal with the processing of mass data. However, if the information is not enough, it will be hard to monitor the voltage raise caused by the incorporation of renewable energy, which will further influence the quality of power utilization. Due to this reason, INER has developed a technique of state estimation, which makes it possible to estimate the condition of power supply for the primary main and branch lines of distribution systems. The estimated results can also be compared with the measured values, and the information can further be shown on the Geographic Information System (GIS) (Fig.1). This can assist the dispatchers to monitor the fluctuation of feeders caused by distributed generation and the position of abnormal equipment.

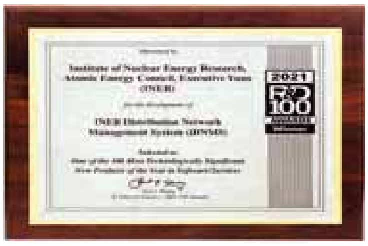


Fig.3. 2021 R&D 100 Awards plaque

Fig.4. The 2021 Public Servant Outstanding Contribution Award issued by President

In order to meet the "Smart Grid Master Plan", in which the project of fast Fault Detection, Isolation and Restoration (FDIR) is included, INER has developed Visualized Feeder Dispatch Management Platform (Fig.2) by combining GIS and the information from the on-site equipment. This provides the dispatchers and maintenance personnel with visualized information when fault occurs. Also, this technique has formulated the "Common Information Module (CIM) " by referencing IEC 61968 and IEC 61970. By adopting the format of CIM, power supervision and geographic information can be integrated, so that the status of one-line diagram of distribution map can be closer to the on-site condition. This means that the distribution map becomes more correct and useable. Besides, the function of supporting feeder dispatch is extended, so that the alarm after fault determination, including power outage, restoration, ring circuit, etc., can appear on the platform, which assists Taipower to perform fast power restoration. The developed "intelligent Distribution Network Management System (iDNMS) ", has won 2021 R&D 100 Awards (Fig.3). This means that the technique developing ability has earn international recognition. The research group also won the Group Award of the 2021 Public Servant Outstanding Contribution Award (Fig.4).

The implementation of the energy transition policy increases the penetration of renewable energy, which causes power system instability and voltage changes at the Point of Common Coupling (PCC) of feeder. Microgrid can provide a solution to improve power quality by integrating Power Conversion Systems (PCS), renewable energy and load. In this project, the "Voltage Control System and Method for Microgrid" (Fig.5) is proposed to suppress the inrush current, induced by the energization of inductive loads, to prevent power system blackout under the threshold protection of the PCS while the microgrid operates in standalone mode. Also, this technology won the Platinum Award at the 2021 Taiwan Innotech Expo (TIE) Invention Competition (Fig.6).

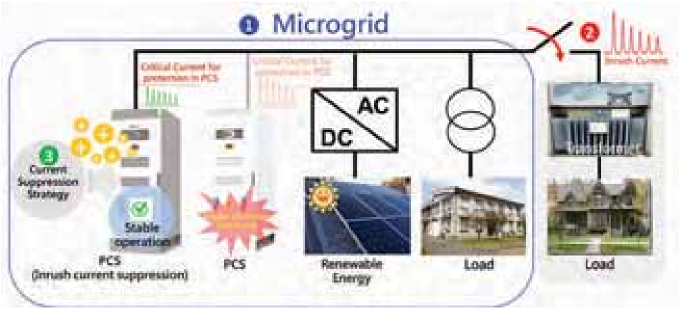


Fig.5. Application of the proposed voltage control method for Micorgrid in standalone mode

Fig.6. Platinum Award certificate of merit and trophy at 2021 TIE

A power transformer is a very important equipment in a power system. The stability of a power system is directly influenced by the safety and reliability of power transformer operations. Power transformer equipment gradually deteriorates due to continuous operation, long duration of service, environmental stresses, etc. Then, failures of the equipment or accidents will occur. Therefore, an AI big-data monitoring and pre-diagnosis system is developed and actually installed in Taipower substations. Six parameters of 161kV power transformers are monitored online, including grounded current, cooling system, dissolved gas-in-oil, partial discharge, body vibration, and On Load Tap Changer (OLTC) (Fig.7). The general fault diagnosis method can detect abnormal OLTC spectrum. After spectrum analysis and further investigation, a seriously worn-out gear in the driving device is indeed detected (Fig.8). The incipient detection helps the power substation respond early and select adaptive strategy. In the future, this research will be expanded to other substation equipment, and new technologies, such as machine vision and asset management, will be added to assist Taipower Company in strengthening the safe operation and maintenance management.

