ISSN:1812-3155

Institute of Nuclear Energy Research
Atomic Energy Council, Executive Yuan

2018 Annual Report

Published in August, 2019

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Contents

1.Preface

Preface

Pursuing excellence

-The proceeding INER

The Institute of Nuclear Energy Research (INER), established in 1968, is the state-level institution dedicated to research and development of atomic energy technologies. INER's major scope of research covers nuclear energy safety, environmental energy conservation, and civilian radiation applications. Besides, to meet the government's demands on strategies evaluation of energy economic development and on decommissioning of nuclear facilities in the future, INER also devotes itself in energy economics research, in R&D of nuclear power plant decommissioning technologies, radioactive waste treatment and disposal technologies.

Based on atomic energy technologies researches, INER has expanded its realms of R&D and has obtained a considerable amount of unique and tradable technologies and patents. Through technology transfer, technical service, and collaborative development, INER assists local enterprises in product development, process innovation, and system improvement and achieves significant results. For example, a technology transferee took part in the "2018 Taipei AMPA" innovative product awards contest with the product named "Top-end Window Film" and won the accessories bronze medal in more than one hundred competitors. Other competition results in invention shows include:

- INER wins nineteen (19) awards in the "Taipei International Invention Show & Technomart", including six (6) gold medals, five (5) silver medals, and eight (8) bronze medals. More than 80% of INER's contenders have been awarded.

➤ INER wins the 15th National Innovation Award with "Theranostic Probes (DOTA-NIR790) for Multimodality Imaging, Radiotherapy, and Photothermal Therapy".

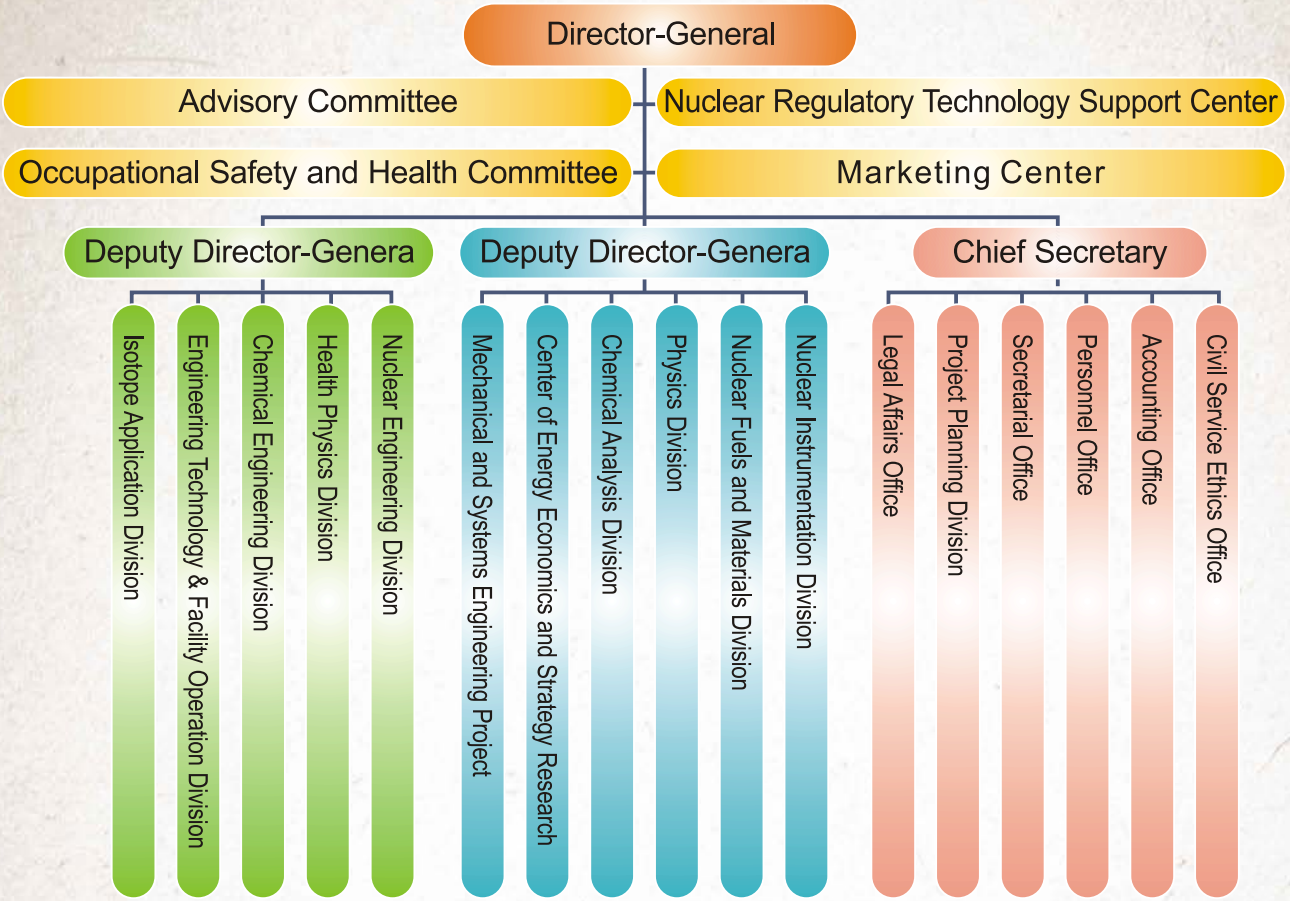
In addition to nuclear safety and green energy, INER has devoted itself to R&D on nuclear medicines and high-leveled medical instruments. With sixteen (16) drug-license permits, two (2) medical-instrument-license permits, and PIC/S GMP examination reassurance, INER is the only decent research institution that legally produces and provides nuclear medicine services. The high-quality radiopharmaceuticals produced by INER meets international quality standards. More than 150 thousand patients benefited from this service this year.

To complement the scientific knowledge and to popularize the public comprehension of atomic energy technology itself and its contribution, INER cooperated with Atomic Energy Council (AEC) in organizing the "Atomic Energy Science and Technology Exhibition" for the first time in February this year. There are sixteen (16) INER's research work regarding nuclear energy safety and green energy exhibited in an easy to understand and approachable way for the populace. It sums up to 3,551 visitors in the three-day exhibition. It is a successful reach-out to cultivate people's comprehension and further interest in atomic energy technology.

INER is established to fulfill national assignments. As the mission change, INER once groped around to affirm its organizational positioning, bearing the firm belief that the accumulated technical capabilities will be implemented and be beneficial to the country. INER keeps contributing to national development and keeps upgrading its technical capacities to gain a rising domain reputation. After a half-century transformation, INER has become the most complete national laboratory in the field of atomic energy research in Taiwan. INER will keep pursuing excellence in the field of energy, environmental protection, and health, providing required technical solutions for better welfare of the people and the country.

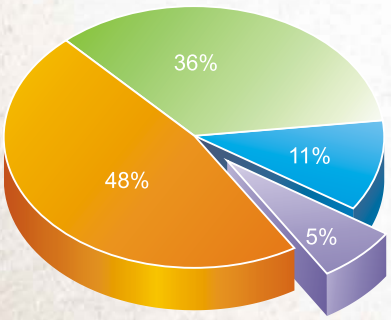
2.Organization Chart、Human Resources and Budgets

Organization Chart of INER



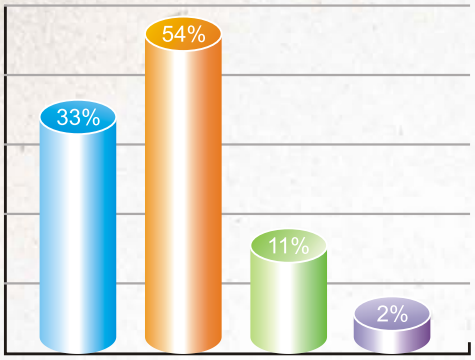
Human Resources and Budgets (Time of data: December, 2018)

Manpower Distribution of INER



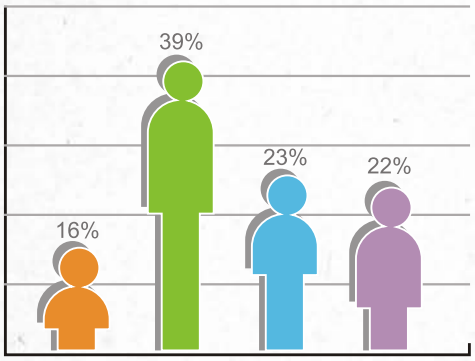
Research Staffs	369 Persons	(48%)
Technicians	282 Persons	(36%)
Administrative Staffs	89 Persons	(11%)
Other Staffs	37 Persons	(5%)
Official Staffs	777 Persons	

Statistics of Educational Background for Research Staffs



Ph.D.	122 Persons	(33%)
Master	199 Persons	(54%)
Vocational School	42 Persons	(11%)
Bachelor	9 Persons	(2%)
Research Staffs	369 Persons	

Statistics of Job Category for Organizational Research Staffs



Researcher	59 Persons	(16%)
Associate Researcher	146 Persons	(39%)
Assistant Researcher	84 Persons	(23%)
Research Assistant	80 Persons	(22%)
Research Staffs	336 Persons	

2018 Annual Budget

Unit: Thousand NTD

Item	Number of Accounts	Percentage
Administration and Safety	1,179,874	57.59%
Management, Operation and Maintenance	180,400	8.80%
R&D Projects	561,909	27.43%
Technology Promotion and Service	126,658	6.18%
Total	2,048,841	100.00%

3.Current Major R&D Activities

3-1 Ensuring nuclear safety to preserve human welfare

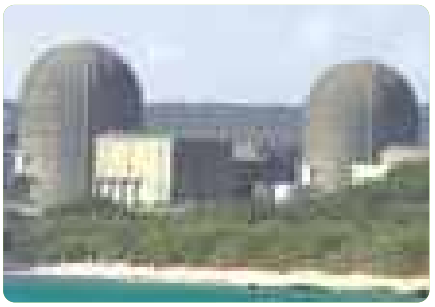
The safe operation of nuclear power plants (NPPs) and the proper disposal of radioactive waste are two major concerns for Taiwan's nuclear energy. INER has gradually shifted major R&D issues from nuclear safety to the proper disposal of radioactive waste and decommissioning activities of current 3 NPPs.

After 50 years of dedicated effort, the INER has established its reputation as the top research institution equipped with complete coverage nuclear safety-related professional and technical capacities in Taiwan. INER's professional techniques of nuclear safety science and technology research on the sustainable life cycle of nuclear power have already provided competent and credible nuclear and radiation safety technologies to support and to ensure nuclear safety and the decommissioning related work preparation of both Taiwan Research Reactor (TRR) and Taiwan's nuclear power plants (NPPs). The research target of this year (2018) includes: (1) the establishment of technologies to enhance nuclear safety measures of current operating NPPs in Taiwan; (2) the decommissioning related work preparation of NPPs and TRR; (3) implementation of low-level radioactive waste issues and mid-term issues of spent fuel dry storage system to resolve domestic technical problems.

For the year 2018, INER's important nuclear safety research outcomes include (1) critical component improvement and system assessment related to nuclear safety; (2) decommissioning technologies, (3) and low-level and medium-term storage techniques. These outcomes include three aspects, respectively: (I) Critical components betterment and system assessment technology related to nuclear safety. This covers maintaining safe conditions in the control room at the NPPs, development of fire PRA (Probabilistic Risk Assessment) methodology for NPPs, criticality safety analysis for the cask loading pools of Kuosheng NPP, R&D of localized rad-hard optical fiber, and safety-control knowledge platform of the transitional stage from operation to decommissioning for Chinshan NPP. (II) Decommissioning of nuclear facility technologies includes a major decommissioning milestone to complete spent fuel pool water treatment of the TRR, construction of NPP decommissioning information management system, development of INER-LRW-C1 low-level radioactive waste container to promote the flexibility of radioactive waste management, and development of crucial dismantling tools for TRR. (III) Low-level and mid-term storage technologies, which include evaluating the performance of canister after closure on isostatic pressure, vibratory ground motion, and earthquake-induced fracture displacement, introduction of the methodology of safety assessment for spent nuclear fuels final disposal repository, the calibration technique establishment and performance assessment of soil activity screening system, introduction of the SNFD2017 Report - the milestone of the first stage of the spent nuclear fuel final disposal program, improvement of the storage safety of radioactive organic liquid wastes - establishing the technical procedure of TOC (Total Organic Carbon) degradation by advanced oxidation, development and application of HPCC (High-Performance Concrete Container), and technology development on the radionuclide migration.

3-1-1

Operator Not a Sacrificial Lamb—Maintain safe conditions in the control room at the nuclear power plant



The Control Room Envelope (CRE) is the area within the confined spaces of the CRE boundary for control room occupants inhabiting to control the unit during normal and accident conditions. The operability of the CRE boundary must be maintained to ensure that the inleakage of unfiltered air into the CRE will not exceed the inleakage limit in the licensing basis analysis of design basis accident (DBA) affecting the ability of the CRE occupants. INER assists Taiwan Power Company (TPC) to develop CRE habitability programs for Chinshan, Kuosheng, and Maanshan nuclear power plants. The CRE habitability programs for each plant will be incorporated into plant's technical specifications and to be implemented accordingly. Based on the CRE habitability program, the operability of the CRE boundary can be maintained to assure that control room operators would be adequately protected against the effects of accidental releases of radioactive and hazardous gases or smoke events and that the nuclear power plant could be safely operated or shut down under design basis accident conditions. Fig. 1 shows the control room of Kuosheng plant.

Fig. 1. Control room of Kuosheng plant

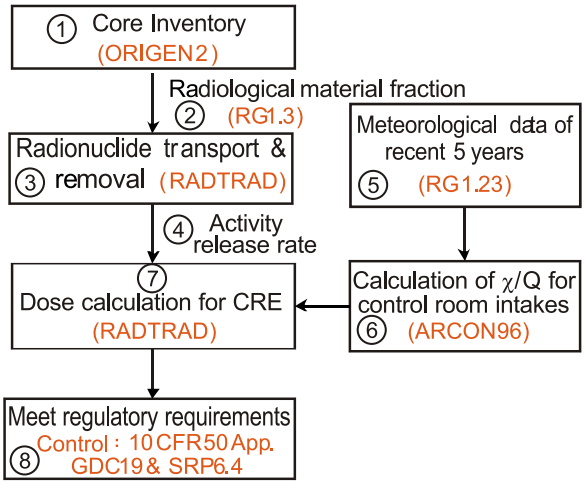


Fig. 2. Flowchart of the radiation dose analysis for Chinshan plant

INER conducted the radiological consequences and hazardous chemicals analyses for the CREs of the three domestic nuclear power plants to determine the maximum unfiltered air inleakage rates in accordance with applicable regulatory requirements for each plant. The RADTRAD v3.03 and HABIT v1.1 are used to perform the radiation dose and hazardous chemicals analyses, respectively. In determining the limiting condition for potential radiological accidents, the most limiting accident (Loss of Coolant Accident, LOCA) and other accidents (e.g., fuel handling accidents) were analyzed to identify the maximum allowable unfiltered inleakage rate for each plant. Fig. 2 shows the flowchart of radiation dose analyses. The calculation mode of whole body dose caused by radionuclide within primary containment is shown in Fig. 3. In addition, Chemicals from mobile or stationary sources, offsite or onsite situated at distance small than 8 km from the plant during and after a postulated external release were considered in assessing the habitability CRE. The calculated maximum unfiltered inleakage rates for each plant (Table 1) will be used to as acceptance criteria for CRE inleakage test based on ASTM E741 and will be conducted by international professional team commissioned by TPC.

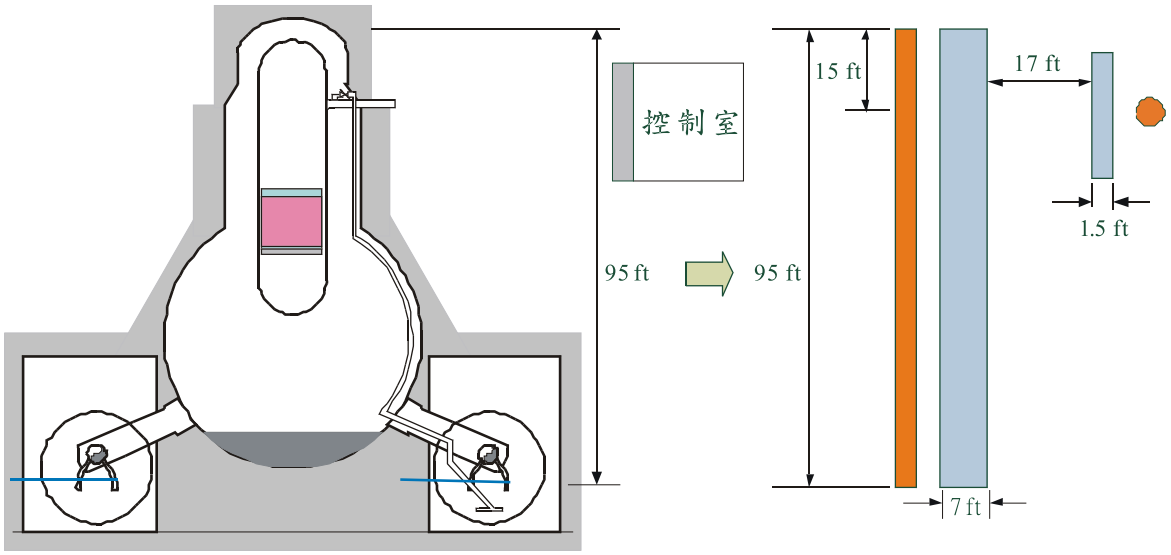


Fig. 3. Calculation mode of whole body dose caused by radionuclide within primary containment for Chinshan plant

Table 1. Test Acceptance Criteria for CRE unfiltered air inleakage rate

Test mode	Unfiltered air in-leakage rate limit (cfm)				
	Chinshan		Kuosheng	Maanshan	
	Unit 1	Unit 2		Unit 1	Unit 2
Isolation	314	442	2000	2000	2000
Pressurization	446	633	450	107	107

After studying the "Control Room Habitability Guidance" developed by the US Nuclear Energy Institute, the US nuclear power plants operating experience and practices, and related technical documents. INER developed the CRE habitability programs for Chinshan, Kuosheng, and Maanshan nuclear power plants. This habitability program includes (1) CRE and CRE boundary definition, (2) CRE boundary integrity control, (3) design control, (4) maintenance control, (5) safety analyses control, and (6) hazardous chemicals control. (7) Smoke control, (8) CRE inleakage test, (9) Quantitative limits on CRE air inleakage, (10) CRE differential pressure test, (11) CRE habitability assessment, (12) evaluation of CRE habitability assessment results, and (13) training etc. This CRE habitability program will be incorporated into each plant's technical specifications and then to be implemented mandatory for the three plants to ensure safe operations of the domestic nuclear power plants.

Plant design bases and severe accident risk analyses both assume that the control room operators can remain safely within the control room to monitor plant performance and take appropriate mitigating actions. The habitability of the control room and the operability of the control room habitability systems (CRHSs) in the event of adverse environmental conditions external to the CRE have a direct link to maintaining public health and safety. It is essential that operators be confident of their safety within the control room at all times.

3-1-2

FPRA for Nuclear Power Plant - Keeping a Single Spark from Starting the Prairie Fire


Fire Drill for NPP

In Regulatory Guide 1.200, the U.S. Nuclear Regulatory Commission (USNRC) endorsed the PRA standard of ASME/ANS RA-Sa-2009 as a basis for the judgement of the technical adequacy of a probabilistic risk assessment of nuclear power plant (NPP). INER applies the Fire Probabilistic Risk Assessment(FPRA) methodology, ie. NUREG/CR-6850 published by USNRC, to evaluate the fire risks of the domestic NPPs.

FPRA adopts a gradually progressive process to screen qualitatively and quantitatively by fire compartments, then by fire scenario, to obtain the fire risk. In order to establish the fire scenarios, it needs to identify the components (equipment and cables) included in the fire risk model to assess core damage frequency(CDF) , count up the challenging ignition sources, define the targets and the fire scenarios. Several plant walk-downs are conducted to scope the fire range, possible fire scenarios, and high-risk areas. The candidate scenarios would be refined in detail and then quantified.

The fire scenarios are classified into three categories: (1) single compartment, (2) main control room, (3) multi-compartment. Different from the normal compartment, the main control room is unique and could be much more risk significant, so warrants a more detailed estimation. Furthermore, those scenarios involving fire spreading to other areas also need to be considered as multi-compartment fire scenarios. The full fire risk can be quantified by integrating the above scenarios.

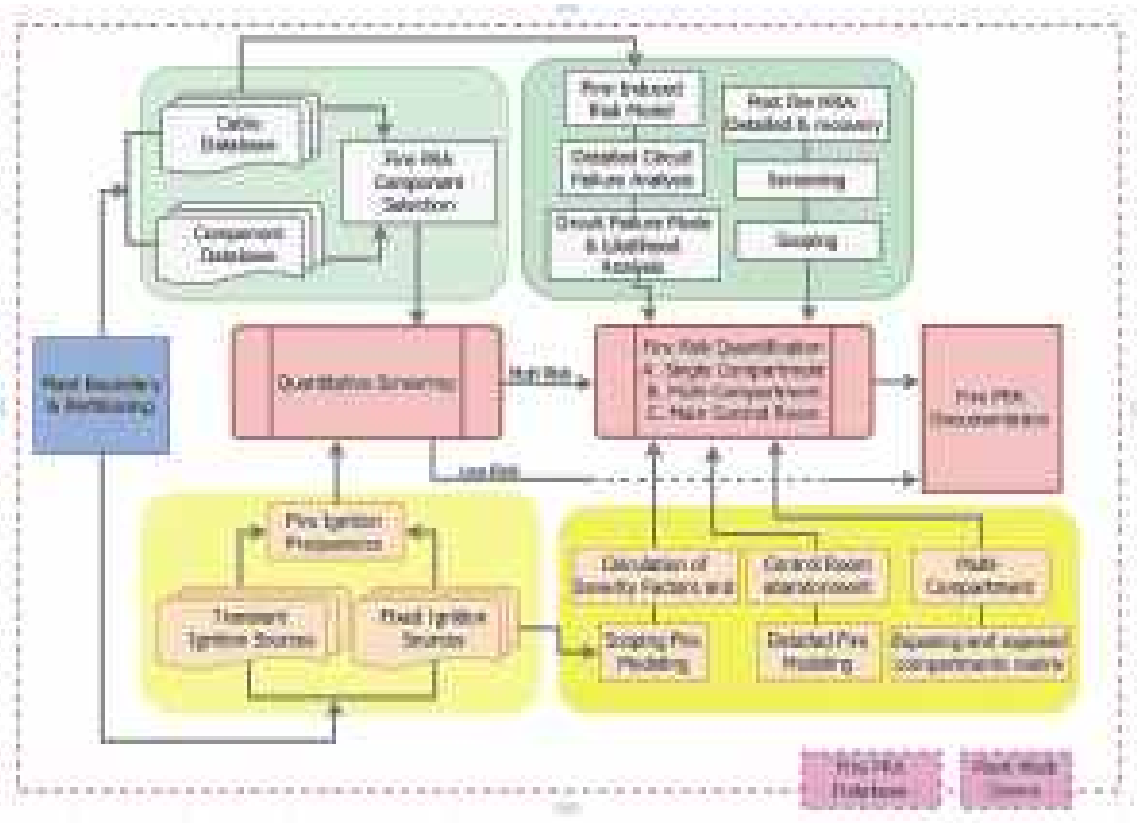


Fig. Overview of the Fire PRA Process

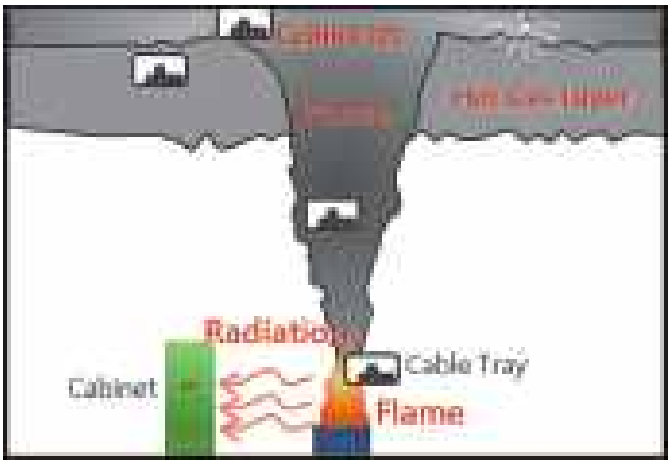


Fig. Concept of Fire Damage Mechanisms

The result of FPRA shows that more than 50% of the fires happen in the case NPP (52.52%) will not affect the normal operation of the plant (None IE) and do not contribute to the fire risk. The fire scenarios contributing to the fire risk are fire-induced transient events which would cause automatic or manual reactor trips. Most scenarios being included in the analysis come from so-called general transient event, accounting for 42.07% of the fire occurrences. Scenarios with initial events (such as loss of feedwater, loss of circulation water, loss of AC bus, etc.) more challenging than general transient events contribute only about 5.4% of the total fire occurrences.

The FPRA assumes as long as a fire affects PRA components, it will cause transient event and contribute to risk. This is a conservative assumption.

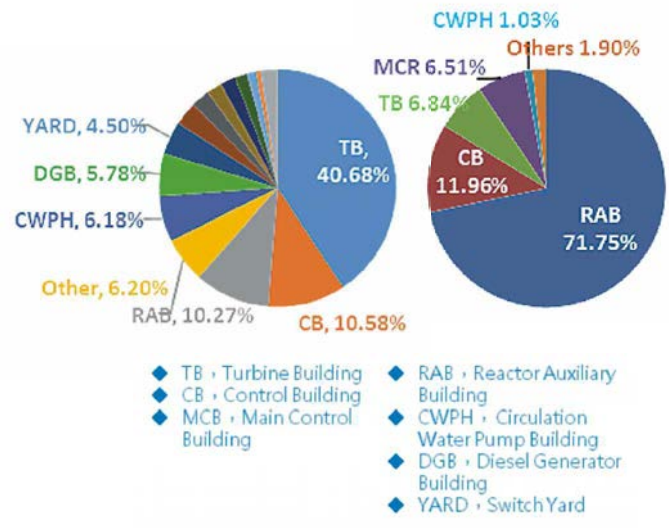
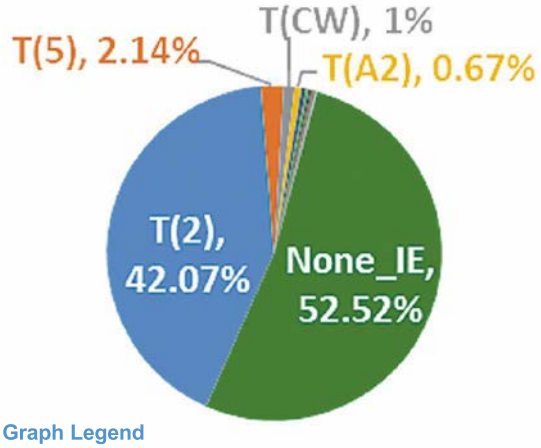


Fig. Fire Occurrence Probability and Risk in the Case NPP

To characterize a fire scenario, one should identify the ignition sources, figure out the impacted targets, and delineate the characteristics of the fire model such as: fire damage mechanisms, combustion severity, time window, fire protection features and operators actions. In order to quantify the risk of fire scenarios in nuclear power plant, the probabilities of fire scenarios and the failure modes of fire damaging equipment and cable should be estimated.



Graph Legend

◆None_IE，The fire effect to the power plant is not significant, and no initial event
◆T(2)， The fire causes MS isolating failure, set as general transients event
◆T(5)， The fire causes loss of feedwater
◆T(CW)， The fire causes circulation water system
◆T(A2)， The fire causes loss of AC bus (1A2)

Fig. Fire Occurrence Consequence and Probability in the Case NPP

Overall, the area with highest fire occurrence probability is turbine building, accounting for about 40% of occurrence rate, but contributes to CDF by only 6.84%. It means that the fire scenarios of turbine building are usually less severe with respect to core damage risk.

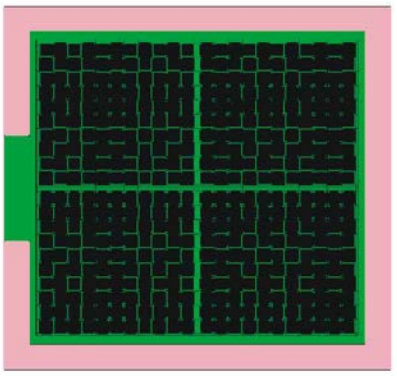
Fire occurrence probability of reactor auxiliary building accounts for 10%, but its CDF contribution is higher than 70%. Therefore, it should be cautious while fire happens in this area.

The fire occurrence probability of the control building is 10.58%, that contributes to CDF by 18.47%, mostly from the main control room.

Via FPRA, the areas with significant risk are to be filtered out directly. Focusing the improvement efforts to those risk significant fire scenarios will be cost-beneficial and fruitful .

3-1-3

Relieving the Power Shortage Crisis - Criticality Safety Analysis for the Cask Loading Pools of Kuosheng Nuclear Power Plant



In order to solve the problem of gradually crowded spent fuel pools of Kuosheng Nuclear Power Plant (KNPP), Taipower plans to install four sets of B-type racks from the Lungmen site into the Cask Loading Pool of KNPP unit 1 and unit 2, respectively. The criticality safety analysis is performed to ensure that the spent fuel pool systems remain sub-critical. In this criticality safety analysis, CASMO-4 code is used for calculating the effective neutron multiplication factor (K_{eff}), including the calculations of various manufacturing tolerances and fuel depletion uncertainty. The MCNP5 Monte-Carlo code is used to verify the accuracy of the CASMO-4 model and to calculate the reactivity effect under accident conditions. The results of the criticality safety analysis show that the maximum reactivity has met the regulatory criteria, which is that the neutron multiplication factor must be less than or equals to 0.95.

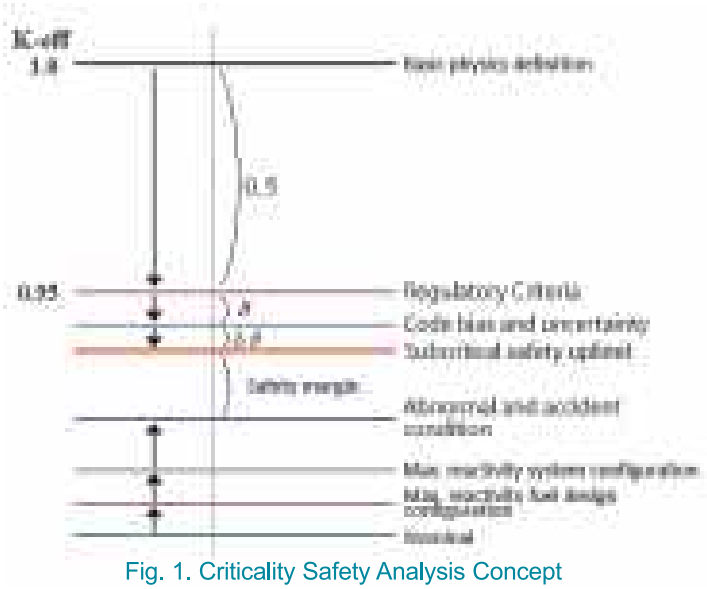


Fig. 1. Criticality Safety Analysis Concept

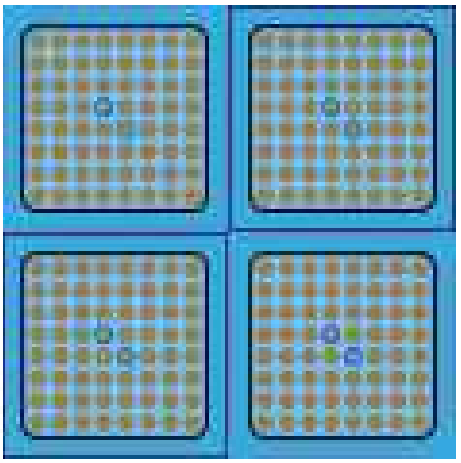


Fig. 2. CASMO-4 CRD2X2 Model

The Cask Loading Pool rack is simulated by a 2x2 model using the CASMO-4 code. A rack cell is formed by stainless-steel (SS) squared tubes, with the outer surfaces attached by BORAL panels. Each rack cell is welded to the neighboring cells on four corners, constituting a checkboard configuration. The fuel bundles are emplaced inside the rack cells, as well as in the space between the neighboring cells. The uncertainty and bias of MCNP5 are directly taken from the dry storage analysis of Chinshan Nuclear Power Plant, wherein a total of 138 critical experiments were simulated.

