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2020 Annual Report

Institute of Nuclear Energy Research
Atomic Energy Council, Executive Yuan

Published in August, 2021

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Contents

1.Preface

Strive to be the most reliable nuclear energy R&D institution in Taiwan

The Institute of Nuclear Energy Research (INER) was founded in 1949. After half a century of transformation and growth, INER has not only become the only professional R&D institution in Taiwan that combines nuclear safety/nuclear back-end technologies, civil application of radiation, and green energy technology, but also continued to innovate, conduct R&D, and promote the industrial applications of these technologies, yielding fruitful results in the process.

In terms of nuclear safety and nuclear back-end technologies, INER not only have attained impressive research achievements in nuclear power plants operating safety but also enhanced to the nuclear back-end technologies research on decommissioning and radioactive waste management of nuclear power plant. We believe that the operation, decommissioning and waste management of nuclear facilities will demonstrate satisfactory execution results. Furthermore, we have been implementing the decommissioning plan of Taiwan Research Reactors (TRR), a pioneer of nuclear reactor decommissioning, for more than 10 years, which development of the key technologies can operate in the nuclear power plants and establish the domestic decommissioning capabilities.

In terms of radiation applications for people's livelihood, in response to the shortage of nuclear medicine importation in Taiwan during the current COVID-19 pandemic situation, INER had launched an emergency production of diagnostic radiopharmaceuticals for cardiac disease or malignant tumor, including "Thallous Chloride (Tl-201) Injection" and "Gallium Citrate (Ga-67) Injection". During the period from April 20 to December 31 in 2020, these pharmaceutical productions (68,152 mCi in total) had been used in medical imaging procedures for 25,700 patients. In June 2020, INER successfully synthesized REMDESIVIR by applying the latest AI technology on chemical retrosynthesis to optimize synthesis steps. The innovative ability of INER in the technologies of nuclear medicine synthesis by applying artificial intelligence has been demonstrated.

In terms of green energy and system integration technologies, INER has been engaged in the R&D of related projects since 2002. INER also dedicates to industrial applications based on those research achievements in the fields of energy generation, energy storage, energy conservation and system

integration. For example, "The Research and Technology Development for Resiliency Enhancement of Regional Distribution Power Network" and "Key Technologies R&D and Certification for the Anti-Typhoon Type Floating Offshore Wind Turbine", the joint research programs on green energy, were awarded as MOST's Highlight Programs in 2020."

In order to promote as well as to demonstrate our R&D achievements, we have actively participated in international invention patent exhibitions and both major domestic and foreign award-competing events. In the 2020 Taiwan Innotech Expo, there are two of INER's patented technologies received the platinum awards. Also, INER won three gold medals, won one silver medal and two bronze medals in the event. In addition, INRE's patent titled "Hexamer Lactose NOTA Derivatives, Hexamer Lactose Positron Liver Receptor Contrast Agent Ga-68 Radiolabeled Method, and Hexamer Lactose Positron Liver Receptor Contrast Agent" won the silver medal of the "2020 National Invention and Creation Award" organized by the Ministry of Economic Affairs. It is more to be mentioned that INER also won three "2020 Renewal Awards" in the 17th National Innovation Award organized by the Research Center for Biotechnology and Medicine Policy.