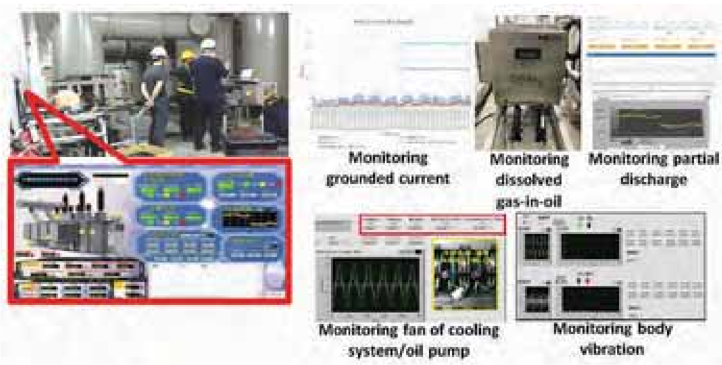


Fig.7. Donglin Substation 161kV Power Transformer Monitoring Platform

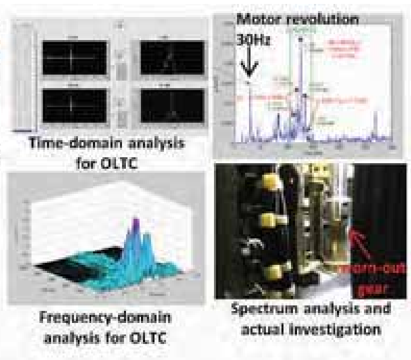
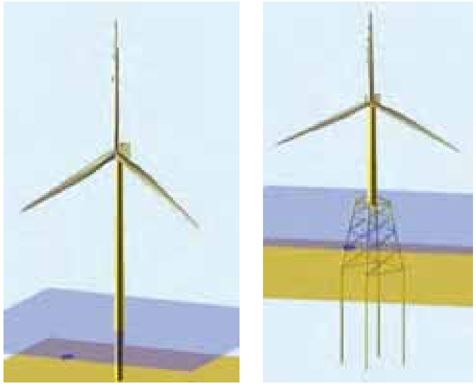


Fig.8. The general OLTC fault diagnosis

To fit the goal of strengthening the resilience of domestic grid, INER will keep developing techniques such as operation sequence of feeder switch, feeder connectivity tracing and computing functions, emergency ancillary decision-making system of microgrid, three-phase power conditioning system, and operation performance evaluation of power transformer components, so as to enhance the stability of distribution network, distributed generation and power transformation equipment.

3-3-5

Establishment of Parallel Verification and Design Technical Specification for the Giant Offshore Wind Turbine



The first domestic offshore wind farm was successfully commissioned in 2019. Offshore wind power developers also proposed giant offshore wind turbine (OWT) systems in recent years. It is estimated that the capacity of a single wind turbine will reach 14~15 MW in the near future. The developers imported OWTs that meet international standards from abroad and cooperated with domestic manufacturers to build support structures suitable for Taiwan. In recent years, the onshore wind turbines were occasionally damaged by typhoon. Nevertheless, the design requirements of extreme environmental conditions, such as the influences of typhoon and earthquake are not adequately implemented in current international standards. In this work, INER assists the MOEA to conduct domestic offshore wind farm site survey and design technical specification establishment. This specification will improve the reliability of OWT structures, promoting the policy and technology of OWTs in Taiwan.

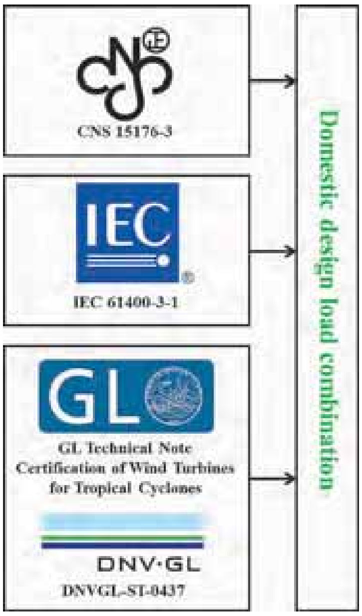


Fig.1. Analysis of international and domestic offshore Wind turbine Standards

Typhoon Design load Cases
(for the design of the support structure only)

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
Parked (standing still or idling)	10.1	EWM $V_{hub} = V_{10min,50}$	ESS $H_s = H_{s50}$	MIS, MUL	ECM	EWLR		ULS	1.0
	10.2	EWM $V_{hub} = V_{10min,Recp}$	ESS $H_s = H_{s,Recp}$	MIS, MUL	ECM	EWLR	Loss of electrical network	ULS	1.0