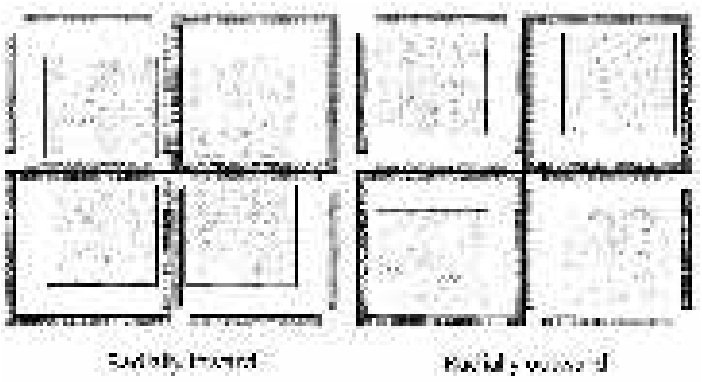


Fig. 3. Analyzed Items - Fuel bundle displacement

The analysis includes two types of fuel to be stored, GE8 and ANF8 fuel, with a total of 9 kinds of fuel lattice designs. All reactivity biases should be added directly to the nominal reactivity, and the reactivity uncertainties should be combined statistically. The negative biases and uncertainties are treated as zero for conservatism. The maximal reactivity is 0.80635 for the lattice GE8X8-2_303_6G3.0 The maximum neutron multiplication factors for all design lattices are below the regulatory criteria and the safety margin is quite sufficient.

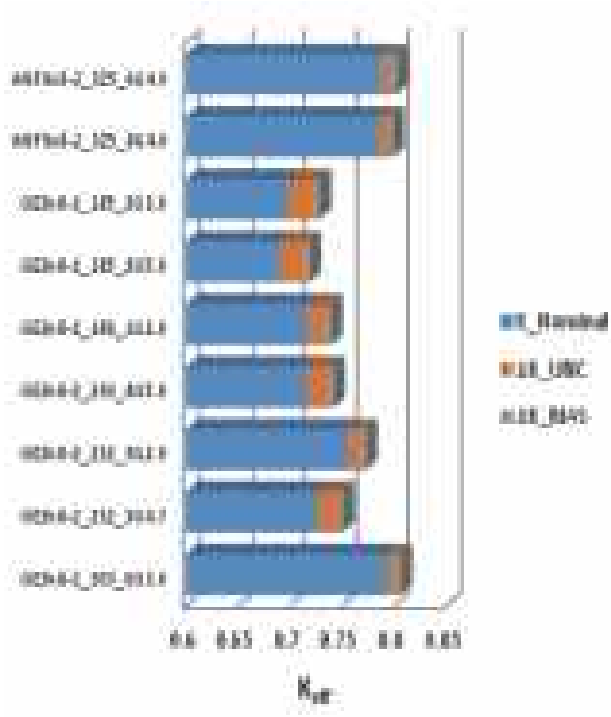


Fig. 4. Summary of maximum reactivity

Critical safety analysis needs to consider all items that may affect reactivity, including:

1.Fuel design and manufacturing tolerances
2.Rack design and manufacturing tolerances
3.History of core depletion
4.Fuel bundle displacement
5.Shutdown cooling time

In addition, all possible abnormal and accident conditions should be accounted for, such as:

1.Abnormal pool water temperature and density
2.The drop of fuel bundle in horizontal or vertical direction.
3.Misloading of fuel bundles

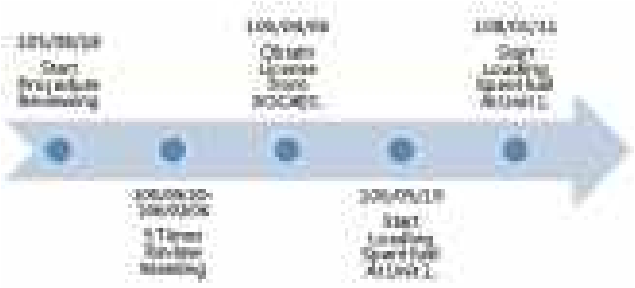
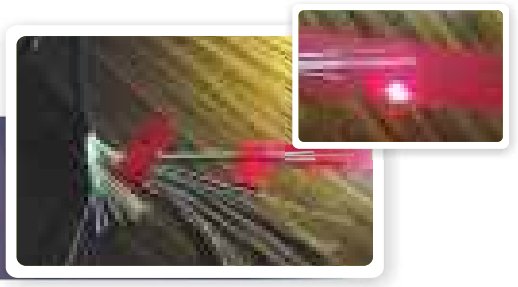


Fig. 5. Milestone of Project

The analysis successfully assisted Taiwan Power Company in licensing the modification of the cask loading pool, and the safety analysis report was completed in early 2017. INER also assisted TPC in responding the review comments from ROCAEC committee. The cask loading pool modification project was formally approved and the construction permit was issued by Taiwan's regulatory body, ROCAEC on April 6, 2017. Following that, the blackness test of KNPP was completed on May 19, 2017 and Jan 11, 2019, respectively prior to storing the used nuclear fuels in the cask loading pool. This facilitates KNPP to start up in time before the peak of the electricity demand in summer, preventing taiwan from suffering the risk of power shortage.



3-1-4 Research and Development of Localized Rad-Hard Optical Fiber

Optical fiber is often used to transmit the Internet, or cable TV signals, and a large number of signals can be transmitted simultaneously by only one fiber. Compared with the traditional coaxial cable, the signal attenuation and interference of the optical fiber are much improved. The advantages of optical fiber are obvious, especially in the long-distance and large-transmission applications.

Although Taiwan produces fiber optics, it does not focus on the applications in harsh environments such as high temperature, high humidity and high radiation. Therefore, these optical fibers used in special fields, such as national defense, space, etc., need to be imported from abroad, but they are also limited by the export license of foreign manufacturers, which is quite difficult and expensive.

In view of this, INER has allied with local manufacturers and invested in the development of optical fibers for use in special environments to improve the ability of the local industry.

Fig. 12-core fiber optic cable and ST connector for testing

In the initial stage, the project aims to seek fiber comply with the needs of nuclear power plant, which requires multi-mode fiber with a gamma radiation dose of 10 Gy to 1,000 Gy.

However, most of the market-available optical fibers irradiated by Co-60 source at INER, have been damaged by exposure to radiation dose less than 100 Gy. After many correction processes, the 1,000 Gy-resistant fiber has successfully been produced and is able to meet the nuclear power plant requirements.

Fig. Fiber test joint splicing

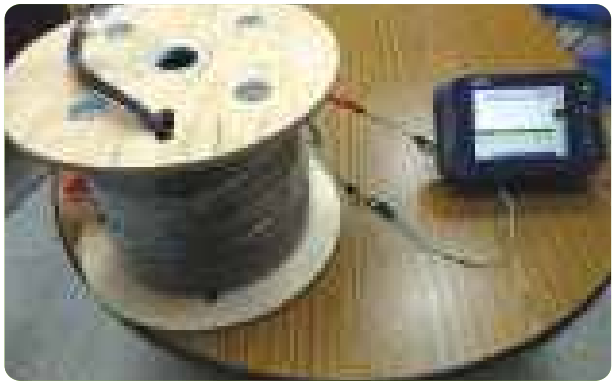


Fig. OTDR Test : transmission attenuation

Based on references, multimode optical fibers for radiation environment applications are irradiated at a dose rate of 1,000 Gy per hour, and at a dose of 200,000 Gy. The OTDR (Optical Time Domain Reflectometer) is used to measure signal transmission attenuation, and the 1310 nm wavelength signal transmitted at room temperature can achieve a lower attenuation of 9 dB/km.

INER has completed the fiber verification with the irradiation dose of 10,000 Gy by Co-60 source. The transmission performance of the fiber at 1,310 nm reaches 15 dB/km attenuation at room temperature. There is still a considerable gap between the current international specifications.

However, for local manufacturers, the production of optical fibers has created the first step from scratch in the application of radiation environment.

Fig. Temperature and humidity test equipment

The fiber connector is designed for the general environment, so in the verification process, the radiation exposure would damage the fiber and thus making measuring the signal impossible. Therefore, after each verification, the new connector needs to be replaced by splicing the fiber to ensure the accuracy of the fiber attenuation.

In addition, after the fiber has been irradiated, it is almost impossible to transmit signals in the visible light band, which is also quite troublesome for splicing and testing.

Fig. Radiation exposure site

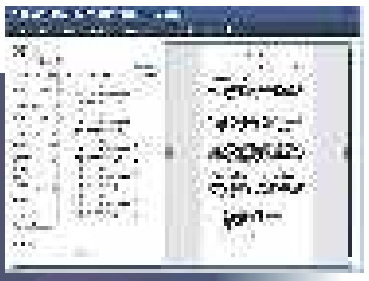
Although the application of currently completed optical fiber in the radiation environment has been verified, it is still necessary to confirm its application under different temperatures and humidity, and to implement higher gamma radiation dose and neutron radiation.

In the future, It is expected to promote to a wider range of special conditions such as defense weapons, space satellites, etc.

3-1-5

The Latest Information Package about Nuclear Industry Safety

-Safety control knowledge platform of transitioning phase from operation to decommissioning for nuclear power plant



Before the expiry of the operation license, the nuclear power plant, the world's advanced countries will enter the transitional stage of the pre-decommissioning period if they announce that the nuclear power plant unit will be permanently shut down and submit the decommission plan. According to regulation guidance, nuclear facilities must be decommissioned after being permanently shut down; however, for the current state of nuclear power plants in Taiwan, the dry spent nuclear fuel storage facilities have not been granted operating licenses.

Although the nuclear power plant is no longer in operation, some mechanical systems, structures, and electrical facilities still have the safety maintenance requirements. The purpose of this knowledge platform is to respond to all the relevant information needed at this stage. It includes foreign regulations, guidelines, research reports, and even lesson learned cases to enhance the safety of the associated facilities at this stage. The basic concept of the platform is to ensure that safety related information could be obtained without difficulty.

The content of this knowledge platform does not fully cover the information required for the overall decommissioning activities, and the focus is on the maintenance and management of the retained equipment. Fig. 1 presents a schematic diagram of the mechanical system components of a nuclear power plant. In the case where the spent nuclear fuel has not completely been removed the core, the safe maintenance of the reactor pressure vessel must be compared with the requirements of the operation phase, and Fig. 2 shows one of the report in the database of International Atomic Energy Agency (IAEA).

Fig. 1. Reactor pressure vessel (3D)

Fig. 2. Database for reports

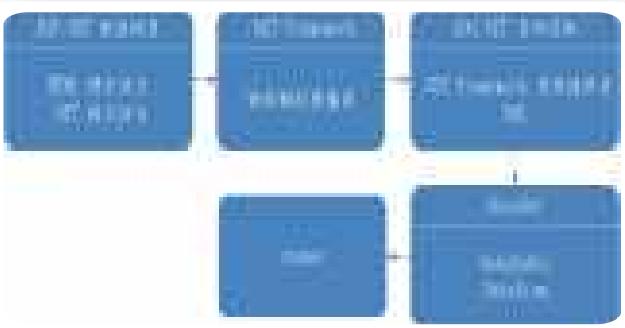


Fig. 3. Developing of the knowledge platform

Users can search for relevant reports by keywords, the data has been classified in an intuitive and clear way. Fig. 3 shows the development process for this knowledge platform. The maintenance and management in the future can be carried out in accordance with this simple structure, and the platform data content can be expanded or improved according to the needs of the control unit.

Table 1. International Status (Japan)

The content in line with international trend and updated frequently (Table 1). Since this platform focuses on relevant regulations and case experiences in the transitional stage of the pre-decommissioning, in the current situation of Taiwan, this is a case that has not occurred in other countries. The knowledge platform provides and records the complete experience cases of the transition period, thereby benefiting NPPs in terms of maintenance and management of nuclear power plants.

In the transition period of the pre-decommissioning for domestic nuclear power plant , the unexpected events and cases abroad (Table 2) are quite worthy of reference in decommissioning preparation work.

In the future, this knowledge platform will expand more classification topics, such as maintenance management strategies for nuclear power plants that are still in operation (Fig. 4), emergency response procedures for unintended events, fire regulations, equipment certification, and other issues of decommissioning equipment.

Table 2. Unexpected events (from IAEA)

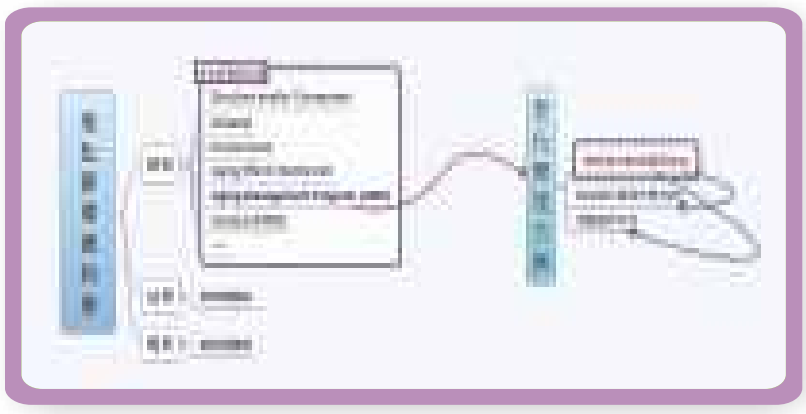
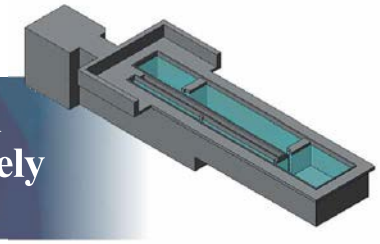


Fig. 4. Structure of maintain management

Finally, the maintenance management and other related information about regulatory activities of the platform is expected to draw a more solid and complete draft guide.

3-1-6

The Major Milestone of the Nuclear Research Facility Decommissioning in Taiwan-Completely Pool Water Treatment



The TRR is the largest nuclear research facility under decommissioning in Taiwan and the cleaning of spent fuel pool is the phase one primary activity and the completely pool water discharged is the significant milestone in 2018 for INER. In the past, elements include spent flow tubes, spent fuels, spent resins, isolation tank and thousand cubic meter of contaminated water are the major challenges for the pool cleaning (Fig. 1). The cleaning technologies, dismantling methods and treatment units were developed according to the principles of prevention contaminants spread, radiation protection for workers and secondary wastes control. Finally, the we erase the potential risk of the contaminants leakage by overcoming the space limitation, adapting suitable radiation shielding and simplifying the operation procedures.

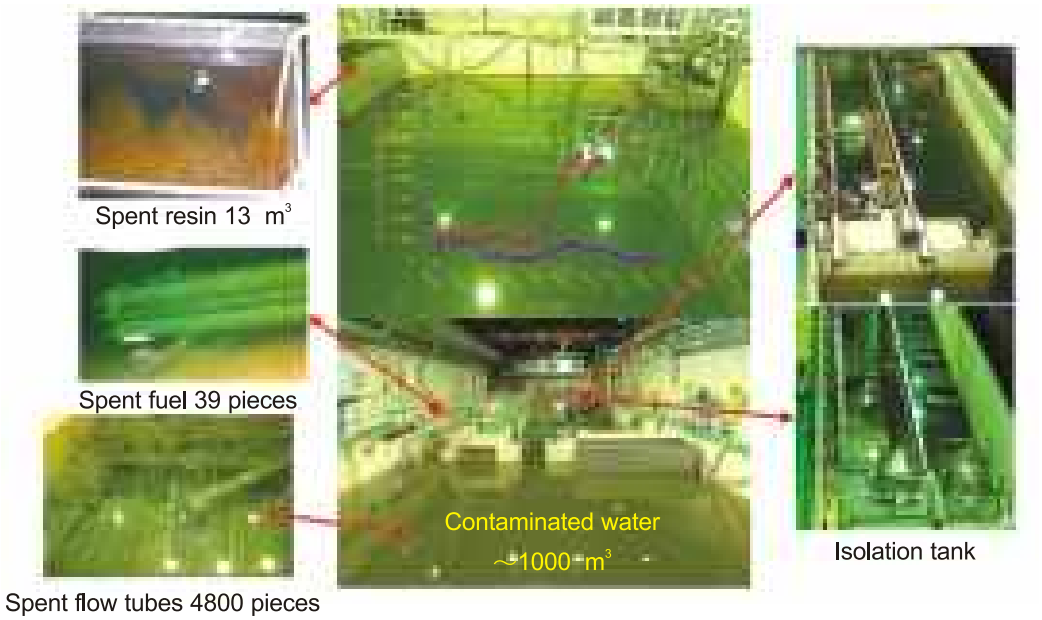


Fig. 1. Items required for cleaning in TRR spent fuel pool

Cleaning history

During the retrieval of spent fuel rods and spent resins, to maintain a significant water was necessary for radiation shielding. The removal of spent fuels and spent resins were respectively completed in 2012 and 2014.

Approximately 1000 m^3 of pool water was contaminated by spent fuel debris with high Cs-137 content and was required to be treated before pumping to the liquid treatment plant in INER. Hence, two stages treatment strategy were therefore proposed, 90% of radioactivity was firstly removed in spent fuel pool using adsorption, flocculation and filtration technologies. Furthermore, the treated water was pumped out step by step according the isolation tank dismantling schedule to protect the environment and workers (Fig. 2).

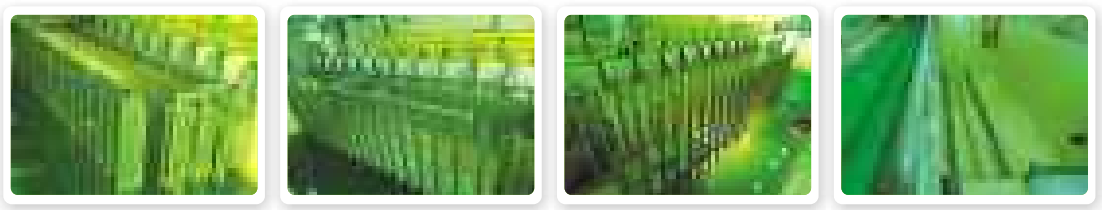


Fig. 2. Dismantling status of the isolation tank in the TRR spent fuel pool

Water treatment and secondary wastes control

All the water treatment units for first stage were installed in the pool (Fig. 3) to prevent contaminants spread.

- Adsorption:After screening various adsorbents, one of proper inorganic adsorbent was selected. The simple disassembled adsorber unit was designed by consideration of further packaging.
- Flocculation:The inorganic flocculant with good removal efficiency for suspended solids was employed.
- Filtration:To avoid much secondary wastes the ceramic filters were not used, but bag filter was employed for the treatment of supernatant.

After completely treated 1000 m^3 of water in first stage，2.8 m^3 of secondary wastes include used adsorbent, sludge and filters were generated. The treatment experiences are very attractive for the members of OECD/NEA Cooperative Program on Decommissioning Technical Advisory Group.

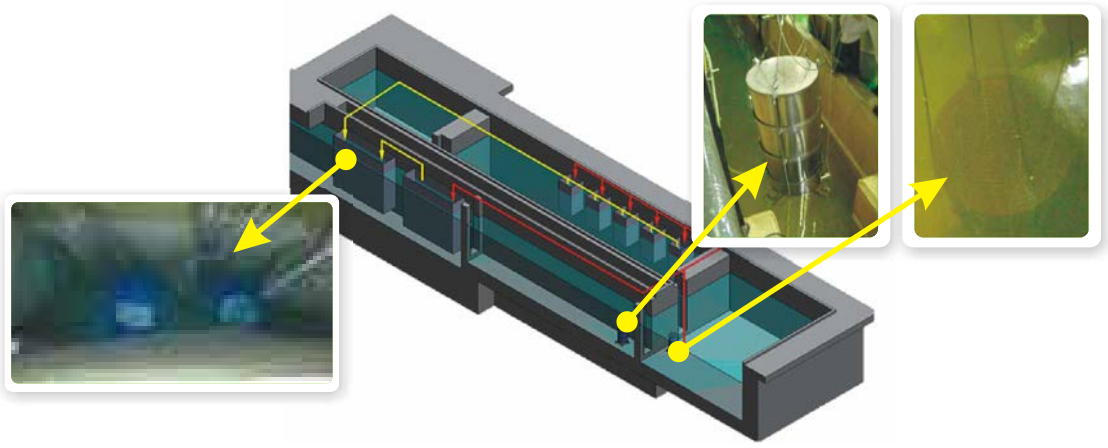


Fig. 3. The installation layout of the water treatment units

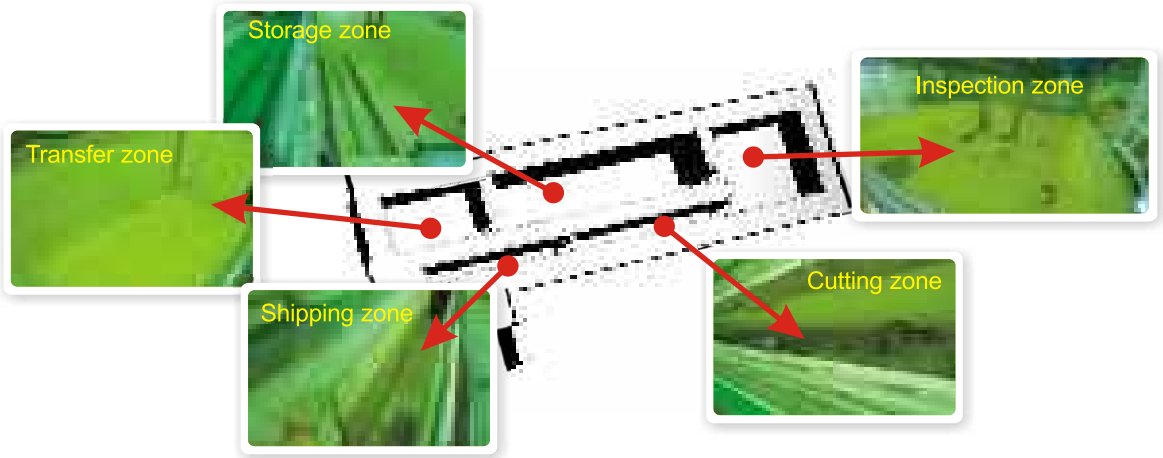
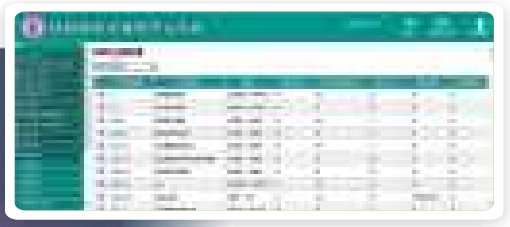


Fig. 4. The image of each zone in the TRR spent fuel pool after water discharged

To achieve the cleaning target of TRR spent fuel pool, INER invest many efforts to clarify problems, select proper technologies, verify process and control wastes. In terms of the treatment technologies of fuel debris contaminated water, the employed materials, units and handling mechanism were self-developed. The mythologies of INER' s experiences in the cleaning of TRR spent fuel pool are attractively for similar international organizations.

3-1-7 Knowledge Management and Technique Heritage-Construction of NPP Decommissioning Information Management System



Nuclear power plant (NPP) decommissioning is the final stage of the NPP life cycle. Because the NPP decommissioning operation is complex and takes a long period, it is suitable to be managed by a large-scale project. By the effort of professional team and implementation of the decommissioning information management system (DIMS), the data related to NPPs can be systematically collected, analyzed and managed which include the design, construction, operation and maintenance of materials such as plant, architecture. By the way, engineering drawings such as structures, systems, components are converted into 3D models which bring huge benefit to implement the NPP decommissioning plans, knowledge management and technology transfer.

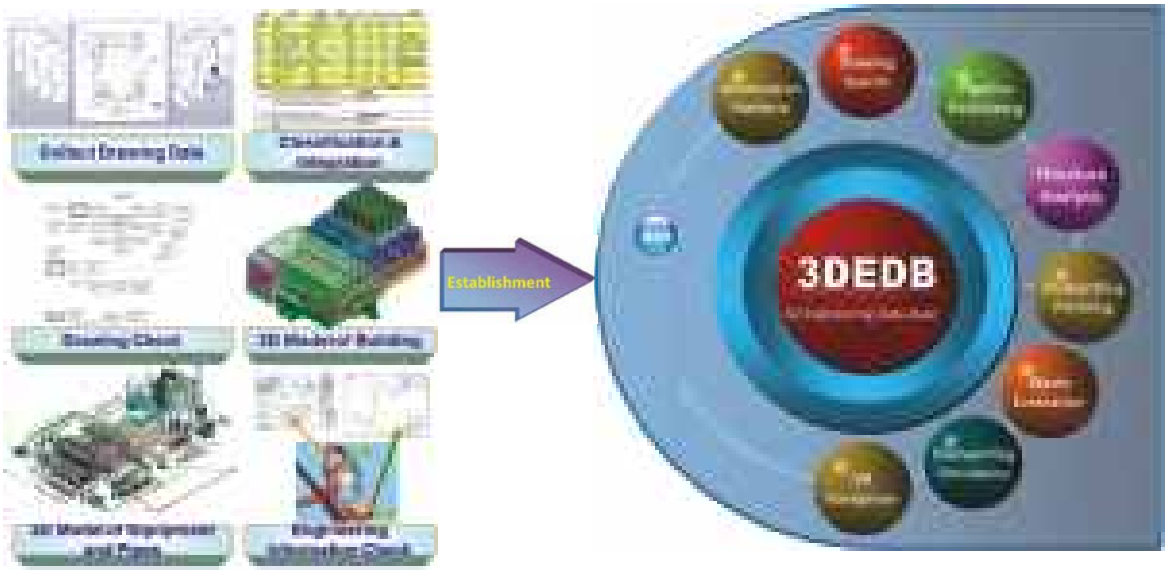


Fig. Process for the construction of 3D engineering database

Mission and Challenges

The Unit 1 of Chinshan NPP has been permanently shutdown and entered the decommissioning phase on December 5, 2018. Comply with government policies and the needs of domestic NPP decommissioning technology R&D, INER has undertaken the NPP decommissioning planning project entrusted by Taipower Company. The challenge faced: how to integrate engineering information such as engineering drawings and system data, from design, construction to operation which are essential for NPP decommissioning, also feed into knowledge management domain, and provides the basis for subsequent implementation of cost estimation, radioactive waste inventory, dismantling management, radiation protection and administrative management.

Fig. Integration of 3D Models and radiological characterization data

Fig. System Structure of NPP information management system

Planning and Implementation of DIMS

The design of DIMS is based on the implementation of NPP decommissioning plan, and the development of sub-systems of DIMS including project management, historic site survey, radiological characterization, dismantling management, waste management, knowledge management, radiation protection, cost estimation and integrated management, which systematically preserve knowledge of decommissioning technical reports, articles, 3D models, engineering simulations, VR training, and utilize as the basis for future development of dismantling technologies and provide knowledge management capabilities for technical inheritance.

Throughput and Benefits

1.Establish 3D models with engineering data of structures, systems, components, and various functions such as radiation protection, knowledge management, risk management and waste management, which benefit the subsequent stages of decommissioning .

2.Integrate databases such as planning, cost estimation, waste, radiation and 3D simulation, and establish knowledge management functions to store NPP decommissioning related documents, drawings, 3D models, etc., and achieves the goal of technology inheritance and talent cultivation.

Fig. Gann Diagram for WBS

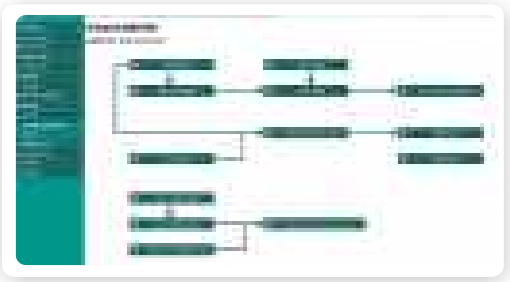


Fig. Maintenance of cost estimation data

Fig. Query for pipelines

Fig. Monte Carlo Risk Analysis

Future Planning and Application

1.Complete the integration of DIMS and 3D engineering data, carry out the simulation of structures, systems, component segmentation and waste packaging.

2.Establish waste tracking and management functions, including the history and tracking for waste sorting, packing, transportation and storage.

3.Establish the NPP 3D model combined with radiation mapping and VR training environment to provide immersive drills for decommissioning workers.

3-1-8

The development of INER-LRW-C1 low level radioactive waste container to promote the flexibility of radioactive waste management in Taiwan

No-nuke homeland is part of the environmental policy in Taiwan. To reach this goal, Unit 1 of Chinshan Nuclear Power Plant has permanently shutdown and entered to the decommissioning phase in last December. Besides, Taiwan Research Reactor will be dismantled in the coming years. Dismantling nuclear facilities will produce lots of low level radioactive wastes. Efficiently handling theses wastes could significantly reduce the resources of decommissioning activities. Therefore, Institute of Nuclear Energy Research has developed INER-LRW-C1 low level radioactive waste (LLW) container to promote the container selection flexibility during decommissioning.

Fig. External dimensions

Design specification

INER-LRW-C1 LLW container is devised to store and transport low specific activity materials (LSA) and surface contaminated objects (SCO). Its design gross weight is 3,200 kg, and it has 20 year design service life. This container is constructed by low carbon steels and is coated with hot dip galvanization and epoxy to promote the capability of erosion resistance. 30 bolts are used to fasten the lid and container body, and a gasket is installed between the lid and body to keep the confinement function.

Analysis

Before INER-LRW-C1 was fabricated, a total of 3 conditions were evaluated numerically to meet the design proposes, including lifting, stacking, and dropping analyses. The evaluation results met the design requirements.

Fig. Lifting analysis

Fig. Stacking analysis

Fig. Dropping analysis

Fabrication

INER entrusted domestic vendors to produce a prototype of INER-LRW-C1 LLW container. The fabrication was mainly consisted of steel sheet forming and welding, hot dip galvanization, and epoxy coating processes. After the testing, the mass production capability of the container was confirmed.

Fig. After hot dip galvanization

Fig. After epoxy coating

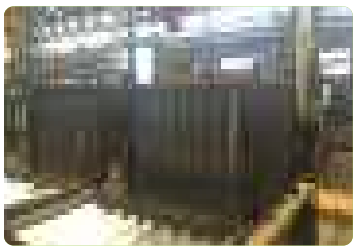


Fig. Fixing during welding

Test

The regulation requirements including spray, vibration, lifting, penetration, stacking, and dropping tests must be performed before applying the operation license. Here, the dropping test includes side and edge/corner droppings. After all the tests, INER-LRW-C1 LLW container met all the requirements of the corresponding regulations.

Fig. Spray test

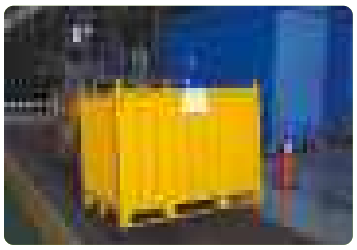


Fig. Vibration test

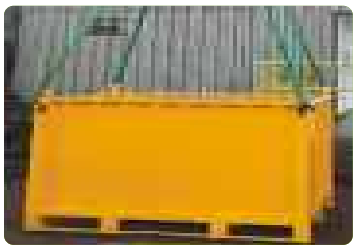


Fig. Lifting test

Fig. Penetration test

Fig. Stacking test

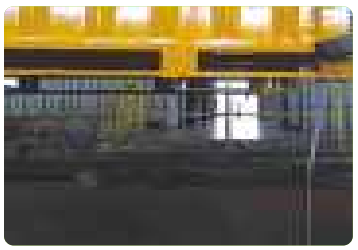


Fig. Side dropping test

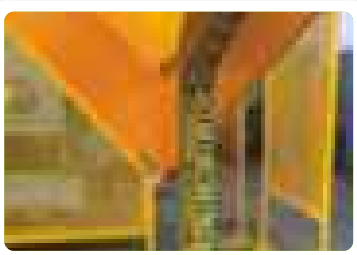
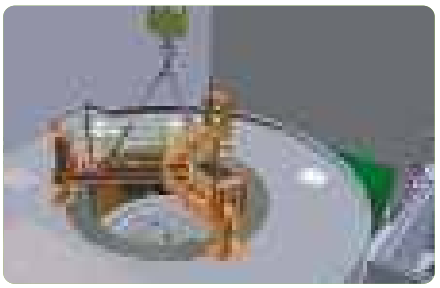


Fig. Corner/edge dropping test

INER-LRW-C1 LLW containers have already passed the corresponding analysis and test requirements of the storage and transportation regulations. The operation license application will be proposed in 2019. After the license is granted, the container will be used to store and transport LSA and SCO wastes to save the associated resources spent on decommissioning.