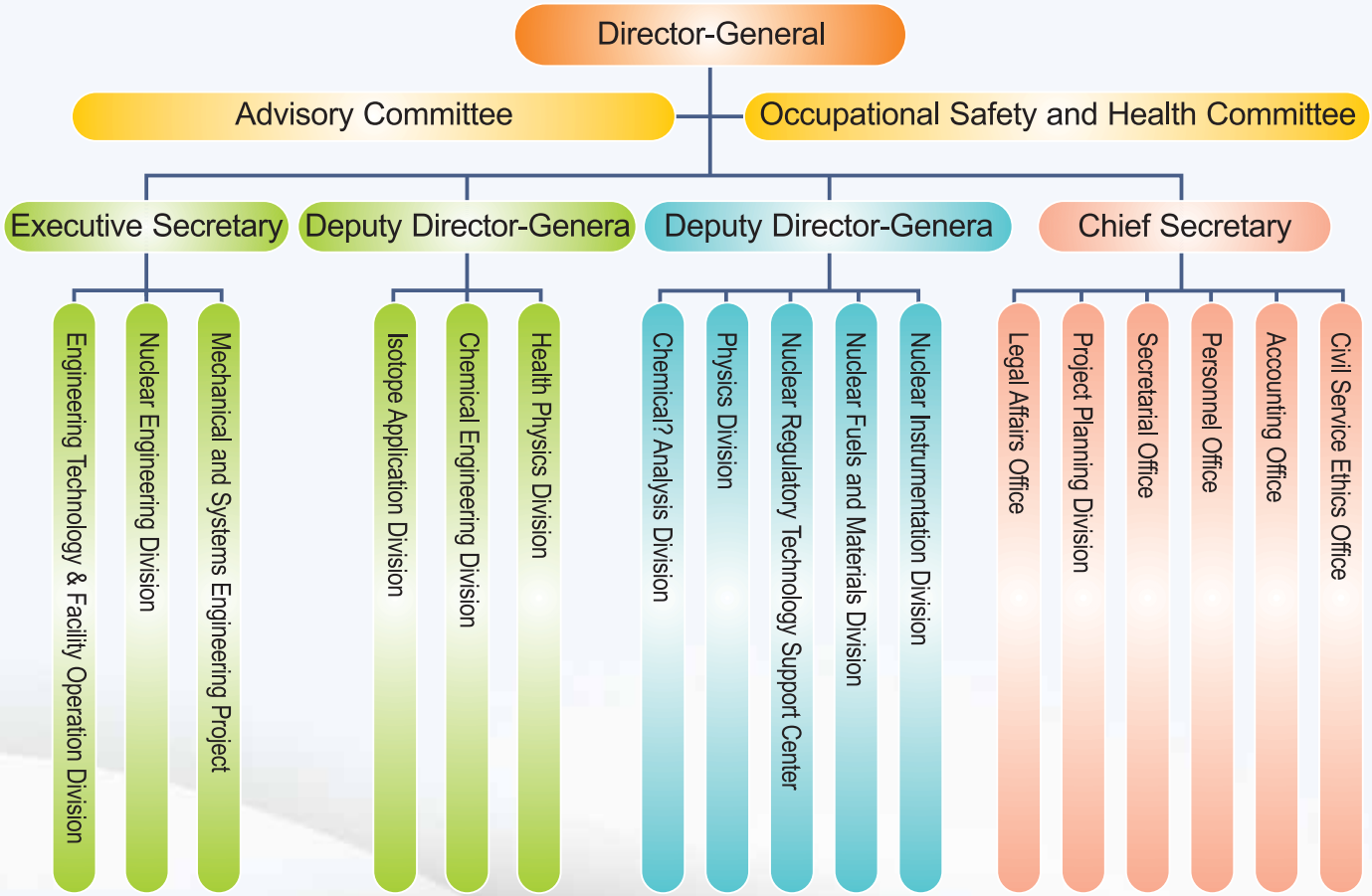
In order to enhance our centripetal force and produce excellent R&D achievements, since 2020 we adopt the successful business management methods employed by major firms and incorporate Objectives and Key Results (OKR) to commit creating a new organizational culture. INER with limited resources devote more attention to priority tasks and meet our vision and mission, while continuously tracking the progress of management and R&D to achieve breakthroughs.

In the future, to conjunction with organizational reform by the Executive Yuan, INER will transform into an administrative corporation known as the "National Longtan Institute of Atomic Energy Technology", which will exert organizational effectiveness through easing of the system. After our incorporation, INER will continue to fulfill our mission as a national laboratory which focuses on the development of various fields, including decommissioning of nuclear power plants, nuclear waste treatment and disposal, nuclear medicine and civil application of radiation, new energy, and cross-domain system integration, with a view to realizing a low-carbon society and enhancing people's livelihood and well-being. At the same time, INER itself will remain the most reliable nuclear energy R&D institution in Taiwan in accordance with national policies and focus of science, technology, and industrial development.

Director General Chern-Jing Chen

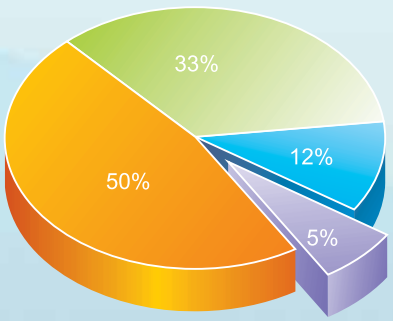
2.Organization Chart、Human Resources and Budgets