Earthquake Design load Cases

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
Earthquake (power production)	9.1	NWP $V_{hub} = V_r$	$H = H_s(V)$	COD, UNI	NCM	NWLR		ULS	1.0
Earthquake plus grid loss (power production)	9.2	NWP $V_{hub} = V_r$	$H = H_s(V)$	COD, UNI	NCM	NWLR	External or internal electrical fault including loss of electrical network	ULS	1.0
Earthquake plus grid loss (parked, standing still or idling)	9.3	NWP $V_{hub} = V_r$	$H = H_s(V)$	COD, UNI	NCM	NWLR	Loss of electrical network	ULS	1.0
Earthquake (power production)	9.4	NWP $V_{hub} = V_r$	$H = H_s(V)$	COD, UNI	NCM	NWLR		SLS	1.0

Fig.2. Domestic extreme environment design load cases

INER conducts the comparison of differences with domestic and international OWT standards (as shown in Fig.1), and builds the design load cases for specific offshore wind turbine (as shown in Fig.2), INER assists MOEA to conduct domestic offshore wind farm site survey and design technical specification (draft) establishment with NTUT, CECI, etc. (as shown in Fig.3). According to Taiwan's local environment, the performance and safety requirements for offshore wind turbine plants are established in 2021.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(草案)

Fig.3. Offshore wind farm site survey and design technical specification (draft)

Fig.4. Offshore wind farm project certification review teams

INER has assisted the certification review of domestic offshore wind farm project with MIRDC and other members (as shown in Fig.4). Currently, the technical review of the design basis of the two wind farms are being carried out. Through cooperation and exchange with domestic institutions, the engineering technology of INER offshore wind turbines can be thus upgraded.

Using DTU 10 MW wind turbine as the reference unit (as shown in Fig.5), the design load cases were defined in compliance with the requirement of IEC 61400-3-1. Combining wind, wave, and current conditions, the extreme loads as well as fatigue loads were calculated and analyzed. By this way, the design evaluation technique of giant offshore wind turbine can be established in the near future.