3-1-9 Development of crucial dismantling tools for TRR



Dismantling Plan for TRR

Dismantling Plan

- Taiwan Research Reactor (TRR) have been dismantled and stored safely, At present, INER have followed the regulation to complete the "Dismantling Plan of Taiwan Research Reactor (TRR) ", and submitted to the competent authority for review.
- The dismantling operation schedule will begin on January 1, 2021, and complete on December 31, 2027.

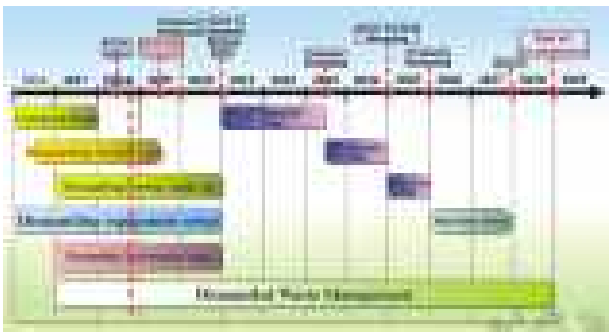


Fig. Dismantling schedule

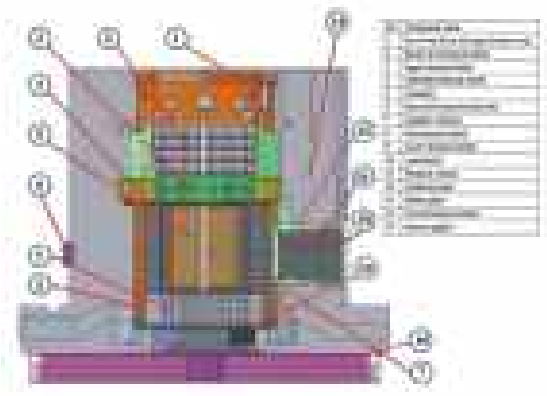


Fig. The components of reactor waste

Strategy and method

- The reactor type of TRR have no precedent in the international decommissioning experience. Therefore, it is necessary to develop the dismantling method and technology by INER.
- In the dismantle strategy, the components of TRR will be completely removed from top to bottom, from inside to outside, and then segmented piece by piece for further packaging.
- The high-activity components are planned to be shielded by the underwater environment and remote operation to meet the ALARA (as low as reasonably achievable) principle.

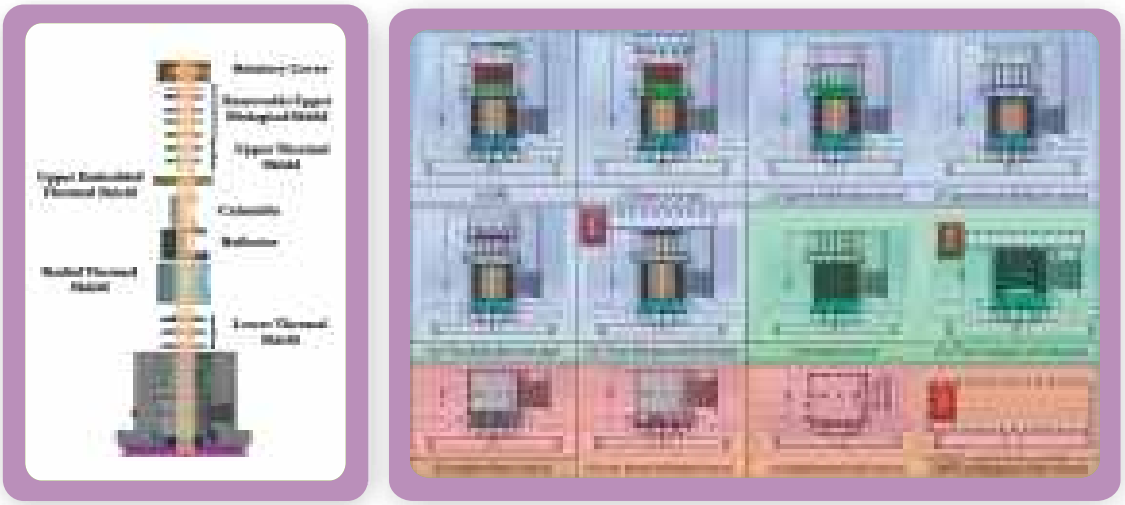
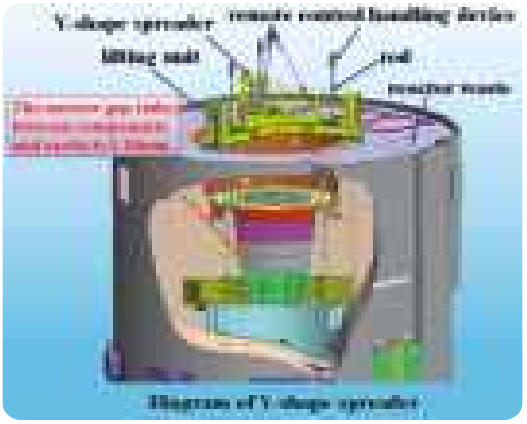


Fig. TRR dismantling procedure

Dismantling technology for TRR

Development of 3D engineering simulation technology

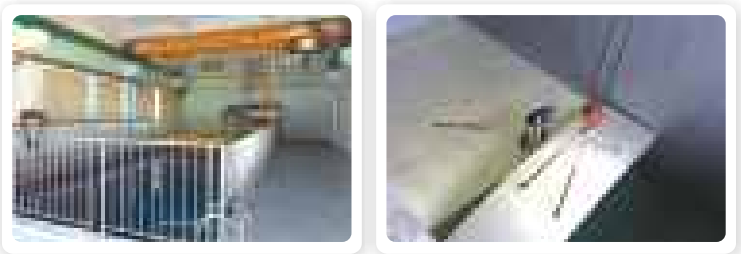
Through the complete and accurate design data of the manufacturer's drawings and technical reports, INER have established TRR digital 3D model database. It will provide as the basis to develop the engineering simulation of dismantling, packaging, lifting, transportation, radioactive waste management and personnel training of TRR decommissioning.



Dismantling tool design

- Handling tool design : the remote-handling tool that have the special device composed by controller and operation rod have been completed, it can get over the problem about high radiation dose rate and the margin between components and bio-shield .
- Development of underwater remote control cutting tool : in preparation for cutting tools of dismantling tasks, it is hard to obtain items that can be directly applied and functioned immediately in the commercial products. Hence, INER are working on cutting tools development including all the designing, manufacturing and demonstration. The most representative indicator of the cutting tools is a circular saw for the TRR calandria.
- Build up the mockup facility : Through the mockup testing of dismantling scenes condition with the physical model meets the cutting capability verification and dismantling requirements.

Fig. Diagram of circular saw



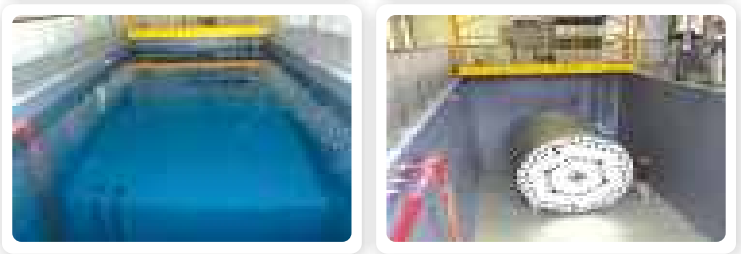


Fig. Mockup facility and physical model construction

3-1-10

Evaluate the Performance of Canister after Closure on Isostatic Pressure, Vibratory Ground motion, and Earth quake induced Fracture displacement

INER carries on the performance evaluation on canister used in the spent nuclear fuel final disposal program. The spent nuclear fuel disposal program adopts the "KBS-3 disposal concept". Multiple barriers including canister, buffer, backfill, and host rock are used in the concept. Spent nuclear fuels will be emplaced in the canister, and surrounded by buffer materials, and will be backfilled in the deposition tunnels which are covered in the depth of about 400 meters to 700 meters under ground level.

Because of disposal depth, canister must to withstand the pressure caused by groundwater, soil and rocks, as well as the effects of earthquakes such as vibratory ground motion and earthquake induced fracture shear displacement on the disposition hole. Therefore, INER perform the numerical analyses using Abaqus code to quantify the effects on canister, and the results show safety margins exist under current design requirement. Through the development, the information for canister performance can be obtained to ensure the safety of final disposal and increase public acceptance on final disposal activities.

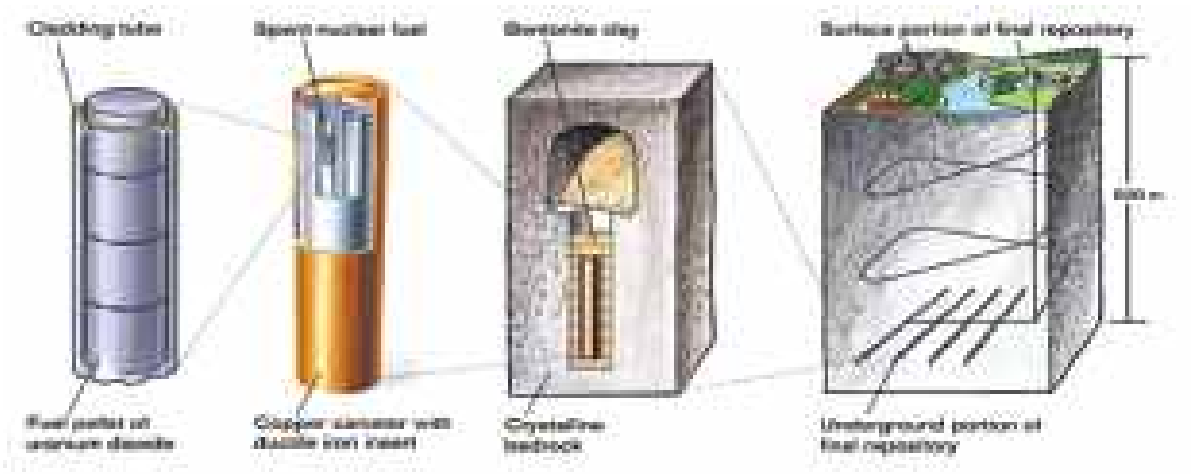


Fig. The deep geological disposal method

Abaqus code is a software suite for finite element analysis. Not only structural problems can be solved, but also metal-to-soil contact problems between canister and buffer materials are easily to handled. Hence, Abaqus code has widely adopted among international final disposal research communities. For isostatic pressure numerical analysis, the finite element model has been established, and the results show (in the right figure) safety margin exists compared to allowable stress.

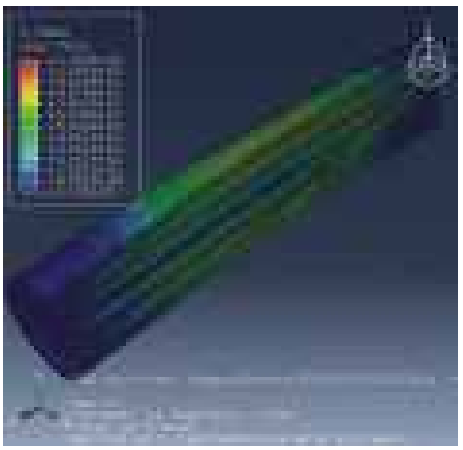


Fig. Von Mises stress under isostatic pressure for canister by Abaqus code

Fig. Seismic test sample and measurement sensor setting

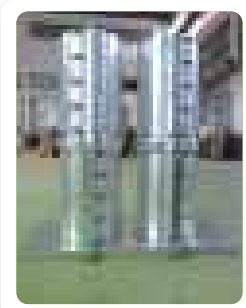
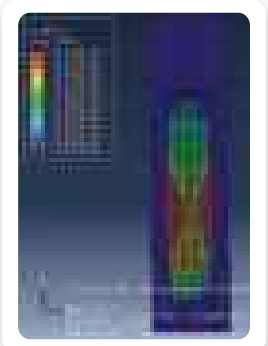


Fig. The centrifuge and the test fixture in NCU

For the influence of earthquake induced fracture displacement on canister, the canister and buffer integrated model is built in Abaqus code, and numerical analysis is performed. The result shows margin exists under current design requirement. INER also compare with other literature to verify the analysis technique.



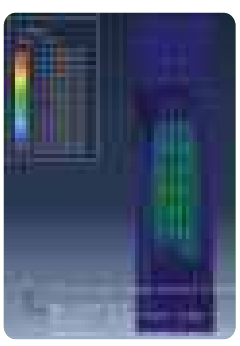


Fig. Earthquake induced Fracture Shear Displacement on the canister

In terms of vibratory ground motion effect, INER collaborate National Central University to conduct seismic experiments. Referring to KBS-3 concept and geometry, the test model is built with 1/10 scale of prototype. Through the centrifuge modeling, 10 g artificial acceleration field is created to simulate in situ stress of canister from buffer material. Seismic events of shaking table are simulated with 15-cycle sinusoidal waves. During shaking, acceleration, pore water pressure and total pressure histories are measured as the benchmark for numerical model. Abaqus model is created, and the model has been calibrated with the experiment conditions and measurements. The results (shown below) show the consistency in the natural frequency and acceleration responses.

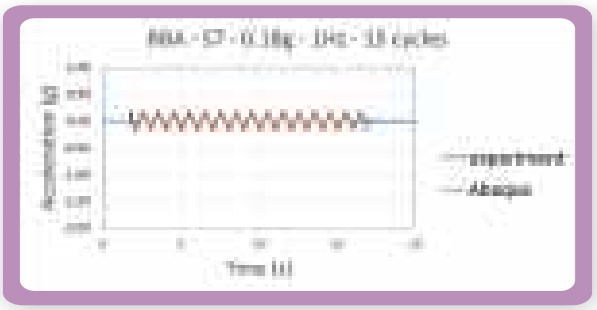


Fig. Compare the shaking test results with the Abaqus model

In the future, the improvement of numerical analysis model technique for canister will be enhanced. According to the design requirement based on different site conditions, the information can be provided to meet the long-term safety function of the canister is satisfied.

3-1-11

Introduction of the methodology of safety assessment for Spent nuclear fuels final disposal repository

A safety assessment is consisted of a series of analyses and assessments of all aspects of the system functions to identify the potential behaviors and effects that are relevant to safety. Logical methods are employed to analyze the characteristics, design and related risks of the repository site and to determine their compliance to the safety requirements. A safety assessment should include comprehensive quantitative analyses of the safety functions of the disposal facility, relevant uncertainty analyses and the comparison of engineering design requirements to the safety standards. The safety assessment should also be used to evaluate any scientific knowledge and data that can affect the results of the assessment, as well as to analyze any potential uncertainties.

The results of the safety assessment verify the safety functions made possible by the individual systems in the disposal facility. For this reason, the methodology recommends importing the concepts and processes of safety functions and safety function indicators and combining them to the front-end engineering design in order to predict the behavior of the disposal system in terms of the individual safety functions. The projections serve as feedbacks to the engineering design to ensure that the designed functions remain effective. The procedure also builds up confidence in the safety functions of the disposal system.

The safety assessment method is modelled after the SKB-developed SR-Site 11-step procedure, which are then revised to meet the local conditions in Taiwan and transformed into the relational diagram(Fig. 1).

The procedure begins with the development of a FEPs (Features, Events, and Processes) database by screening to identify the FEPs that are to be considered in the assessment of the disposal facility in Taiwan (Fig. 2) (Step 1).

Fig. 1. The relational diagram of safety assessment methodology

The researchers examine how the external conditions, compiled as part of the FEPs, affect the disposal system, including the issues related to the global warming and the future human actions (Step 3). The researchers proceed to perform an experiment and simulation modelling of the interactions between the confirmed FEPs(Step 4). The individual safety function indicators for each system in the disposal facility are also made (Step 5). In the quantitative analysis as a phase of the safety assessment, the related parameters are compiled according to a conceptual geological model (Step 6). The reference evolutions that can potentially affect the repository over the period of the safety assessment time scale are developed at this stage (Step 7). A combination of the work accomplished from Step 3 to Step 7 leads to the development of a main scenario and building of a base case(Fig. 3). A series of variant cases can also be systematically put together (Step 8). The doses as a result of the radiation exposure in the individual cases are calculated with the assistance of an integrated full-system model (Step 9). In addition, some external conditions that are considered significant perturbations are analyzed under the case study of the perturbation scenarios in Step 10. Finally, through the impact analysis of different scenarios at every step along the way, the safety assessment produces several conclusions (Step 11).

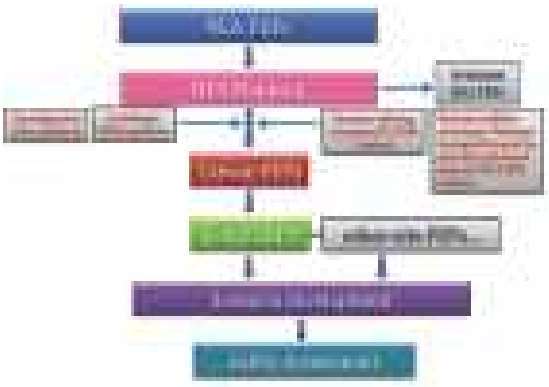


Fig. 2. The construction concept of Taiwan FEPs database

Fig. 3. The classification of scenarios and cases

The safety assessment is the best way to quantitatively demonstrate the credibility of the long-term safety of the disposal facility. The multilateral exchange of feedbacks from the geological survey, engineering design and safety assessment will optimize the repository design, improve the technological feasibility and maximize the cost-effectiveness.

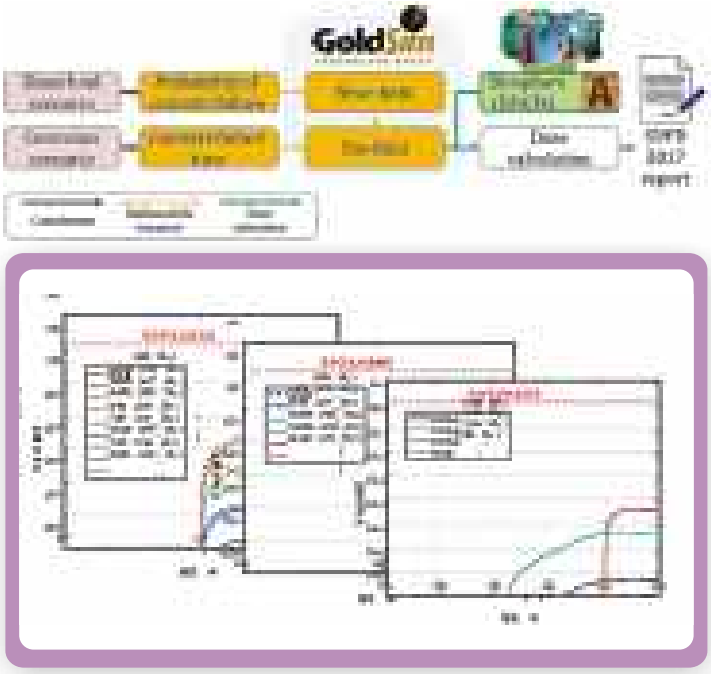


Fig. 4. Modeling and quantitative Analysis of radionuclides transport by GoldSim and results of safety analysis

3-1-12

The calibration technique establishment and performance assessment of soil activity screening system

In this study, a soil phantom used to evaluate the soil activity screening system had been developed for the purpose of measurement the radioactivity contained in soil in INER. The performance of this system was verified according to the ISO standards, and the results could be used as reference for the planning of the classification of contaminated soil.

For the decommissioning of nuclear facilities in Taiwan, a large number of extremely low activity solid wastes that may be produced at the site, if such as all treated as radioactive waste, it may increase the subsequent disposal cost. Therefore, various types of measuring instruments for those waste have been developed in INER since 2003. Currently, several sets of large-scale waste measuring systems have been established and applied for the radioactive waste classification measurement process.

The objective of this study is to establish calibration techniques for the screening system for soil waste that may be generated by the decommissioning of nuclear facilities in Taiwan. The investigation level of soil Cs-137 from environmental radiation monitoring regulation and the acceptance criteria of low-level contaminated soil radioactive waste underground storage facility were used as the soil activity screening levels, as shown in Fig. 1.

In the study, the area sources were prepared by using a standard Cs-137 liquid source which was traceable to the National Radiation Standard Laboratory (NRSL) in INER. The completed area source could be divided into four activity values, namely 2,000 Bq/piece, 8,600 Bq/piece, 34,300 Bq/piece and 143,600 Bq/piece.

In order to evaluate the uniformity of those area sources, the testing was performed by using a shielded NaI detector, as shown in Figure 2. The testing result of uniformity showed that all radioactive levels of area sources were within the error range of ± 10 %.

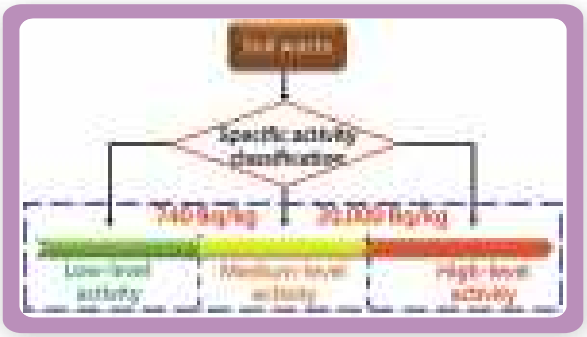


Fig. 1. The soil activity screening levels

Fig. 2. Uniformity testing for different radioactivity levels of area sources.

The source location and container specifications used in the soil phantom were shown in Figure 3. In this study, the soil filling rate of the container was designed to be about 50%. The differential activity of area sources were placed in specific positions to simulate a uniform volumetric source. By combining different radioactivity area sources, the Cs-137 specific activity of the phantom was obtained from 100 Bq/kg to 24,000 Bq/kg to use for testing and calibration of the measurement system.

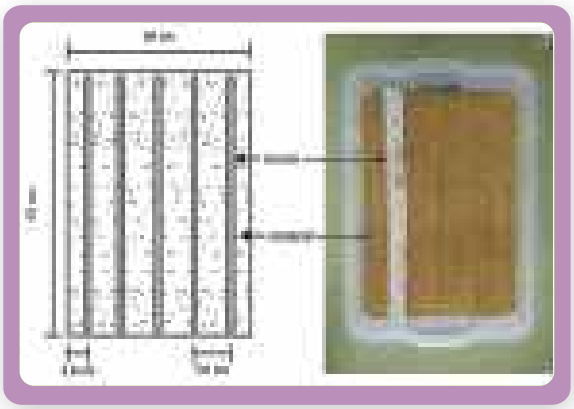


Fig. 3. Specification for soil phantom.

In terms of system performance evaluation, it showed that the measurement bias were all less than 20% when using different radioactive levels of soil phantom (see Fig.4). Furthermore, in Fig.5, it showed that the MDA (Minimum of Detective Activity) of Cs-137 could be reached around 30 Bq/kg with 1 minute counting time. In accordance with ISO standard (ISO GUM), the combined standard measurement uncertainty of 13.2% for Cs-137 in soil was also evaluated by accounting for the uncertainty from standard source, net counting rate etc. (as shown in Fig. 6).

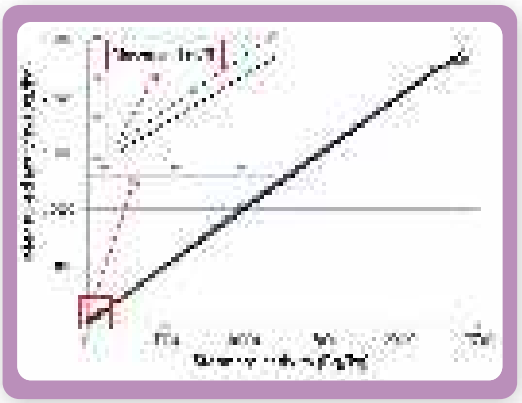


Fig. 4. Comparison between measured and standard activity.

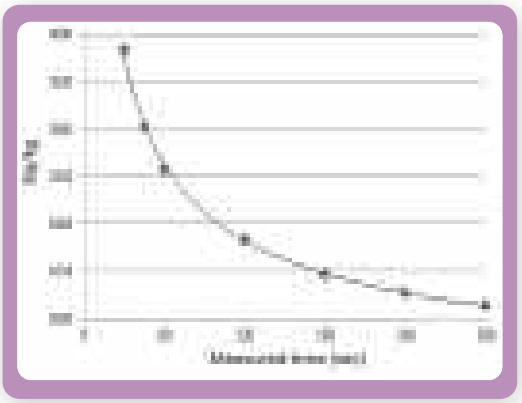


Fig. 5. MDA evaluation for Cs-137 with different counting time.

Item analyzed	Relative standard uncertainty (%)	
	Class A	Class B
Standard source: Provided by NRSL Decay of radionuclide Gamma-ray emission probability		 0.75 0.27 0.24
Net counting rate	2.99	
Background peak-area variations	1.47	
Efficiency calibration	0.76	
Weighing	0.03	
Long term stability	2.78	
ACD live		0.003
Full energy measurement	4.87	
Combined standard uncertainty (k=2)	13.2	

Fig. 6. Measurement evaluation for Cs-137 in soil.

In this study, the performance evaluation of the soil activity screening system has been demonstrated by considering the measurement accuracy, stability and uncertainty through the soil calibrated phantom. This result could provide as a reference for the classification of soil samples produced from the decommission sites in the future.

3-1-13

Introduction of the SNFD2017 Report – the milestone of the first stage of the Spent Nuclear Fuel Final Disposal Program in Taiwan.

The schedule of this disposal program in Taiwan is from 2005 to 2055. The aim of the first stage, period from 2005 to 2017, is not only to complete the investigation and evaluation of the potential host rock and the suggestion of the survey area, but also to establish the performance/safety assessment technology, and complete the feasibility assessment report for the Spent Nuclear Fuel Final Disposal in Taiwan (SNFD2017 Report) as the milestone. This means that domestic preparatory work before siting stage has the appropriate technical capabilities to meet the challenges of the future stage.

The program is promoted by Taipower Company (TPC) with the technical research and development teams including INER and the Industrial Technology Research Institute (ITRI). Site investigation is led by ITRI, and two core technologies, namely facility design and engineering technology and safety assessment, are developed by INER. At this stage, under the situation of no candidate site is selected, the development of technology has met the needs of this stage, and can further link the R&D plan of the subsequent siting stage.

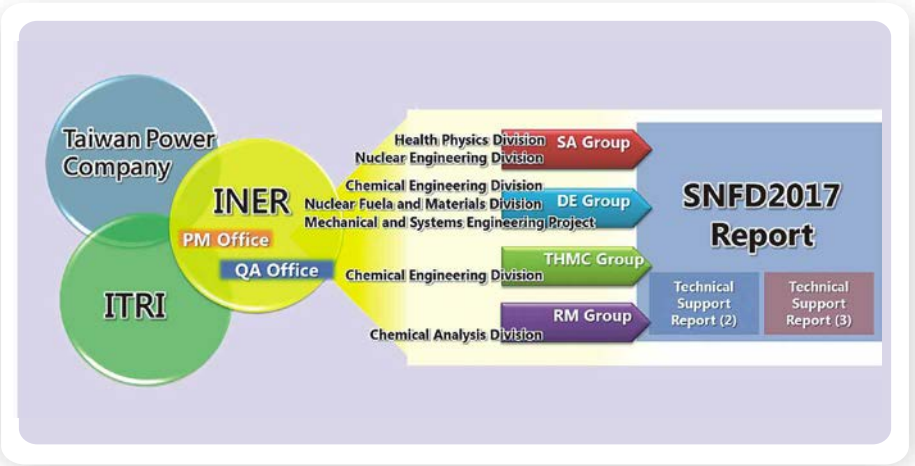


Fig. INER has joined the R&D team to promote the project.

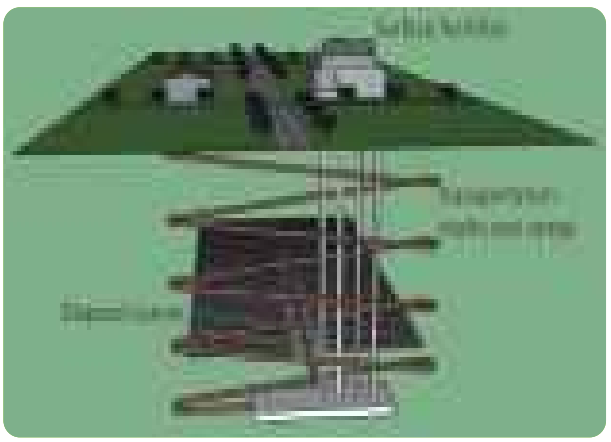


Fig. The concept of the disposal facility designed by INER was shown in SNFD2017 report.

Development of concept design in SNFD2017

Based on the preliminary feasibility study results proposed in 2009 and the current geological information of Taiwan, granite is the priority potential host rock to be evaluated. Thus, INER adopted the Swedish KBS-3 disposal concept as the basis, and gradually developed the concept design capability of deep geological disposal with the reference case of the granite virtual site, and established various performance evaluation techniques, including the calculation tools, numerical models, test techniques and evaluation methods required.

Development of safety assessment in SNFD2017

Based on the safety requirements of the disposal facility, the disposal system composed of engineering and natural barriers must be able to achieve the functions of containment and retardation to isolate the radioactive material for a long time.

The safety assessments have considered the effects of external conditions such as climate change, regional geological processes, future human behavior and the effects of internal processes. The features, events and processes (FEPs) database was constructed for the effects screening, then develop various safety function indicators of the disposal system.

Fig. The framework of safety assessment for SNFD2017

Through the scenario development, analyzing the cases of corrosion, shear load and confining pressure failure, followed by quantitative calculation, and also carry out case analysis of the extreme global warming and seismic frequency, and future human activities as the disturbance scenarios were all conducted. The safety case study has been completed totally and discussed in SNFD2017 report.

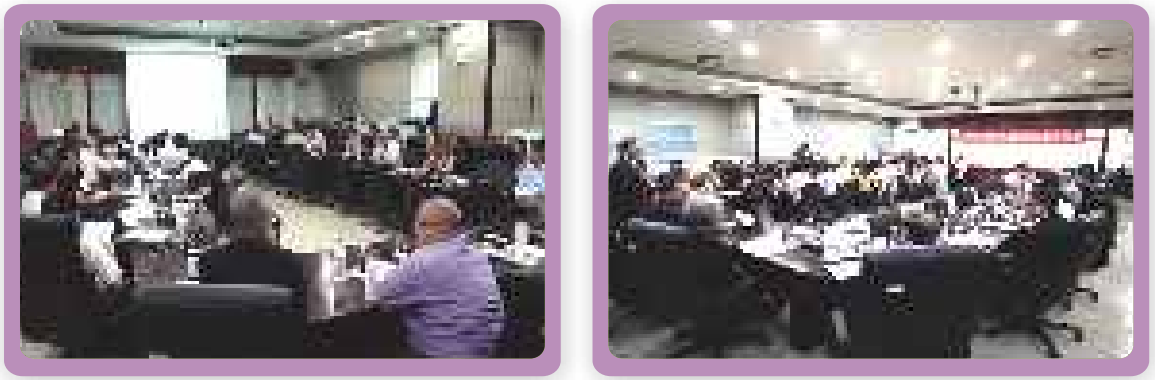


Fig. The US-Taiwan disposal technical seminar (left) and the Taiwan-Japan disposal technical seminar (right) were held during the review of SNFD2017 Report.

INER's development of the disposal facility design and engineering technology, as well as the core technology of safety assessment, has demonstrated the technical capabilities in SNFD2017 report. The regulatory authority, AEC, conducted a one-year review process in 2018. The conclusion of international (US and Japan) peer experts review meetings, according to international standards and experience, the results of the SNFD2017 report are suitable for upcoming decision-making. Also, its proven site investigation, repository engineering and safety assessment capabilities and technical capabilities are sufficient to allow Taiwan's disposal plan to move forward.

INER will continue to actively promote the R&D project. In line with the schedule of disposal program, the R&D technology will be kept up with the times and also the quality improvement.

3-1-14

Improvement of The Storage Safety of Radioactive Organic Liquid Wastes-Establishing The Technical Procedure of TOC Degradation by Advanced Oxidation Method

Introduction of The radioactive wastes from small producers

The radioactive wastes from small producers are generally generated from nuclear application of radioisotope in medicine, industry and agriculture have been stored in INER. INER have also received low-level radioactive liquid wastes generated from domestic hospitals and research institutions in Taiwan. The most proportion of the radioactive waste from small producers is liquid form with organic compounds. With the stricter tendency of environmental and safety requirements, the treatments of radioactive liquid waste containing organic compounds have become one of the most important issues in the field of nuclear facility. In order to reduce the risk of those hazardous radioactive organic liquid wastes, we have established a feasible treatment technology to degrade organic compounds by utilizing Fenton-like reaction.

Fig. The support service of radioactive wastes from small producers by Institute of Nuclear Energy Research in various field of radioisotope application.

The development of ferrite catalysts for Fenton-like reaction

The mixture of liquid wastes stored in T61 tank has been separated into oil (upper layer) and aqueous layer (lower layer) by natural sedimentation for decades. The organic oil phase is unstable and flammable so that the immobilization or incineration of the oil wastes provide a feasible method for further volume reduction treatment and disposal. As regards the aqueous wastes containing organic compounds, Fenton oxidation technology is the general strategy for the treatment of organic compounds-contained wastewater. The degradation of wastewater pollutants in heterogeneous catalytic Fenton system were developed as a feasible and environmentally benign process. Therefore, the heterogeneous catalysts of ferrite oxide (Cu-Fe-Ce-O) were prepared and utilized in Fenton-like reaction for the TOC degradation treatment of the aqueous phase of radioactive wastes from small producers.

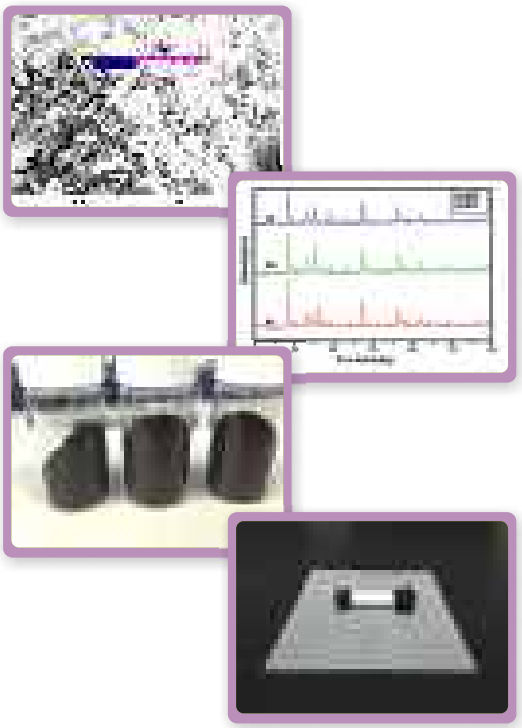


Fig. The morphology, XRD characterization, and samples of ferrite-based catalysts fabricated by co-precipitation method

Fig. The ferrite-based catalysts patents issued by TIPO and USPTO

The control factor and the effect of the TOC degradation process

It was known that H_2O_2 was reactive and unstable reagent under thermal or light condition, which leading to the production of OH radicals for the oxidation and degradation of organic components. For the TOC degradation treatment of the aqueous radioactive wastes, the heterogeneous catalysts based on ferrite oxide (Cu-Fe-Ce-O) were applied for Fenton-like oxidation of simulated and actual radioactive organic wastewater was investigated. The results of TOC decomposition efficiency around 54% ~ 99% were obtained when the catalyst loading, H_2O_2 loading, pH, temperature, and reaction time were controlled. In this case, only small amounts of wastes formed from and the given catalysts were able to be separated by magnetic devices and to be reused again.

Fig. The process of the TOC degradation (upper images) and the final samples after treatment (lower images)

The patents issued by TIPO and USPTO

Fenton reagent, developed by H. J. H. Fenton in 1890s, has still attracted much attention in the application of the treatment of wastewater containing organic pollutants. Taking account of the ferric sludge formed by homogeneous Fenton reaction, heterogeneous catalysts based on iron oxide were studied, and their magnetic properties allow their easy, fast and inexpensive separation from the treated medium. The fabrication process for ferrite-based catalysts used for heterogeneous Fenton-like reaction have been applied for the patent and issued by TIPO and USTPO. The ferrite -based catalysts with magnetism are formed by using co-precipitation method and the cost of the process is relatively lower than other process such as hydrothermal technique, microwave-hydrothermal, sono-chemical, sol–gel, supercritical hydrothermal reaction, and supercritical anti-solvent precipitation.

Fig. The apparatus of TOC degradation of aqueous radioactive wastes for Fenton-like reaction

In this work, ferrite-based catalysts were prepared and applied in the Fenton-like oxidation reaction instead of using traditional water-soluble catalysts and commercial available catalysts. According to the results of catalytic oxidation, the TOC concentration of either simulated solution or aqueous radioactive wastes were reduced obviously with small amounts of forming sludge. It was also found that using patented catalysts is very helpful and feasible for the improvement of TOC degradation.

3-1-15

Developments and Applications of High Performance Concrete Container (HPCC)

The HPCC for low-level radioactive waste with long-term stability has successfully developed by chemical engineering division of INER (Fig. 1). It was approved by Fuel Cycle And Materials Administration (FCMA), Atomic Energy Council (AEC) of Taiwan in July, 2016. The container has been commercially produced and developed in Kuosheng Nuclear Power Plant as the direct overpacking of swelled waste form and corroded, deformed drums. The technology license of the container and Kuosheng Nuclear Power Plant procurement contract with a total of 800 containers have been successfully gained by Lion-Young Co., Ltd.. INER will continue to develop High Integrity Container (HIC) with the operational life of 300 years in the future, and external part of the container will be strengthened with stainless steel coating (Fig. 2) to enhance its structural integrity.

Fig. 1. HPCC finished products

Fig. 2. Production process of stainless steel coating

The container can be used for the stabilization of radioactive waste which is difficult to solidified in existing power plant. As the overpack of wastes, it can be transported to the final repository site directly, which increases the safety of disposal process and the stability of engineering barrier system. The total output value is over 1 billion. The HPCC has been included in the decommissioning plan of nuclear power plant (Fig. 3) with an output value of more than 3 billion.

Fig. 3. Containers loading and transportation

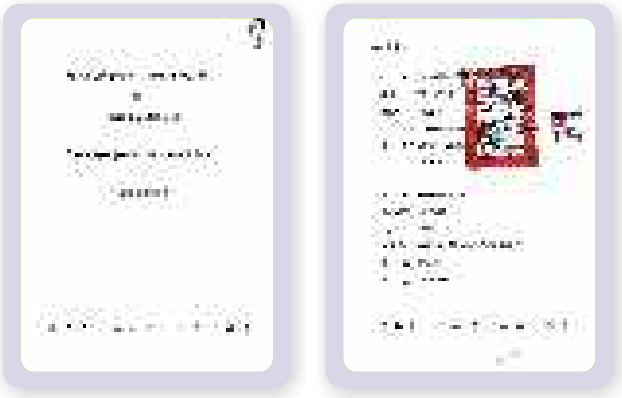


Fig. 4. The technology license of HPCC

The container developed by INER is the first one in Taiwan with final products passing the inspection of Nuclear Safety Department of Taiwan Power Company. It was approved by Fuel Cycle And Materials Administration (FCMA), Atomic Energy Council (AEC) of Taiwan in July, 2016 (Fig. 5). The HPCC has been in the process of commercial production. The technology license of the container and Kuosheng Nuclear Power Plant procurement contract have been successfully granted to Lion-Young Co., Ltd.. In December, 2016 and February, 2018, a total of 800 containers were purchased, with a total price of about 60 million NT dollars.

In March, 2018, INER obtained the patent for concrete proportion for preparing low-level radioactive waste in Taiwan (invention No. I 616895)(Fig. 6).

The technology license of the container has successfully granted to Lion-Young Co., Ltd. on October 23, 2014 (Fig. 4) with total upfront payment 1 million and royalty 1.5 million NT dollars, and the associated required education and training have been completed. The royalty income was 100,000 NT dollars in 2015 and 820,000 NT dollars in 2016.

On August 8, 2017, the first technical service income was 2.6 million NT dollars (excluding tax). The second b technical service income amounted to 2.6 million NT dollars (excluding tax).

Fig. 5. The container was approved by FCMA

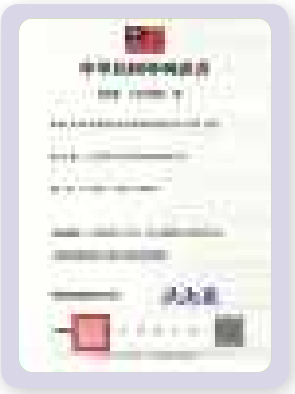


Fig. 6. Taiwan patent certificate

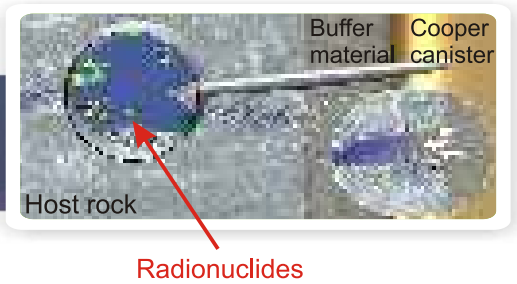
Fig. 7. HPCC in Kuosheng Nuclear Power Plant

The HPCC developed by INER is adopted by Taipower Nuclear Plant; direct overpacking operation of swelled waste form and corroded, deformed waste form drums has been performed with hundreds of containers.

In order to respect the demand in decommissioning plan of nuclear power plant, INER will develop square containers using HPC with life of 100 years approved by the FCMA as lining materials, and continue to develop High Integrity Container (HIC) with the operational life of 300 years in the future.

3-1-16

Research and technology development on the radionuclide migration



To understand the ways in which nuclides are diffused and how to prevent them is important!

The safe operation of nuclear power plants and the proper disposal of radioactive waste are important for the applications of nuclear energy. In particular, the final disposal of high-level radioactive waste is strongly related to long-term scale and isolation of human life. With the construction of the first final repository of spent nuclear fuel in Finland and the Swedish environmental licensing in September 2017, countries engaged in nuclear power generation cannot avoid the issue of high-level radwaste repository. Based on the design concept of multiple barriers and retardation to reduce the release of radionuclides from spent nuclear fuel, through copper canister, buffer and backfill material, and fractures in the host rock , an acceptable range can be ultimately obtained for risk reduction of affecting the human life. At present, the study on the migration of radionuclides in the natural environment has become a key project in many national laboratories in Europe, America and Japan.

The researches on the radionuclides migration cover the chemical properties of actinide elements and fission products, interaction between radionuclides and environment, migration behavior of radionuclides, and geochemical modelling for radionuclides. Fig. 1 shows the overall R&D infrastructure of radionuclide migration. During 2015 to 2018, the sorption and diffusion techniques were established to obtain transport parameters. These experimental results can enhance the reliability and accuracy of safety assessment.

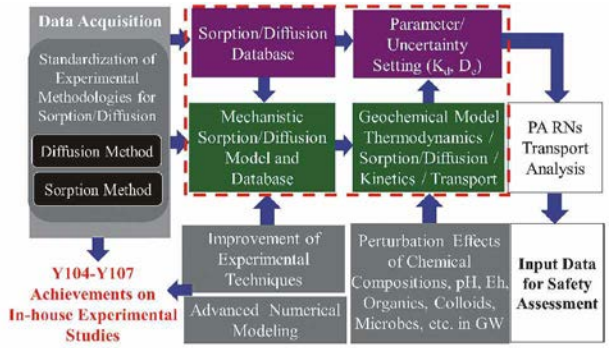


Fig. 1. The overall R&D infrastructure of radionuclide migration

As shown in Fig. 2, the safety assessment for the repository of high-level radwaste, the local thermodynamic database of radionuclides geochemical reactions will be established. The 3-D transport code with geochemical model can be used to calculate the released radionuclide concentrations in the groundwater. The overall safety assessment and the appropriateness and safety of the simulated disposal system can be obtained to enhance the nuclear peace development of nuclear energy applications in the people's livelihood society and promote environmental protection safety.

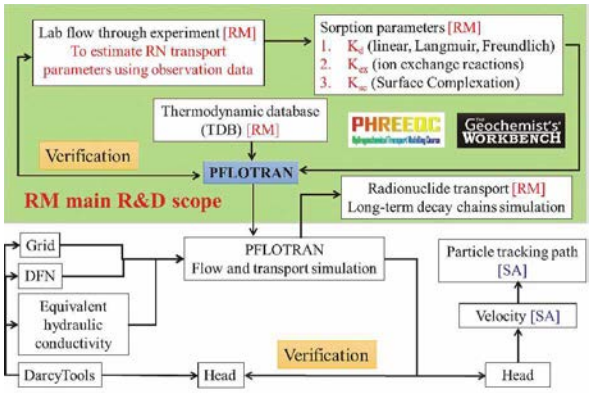


Fig. 2. Future works on the geochemical modeling of radionuclide migration applied to T (Thermal)-H (Hydrological)-C (Chemical) coupling

MEMO

Date . .

3-2 Keep Moving Forward for An Era of Sustainable Development

The issues related to the energy for development and environment protection have become equally concerned by the international society due to their closed interconnections and being treated within the same topic. They are critical to our future and wellbeing and even more the core value of us representing the role and responsibility to the world. We have constantly devoted to the research in civil application of nuclear technologies, looking for the balance between energy and environment coming from the principle where we stand. Some achievements have been made after years of endeavored efforts.

In recent year, we have had following advancements from different aspects:

In the energy saving technology, INER has developed high performance heat pipes, for the industrial needs of waste heat recovery in Taiwan as well as the reduction of carbon emission. And our team has successfully developed a computer-aided program. Through this analytic tool, the users can easily understand the maximum heat capacity of heat pipes in any size. With this convenient tool, INER could therefore focus on the key performance factors of heat pipes, and facilitate the R&Ds progress. Currently, we have developed an innovative high-density plasma source plating system to apply electrochromic film, and improved conditions and stability in this process. Furthermore, this technology with low cost advantage has great commercial potential in the future and has transferred to private firms.

In the energy storage system technology, INER has developed key materials for Vanadium Redox Battery (VRB) and mastered key technologies for materials such as PEM, MEA, electrode materials, and bipolar plates. And our team established a research and development test platform to provide validation and testing of domestic industrial materials, effectively integrated product applications and feedback from domestic battery components or material suppliers, increased technological competitiveness and increased the proportion of domestically produced materials, and developed energy storage industry value chains to support renewable energy policies.

In the new energy technology, our solid oxide fuel cell (SOFC) technologies from powder to power are linked closely with domestic industries. In combination with local technical capacity, we and private businesses are jointly constructing a 3-5 kW power generating system. In terms of wind turbines, we established the dynamic load calculation procedure of the OWT to evaluate the effects of Taiwan's extreme environmental conditions on offshore wind turbines. This technology will improve the reliability of offshore wind turbine structure, promoting the policy and technologies of OWT.

Moreover, we not only promotes the technology of cellulosic ethanol to industrial development by using non-food biomass as resources, with the objective of lowering the dependence on petroleum, reducing carbon emissions and building a new low-carbon industry; but also integrates the biogas and other biomass thermoelectric technologies at the same time, to help increase the domestic contribution of green electricity and achieve the purpose of low-carbon products valorization, with the strategy of high-value by-product application.

In addition to the technology development, we were also involved in the planning of future energy development strategy and policy. We used the Marginal Abatement Cost Curve(MACC) to explore the cost, low-carbon technology portfolio, and technical carbon contribution needed to achieve this goal. To meet the national carbon emission reduction targets and propose strategies.

UN has raised Sustainable Development Goals(SDGs) to integrate the efforts from member states and organizations to deal with critical issues and challenges we are facing in upcoming years. Most of them are linked to the advanced development and use of energy to preserve a sustainable future. We are in a position taking the responsibility to catch the international focuses and trend in both energy and environment, helping our country get involved the global effort in resolving the mutual and imminent critical problems. We are proud of our role in the endeavors for a better future!

3-2-1 All-solid-state electrochromic filter in vehicle cameras

Some vehicle cameras operate in one of two modes (i.e., Day mode and Night mode) depending on the ambient lighting conditions. A vehicle camera configured to operate in both Day mode and Night mode often includes an infrared (IR) filter that is disposed at two distinct locations associated with Day and Night modes, respectively. As part of initiating a change of the camera mode, the IR filter has to be mechanically moved between two positions. Thus, it would be beneficial to use a more reliable and lightweight filtering mechanism than the current mechanically driven IR filter design. According to the market report, the global market of vehicle cameras has been achieved 8.538 million units (i.e. US $2.75 hundred million) in 2017 and will increase to 11.8 million units (i.e. US $6 hundred million) in 2020 at a compound annual growth rate of 30% with the coming of the internet of vehicles and autonomous vehicles.

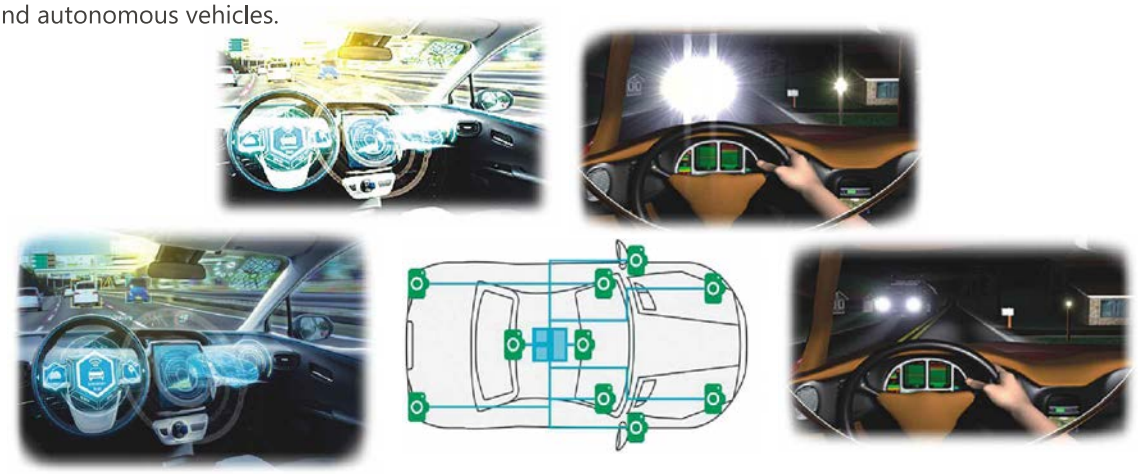


Fig. The challenge of cameras as the eyes of autonomous vehicles

Just like our eyes need sunglasses for protections under the sun, the cameras considered as the eyes of autonomous vehicles also need the fast color-changing technology that can control the strength of incoming light corresponding to ambient lighting conditions to provide further protection. We have implemented the low cost and plasma coating technology to develop the fast color-changing electrochromic(EC) filter thin film technology for the lenses of autonomous vehicles for further improvement on the stability and image accuracy of the vehicle imaging system .

Fig. The plasma coating fast color-changing glasses

The film thickness is only 1/50 of the hair diameter with the function of the iris to control the amount of incoming light depending on the ambient lighting conditions. It is expected that this innovative technology will replace the existing mechanical aperture and enter a blue ocean market for high-level automotive lens applications and help the domestic industries to breakthrough the patent portfolio and bottleneck of the foreign competitors.

Fig. The research item has been reported before the show and the patent wins the bronze medal in Tie 2018.

The all-solid-state EC filter in vehicle cameras with the integrated sensors and control units has been demonstrated in Taiwan Innotech Expo 2018 (TIE 2018) and recommended by the journalists before the show. Furthermore, the related patent also won the bronze medal in a patent contest. In addition the research findings have been published in international technical journals.

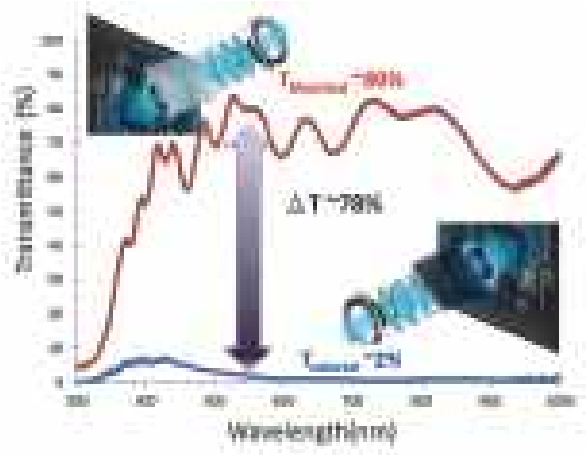


Fig. Spectra of the EC filter in bleached and colored states

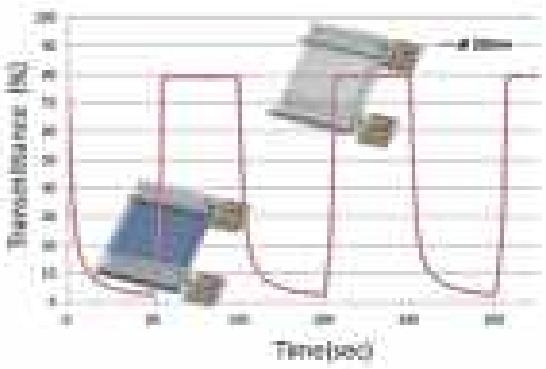


Fig. The switching performance of the EC filter

The developed EC filter by INER has demonstrated a visible light transmittance variation of 79% (from 81% to 2 %) and shown a transmittance variation of 40% within 3 secs. The EC filter integrated with sensors and control units has also provided the wireless setting for the eyes of autonomous vehicles to further improve the stability and image accuracy of the vehicle imaging system.

INER has overcome the previous bottleneck of the EC filter with the plasma coating technology. The coating technology also makes it possible for lower production and construction costs. In the near future, the lower cost and less energy consumption materials will be further introduced into the device structure. As a result, the EC filters fabricated with the environmental protection processes and environmentally friendly materials can be achieved in the near future.

3-2-2 Solid Desiccant Wheel for Industrial Dehumidification Application

The manufacturing method of solid desiccant wheel was developed by our team to meet the need of low temperature dehumidification for our industries. It comes from the unfavorable situation that the production of solid desiccant wheel was not available in Taiwan and the cost of dehumidification equipment was higher than other countries. In this study, the alumina was extracted from aluminum dross and applied as raw material to fabricate solid desiccant wheel by INER. The benefit of energy saving, environmentally friendly and cost effective could be achieved through combining heat regeneration and solid desiccant wheel dehumidification apparatus.

Fig. Development of extracting aluminum hydroxide and alumina

The solid desiccant wheel manufactured with alumina derived from aluminum dross has a three dimensional random porous structure and can adsorb humidity from the atmosphere. The desiccant wheel can be divided into two working areas: adsorption and desorption. As the adsorption capacity of desiccant wheel is saturated, the wheel will be turned to regeneration area with water desorption through heat pumps.

Fig. Microstructure of desiccant wheel

The adsorption capacity of solid desiccant wheel with different porosity was a function of time at 25°C and 60% relative humidity. As the operating time increased, the removal of water from the air ascends. The adsorption equilibrium time of desiccant wheel with 15 cm diameter and 5 cm thickness was twelve minutes and the maximum adsorption capacity is 51.4 g. The maximum adsorption capacity of desiccant wheel is 257 g per hour that means one gram of the material has the capacity to remove 0.184 gram of water from the air in an hour.

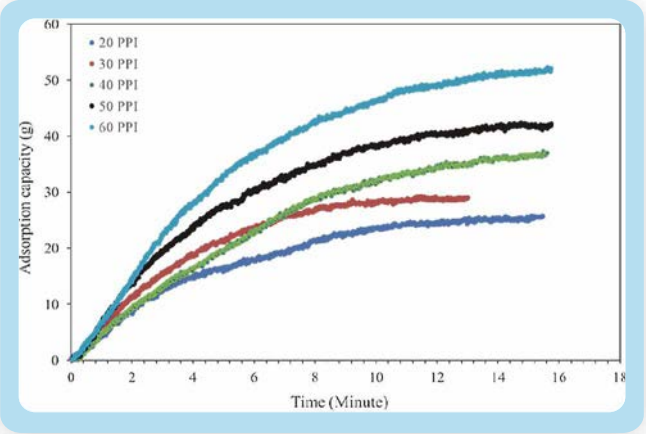
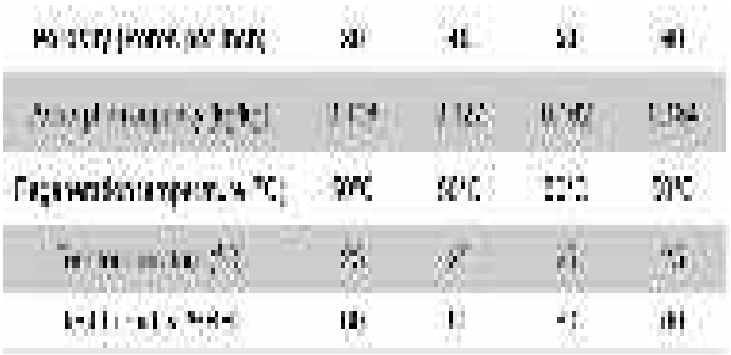


Fig. Adsorption isotherm of different porosity
(At 25°C、60% R.H.)



The further improvements in manufacturing process for solid desiccant wheel such as better proportion of additives, sintering temperature and enlargement of the wheel size (30 cm diameter) will be enhanced in 2019 to avoid collapse and obstruction of porous structure. The sintering temperature is going to be adjusted < 1300° C to improve the strength of desiccant wheel and increase the adsorption capacity.

The fabricating technology of solid desiccant wheel has been transferred to local firm with the total contracted price of one billion Taiwan Dollar. The technologies in extracting aluminum hydroxide and alumina from aluminum dross were competitive and also considered as candidate items for technology transfer by many local firms. The needed review and verification to their applications have been under our internal administrative process.

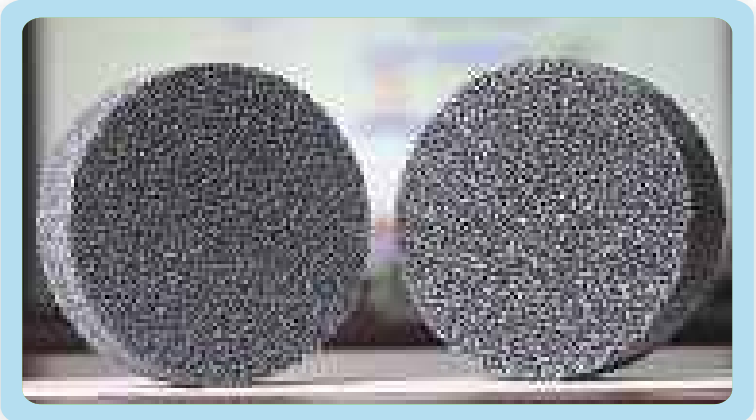
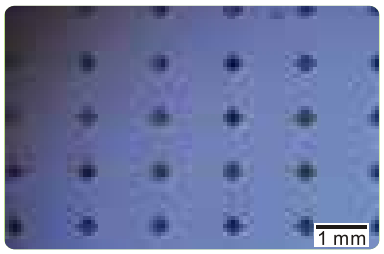


Fig. Solid desiccant wheel manufactured by INER

3-2-3 Pseudo GaAs Substrate on Si - Epitaxy Growth of III-V material on Si substrate



Why on Si ?

Silicon is the second most abundant element in the earth's crust, and Si substrate is cheep and easy to get; additionally, it has higher thermal conductivity than III-V materials. Thus, it has good potential on making the pseudo GaAs/Si substrate to replace the expensive GaAs substrate. There are many GaAs related industries, so the technology of epitaxial growth for III-V on Si substrate could be applied on PV, LED and other opto-electrical industry, and makes it more competent in the future.

Challenge

Both lattice mis-match and difference of thermal coefficient between III-V materials and Si substrate will generate micro-cracks during the epitaxial growth of III-V material on Si substrate, and strongly degrade the associated device performance.

How to fix it?

- **Patterned-silicon substrate formation :** which could confine the formation of micro-cracks and form the crack-free regions on Si substrate for the following applications.
- **Thermal cycle annealing (TCA) method :** which could greatly improve the epilayer quality.

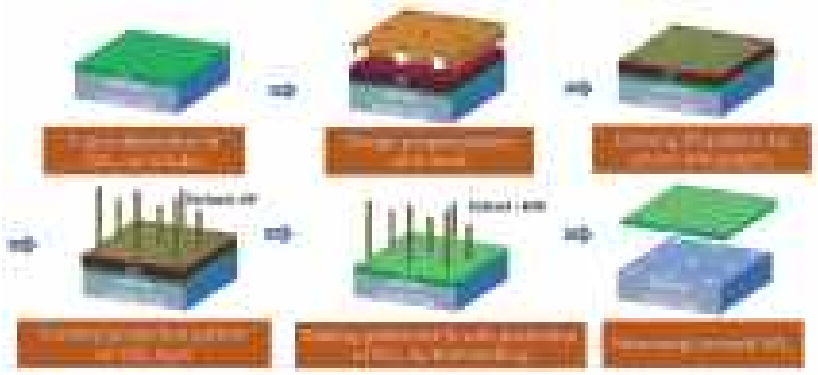


Fig. Process flow of the patterned-Si substrate formation

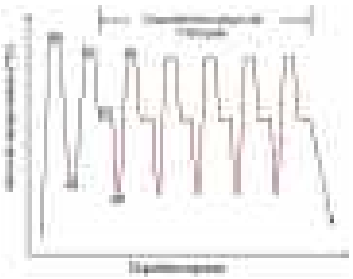


Fig. Schematic diagram of the epitaxial growth temperature during TCA process

Results

- Achievement of low-temperature SiO_2 mask layer deposition technology for patterned-Si process, and the patterned Si substrate could confine the micro-crack formation and form the crack-free regions on the pseudo GaAs substrate.
- Successful integration of the patterned-Si technology and TCA epitaxial growth method, in which the XRD FWHM of the GaInP/GaAs dual-junction solar cell on Si substrate less than 100 arcsec is obtained.
- Demonstration of GaInP/GaAs dual-junction solar cells on Si substrate, in which the best efficiency of solar cells has reached 20.2 % under 34-sun concentrated-sunlight.

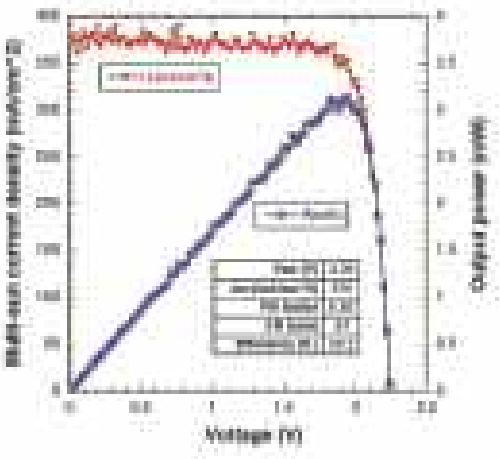


Fig. Multi-sun characteristics of GaInP/GaAs dual-junction solar cell on Si substrate

MEMO

Date . .

3-2-4 The mobility of solid oxide fuel cell in transportation application

INER has been devoted to the development of metal-supported solid oxide fuel cell (MS-SOFC) technology. MS-SOFC has great potential to be a power unit of transport vehicle in the near future. A technology cluster named as Sofciner-MS for fabrication of MS-SOFC is now successfully developed. From powder to power, we establish a procedure to manufacture Sofciner-MS cell unit implemented by many industry technologies. Our proprietary atmospheric plasma spraying (APS) technology allows SOFC to overcome its traditional problems in structural and thermal strengths. Sofciner-MS costs less in terms of simplified processing and reduced energy consumption for manufacture. Furthermore, we have signed a technology transfer contact with a local firm in 2016. We aim to be a strong technology supporter to the industry and promote the commercial production of SOFC in Taiwan. SOFC will play an important role in energy use that Sofciner-MS could make SOFC more applicable in daily activities such as those related to transportation.

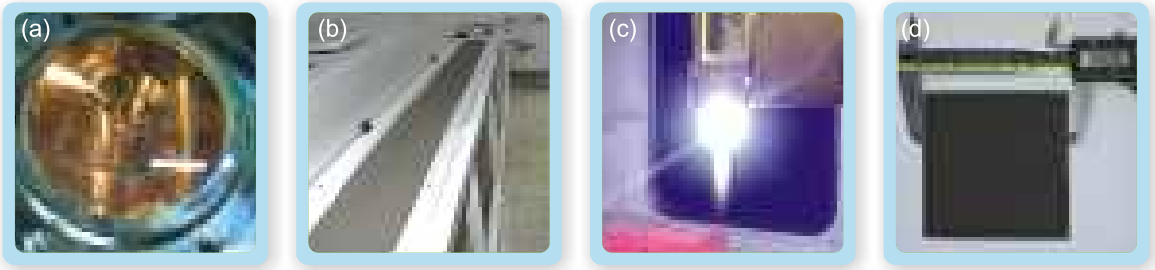


Fig. Photos of (a) powder re-granulation equipment, (b) tape-casting equipment, (c) APS torch and (d) Large-size MS-SOFC cell.