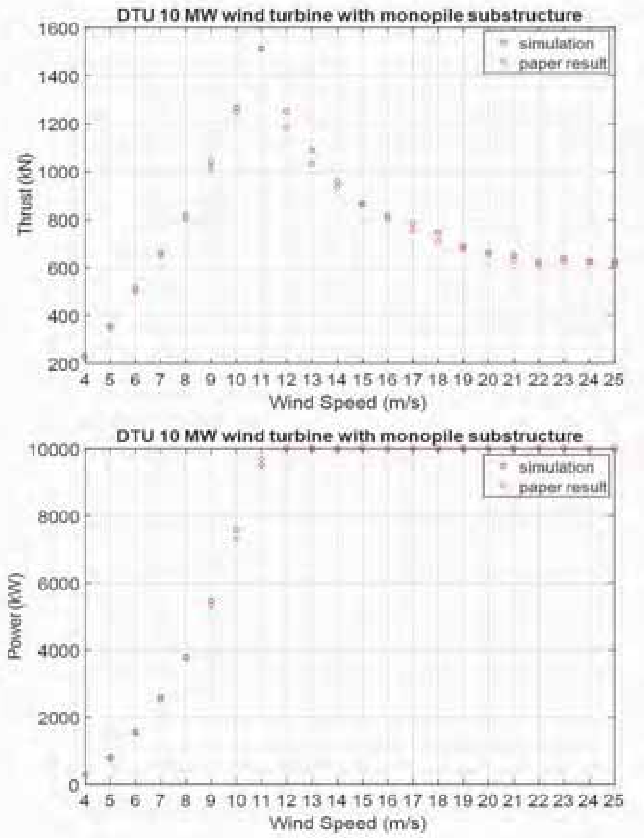

Fig.5. DTU 10 MW wind turbine power characteristics

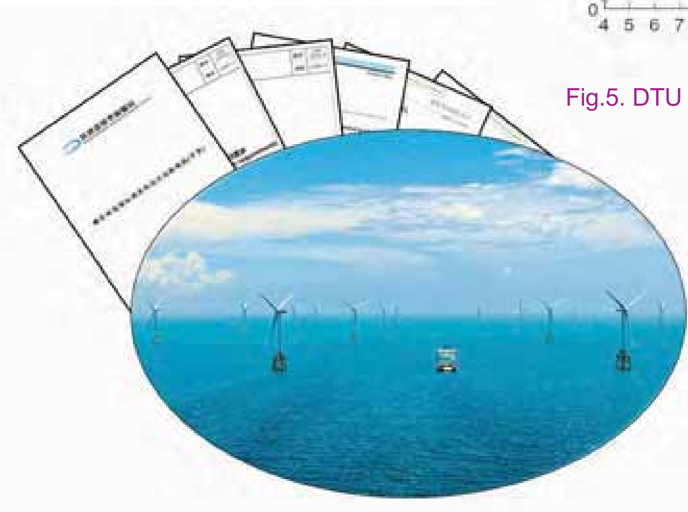

Fig.6. Domestic offshore wind farm

Based on the European site conditions, the international standards such as DNVGL-ST-0437 were developed. Typhoon and earthquake are the unique site conditions in Taiwan and the impact should be studied and analyzed in order to increase the reliability and safety of domestic offshore wind farm (as shown in Fig.6). The design evaluation technique must be gradually improved to assist the establishment of domestic technical specification and the industrial development.

4. 2021 highlighted events

4-1

2021 highlighted events

1 .*2021.01.01-12.31* INER produced "INER THALLOUS CHLORIDE (T1-201) INJECTION" and "INER GALLIUM CITRATE (GA-67) INJECTION" in emergency to make up the deficiency of imported radiopharmaceuticals during the pandemic. It supplied the radiopharmaceuticals for about 65,500 patients in 2021.

2. *2021.03.10-03.11* INEA safeguards officers came to INER for TWL (Hall 036) inspection. The result showed a compliance in the nuclear materials accounting.

3. *2021.03.12* With five Green Energy Technology Joint Research and Development Program, INER participated in the "Taiwan GET! International Forum and Result Presentation Conference" hosted by the Ministry of Science and Technology in Shalun Smart Green Energy Science City. INER's "Research and Technology Development for Resiliency Enhancement of Regional Distribution Power Network" was selected as one of the 17 highlights and won the first prize in the presentation contest.

4. *2021.04.09* Director Miss Tina Wilson, a business representative of the New Zealand Trade Development Center , and others visited INER for the matters concerning the technique service agreement on the "Ton-scale testing for the conversion of New Zealand wood chips into lactic acid" between INER and X Company in Taiwan.

5. *2021.04.09* INER cooperated with the largest electrochromic rearview mirror production and sales company in Taiwan. INER signed the "Technologies of large-area electrochromic film deposited by high-density plasma" licensing agreement, with a contract value of NT$16 million.

6. *2021.05.03-05.14* INER commissioned Taipei Medical University Hospital to provide physical examinations for employees. In addition to the employees of the AEC, INER and FCMA, the head of the neighborhood arranged 82 residents for the physical examination as well.

7. *2021.09.16-09.30* INER organized a result presentation for the "2020 Research Project under Commission of the Atomic Energy Council, Executive Yuan." It was the first presentation held via video conference in consideration of the COVID-19 pandemic and a total of 171 persons from our industry, university and institute partners were invited for the presentation.

8. *2021.10.20* The winner list of the "2021 Taiwan Innotech Expo" competition was announced online, and INER won two platinum awards, three gold medals, two silver medals and three bronze medals in the competition with a prize winning rate of 77% (much higher than the overall average prize winning rate of 58%).

9. *2021.10.22* INER organized the "2021 International Workshop of Nuclear Facility Decommissioning Technologies" and invited the experts from Taipower, universities and industries for the workshop in order to form the teams needed for the expected decommissioning of the nuclear power plant in Taiwan.

10. *2021.10.22* The list of the winners of the R&D 100 Awards was announced in 2021. INER took "Intelligent Distribution Network Management System (iDNMS)" to participate in this competition and won the prize.

11. *2021.10.25* Research Center for Biotechnology and Medicine Policy announced the winner list of the 18th National Innovation Award and INER won two "research and innovation awards" and four "2021 renewal awards" in the competition.

12. *2021.11.24-11.25* IAEA safeguards officers conducted the regular 2021 nuclear safeguards inspection at the INER. The result showed a slight difference between the floor plan of some buildings and the reports submitted earlier. Update will be made in the 2022 Design Information Questionnaire and Additional Protocol for the deficiencies.

13. *2021.12.06* MOHW announced winner list of the "2021 Drug Research and Development Science and Technology Awards, jointly organized by the MOHW and the MOEA." INER won the silver medal in the medical device category with its "Low-dose 3D X-ray Imaging Scanner-Taiwan TomoDR" technology.

14. *2021.12.14* The "Research Team of Intelligent Distribution Network and Microgrid Technique Incorporating Renewable Energy" of INER won the 2021 Public Servant Outstanding Contribution Award. The awardee went to the Ministry of Civil Service to attend the awards ceremony, where President Tsai delivered a speech and awarded in person.

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