Raw powder preparation method, porous super-alloy metal substrate fabrication and APS technique are integrated into INER's Sofcincer-MS technology cluster. The SOFC powder preparation includes oxide powder synthesis and powder re-granulation . Porous metal substrate is fabricated by tape-casting method and powder metallurgy. All MS-SOFC entire set of cell layers are produced by APS technology. The size of the MS-SOFC cell is 1010 cm^2.

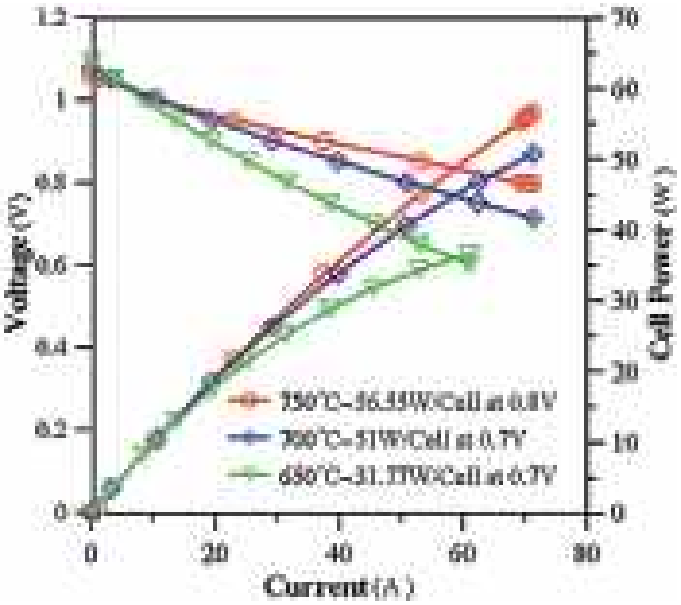


Fig. Performance of the standard-type MS-SOFC cell tested in cell mode.

Two types (standard-type and thin-type) of MS-SOFC cell have been developed by INER. The main difference between them is the cell thickness. The thickness of the standard-type cell is 1.2 mm while 0.3 mm for the thin-type cell. The 1010 cm^2 standard-type cell can deliver about 56.5 W (~698 mW/cm^2) at the cell voltage of 0.8 V and test temperatures of 750°C. Power outputs of 51 and 31.7 W can be achieved at 0.7 V and 700 and 650°C, respectively. This cell also shows a great long term degradation rate around 1.0 %/khr.

The thin-type 1010 cm^2 MS-SOFC cell also reveals impressive performance in single-cell stack mode. It can deliver about 40 and 47 W (~500 and 588 mW/cm^2) at the cell voltage of 0.8 V and test temperature of 700 and 750°C, respectively.

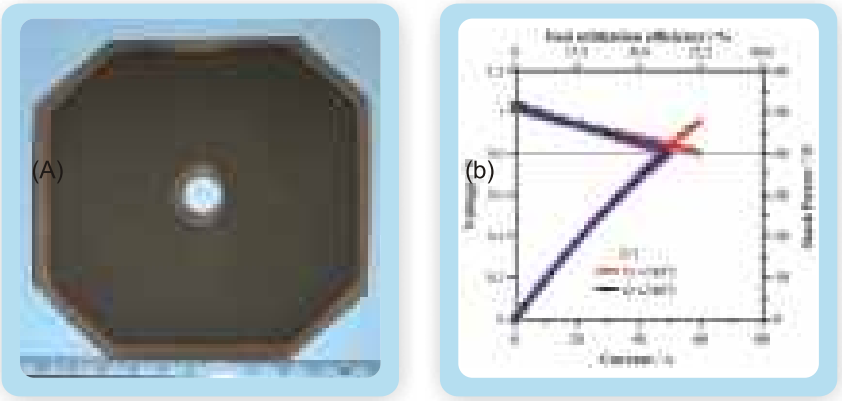


Fig. (a)Photo of thin-type MS-SOFC cell. (b) Performance of the thin-type MS-SOFC cell tested in single-cell stack mode.

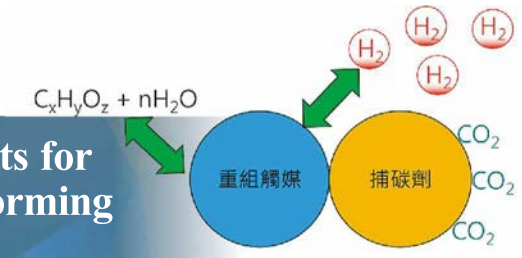
Table. Comparison between Sofciner-MS and commercial ceramic-supported cell products

Developer	INER	H.C. Starck	Elcogen
Technology/Model	Sofciner-MS	ASC-3	ASC-300C
Structural construction of SOFC cell unit	Metallic substrate	Ceramic substrate	Ceramic substrate
Manufacturing technology of SOFC cell unit	Atmospheric plasma spray-sintering for all cell unit structural layers	Multiple co-sintering of entire cell unit in furnace	Multiple co-sintering of entire cell unit in furnace
Warm-up time	Tens of minutes	At least half a day	At least half a day
Thermal shock susceptibility	Good	Poor	Poor
Mechanical vibration susceptibility	Good	Poor	Poor
Cell size, mm (L x W x T)	100 x 100 x 1.2	100 x 100 x 0.65	100 x 100 x 0.55
Power density, mW/cm^2	698 (@750 deg-C and 0.8V)	347 (@700 deg-C and 0.680V) [a]	600 (@750 deg-C and 0.8V) [b]
Degradation, %/1,000Hrs	~1.0 (@700 deg-C 400 mA/cm^2)	<1 (@750 deg-C and 320 mA/cm^2) [a]	<1 (@700 deg-C and 400 mA/cm^2) [b]

[a] H.C. Starck GmbH: www.hcstrack.de tested in INER
[b] Elcogen AS: www.elcogen.com tested in INER

This table on the left shows the comparison of specifications between the commercial ceramic-supported SOFC and the INER MS-SOFC that reveals many advantages such as fast start-up, robustness to mechanical shock, and better operating performance.

3-2-5 Development of innovative catalysts for renewable hydrogen by steam reforming of multiple sources



The demand of green energy with technology development has become a main stream worldwide today that hydrogen is certainly one of the interested resources. The conversion efficiency of hydrogen energy combined with fuel cell can reach 40~60%, which is much higher than that of the internal combustion engine with around 20%. It can also be used as one of the options for energy storage. Hydrogen, when coming from ethanol or biomass, can be considered as one of the renewables. In addition, hydrogen itself is not easy and cheap to compress, store, and transport. Therefore, if hydrogen can be produced with multiple sources in the field, such as methane from existing pipeline or high energy density liquid fuel, the aforementioned drawback could be overcome. INER has developed a new sorption-enhanced steam reforming (SERE) technology, in which the high-efficiency CO_2 capture sorbents combined with reforming catalysts as mixed or hybrid materials were used. When the hydrogen is produced, Co_2 can be removed at the same time, so that the thermodynamic equilibrium of the reaction tends to the product end, and the CO by-product can be effectively inhibited. The H2 production can be increased with higher than 90% concentration. By using the SESR technology, the high-quality hydrogen can be obtained, which simplifies the procedures of gas separation and purification, and increases the applicability and feasibility of this system.

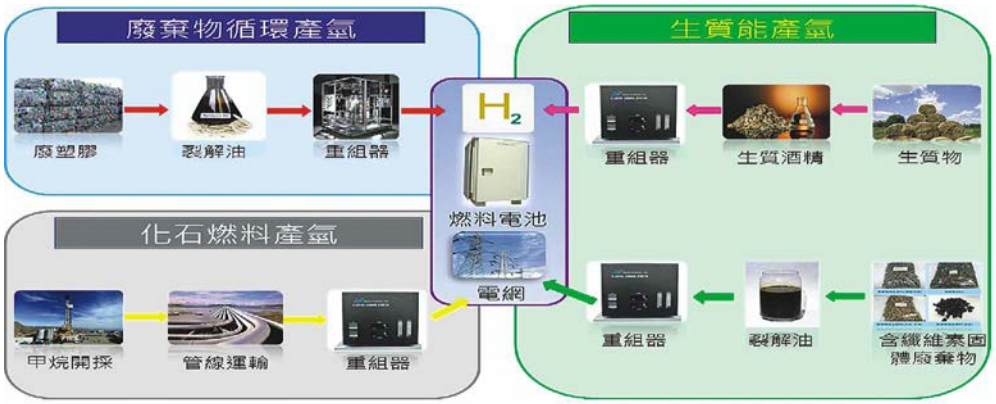


Fig. Pathways of renewable hydrogen production from multiple sources

If the hydrogen produced by the hydrogen production system is applied to a proton exchange membrane fuel cell (PEMFC), the CO content in the hydrogen must be less than 1 ppmv to avoid poisoning the platinum anode of the fuel cell. Therefore, the rear end of the conventional hydrogen production system must be equipped with a gas purification system (such as pressure swing adsorption unit, PSAU) to improve the purity of hydrogen and reduce the concentration of hazardous components, but it also increases the volume and complexity of the overall equipment. The SESR technology developed by INER can simplify the procedure by which the H_2 concentration can reach over 90% without purification and the goal of miniaturization of the system can be achieved.

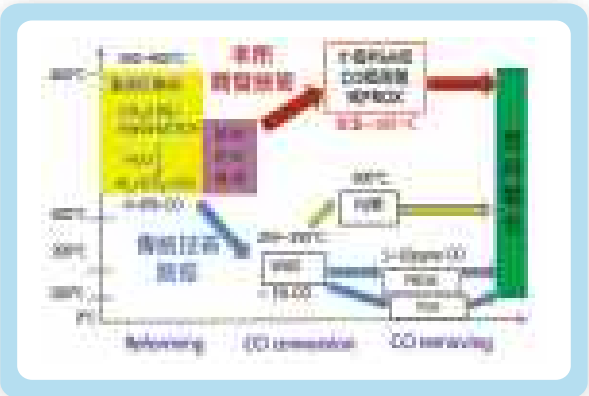


Fig. Comparison of technologies developed by INER and current technologies

Fig. The list of awards for CO_2 capture and reforming for hydrogen technologies developed by INER

The high-temperature CO_2 solid sorbents have been developed for many years in INER. This year, the sorbents have combined with reforming catalysts as innovative catalytic materials for steam reforming to produce H_2. In addition to publishing many domestic and international journal papers, the related technologies have also obtained a number of domestic and foreign patents. Furthermore, this technology were awarded the silver and bronze medals at the "2012 Taipei Int' l Invention Show & Technomart Invention Contest" and "2018 Taiwan Innovation Technotech Expo Invention Contest", respectively.

In general steam reforming, the gases involving ~70% H_2, ~20% CO_2, ~5% CH_4, and ~5% CO are produced by using Ni based catalysts. In SESR, the products with > 90% H_2 can be generated. For INER's work, the H_2 of 97%, the CO_2 and CO of 0.1%, and the CH_4 of 1-3% are stably produced by SESR technique. The results have approached to the international level. Obviously, the hydrogen production via SESR technology (using novel catalyst/sorbent materials) has significant advantages, such as high H_2 concentration, low by-products, suppressed coke formation, even simplifying the following H_2 purification.

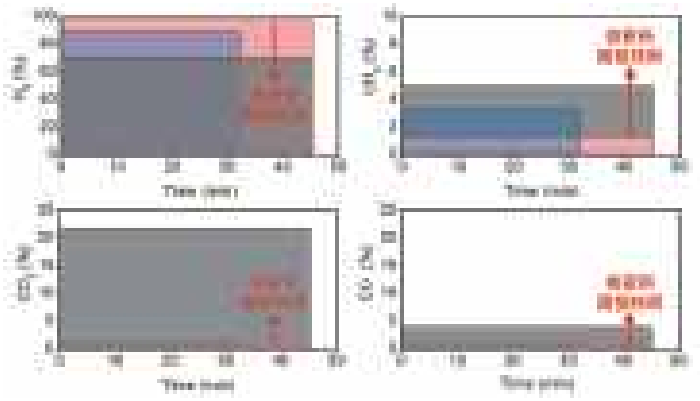


Fig. Comparison of SESR of ethanol related technologies (Red: SESR technology in INER, Blue: International SESR technology, Gray: General steam reforming technology)

The innovative catalytic materials developed by INER are mainly used in hydrogen production from multiple sources to develop a new generation of hydrogen fuel cell system in energy storage field. It can effectively overcome regional differences and transportation problems caused by the sources of hydrogen. It also has ready-to-use and high-quality hydrogen characteristics. INER will continue to conduct hydrogen production tests and increase production from a variety of sources. In the furfure, it can be used with a 5-25 kW fuel cell system for backup power systems and off-island power generation for important domestic vital equipment, achieving the goal of decentralized power generation.

Fig. Application blueprint and development process of high-efficiency hydrogen production from multiple sources technology

3-2-6 Capacity building of flow battery stack module and energy storage system

Electrochemical energy storage system of power-grid grade is very important in mitigating the fluctuation of unstable green energy. It is of great marketing potential. Our government addressed the energy storage system as one of the core items in the deployments of local green energy industries. In addition to the built storage system of pumping water, both of the lithium-ion battery system of hundred kW grade and vanadium redox flow battery (VRFB) system were launched for pre-validation and demonstration.

This VRFB project focused on the studies of improvements of key components, applications and scale-ups, on the bases of the present capabilities of our domestic industries of related. The target is to achieve domestic-homemade VRFB stack modules, accompanied with domestic industries. Hopefully, the corresponding pre-validation and demonstration VRFB system may support to the political goal of green energy.

Fig. Domestic homemade flow battery energy storage system

Domestic-homemade flow battery module:

this stack modulus is rated of 3kW at 48V, @ 100~200mA/cm^2, composed of 38cells, with improved design of internal runners, advanced sealing technology, integrated bipolar plates, improved carbon felts and advanced constructional design.

Fig. Domestic-homemade flow battery module

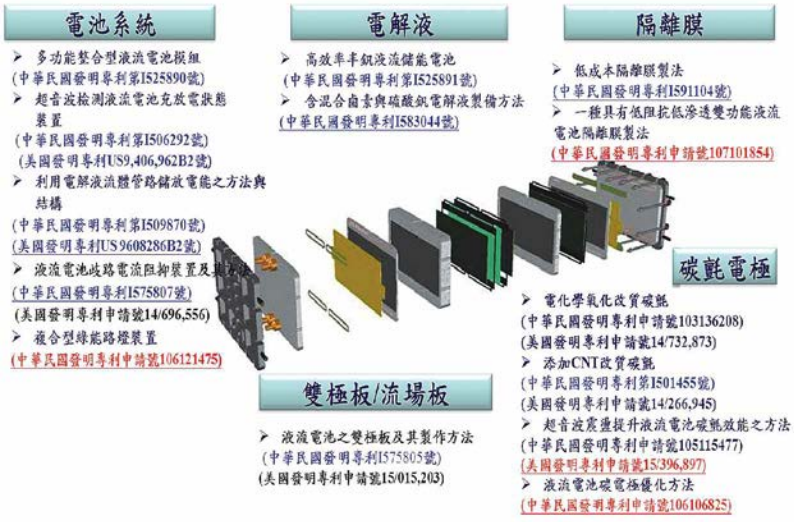


Fig. INER patents about VRFB

Cooperation items with domestic industry cooperation includes: (1) the design and assembling technology of battery modules, (2) performance tests and evaluations on electrolyte, (3) advanced process studies about membranes of flow battery.

There are 13 patents of related gained officially, and 4 among them had been used for further profits application at present.

Different scales of battery modules were produced by several companies. Small-scale battery modules, such as 2~5kW, might be easy for trial and testing, trouble shooting, quality control, modulariization and automation. Large-scale battery modules, such as 22 ~ 35kW, might be good at cost reduction and less piping works while in mass production. INER stepped in the former and was expecting to earn the most skills of the vanadium flow batteries soon.

Table A comparison of the modules of flow battery

		基本組成單元~電池模組	能量轉換效率	使用壽命(年)	循環次數(次)	充放電電流密度(A/m^2)
中華民國	核能研究所/能源局	5kW	>70%	20	>10,000	1,000-2,000
德國	Gildemeister AG	1~2 kW	65~80 %	20	無限制	
	Schmid	5kW	70%	20	20,000	200
日本	住友	35 kW	70%	20	>10,000	800
韓國	H2 Inc.	5 kW	n/a	20	>20,000	
中國大陸	普能	5~20 kW	65-75%	n/a	>10,000	200-800
	大連融科	22~30 kW	75%	>15	>10,000	800-1,200
美國	UET	22~30 kW	75-80%	20	>10,000	
	IMERGY Power system	5kW	75%	10	無限制	

INER has built most of the related skills about vanadium flow batteries, and gained 13 patents right now. We are cooperating with several local industries, progressing to build our local flow batteries modules. A pre-validation and demonstration VRFB system will be set at Southern Science Park of Taiwan at near future. That will benefit the development of our green energy policy.

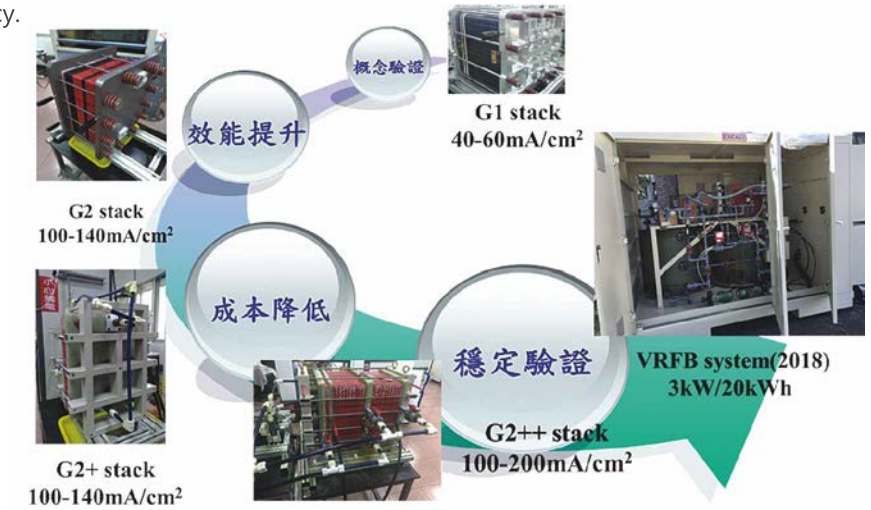


Fig. Flow battery R&D progress in INER

3-2-7

For more effiecient Biogas production – lignocellulosic biomass depolymerization technology

The organic materials could be decomposed to generate biogas and become the source energy. Since their compositions contain a large amount of methane, they can be used as an energy source for power generation and gas. However, the decomposition of organic matter by microorganisms alone is inefficient in biogas production. The technology of lignocellulosic biomass depolymerization can be applied for biogas production, effectively destroys and decomposes lignocellulosic biomass, and makes it easier for microorganisms to convert them into biogas. However, the efficiency could be increased by 2 to 3 times if the depolymerization is applied. The reaction time could be saved by 50% that can effectively reduce environmental pollution problems and GHG emissions. Through this technology, the bio-refining could play an important role to promote the sustainable development of energy.

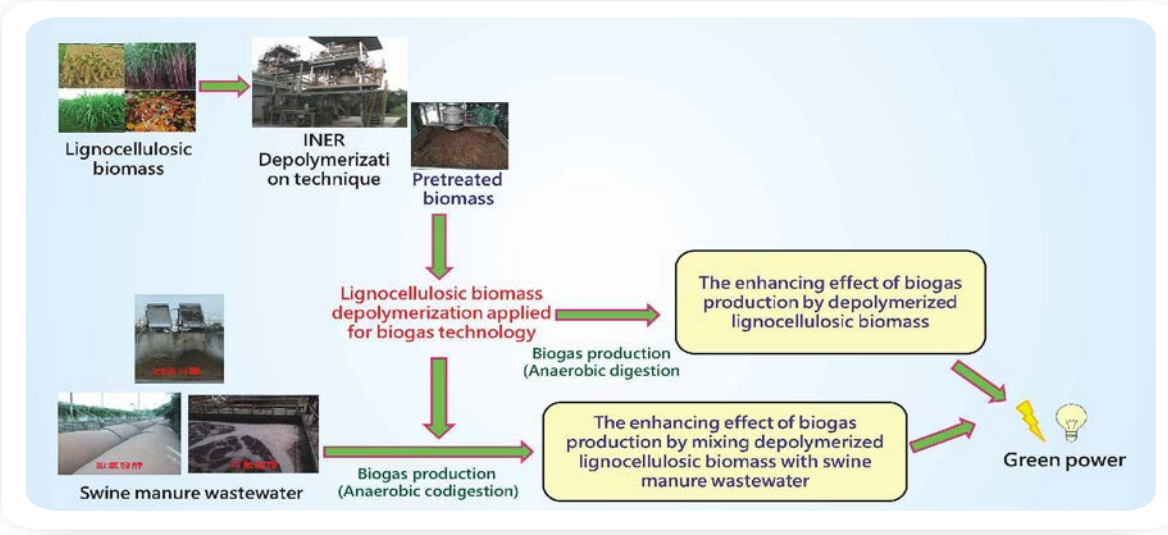


Fig. The process of the depolymerization technology applied for biogas production

Lignocellulosic feedstock depolymerization technology

The lignocellulosic biomass depolymerization technology combines physical and chemical processes with pre-treated feedstock to obtain some useful substances in the complex structure for following applications. In EU, the application has been advanced from direct mixing of feedstock materials to an implemented stage of depolymerization and decomposition before mixing. It can theoretically improve the methane production and biogas production rate of lignocellulosic biomass.

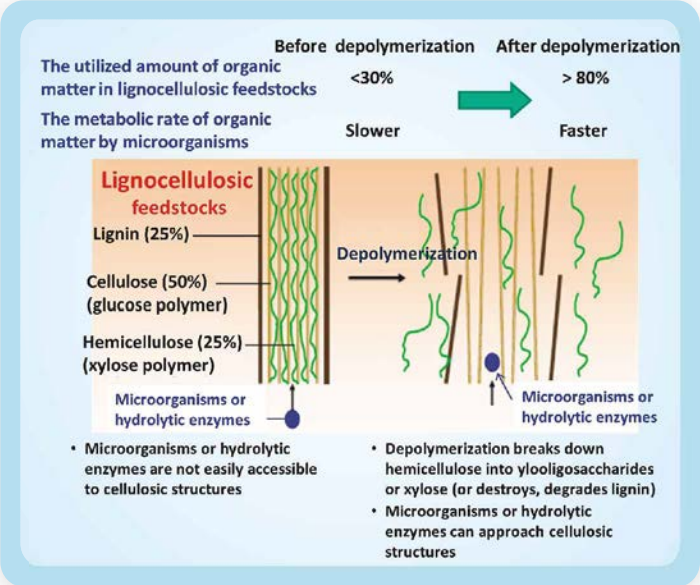


Fig. The difference between lignocellulosic feedstocks before and after depolymerization

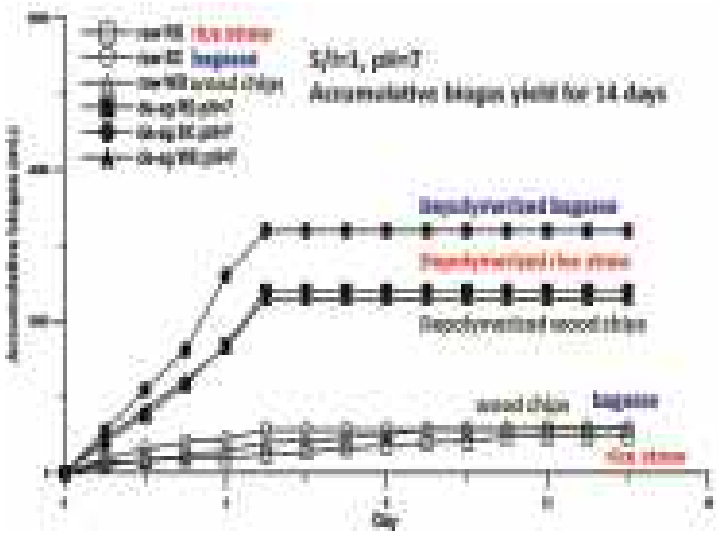


Fig. Effect of the depolymerization technology on the biogas yield of lignocellulosic feedstocks

The enhancement of biogas production while the lignocellulosic biomass has been depolymerized: the potential yield of biogas from depolymerized rice straw, bagasse, and wood chips ranges from 213 to 338 cubic meters of biogas per ton of total solid weight. The efficiency of biogas generation without depolymerization process is very low. However, the yield could be increased by 4-5 times if the pH of the depolymerized biomass is properly adjusted.

The effect on biogas production by mixing depolymerized lignocellulosic biomass with swine manure wastewater: wastewater itself can produce about 116 liters of biogas per 30 liters of wastewater for each pig. After adding following depolymerized biomass separately: 3% rice straw, 1% bagasse, 3% wood chips and 1% Pennisetum, the biogas yield achieves 389, 221, 284 and 192 liters for every 30 liters of wastewater, respectively. Compare to the biogas production from the poultry manure wastewater, the yield can be increased by 104%, 64%, 65% and 44% respectively, after mixing with the depolymerized biomass.

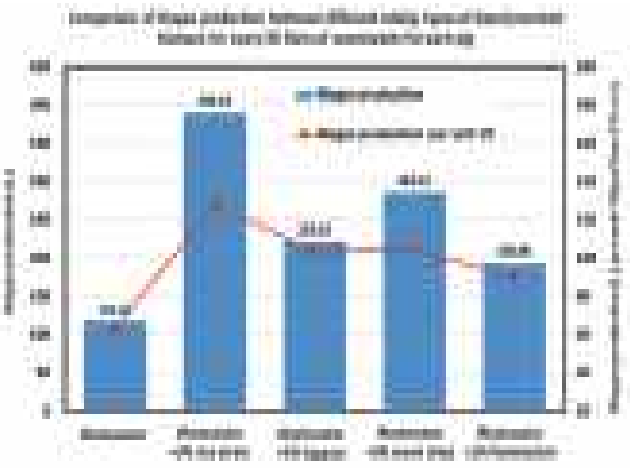


Fig. The enhancing effect of biogas production by mixing depolymerized lignocellulosic biomass with poultry manure wastewater

The depolymerization technology finds a way out to resolve the problems of waste disposal from agricultural and forestry fields. It can convert waste into energy and chemicals through biorefineries, and introduce resources for recycling and thus ease the pollution caused by those wastes. This technology could enhance the value of the associated industrial chains and get more benefits economically. Looking ahead, we hope we will have the chance to create more biomass energy models with site-specific characteristics.

3-2-8 Gold from waste - the technology for dreamers

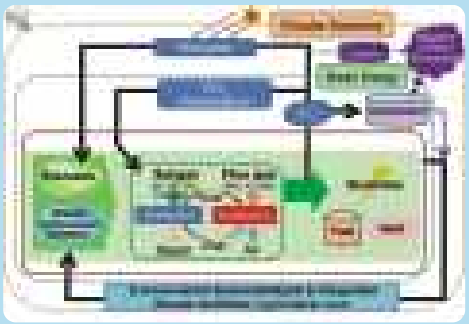


Fig. Gasification Technologies to Fulfill the Concept of Circular Economy

A poly-generation energy system based on gasification technology has been commissioned in INER. Carbonaceous feedstock, like biomass, waste, coal, and mixture of them, could be converted into valuable syngas, which can be further utilized in various application processes to meet the multiple energy and resource demands from the industry.

Waste to Energy can enhance the portfolio of indigenous green energy, and comply with circular economy. Carbon dioxide emission can be further reduced, when it is captured and prevented from exhausting to atmosphere in the processes; hence, it can realize "negative emissions" benefit, which could be applied to balance unavoidable carbon dioxide emissions from human activities to achieve the "zero emissions."

A 100kW$_{th}$-class fluidized-bed reactor system consisted of gasifier and warm/hot acid gas removal (AGR) facilities was commissioned in INER. For example, the hydrogen sulfide in syngas could be controlled down to 1 ppm level at the outlet of AGR from 1,000 ppm at inlet.

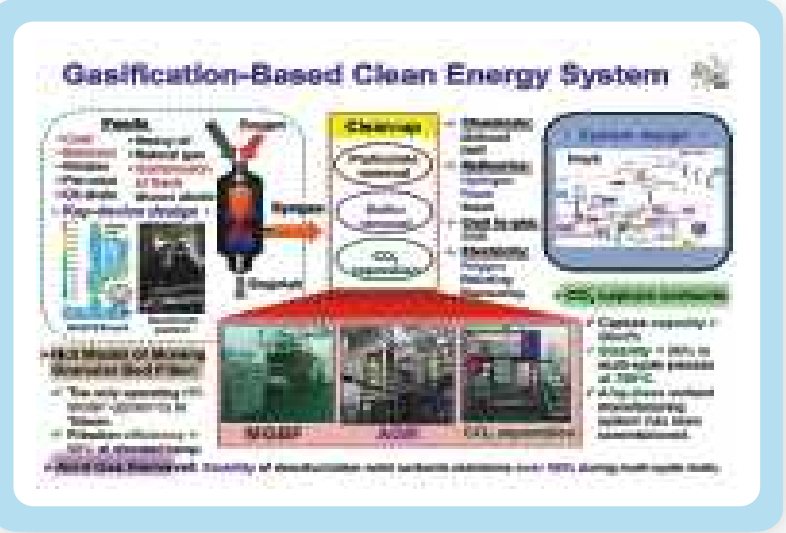


Fig. Concept of Multi-application based on Gasification Technologies

Fig. Woody Chip

Fig. Waste Pellet

Fig. Waste plastics

Fig. Fluidized-Bed Gasifier

Fig. Warm/Hot Acid Gas Removal (AGR) Unit

Fig. Invited Dr. K. Svoboda, Czech Academy of Sciences (CAS), to INER

Fig. Convened 2018 Clean Energy Technology Application Forum

International Communication & Industrial Promotion

1.2018 Clean Energy Technology Application Forum was held to link domestic technical energy and industrial demand.

2.Dr. Karel Svoboda from CAS was invited to INER to exchange the experience of waste to energy.

3.A technical service of biomass to electricity was carried out to assist the company for starting the business of green power.

Progress Results

1.Biomass and waste were gasified with various gasification agents, and the heating values (MJ/Nm^3) of syngas in the cases of air gasification are coincided well with international data.

2.(1) The concentration of hydrogen sulfide (H_2S) could be controlled from 1000 ppm at the inlet to 1 ppm level at the outlet by warm/hot acid gas cleaning unit in 4 hours testing period.

(2) An average concentration of hydrogen sulfide at outlet in the range of 10~30 ppmv, as compared to a value around 10,185 ppmv at inlet, was measured by RTI at the 50MW demo plant in Tampa Electric Company's Polk 1 IGCC Site, Florida, USA.

3.Higher temperature promotes endothermic reactions, increases the feedstock conversion rate, and results in producing more CO, CO_2, H_2, and Ch_4.

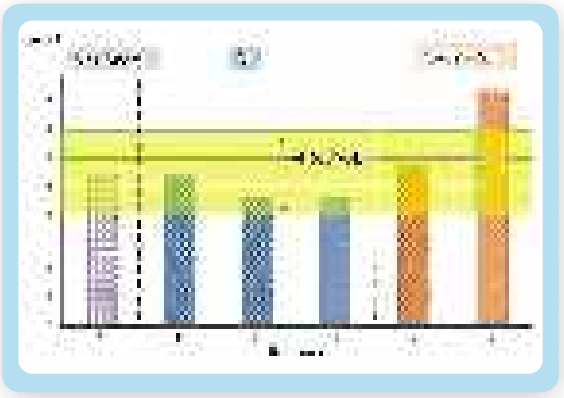


Fig. Heating Values of Syngas with Various Gasification Agents

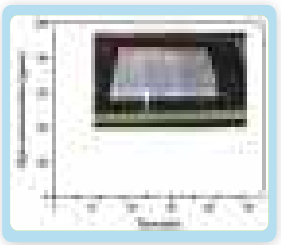


Fig. Outlet Concentration of Hydrogen Sulfide (H_2S) Varied with Time

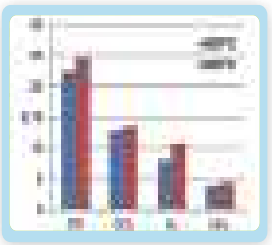


Fig. Syngas Compositions with Different Temperature

Future Work

1.The gasification and related technologies provide features of feedstock flexibility, low emission, multiple applications, etc. The working team will cooperate with industry to pursue follow-up efforts for mitigating greenhouse gas emissions.

2.To develop gasification- based multi-energy systems:

(1)The efficiency of gasification combined with solid oxide fuel cell (SOFC) is expected as 65%, with superior emission characteristics.

(2)Syngas converted to dimethyl ether (DME) could meet the industrial demands, such as chemical, alternative fuel to diesel, or liquefied petroleum gas (LPG). DME could be used as the fuel to feed fuel cell, diesel engine or gas turbine, and it is beneficial to system design due to the flexibility in generating electricity.

(3)Developing thermochemical-based multi-applications of biomass and waste would lead to increase the capacity of green energy, and the resilience of the system; furthermore, the onset of studying the so-called "E-fuels" would be pursued.

3-2-9
To help the formation of SOFC industry chain by our technologies

INER has had close partnership with local firms to transfer technologies for commercialization of solid oxide fuel cell (SOFC). We have assisted the licensee of anode-supported cell technology with continuous improvement on cell performance, manufacture process optimization, construction of mass production factories, procurement of equipment, setup of production line, and small scale mass production for the use in stacks. We have trained the company staffs to prepare glass sealant, assemble multi-cell stacks and conduct performance testing. INER directed the licensee of metal-supported cell technology to set up the processes for powder granulation, powder collection, and cell fabrication with porous metal substrates by plasma spraying. Moreover, a licensing contract was signed with a firm for the patent about fabricating fuel reforming catalyst. A multi-part cooperation letter of intent was concluded with several state-run and private enterprises to develop self-designed SOFC power generating systems based on indigenous technological capacity. We are in charge of testing of system performance and procurement of domestic cells and interconnect for the following stack assembling and system testing. Through technology transfer and cooperation with local firms, INER promotes the building-up of a complete supply chain for the emergence of clean energy industry.

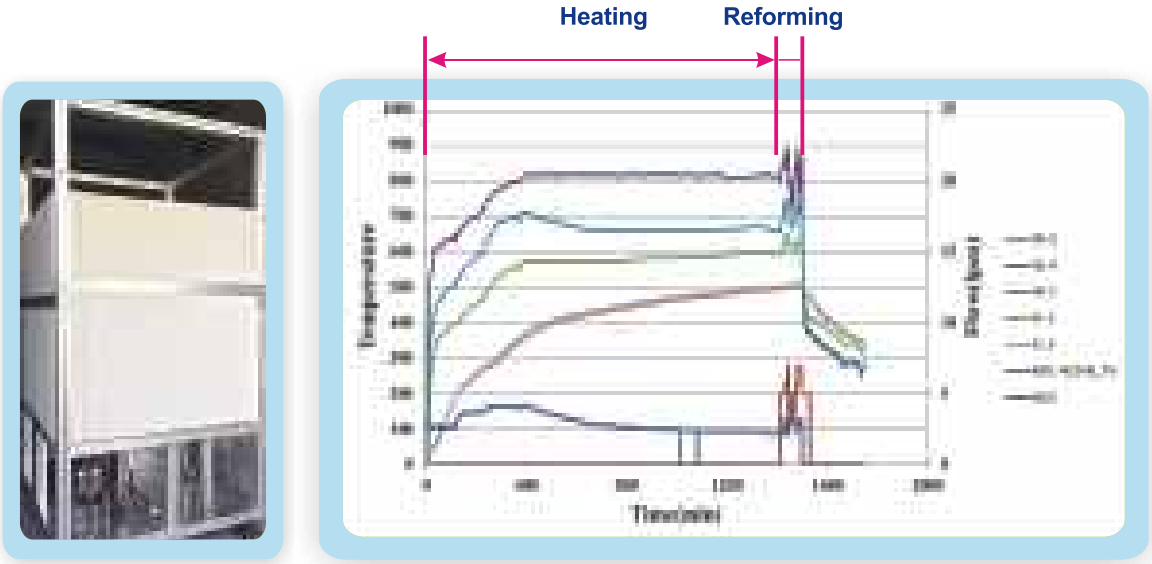


Fig. 3.5 kW SOFC power system and testing

3.5 kW SOFC power generating system

INER and Green Technology Research Institute have developed a 3.5 kW SOFC power system. A prototype SOFC power system comprises stacks, a porous media afterburner, nature gas reformer, heat exchangers, water supply system and data acquisition and control system. From the experiments, it was found the exhaust gas retained sufficient thermal energy to heat up the cathode air and the reformer.

Plasma sprayed metal-supported solid oxide fuel cell

Metal-supported solid oxide fuel cells with 1.2 mm in thickness and 10× 10 cm^2 in size were produced. The single cell can deliver about 56.5 W (698 mW/cm^2) at 0.8 V, 750° C. This cell shows a great long term degradation rate around 1.0 %/khr.

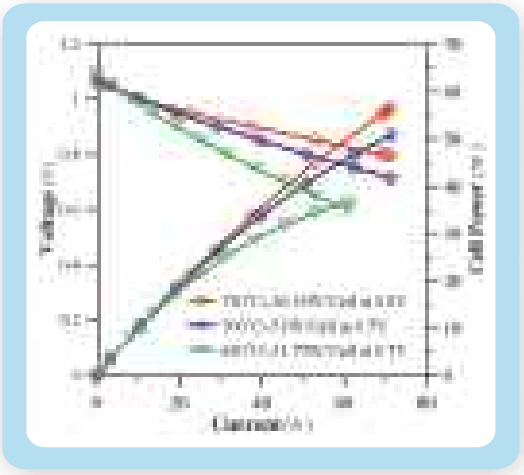


Fig. Performance of plasma-sprayed metal-supported SOFC

Ceramic based anode-supported solid oxide fuel cell

- INER-SOFC-MEATM (~11×11 cm^2 / 430±25 μm) with novel geometry design have been realized via small-scale production line. Cell product exhibits process and performance reproducibility for commercial available specs.
- The YSZ-based cell product exhibits power 30~35 W at 800 °C, 0.7~0.6 V for kW scale system application.

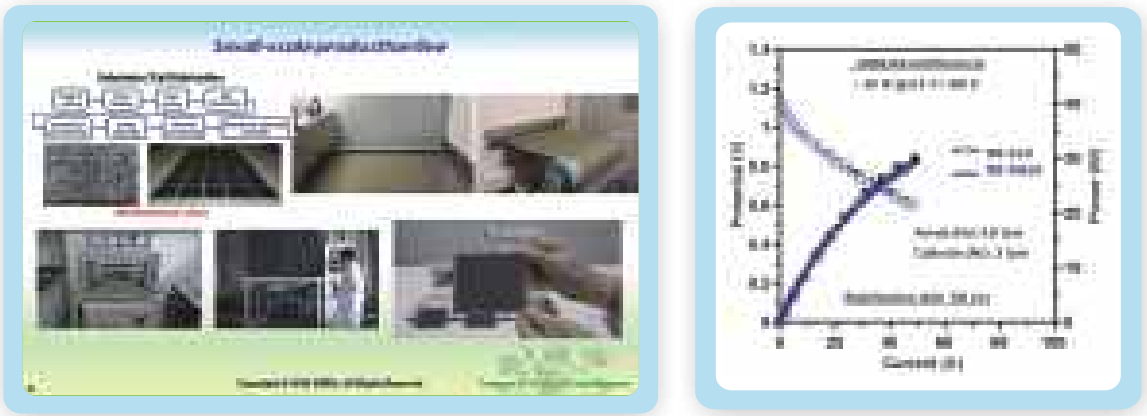
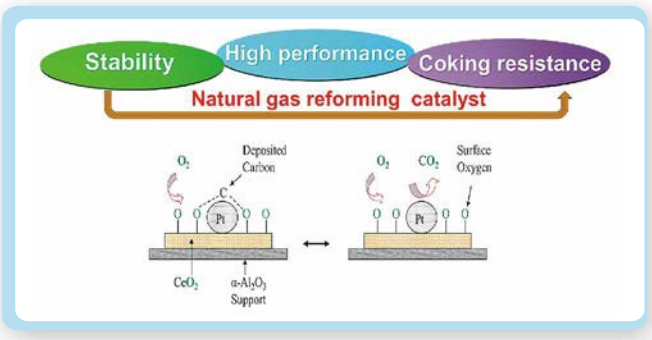


Fig. Ceramics-based anode supported solid oxide fuel cell technique and performance



Awards

- 2018 Taiwan Innotech Expo Invention Contest：Silver medal award：Membrane electrode assembly structure of fuel cells and the method of fabrication
- 2018 MRS-T Annual Meeting Poster Paper Contest Best poster award ：Electrode/electrolyte interface analysis for solid oxide fuel cell By FIB 3D reconstruction technique

Fuel reforming catalyst

- Key technology: Developing a two-step honeycomb catalyst process to improve the efficiency of hydrogen production.
- Innovation and breakthrough: Honeycomb catalyst can be applied to large flow rates and reduces the pressure drop for kW scale SOFC.

3-2-10

Indispensable to the Green Energy-Auxiliary Services and Protection Technologies through Microgrid

Our government has set a policy on developing renewable energy generation in order to supply 20% of the total electricity demand by 2025. However, it is inevitable in the future that large amount of power supply by renewable energy will impact the electricity system. As a national research agency, not only has INER built a first hundred-kW-scale microgrid empowered by renewable energy in Taiwan, but also is engrossed in the researches of autonomous control and management technologies on the distributed and regional electricity system. Through the energy storage facility and energy management system, voltage and frequency of electricity within a regional grid can be stabilized, so as to accommodate more renewable energy generation.

Fig. The first hundred-kW-scale microgrid empowered by renewable energy in Taiwan

The first domestic microgrid system has been built, which is empowered by renewable energy, connected to the OQ38 high-voltage feeder line, and capable of receiving dispatch commands from the Taoyuan Distribution Center of Taiwan Power Company (TPC). As receiving power need command, the energy management system automatically coordinates renewable energy resources, conventional gensets, and the energy storage facility, and steadily supplies power as high as 100kW for four consecutive hours. This achievement greatly advances the effectiveness of microgrid auxiliary services.

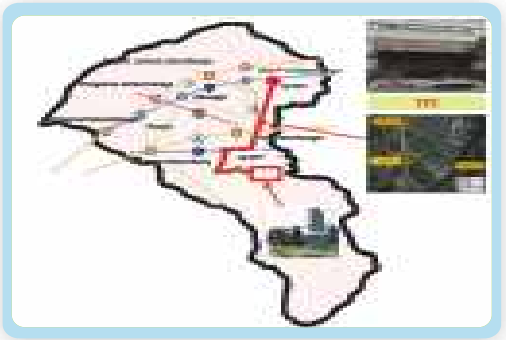


Fig. Receiving Dispatch Commands from TPC

A distribution-grade power modulation system rated at 100 kVA has been installed, including a three-phase inverter, the battery system, the power variation feedback circuits, the power-smoothing algorithm, and a power compensation program. It was used to compensate the PV power variation at Zone 3 of microgrid, and the maximum power variation rate at the connection point is 9.18% during 20 minutes, less than the target of 10%.

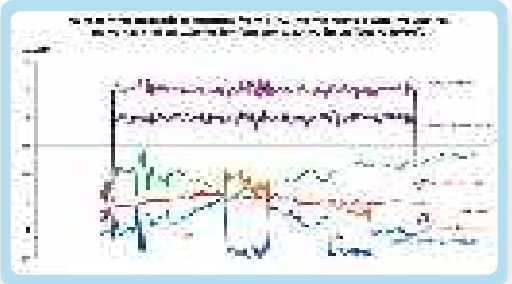


Fig. Steadily supplying power of 100kW

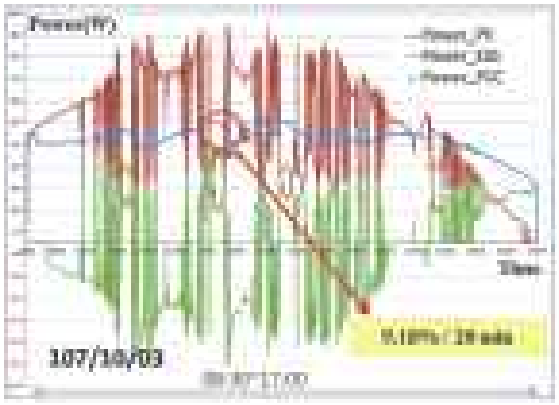


Fig. The maximum power variation rate at the connection point is less than 10%.

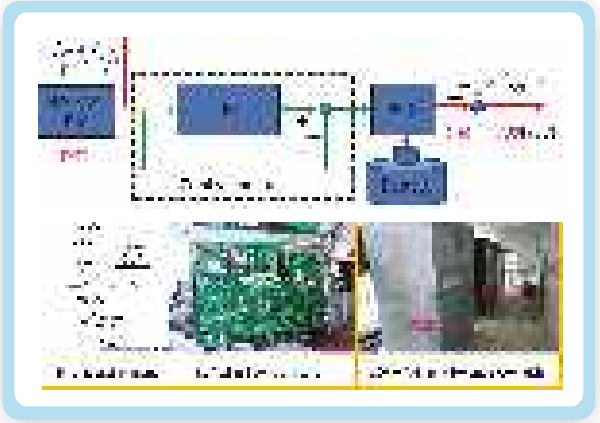


Fig. The configuration of power variation compensation at the connection point

The fault ride through and transient-state compensation technologies have been developed. They also have been integrated with a load shedding platform and a power protection system applied for the distributed regional grid. When exerting a low voltage fault extrinsically, the microgrid could disconnect with the utility and resume stable operation after 99ms. It fulfills the function of autonomous protection for microgrid.

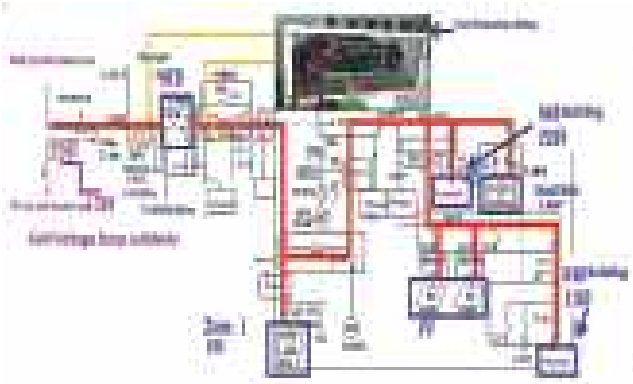


Fig. Tthe power protection for the regional grid

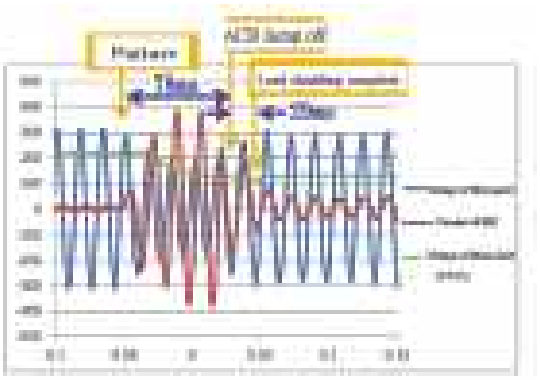


Fig. The waveform of fault ride through and load shedding

- The patent "microgrid energy management instant dispatch method" won a bronze medal in the Taiwan Innovative Technologies Expo in 2018.
- The technology "microgrid voltage stabilizer and frequency regulator" was transferred, and the amount of royalty income was NTD 700,000.
- The technology "microgrid multi-agent day-ahead market power scheduling technology" was transferred, and the amount of royalty income was NTD 500,000.

In anticipation of large amounts of renewable energy feeding into the utility network in the future, INER will continue to enhance microgrid technologies and develop advanced distribution management systems. Furthermore through the cooperative research projects with local firms, INER will uplift their technical level so as to establish a strong local industrial support for the stable operations of power utility and to grab the opportunities for moving into international supply chain markets.

3-2-11
EOS-A Plug & Play Automation Solution

About 98% of Taiwan's energy sources are imported. For an isolated island, electricity cannot be supported from nearby countries. For us, it is crucial to keep a certain level of energy independence and diversity. Therefore, promoting energy transformation to achieve carbon reduction targets, decreasing import energy dependence, and developing green energy technologies are critical issues to achieve the goal above. To be in line with this trend, INER proposes a plug-and-play, auto-configuration Energy Operating System, EOS, which can quickly assemble electric devices into a power system with independent operation capabilities. In addition, EOS has the networking function working with other EOS systems to become a good supporter to integrate green energy.

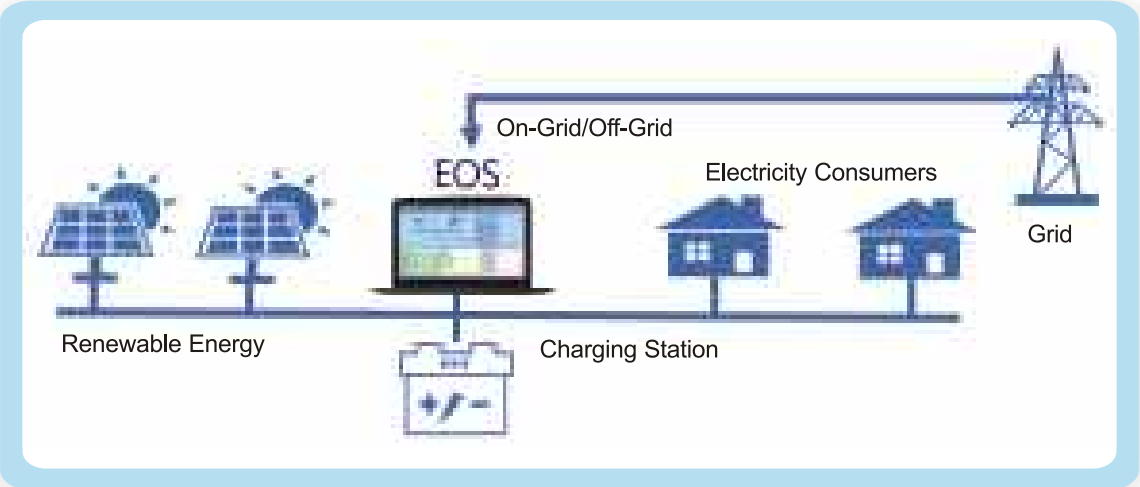


Fig. EOS System Architecture Diagram

EOS features

- Plug and Play: The microgrid device can be added to or removed from the grid system through USB Interface without manual intervention.
- Auto-configuration: Automatic identification of the linked devices according to categories and attributes, and working accordingly.
- Energy management: Monitoring the power supply and demand status, ensure a stable balance between supply and demand.

Independent Operation Mode:

- For Rural Home Users
- Off-Grid Operation
- Self-Sufficiency
- Energy Storage Charging
- Solve the Problem of Power Shortage

Grid mode:

- For communities, buildings, small factories
- Grid Operation
- Self-Sufficient
- Reduce Electricity Bills
- Excess Power: Energy Storage Charge or Feedback to the Grid

Fig. EOS Application Scenario

R&D 100 2018 Finalist

2018 Taiwan Innotech Expo-Bronze Medal Award

INER 50th Anniversary - Honorable Mention

Awards

- 2018 Taiwan Innotech Expo-Bronze Medal Award
- INER 50th Anniversary - Honorable Mention
- R&D 100 2018 Finalist

Patent License

- Plug-and-Play Renewable-Energy Microgrid for Disaster Relief

Technology Transfer

- Plug-and-Play Renewable-Energy Microgrid for Disaster Relief

Fig. EOS Awards, Patent License and Technology Transfer

The main difference between EOS and existing EMSs is that it is non-customized, easy to assemble, and can be dynamically applied to microgrid systems composed of different equipment. In addition to being used at homes, communities, small factories, and rural areas, it can also integrate existing renewable energy power generation facilities and emergency power generation equipment (diesel engines) to build disaster-relieving micro-grids for hospitals or emergency response centers in typhoon or earthquake-stricken areas.

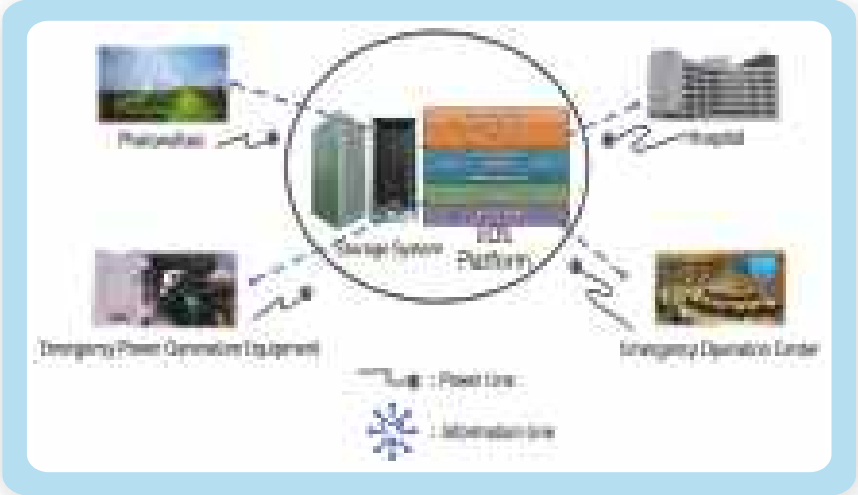
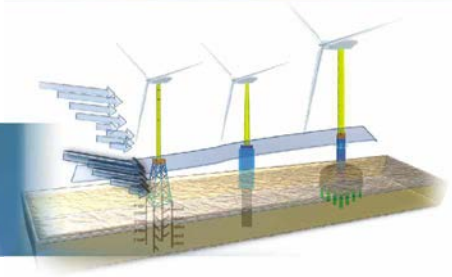


Fig. Microgrid for Disaster Relief

Fig. The Development and Promotion of EOS

Currently, we have implemented EOS into two microgrid facilities and conducted continuous operation tests for more than 100 hours. In the next stage, the functions of EOS will continue to be improved and move toward grid-connected and Internet of Energy (IoE). In addition, from the technical aspect, we will continue to cooperate with microgrid device manufacturers from domestic and foreign to increase the number in the plug-and-play list, and enhance new energy management functions. From the promotion aspect, we will promote EOS by education and training, technology transfer and business investment.

3-2-12
The Underwater Support for the Offshore Wind Turbine



With the special meteorology of Taiwan, typhoon and earthquake are crucial for the structural integrity of offshore wind turbine(OWT). INER has established the load calculation procedure (LCP) and developed localized technology of design verification for OWT through introducing the Offshore Code Comparison Collaboration Continuation (OC4) research outcomes conducted by the International Energy Agency(IEA). In the last few years, INER performed a series of ultimate strength analyses and fatigue analyses for support structure of 5MW reference OWT under domestic environmental conditions such as wind, wave, current, typhoon and earthquake.

To cope with the government's energy policy, we implement the policy vision with strengthened energy security, innovated green economy and promoted environmental sustainability. In addition, INER also assisted China Steel Company (CSC) to establish the technology of design verification for OWT through collaboration between industry and academia.

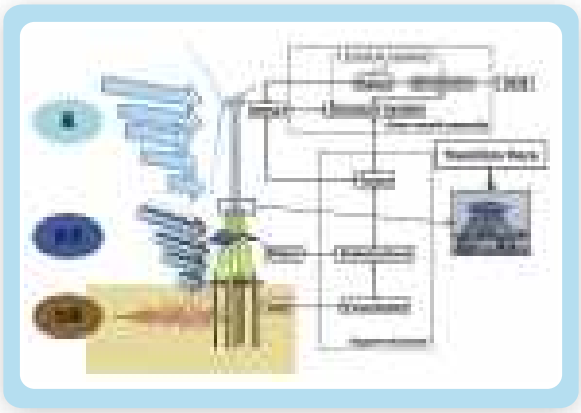


Fig. External loads on offshore wind turbine and support structure

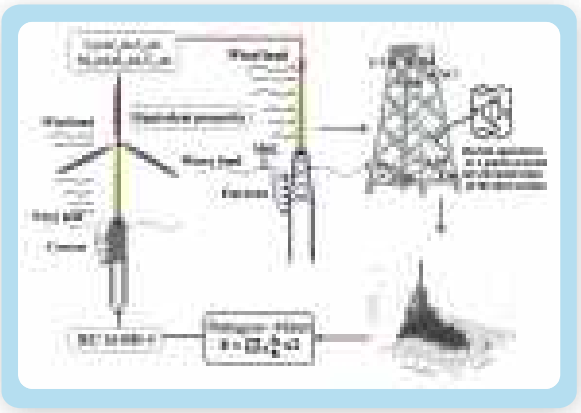


Fig. Fatigue analysis procedure for support structure of offshore wind turbine system

Ultimate strength and fatigue analyses are key points for structural design. Jacket substructure has been widely utilized in the offshore oil and gas industry. However, significant differences in the loading conditions create new engineering challenges. In addition, typhoon and earthquake are crucial for the structural integrity of offshore wind turbines. Therefore, INER has established the calculation procedure for the fatigue and the ultimate strength analyses to evaluate fatigue damage of substructure during 20-25 years and strength margin for support structure of OWT under various design load cases (DLCs) defined in the international design standards.

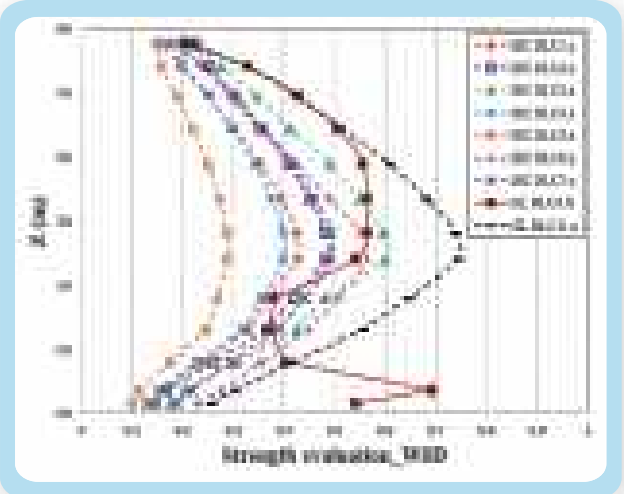


Fig. Ultimate strength analyses for support structure of offshore wind turbine

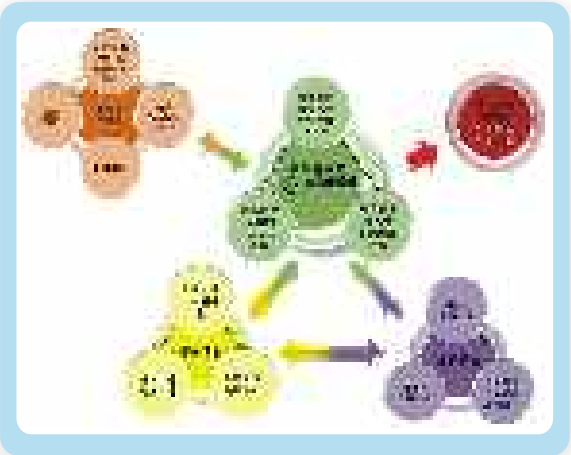


Fig. Research collaboration between industry, universities, research institutes and INER

Because of special meteorological conditions in Taiwan, the development experience of offshore wind farms is different from that in Europe. Therefore, INER has collected domestic long-term environmental data since 2013, and established the LCP for OWT referring to international standard IEC and DNV GL to perform the safety assessment of structure. Above research results are used to assist CSC to manage the development of offshore wind farm. In 2017, CSC collaborated with global companies to successfully build 300 MW of offshore wind capacity and founded the Xingda Marine Foundation Company in Kaohsiung.

To improve the technical capability of design verification and engineering reliability for OWT, INER has cooperated with several international research institutes, such as the Wind Energy Research Center of Stuttgart University in Germany, Aalborg University in Denmark, etc. In recent years, INER actively attended the international conferences and published papers, especially for the paper awarded the honor of outstanding paper in 2018 Taiwan Wind Energy conference.

Fig. Industry-Academic joint research project between CSC and INER

Fig. Different support structure types of offshore wind turbines (Source: NREL)

Development of offshore wind power technology is at a preliminary stage in Taiwan. A 5MW reference OWT has been installed and as a model for engineering research. However, it is necessary to study extra large OWTs to develop related technologies such as support structure, foundation and marine engineering. Regarding the monopile, jacket or other type of fixed substructure, their sizes and material strength must be raised along with the trend of extra large wind turbine. Besides, the cost will increase for the manufacture and construction. Facing the challenges that steel structure is difficult to assemble and fabricate, as a national laboratory, INER will continue to focus on the capacity building of OWT and it will be helpful to promote the development of wind power industry.

3-2-13 Wind turbine noise suppression and remote measuring technologies

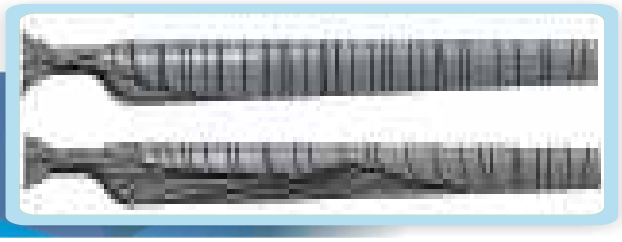


Fig. Simulation Analysis of Bionic Wind Turbine Blades

Wind turbine is one of the most promising green energy equipment that can be installed on the wind farms to provide required electricity. However, the noise generated by rotor blades due to aerodynamic effect introduces impact to the ecology of environment and is criticized. On the other hand, to assure the integrity of the blades for long-term operation, the sonic effect could be measured and used with the ground detection technology to evaluate the structure of the blades. The technology reduces the cost of maintenance and has been applied to the experimental wind turbines in INER.

Fig. Bionic add-ons of wind turbine blade

Fig. INER 25kW horizontal axis wind turbine and support structure

Since the periodic low-frequency noise is dissipated into the environment, it is considered an annoying shortcoming and becomes the barrier to the development of wind turbine industry. To mitigate the noise, geometries of the blade and trailing edges are modified by bionic add-ons to eliminate vortex phenomena, suppressing noise with higher output. The add-ons of the biomimetic device can be applied to commercial wind turbines. We use the spectrum analysis to determine the surface structure of the blade in operation at the ground position and improve the efficiency of inspection.

Fig. Award in INER's R&D contest

Taiwan has developed wind power for more than 10 years and indeed needs the technologies for effective and efficient maintenance. Our technology won the R&D contest of the 50th anniversary of INER and the gold medal of the 2018 Taiwan Innotech Expo. The device has been granted the patent of Republic of China and is applying for US patent. The invented device has also been installed in our experimental wind turbine.

According to the verification, the power output of the wind turbine has 18% increase in the wind speed of 7m/s. The average noise is reduced from 55dB to 49dB, and the maximum aerodynamic noise is reduced from 61 dB to 57 dB, as the figures shown. The device is superior to the full bionic blade and can be easily applied to any wind turbines. Spectrum analysis of the noise through the ground microphone identifies the signal difference caused by the damage of the blades. It clearly shows that the developed technology is superior to the traditional visual inspection.

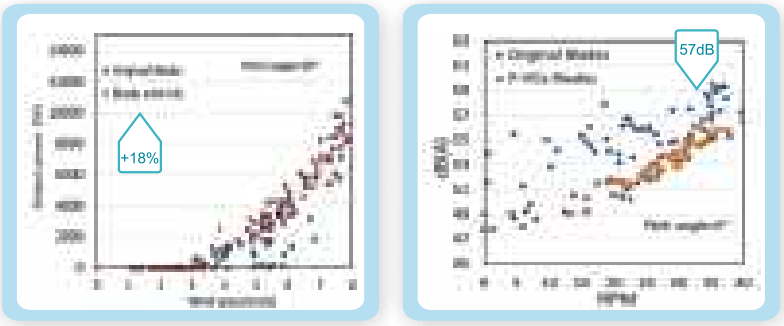


Fig. Comparison of power generation and operational noise verification

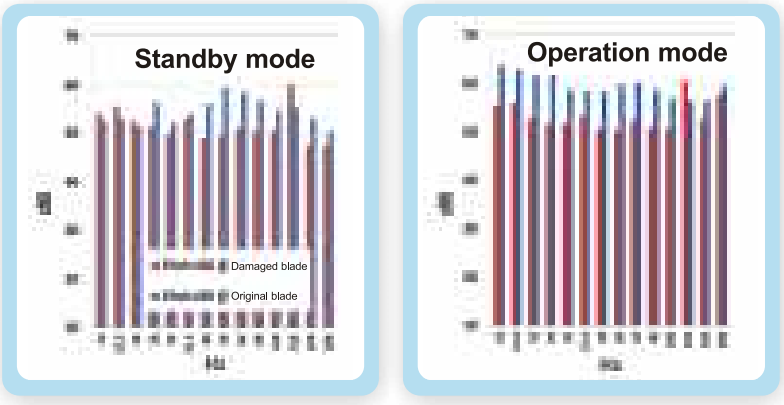


Fig. Comparison of spectrum analysis between original and damaged blades

With the mature development of the wind power industry, O&M will increase the proportion of investment year by year. In the future, the main plan is to achieve noise suppression in a specific frequency and enhance power generation in passive methods. The high-speed photography and infrared imaging will be implemented to enhance blade measuring technology, and it is expected to contribute more key technologies to support Taiwan's offshore wind power O&M and help the reduction in their costs.

3-2-14

An approach to achieve the goal of emission reduction

Flow battery gradually develops after 2040

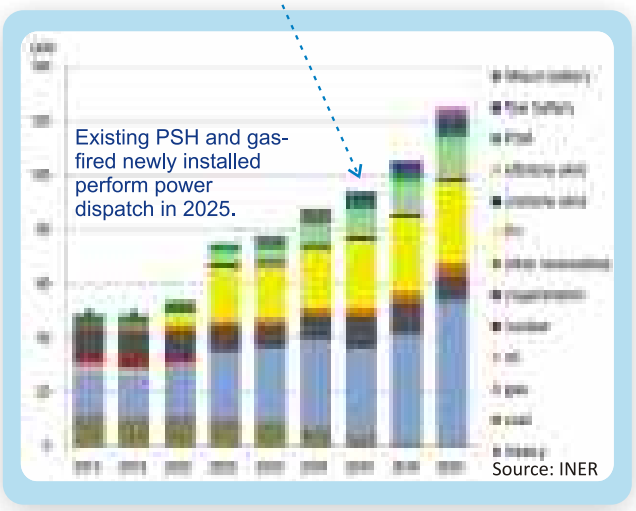


Fig. Installed capacity in emission reduction scenario

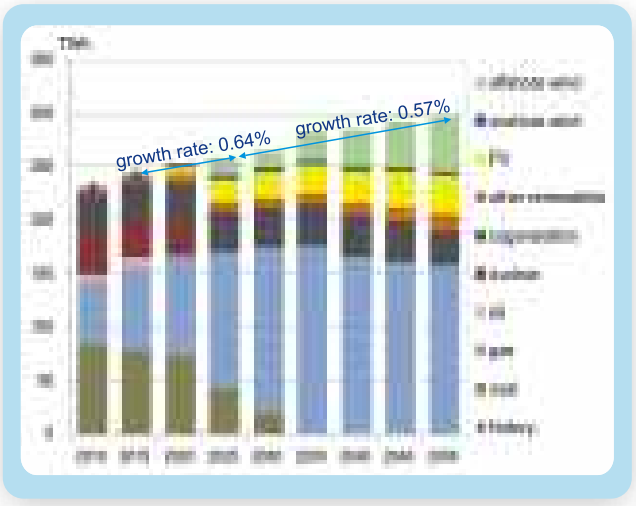


Fig. Electricity generation in emission reduction scenario

INER applied the energy model - TIMES (The Integrated MARKAL-EFOM System) to study the reduction benefit after the clean technologies adopted and plan the low carbon path.

The results can clarify the influence of applying the advance clean energy technologies on energy mix in power sectors, and their importance for the emission reduction.

The result shows:

(1) Based on the "10701 Taipower plan", gas-fired units combined with the existing pumped-storage hydropower (PSH) can provide the requirement of power dispatch for 20% renewables in 2025.

(2) In 2030, new 0.7 GW PSH and 1.2GW lithium battery is needed for the power dispatch; accordingly, the dependence on the regulation by gas-fired units can be reduced and the variation of load demand in day and night can be eliminated. After 2040, flow battery will develop gradually to provide the shift of large-scale electricity.

Note:

- Coal, gas and oil-fired units: the installed capacity for 2017-2028 is based on the 10701 Taipower plan , and their growth rate annually for 2017-2028 is used as the upper limit for 2028-2050.
- Nuclear: 1st off-commissioning, 2nd and 3rd without life extension, 4th mothballed.
- Renewables: the installed capacity for 2017-2030 is based on government s goal, and the PV as well as offshore for 2030-2050 is estimated by INER.
- PSH: the existing installed capacity is 2.6GW, and 705MW is installed in 2030.
- Emission reduction goal: 2030 (Nationally Determined Contribution), 2050 (Greenhouse Gas Reduction and Management Act)

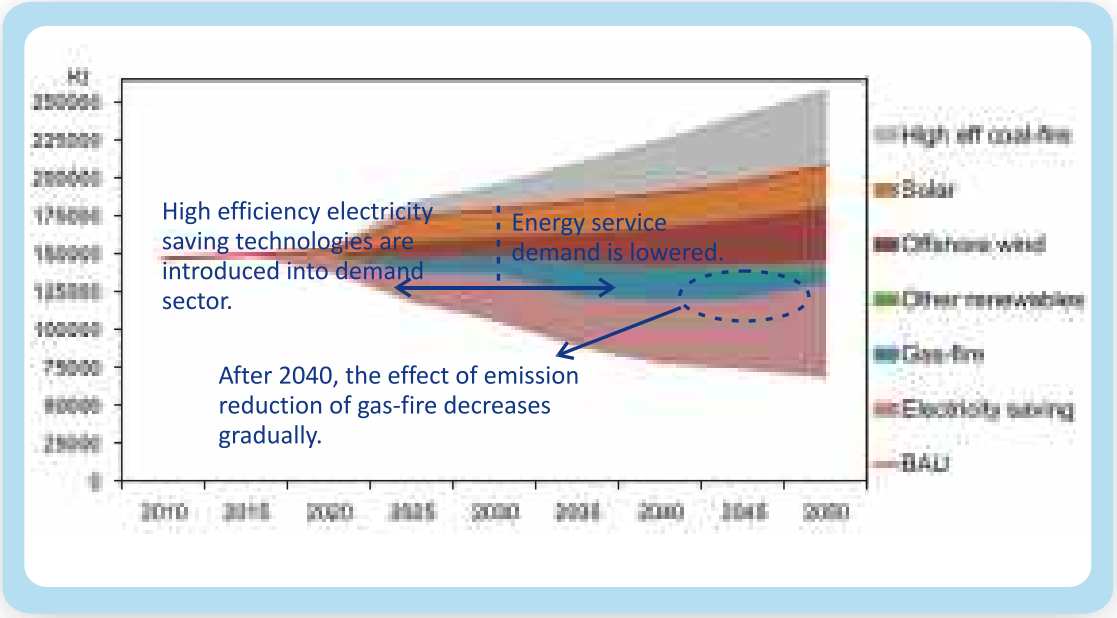


Fig. Co_2 Reduction Prism of Power Sector

Table. Comparison of emission reduction of INER and ETP

Reduction (%)	2030		2050	
	INER	ETP*	INER	ETP*
Solar	23	14	19	24
Wind power	17	19	26	16
Other renewables	0	4	3	5
Electricity saving	42	25	44	16
Gas-fire	17	10	8	-
CCS	-	4	-	11
BECCS	-	-	-	8
Biomass	-	12	-	11
Nuclear	-	12	-	11

Source: INER

- Reduction emission for medium term (2030): electricity saving (42%), renewables (41%), natural gas (17%); for long term (2050): renewables (48%), electricity saving (44%), natural gas (8%).
- Comparing with the ETP 2017*, the reduction emissions for medium term in Taiwan is more dependent on electricity saving, solar and gas-fire due to the lack of nuclear, CCS (Carbon Capture and Storage) and biomass, and for long term, it is the electricity saving, offshore and gas-fire.
- In 2025, the share of generation of solar and wind power achieves 16% totally, and that is almost the same as the one in Sustainable Scenario but is notably higher than 11.5% of New Policies Scenario in WEO 2017 **. That means the Taiwan's government is quite active for developing the renewables even if the available technologies is limited.

Note*: IEA, Energy Technology Perspectives(ETP) 2017, OECD/IEA
**: IEA, World Energy Outlook(WEO) 2017, OECD/IEA

3-3 Research and Development of Radiation Applications

There has been about forty years in ionizing isotope application research and development in INER. Now the nuclear medicine and imaging devices research have become one of the most import radiation application items. After so many years research, INER had succeed in commercializing and transfer several nuclear medicine drugs to market. Even the imaging device and relative software has been also under clinical try. Recently, following the developing of medical science all over the world, nuclear medicine and imaging devices have developed into a new generation, such as PET, SPECT combines with MRI, CT and with 3D tomographic technology. These develops can help doctor look inside the patient's sick foci with 3 D structure clearly, and help doctor's precise therapy much easily.

In nuclear medicine, from research, clinical trial and commercialization, INER has already owned a unique complete chain. INER also has experience in micro PET, micro SPECT and 3 D X-ray and CT and some related hard devices and soft wares. With the recent globe development of precise therapy and personalize medicine, INER has chosen nuclear medicine and imaging technology as a priority research and developing items.

INER Tc-99m TRODAT-1 Kit, a dopamine transfer diagnostic nuclear medicine drug, developed in INER was approved by Taiwan Department of Health in 2005 and sold it internationally. It was finally license-out in 2016. Today this drug had entered the highly competitive global biomedical market successfully. This achievement has encouraged INER continuing further research and development in nuclear medicine. INER I-123 MIBG is the best example in INER. Now Taiwan Food and Drug Administration had agreed the registration trial wavier of I-123-MIBG on the diagnosis of neurogenic tumor and cardiac sympathetic nerve function. We are now currently working on the commercializing this nuclear medicine drug.

In research and development of medical imaging devices, INER are focusing on improving the quality of medical imaging as well as enhancing the measurement sharpness. There is one report in this annual report as "Portable Graphite Calorimeter". This report described some unique improvement for its portable ability and available in the measurement of the proton therapy cancer therapy devices onsite. There are another report as "Multi-energy Radiography Technique for Material Decomposition in 2D X-ray Images" and "Traceability system of dose standard for radiotherapy in Taiwan"They are all focus on the precise and sharpness in the images and dose measurement. All the purpose of these researches will enhance and help the precise therapy and personalize medicine in Taiwan.

In nuclear medicine, INER also begin a lot of new research items. Such as "INER Liver Imaging Agent" , "Molecular imaging platform Significantly reduce the cost of new drug research and development", "Development of cyanine-based theranostic probe (DOTA-NIR790) for cancer" , "Establish the metabolic technology platform for C-14 small molecule Drug". These topics will be the major research and development items for INER in the near future.

With the developing of domestic pharmaceutical biotechnology and nuclear medicine industry, INER is trying to integration the local academy, research center and medical units to enhance the research level to be one of the best pharmaceutical in the world. INER will like to create and fulfill these radiation medical applications, and make them as INERs sustainable development object.

3-3-1 Establish the metabolic technology platform for C-14 small molecule Drug

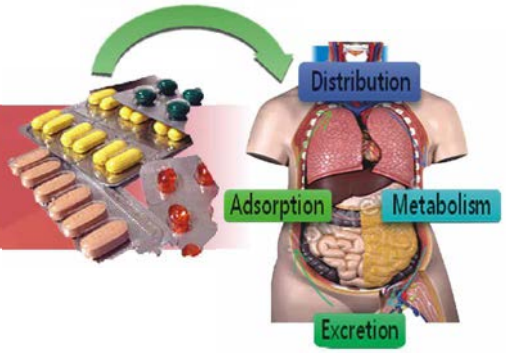


Fig. INER certification for drug development applications

Pharmacokinetics (adsorption, distribution, metabolism, and excretion, ADME) of a drug candidate relies strongly on the data generated from animal studies to assure its safety. The gold standard to quantify metabolites, distribution and mass balance in time course is typically utilizing a C-14-labeled version of investigational drug, which is detectable at very low levels. Currently the analysis of drug metabolites should be conducted by foreign CROs. It is not only costly but also time-consuming. We aim to evaluate the feasibility in establishing the technology as well as the infrastructure for the analysis of ADME utilizing C-14-labeled material. It will fill this technology gap and accelerate the development of domestic biotechnology and pharmaceutical industry.

Fig. The metabolic technology platform equipment

One key element in the development of such a project is imposed by the strict regulations governing the use of ionizing radiation, the management of waste disposal and the control of release. Therefore, the environment for the store and handle of C-14 was improved in order to efficiently comply with all of these requirements. The appropriate management strategy for disposal and emission of the waste containing C-14 is under development in this project.

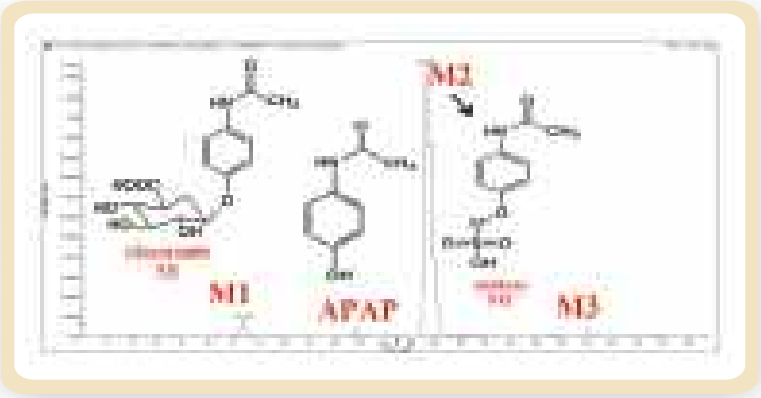


Fig. HPLC-MS/MS Chromatograms of Acetaminophen in Rat Urine

We use commercialized drug as acetaminophen (APAP) were exploited to establish the techniques for the assessment of ADME in advance. An HPLC-ESI-MS/MS analytical method was applied for studying in vivo metabolism of APAP, and their metabolites (M1, M2, M3) in rat urine. The result is consistent with literature reported.

Pharmacokinetics, distribution, metabolism and excretion of acetaminophen were investigated following an oral dose of C-14-acetaminophen in rodents. The tissue distribution was investigated by quantitative whole body autoradiography (QWBA) in mouse. Highest concentrations of radioactivity were mainly observed in the kidney at 30 min after the administration of C-14-acetaminophen. After 72 hours of oral administration of C-14-acetaminophen in rat, the majority of the radioactivity (84%) was excreted via urine. Three metabolites were identified in rat urine, which is consistent with reported. The mass balance of excreted doses showed 91% of total recovery of radioactivity.

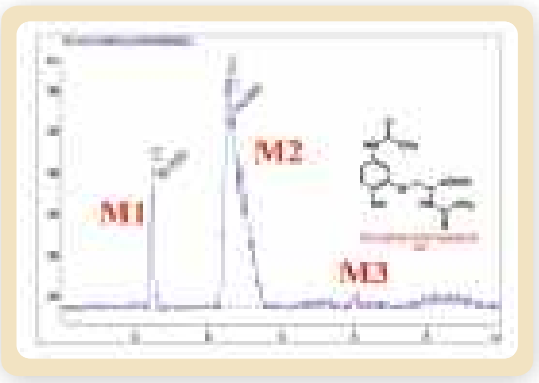


Fig. Radio-HPLC Chromatograms of C-14 Acetaminophen in Rat Urine

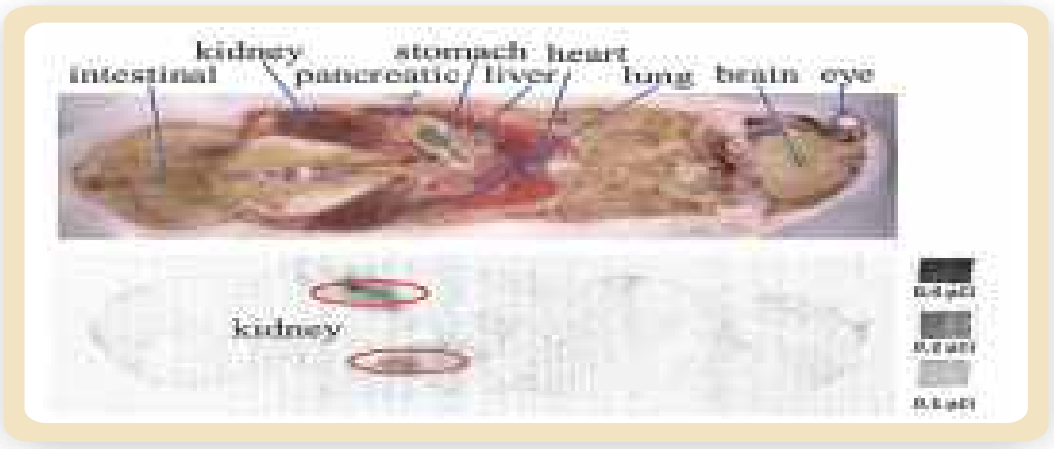


Fig. Representative autoradiogram of whole body section

The facility for handling C-14, the management strategy for disposal and emission of the waste containing C-14, and the technology for assessment of ADME have been investigated in this project, indicating that INER may have the ability to establish the comprehensive technology platform for ADME assessment. We expect to establish and provide the services to domestic pharmaceutical industry for facilitating the drug development in the future.

3-3-2 Molecular imaging platform： Significantly reduce the cost of new drug research and development

Drug development needs: According to the Global Cancer Report 2014 published by the World Health Organization (WHO), the mortality number of cancer cases will increase from 14 (2012) to 19 million (2025), and in 2035, it will reach to 24 million, that is, increase by more than 70% in near 23 years. For many years, oncology drugs have been ranked as the world's largest drug category, and due to the increase in the number of cancers, new anti-cancer drugs are still being produced and approved for marketing. According to statistics from Pharmaprojects, there are currently about 3,000 new cancer drug developments in the world, showing that anticancer drugs are the main targets for the development of various pharmaceutical companies. However, the length of time for new drug development cycle is long, the capital investment is high, and the success rate is low. How to introduce new technologies to shorten the development time and reduce the failure rate has become the direction of thinking.

The importance of molecular imaging: The FDA's revolutionary new policy "Critical Path" was proposed in 2004 to ensure the opportunity to turn the drug being explored into a successful product. Specific implementation projects include toolkits to improve drug development, and molecular image assessment technology is considered one of the most potential ways to break through the development bottleneck. Molecular imaging can be applied to all stages of new drug development, from pre-clinical drug screening and development to post-stage clinical trials (Fig. 1), helping to reduce the time and money wastage. Taking the clinical trial phase II as an example, the introduction of molecular images can quickly decide whether to continue execution (go/no go), save 3/4 realizable value, and lead the follow-up clinical trial strategy.

Fig. 1. Application of molecular imaging in various stages of new drug development. Source from: Mol Imaging Biol. 2017 Jun; 19(3):348-356

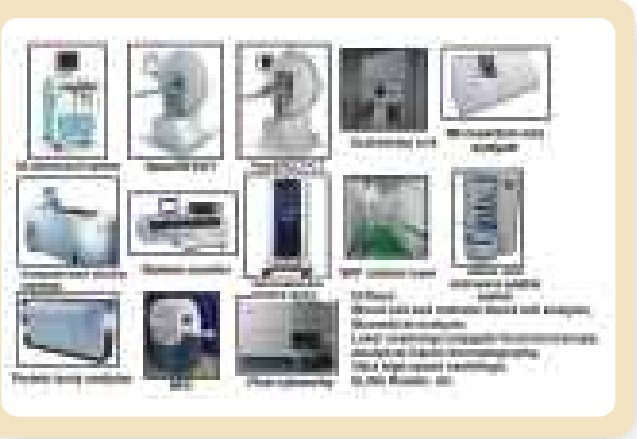


Fig. 2. INER Core Imaging Instruments and Equipment

Technology establishment: The Nuclear Energy Research Institute (hereinafter referred to as INER) has established radiolabeling laboratories, molecular imaging laboratories, biological research laboratories, and a GLP radiotoxicology laboratory, and has bio-related technologies such as drug labeling technology and molecular imaging. INER also has related core instruments and equipment. (Fig. 2). In response to the strong demand for new drug development in Taiwan and the technical gap in the rapid screening of new drugs, INER has continuously upgraded its core technical capabilities and facilities, and gradually established a screening platform for nuclear medicine molecular imaging in line with international standards.

Execution mode: The new drug candidate molecule provided by the new drug research and development unit, INER will radiolabel with the short/long half-life radioisotope according to the actual demand, and cooperate with the disease animal model provided by the new drug research and development unit to perform small animal molecular imaging (nanoPET/ or nanoSPECT/CT). This can quickly assess the absorption and distribution of the drug in various tissues, organs and tumors, and can obtain the drug accumulation, accumulation ratio and distribution over time, and further evaluation of pharmacokinetics. The contents and technical advantages of the molecular imaging screening service of INER, as shown in Table 1.

Table 1. The contents and technical advantages of the molecular imaging screening service of INER

Items	Molecular Imaging Screening Service of INER
Tests	Cell binding, molecular imaging, Biodistribution , Pharmacokinetics
Cost (NTD)	1.0-1.5 million (depending on experimental design)
Time required	3-4 month (depending on experimental design)
Test data obtained	Cell binding,Molecular imaging, Biodistribution , Pharmacokinetics
Main advantages of INER	(1)Transaction Cost is very low, because the contract content is transparent, and the protocol can be modified in time. (2)Good communication platform, easy to use Due Diligence (3)INER has a compact cyclotron, so the isotope sources are easy to obtain, and the screening service only requires 1/3 test time of foreign manufacturers, and the cost of 1/3 or less. (4)Many data can be obtained at one time to quickly confirm whether the drug is suitable for development, and to estimate future drug design, etc. (5)Easy sample delivery (6)The new therapeutic drugs developed by the R&D unit may also be further developed by INER as a nuclear medicine companion diagnostic drug, which will help shorten the time and cost of clinical trials and reduce development costs.

Future planning and development: In the preclinical study of new drug development, screening for pharmacologically active ingredients is a top priority, followed by efficacy (potency) and safety (toxicology) assessments. Therefore, the technology platform with rapid screening, pharmacology and toxicology of candidate new drugs is one of the essential requirements for the development of new drugs. Some domestic units, such as the Development Center for Biotechnology (DCB), Panlabs Biologics Inc., have established pharmacological and toxicological testing technology platforms and provided external services. However, in the early stage of new drug development, the use of in vivo imaging technology for rapid screening of new drugs is still in the development stage. The FDA has promoted the development of new drug development time by molecular imaging for many years; in addition, molecular imaging, radiopharmacology, radiotoxicology and other technologies have been widely used in radiopharmaceutical research and development units. In response to this trend, many domestic hospitals or legal entities such as INER, Taipei Veterans General Hospital, Chang Gung Memorial Hospital and National Health Research Institutes (NHRI) have also begun to invest resources to build core facilities and technologies for nuclear imaging. INER has a compact cyclotron with the advantage of producing a wider variety of radioisotopes. In the follow-up, we will continue to upgrade core technologies, software and hardware, and equipment, and plan to complete the TAF certification of the molecular imaging screening platform, in order to play a key role in the development of new drugs in the domestic biotechnology and pharmaceutical industry. Connected to the upstream research institutions and downstream manufacturers to help improve the rapid screening capabilities of Taiwan's new drug industry, reduce drug development time and money costs, and increase international competitiveness.

3-3-3

INER Liver Imaging Agent has obtained FDA Phase I Clinical Trial Approval in 2018

Read liver function by imaging

INER liver imaging agent is a Taiwan-Brand innovation. It can specifically target to liver asialoglycoprotein receptor. This receptor anticipates most liver functions, including hepatocyte-specific adsorption, metabolism and excretion; therefore its imaging can be an indicator of liver reserve and apply in therapeutic strategy assessment of hepatectomy, liver transplantation and chronic hepatitis. This product has been approved for US FDA and TFDA phase I clinical trial in 2018, which is a first-in-human peptide-based liver function imaging agent in the world.

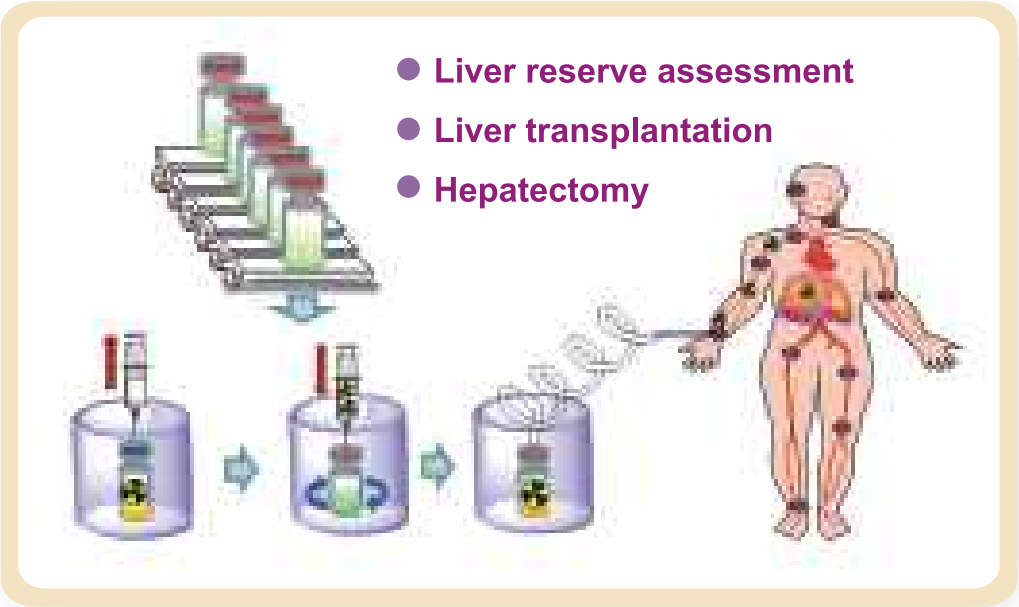
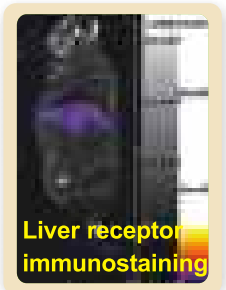
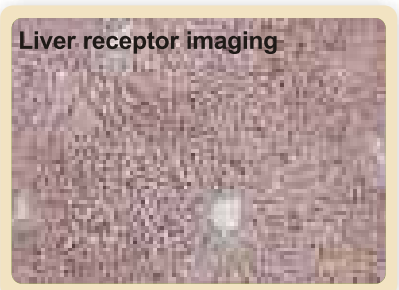


Fig. INER Liver Imaging Agent is the first instant lyophilized product for Ga-68 radiolabeling

INER Liver Imaging Agent is a lyophilized product for the preparation of Ga-68 Dolacga Injection, which is a instant preparation in only one vial. It only spends 15 min to radiolabeling and retains more than 95% radiochemical yield within 4 hr. The animal trial indicates that it is effective to bind only with normal hepatic parenchymal cells and not at all any absorption in hepatoma region. There is positive correlation between receptor imaging and receptor immunostaining. The indication is used as liver reserve assessment.





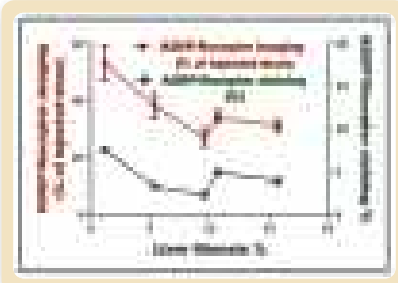


Fig. Liver receptor imaging was in accordance with liver receptor immunostaining (Mol. Pharmaceutics 15:4417-4425, 2018.)

This novelty has obtained more than 13 patents from US, Japan, EU and Taiwan. The awards include National Innovation Award in Taiwan, International Trade Fair Ideas-Inventions-New Products in Nuremberg, and Platinum Award of Taipei International Invention Show and Technomart etc.

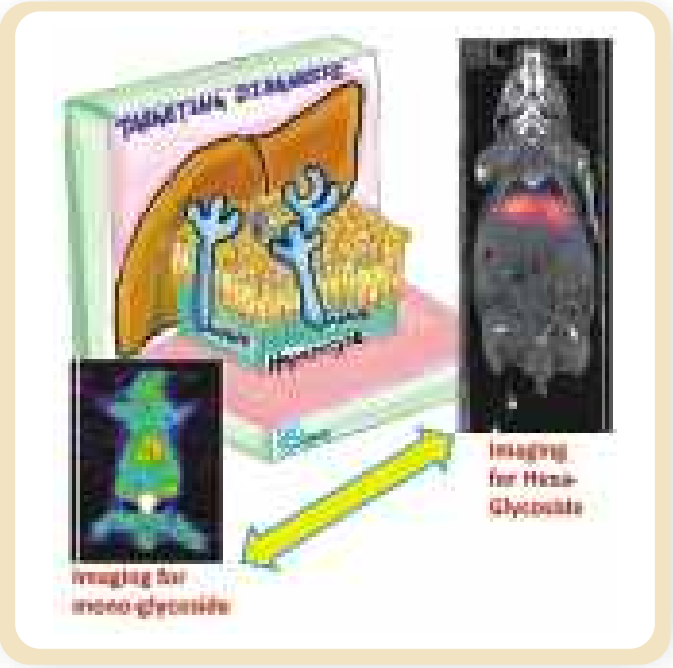


Fig. Evidence for Liver Targeting and Low Background for INER Liver Imaging Agent

Competitive Advantage

1.INER liver imaging agent is peptide-based. The low background is more beneficial for enhancing sensitivity than protein-based agent.

2.This peptide-based agent is small compound with about MW 3000, which is easier to pass the regulatory challenge.

3.The population of chronic hepatitis in the world is 680,000,000. The market estimate is 1230000 per year.

Fig: Patent Map for INER Liver Imaging Agent

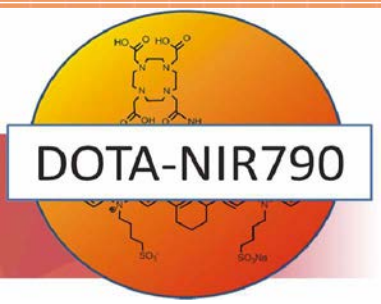
FDA approval **NTUH IRB approval** **TFDA approval**

Fig. Phase I Clinical Approval for INER Liver Imaging Agent

INER liver imaging agent has been approved for US FDA and TFDA phase I clinical trial in 2018, which is a first-in-human peptide-based liver function imaging agent in the world. Helathy volunteer is in recruiting.

3-3-4

Development of cyanine-based theranostic probe (DOTA-NIR790) for cancer



The program "Development of cyanine-based theranostic probe (DOTA-NIR790) for cancer" represented the Institute of Nuclear Energy Research in the 15th National Innovation Award and won the "Science and Research Innovation Award" in the Biotechnology Pharmaceutical Group. Cancer is one of the leading death causes in the world. Cancer-targeted theranostic probe labeled with the radionuclide has been developed to provide multi-modalities for NIR fluorescence and nuclear imaging and for photothermal therapy (PTT) of cancer. In this study, we synthesized NIR dye-based probe (DOTA-NIR790), which could be chelated with In-111, Ga-67, Lu-177, Ga-68, and Cu-64 for nuclear imaging (SPECT, PET), Lu-177 and Y-90 for radiotherapy of cancer. In addition, the NIR dye allowed the probe to have multi-functions in NIR imaging and photothermal therapy (PTT) (Fig. 1). This probe can provide patients more effective diagnosis and treatment of cancer, and enhance the competitiveness of pharmaceutical in our country.

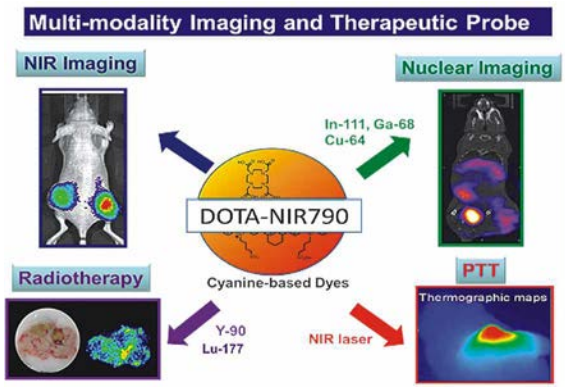


Fig. 1. Development potential of cyanine-based theranostic probe (DOTA-NIR 790).

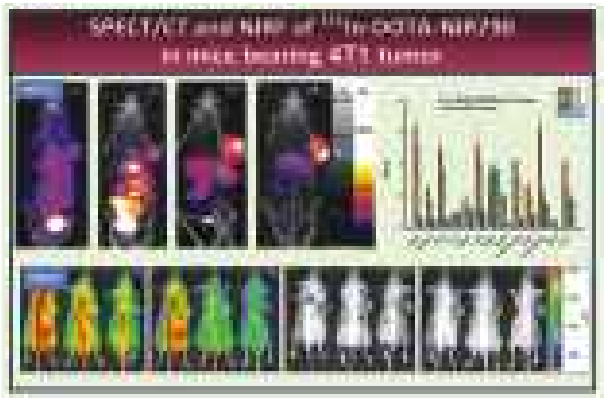


Fig. 2. SPECT/CT and NIRF imaging of multifunctional theranostic probe (^{111}In-DOTA-NIR790) in 4T1 tumor-bearing mice.

Animal experiments demonstrated that theranostic probe (DOTA-NIR790) can effectively target to tumor for diagnostic imaging. This probe can be labeled with radioisotope for single photon computed tomography (SPECT / CT), and can be used for tumor near-infrared fluorescence imaging (NIRF) of cancer. As shown in Fig.2, SPECT/CT image showed a high detection capability for deep tumor, and NIRF image showed a better tumor-targeted image in the superficial tumor. These two imaging modalities have their own strengths, however, both can be used simultaneously to improve the accuracy of tumor diagnosis.

Cyanine-based theranostic probe (DOTA-NIR790) can be labeled with therapeutic isotope Lu-177 for the radiotherapy of cancer. In addition, this probe can also be used for photothermal therapy of cancer (As shown in Fig. 3). After irradiation with a wavelength of 808 nm (1.5 w / cm^2), the tumor temperature showed that aftminutes of light treatment can effectively enhance to about 48.6 ℃. The result of tumor growth also showed that the photothermal er 5 effect caused the tumor temperature to rise, resulting in effective tumor ablation.

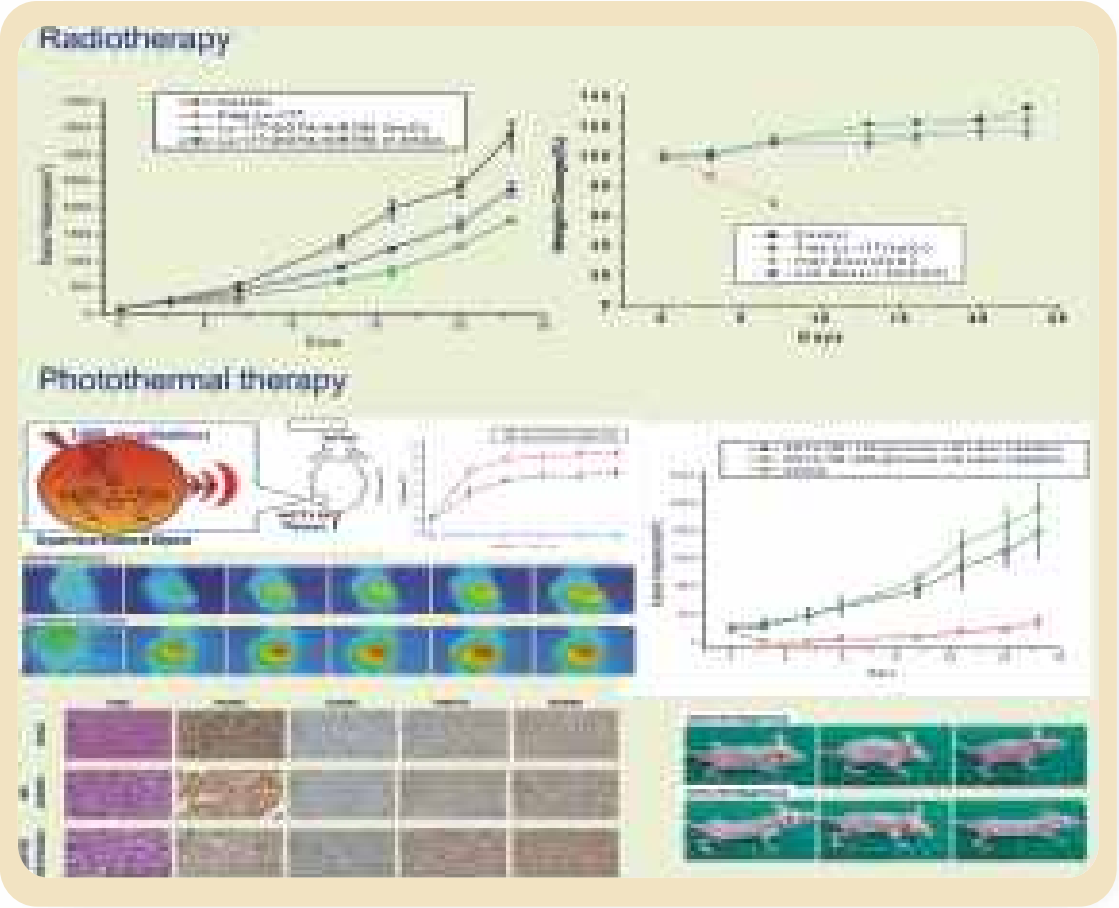


Fig. 3. Anti-tumor efficacy of radiotherapy and photothermal therapy by theranostic probe (DOTA-NIR790) in tumor-bearing mice.

The theranostic probe (DOTA-NIR790) has effective target for various organ tumors, so it has a wide range of tumor indications. This probe has a DOTA that can chelate a variety of isotopes, and can be developed as frozen crystal form to simplify the labeling process. This probe had been developed to provide multi-modalities for NIR fluorescence and nuclear imaging (PET, SPECT), photothermal therapy (PTT) and radiotherapy of cancer. In this study, we synthesized NIR dye-based multifunctional probe (DOTA-NIR790), which could be chelated with isotopes for nuclear imaging (PET, SPECT) and acquired for tumor infrared fluorescence (NIRF) imaging. The NIR dye allowed the probe to have multi-functions in diagnosis and treatment of cancer. In addition, this multifunctional probe will be conjugated with chemotherapeutic drug for the synergistic combination of tumor imaging and photo-chemotherapy in the future.

3-3-5 Effectively improve the dose accuracy of radiation therapy-Portable Graphite Calorimeter

In recent years, major hospitals in Taiwan have introduced proton and heavy particle therapy equipment, making it one of the important options for cancer treatment. Since protons and heavy particles have the characteristics of Bragg peak, they can penetrate human tissues and release energy to destroy cancer cells and thus reduce the radiation dose received by surrounding normal tissues. However, precise treatment needs to be matched with accurate dose to achieve effectiveness. At present, the evaluation method for the therapeutic dose of proton and heavy particles is calibrated in Co-60 gamma rays, and then converted to proton and heavy particle dose according to IAEA TRS-398 protocol. The measurement uncertainty is about 2% to 3%. The portable graphite calorimeter developed by the Institute of Nuclear Energy Research (INER) can be carried to the hospital for direct measurement of proton and heavy particle dose. It does not need to be converted by protocol, which can reduce the measurement uncertainty to 1% and effectively improve the dose accuracy of radiation therapy.

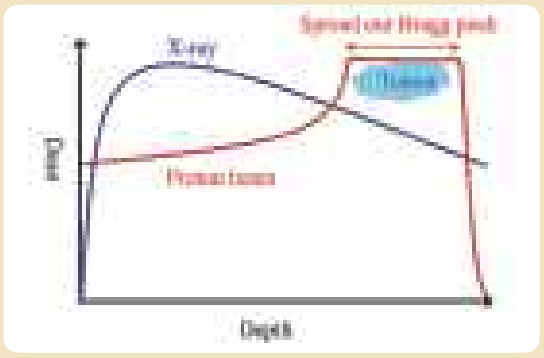


Fig. SOBP of proton and heavy particle beams

Fig. Graphite calorimeter

Calorimeter is a newly developed radiation dose measurement technology. It has the ability to directly measure the heat of the radiation and convert it into absolute dose characteristics, reducing the error caused by the protocol when evaluating clinical doses. Because the temperature change caused by the radiation dose is very small, the graphite calorimeter often needs to be equipped with temperature control equipment and high-precision measuring instrument, which makes the graphite calorimeter bulky and difficult to transport and install and limits the convenience of the graphite calorimeter. INER miniaturized the graphite calorimeter body, temperature control equipment, measurement circuitry, etc., reduced the volume of the graphite calorimeter, and simplified the installation steps so it would be easily carried to the hospital for clinical radiation dose measurement.

Fig. Portable graphite calorimeter

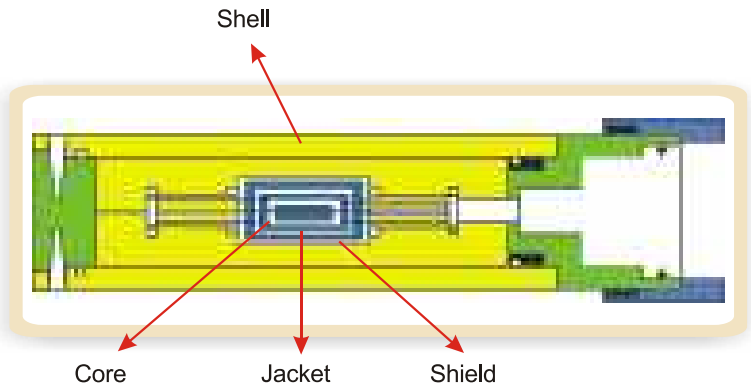


Fig. Structure of portable graphite calorimeter

The original graphite calorimeter has the "core" used to measure radiation dose, the "jacket" and "shield" used to control the temperature, and the "phantom" used to achieve sufficient amount of scattering. The graphite calorimeter weighs 50 kg, making it bulky and inconvenient to carry. It can only be placed in the laboratory as a primary standard for calibrating other dosimeters. In order to increase the convenience of use, the original graphite calorimeter was split into two parts: graphite calorimeter and graphite phantom. The new graphite calorimeter contains the core, jacket and shield, and the weight is only about 3.5 kg. Graphite phantom is designed into sheets of various thicknesses. It is easy to carry and can be assembled into the required phantom thickness according to the type and energy of the radiation to be measured.

To evaluate the measurement capabilities of the portable graphite calorimeter, a comparison was made using the Co-60 absorbed dose to water calibration system in the national radiation standard laboratory of INER. This system uses the graphite ionization chamber as the primary standard. It had been verified through the international comparison of the Asia Pacific Metrology Programme (APMP) several times, and the comparison results were good, so the measurement results can be regarded as equivalent to the international standards. Comparing the measurement results of the portable graphite calorimeter with the results of the primary standard ionization chamber, the difference is less than 1%, so it can be confirmed that the accuracy of the portable graphite calorimeter meets the measurement requirements.

Fig. Co-60 absorbed dose to water calibration system

Fig. Graphite phantom sheets with different thicknesses

In the future, before using the portable graphite calorimeter for proton and heavy particle therapeutic dose measurement, the energy spectrum of the spread out Bragg peak should be obtained according to the individual beam, and the vacuum gap and volume average effect correction factors of the portable graphite calorimeter should be evaluated. Next, the onsite measurement will be performed at the proton or heavy particle facility of the hospital, and the accuracy of the portable graphite calorimeter will be verified by comparing with the dose measurement of the ionization chamber. Finally, the national standard for proton and heavy particle dose can be established based on the measurement results, and delivered to hospitals for calibration and traceability.

3-3-6

Multi-energy Radiography Technique for Material Decomposition in 2D X-ray Images

For X-ray imaging process, the three-dimension (3D) structures of object would be projected into the flat panel detector to obtain 2D images. The materials appear on image are hard to separate when the object contain different materials. Moreover, the image grayscale of high density material with thin thickness is possibly similar to the low density material with thick thickness. The aforementioned factors would increase the difficulty of the image interpretation.

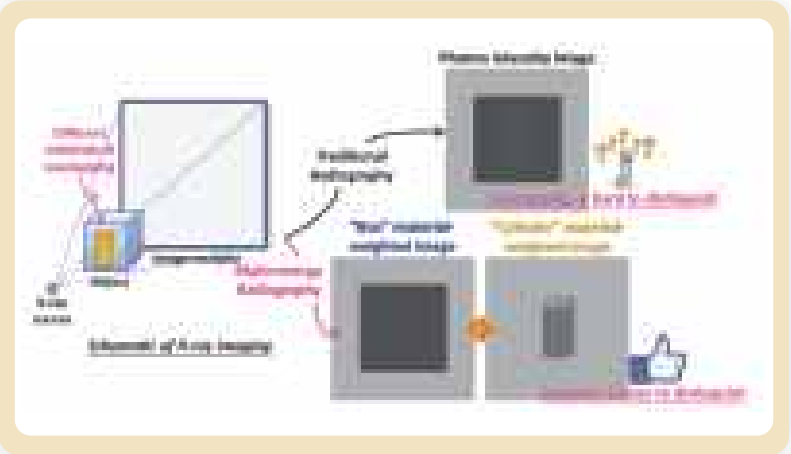


Fig. 1. When the objects are overlapping, the differences of the multi-energy radiography and the traditional radiography.

Hence, the multi-energy radiography technique developed by INER, which can provide more information related to material properties by using the X-ray imaging data with various photon energies. We apply this technique to 2D X-ray images. For the chest X-ray imaging application in medical field, it can increase the diagnostic ability of lung lesions and improve healthcare quality. For the X-ray baggage inspection in non-medical field, it can improve the identification ability and efficiency of different materials. It can also assist security agent to quickly distinguish between normal items and contraband, and enhance aviation safety. (Fig. 1)

For traditional radiography technique, the grayscale value on the image represents the sum of the residual photon intensities after the X-ray penetrates the object. Therefore, when several materials in the object have similar attenuation, similar grays may appear on the image. (Fig. 2) However, for multi-energy radiography technique, the imaging information provided by different photon energy, and substituting into the material decomposition algorithm developed by INER, it can provide weighted images of different materials, which can separate the overlapping objects. (Fig. 1) If the material calibration technique is added into material decomposition process, the effective atomic number of material also can be calculated. The value of atomic number is like the identification of materials, which can be used to estimate the material component. However, that's impossible for the traditional radiography.

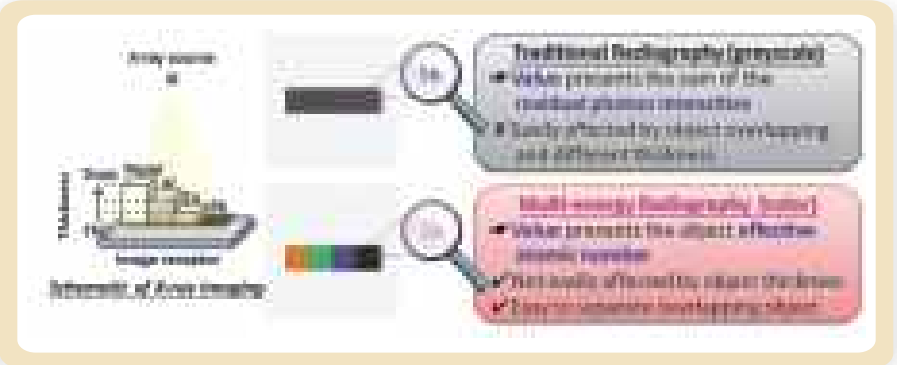


Fig. 2. When the thickness of objects are different, the differences of the multi-energy radiography and the traditional radiography.

Medical Application: Chest X-ray Imaging

The multi-energy radiography technique developed by INER is applied to medical chest X-ray imaging, which can output two different material weighted images. Compared with general chest X-ray images, soft tissue weighted image can show lungs and trachea contours clearly, and the image contrast can be increased by 65% for small tumors hidden behind the ribs, which can help improve the diagnosis of early stage lung cancer. Bone weighted image clearly shows bone edges and textures and can assist doctor for fracture diagnosis.

Non-medical Application: X-ray Baggage Inspection

The multi-energy radiography technique can not only used for medical X-ray imaging to improve the diagnosis ability, but also used for X-ray baggage inspection in non-medical field. If the material calibration and image processing techniques developed by INER are applied in to material decomposition algorithm, the effective atomic number of the object can be obtained, which can be used to confirm which type of material the object is. Generally, the atomic number is divided into three categories: organic, inorganic and metal, and the corresponding color is given in Table 1. Most of the plastic explosives are organic materials, when they are hidden in the baggage, it's hard to be detected by using traditional X-ray, and it's extremely dangerous to aviation safety. Such techniques are very useful to the applications with high throughput requirement like X-ray baggage inspection.

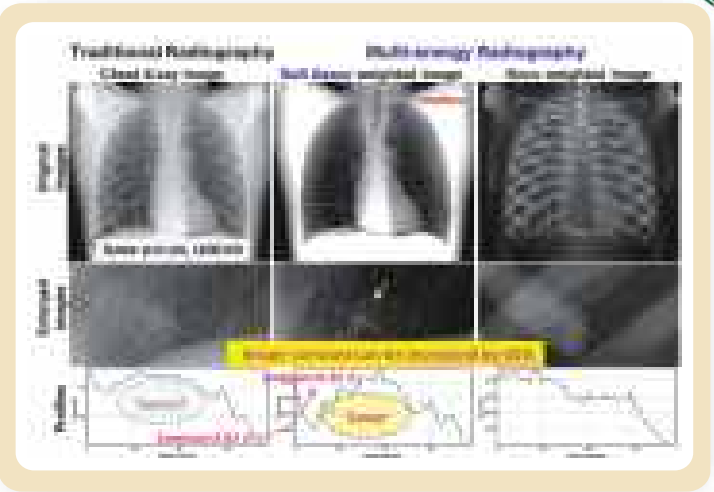


Fig. 3. The results of 2D multi-energy radiography technique applied to medical chest X-ray imaging.

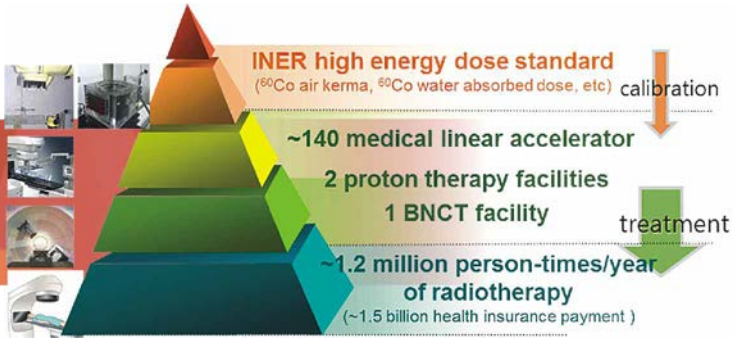
Table 1. Different material types and atomic numbers in X-ray baggage inspection.

To evaluate the performances of multi-energy radiography technique, we performed the X-ray imaging tests with image quality assurance phantom, which is according to the standard of European Civil Aviation Conference (ECAC). For the multi-energy radiography technique, the results reveal that different types of materials are coded in predefined colors, which is impossible for general X-ray images.

Conclusions and Future Works At present, INER has the capability of multi-energy radiography technique for 2D X-ray imaging, and has been applied in medical and non-medical fields. The results show good performances. In the future, we will keep work on relative techniques development (e.g. 3D multi-energy computed tomography technique), which can be applied to non-destructive testing (NDT), baggage inspection and medical CT imaging to improve industrial inspection and medical diagnosis performance.

Fig. 4. The results of 2D multi-energy radiography technique applied to non-medical X-ray baggage inspection.

3-3-7 Traceability system of dose standard for radiotherapy in Taiwan



With the development of atomic energy technology in radiation therapy, the combination of radiotherapy and other medical technologies has become a useful tool for personalized medicine and precision medicine in recent years. Based on the sources, the advanced cancer radiotherapy technologies can be divided into: Co-60 treatment, medical linear accelerator photon / electron treatment, Ir-192 brachytherapy, proton therapy, particle therapy, fast neutron therapy, and boron neutron capture therapy (BNCT), etc. The widely-used technologies of radiotherapy include: 3D-CRT, IMRT, IGRT, SRS, Tomotherapy, Gamma Knife, CyberKnife, VMAT, Axesse, TrueBeam, Novalis, RapidArc, HyperArc, and MR-guided radiation therapy, etc. Regardless of the techniques, the most important factor of efficacy is radiation dose. The absolute dose and accuracy are directly related to the traceability system of dose standard for radiotherapy.

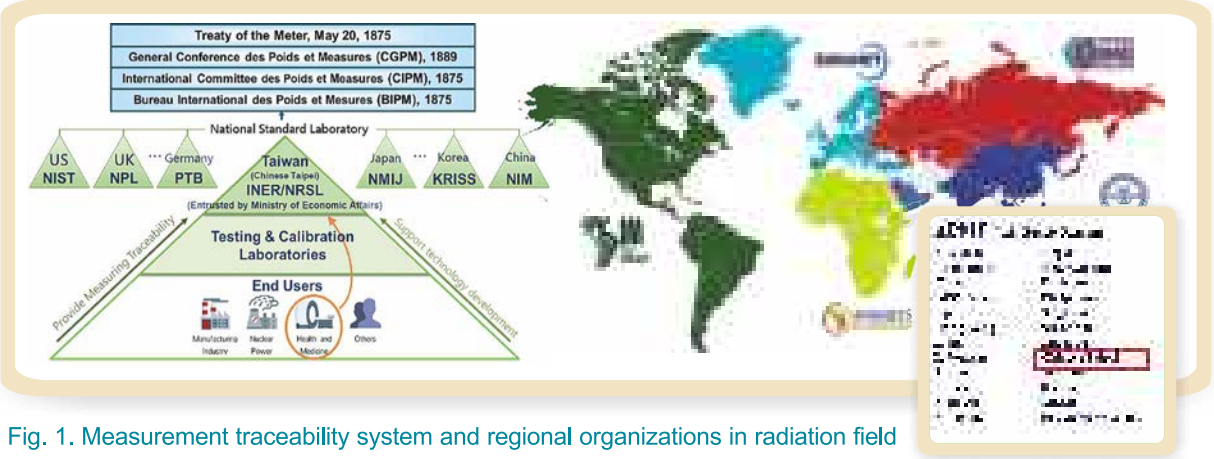


Fig. 1. Measurement traceability system and regional organizations in radiation field

INER was entrusted by the Bureau of Standards and Inspection of the Ministry of Economic Affairs and established National Radiation Standard Laboratory (NRSL) to ensure the accuracy and international equivalence of measurement in the radiation field. Adapting the ISO 4037 series (photon radiation), ISO 6980 (beta radiation), ISO 8529 (neutron radiation), etc. and employing professional manpower, NRSL/INER has established and maintained the highest dose measurement standards in our country. NRSL/INER is a regular member of the Asia Pacific Metrology Programme (APMP) and had signed the Global Mutual Recognition Agreement (CIPM MRA), which links standards to global organizations such as the International Bureau of Weights and Measures (BIPM). The laboratory complies with ISO/IEC 17025 quality specifications. (Fig. 1) Its radioactivity and radiation dose standards are connected to the world through international comparisons (Fig. 2), and the standards are delivered to domestic users through calibration services.

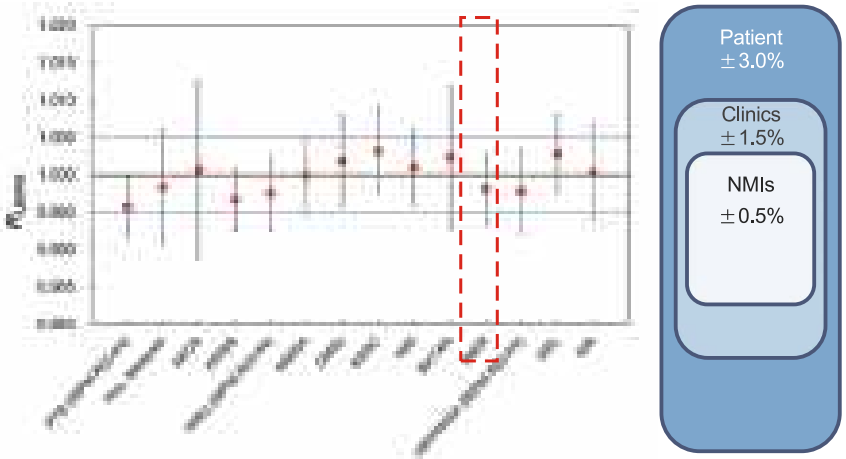


Fig. 2. The results of APMP.RI (I) K4 60Co absorbed dose to water international comparison held by NRSL/INER. For patients, a over-treatment dose by as little as 3% can result in severe side effects.

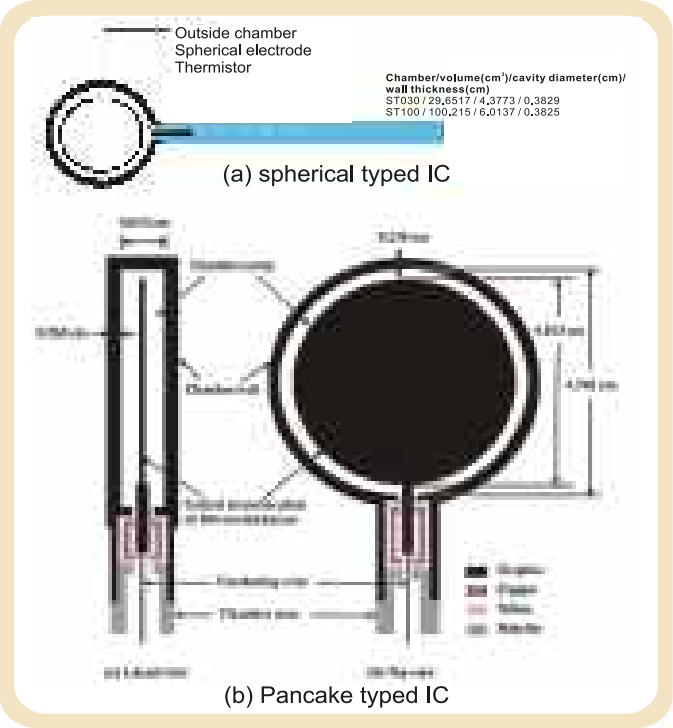


Fig. 3. The primary standard IC for the radiotherapy dose traceability system in Taiwan. (a) Co-60 air kerma; (b) Co-60 water absorbed dose calibration systems.

Currently, the source of the traceability system for radiation therapy dose standards in Taiwan is the Co-60 air kerma and water absorbed dose standards established by NRSL/INER. The two series of self-made ionization chambers (ICs) are used to determine the standard radiation field (Fig. 3). The average number of calibration services of radiotherapy ICs from 2008 to 2018 was ~138 ; the total numbers reached the max. of 190 in 2018. The number of water-absorbed dose calibration services was 38 in 2008 and 105 in 2018. About two-thirds of the calibrations in the laboratory come from the hospitals each year. Fig. 5 shows the research results of the quality assurance for photon reference dosimetry of AAPM TG-21 and TG-51 protocols which was a cooperation action of NRSL/INER with hospitals.

Fig. 5. Quality assurance for the conversion of photon reference dosimetry stated in AAPM TG-21 and TG-51 protocols.

For a society with advanced radiotherapy treatment technology, the protection of medical staff and the public is derived from the quality assurance and guarantee of the whole process, so that the used equipment of radiotherapy could meet relevant standards and criteria. Under the principle of accurate radiation dose, the practice under international consensus is to achieve a consistent trace of the standard physical quantity (commonly Co-60 air kerma or Co-60 water absorbed dose) through calibration. Then, according to two major international dosimetry protocols (Fig. 4), the clinical reference dose can be evaluated with different parameters depending on different conditions such as the detector and radiation type, so that the prescription doses in hospitals can reach international consistency.

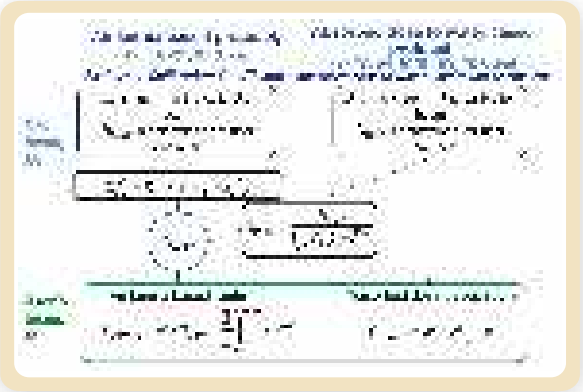


Fig. 4. In radiation therapy field, the reference dose assessment depends on air kerma and water absorbed dose based dosimetry protocols for calibration and clinical beams conversion.

Medical linear accelerators are the most important equipment for modern radiation therapy, and various new technologies have been developed based on them (such as adaptive radiotherapy, ART). In addition, domestic proton/particle treatments are booming and there are now two proton therapy facilities available. In Taiwan, NRSL/INER currently provides the primary dose calibrations of Co-60 air kerma and water absorbed dose as the highest measurement standard for domestic radiation therapy dose verification. In order to comply with international trends and dose standard development, the linear accelerator dose standard and calorimeter system will be gradually established.

4. 2018 highlighted events and memorabilia

4 2018 highlighted events and memorabilia

1.INER provided microgrid power conversion equipment and bidirectional power control and other technologies to the "2018 Taoyuan Agriculture Expo" to support its exhibition on green energy and zero carbon.

2.A manufacturer, a transferee of a technology transfer with INER, entered the "2018 Taipei AMPA" Innovative Product Awards contest with the entry of top-end window film that INER assisted in developing. It won the Bronze Medal in the accessories category.

3.INER and the Taiwan Institute of Economic Research jointly convened the inaugural meeting of the"Taiwan Organic Solar Cell Industry Research Association", and organized the "Industrialization of Organic and Perovskite Solar Cells Conference" to promote the solar cell industry and facilitate exchanges and integration among industry, academia, and research institutes.

4.INER, the Asian Society for Integrity of Nuclear Components, and Lunghwa University of Science and Technology jointly held the 12th International Workshop on the Integrity of Nuclear Components (ASINCO-12), wherein the keynotes of the decommissioning of back-end nuclear facilities and structural safety technology for spent nuclear fuel disposal were added to its agenda.

5.INER organized the "Presentation of Results from Research Projects Commissioned by AEC". Partners from industry, academia, and research institutes were invited to attend the event; there were 463 participants.

6.INER entered the 2018 R&D 100 Awards competition with the entries of "EOS-Energy Operating System" And "RollnCoat", which were placed by an independent panel of judges on the finalists' lists in the IT/Electrical category and the Mechanical Devices/Materials category, respectively.

7.INER celebrated its 50th anniversary together with parent-child activities and the general celebration assembly. Those celebration activities also include open-house visit to the offices, research results show, family fun activities, parent-child marketplaces and movie appreciation, etc.

8.Dr. James C. Liao, President of Academia Sinica, was invited to INER to give a speech entitled "Sustainable Energy and Carbon Cycles". He was also accompanied to see research results in cellulosic ethanol and biorefinery, and to visit facilities which conduct research in renewable energy, nuclear medicine, etc.

9.INER's "Energy Management System and Resilient Control of Distribution Feeder with Microgrid Technology" won the Best Poster Award in the Bucharest 2018 Symposium on Microgrids held in Romania.

10.INER technology "RollnCoat: Roll-to-Roll Hybrid Plasma Modular Coating System for High-Performance Thermal Control Films" was recognized by international peers and awarded in the Robotics/Automation/Manufacturing category for the 2018 Create the Future Design Contest held by NASA Tech Briefs, a leading aviation and aerospace publication.

11.INER was awarded six Gold Medals, five Silver Medals and eight Bronze Medals (a total of 19 medals) in the "2018 Taiwan Innotech Expo".

12.INER provided 15 technology exhibits to the "Presentation of Project Results from NEP-II" held by the NEP-II Program Office.

13.INER signed a memorandum of understanding on cooperation with the U.S. Southwest Research Institute (SwRI) to conduct technical exchanges in areas such as radioactive waste disposal technology and nuclear facility decontamination technology.

14.IAEA came to Taiwan to hold the "2018 Seminar on the Declaration of Nuclear Materials Accounting and Supplementary Protocol" with AEC and INER.

15.INER held the "2018 Forum on the Application of the Flow Battery and Energy Storage Industry", and invited over 70 attendees from industry, academia and research institutes.

16.INER technology "Theranostic Probes (DOTA-NIR790) for Multimodality Imaging, Radiotherapy, and Photothermal Therapy" was awarded the 15th National Innovation Award by the Institute for Biotechnology and Medicine Industry.

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2018 Annual Report
Institute of Nuclear Energy Research

Publisher：Institute of Nuclear Energy Research
Editor Group：Institute of Nuclear Energy Research
Address：No.1000, Wenhua Rd., Jiaan Village, Longtan District, Taoyuan City 32546, Taiwan (R.O.C.)
Tel：886-2-8231-7717 886-3-471-1400
Fax：886-3-471-1064
URL：http://www.iner.gov.tw/
Price：NT$750
GPN：2008200099
ISSN：1812-3155
Published in August 2019
Fist Issued in July 1993
Frequency：Annual
Sales Outlet：

- Government Publications Bookstore
  1F, No. 209, Sung Chiang Rd., Taipei City 10485, Taiwan (R.O.C.)
  TEL：886-2-2518-0207
- Wu-Nan Book Co.,Ltd.
  No. 600, Junfu 7th Rd., Beitun Dist., Taichung City 40642, Taiwan (R.O.C.)
  TEL：886-4-2437-8010

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E-mail：iner@iner.gov.tw

ISSN 1812-315-5
9 771812 315002
GPN:2008200099
Price：NT$ 750