Organization Chart of INER

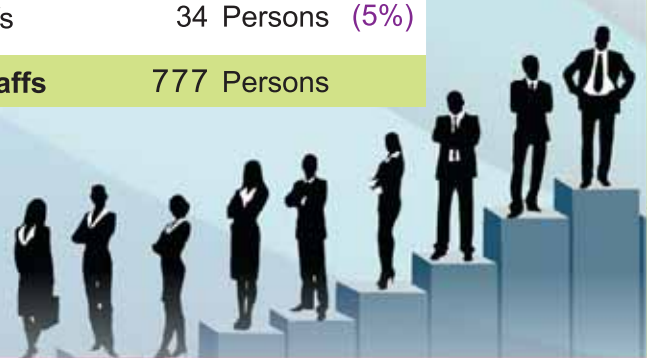


Human Resources and Budgets (Time of data: December, 2020)

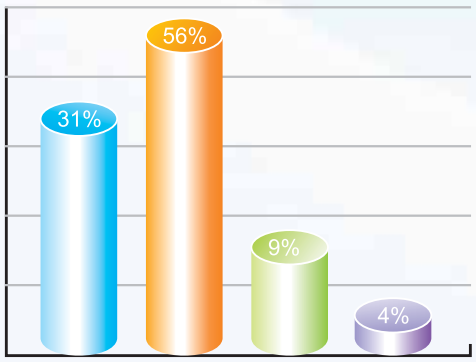
Manpower Distribution of INER



Research Staffs	390 Persons	(50%)
Technicians	259 Persons	(33%)
Administrative Staffs	94 Persons	(12%)
Other Staffs	34 Persons	(5%)
Official Staffs	777 Persons	

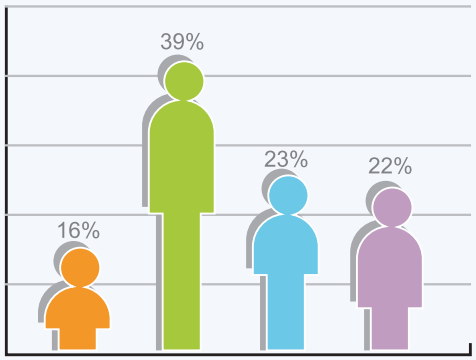


Statistics of Educational Background for Research Staffs



Ph.D.	121 Persons	(31%)
Master	217 Persons	(56%)
Vocational School	37 Persons	(9%)
Bachelor	15 Persons	(4%)
Research Staffs	390 Persons	

Statistics of Job Category for Organizational Research Staffs



Researcher	62 Persons	(16%)
Associate Researcher	154 Persons	(39%)
Assistant Researcher	90 Persons	(23%)
Research Assistant	84 Persons	(22%)
Research Staffs	390 Persons	

2020Annual Budget

Unit: Thousand NTD

Item	Number of Accounts	Percentage
Administration and Safety	1,151,358	67.03%
Management, Operation and Maintenance	113,118	6.59%
R&D Projects	328,632	19.13%
Technology Promotion and Service	124,540	7.25%
Total	1,717,648	100.00%

3.Current Major R&D Activities

3-1 2020 Research on Nuclear Safety and Nuclear Back-end Technologies

In accordance with the national energy transition and no-nuke homeland policy, the nuclear power plants (NPP) in Taiwan plan to be decommissioned as scheduled after the expiration of the 40-year operating license. The two units of the Chinshan NPP were officially shutdown on December 5, 2018 and July 15, 2019, respectively. The two units of the Kuosheng NPP will expire in December 2021 and March 2023, respectively, and the two units of the Maanshan NPP will expire in July 2024 and May 2025, respectively. In the early years of the Institute of Nuclear Energy Research (INER), due to the implementation of nuclear energy technology development tasks in accordance with national policies, nuclear facilities such as research reactors built and used are also being decommissioned and cleaned up in accordance with laws and regulations. Therefore, the current research and development (R&D) topics in INER mainly focused on the application of safety analysis technology in operating nuclear power plants, the safety assessment technology of spent nuclear fuel, the decommissioning and cleaning of nuclear facilities, and radioactive waste management. Moreover, the application of nuclear safety technology in other cross-domain system safety assessments also showed excellent results. Selected R&D achievements in the field of nuclear safety and nuclear back-end technologies in 2020 are as follows:

(1) Applying Alternative Source Terms (AST) analysis technology to raise the acceptance criteria of the Control Room Envelope (CRE) inleakage rate and increase the safety margin for meeting habitability requirements of the main control room while not sacrificing the safety of the nuclear power plants.

(2) The use of Quantitative Risk Assessment (QRA) technology in the construction project of the CPC Corporation's Liquefied Natural Gas (LNG) receiving terminal station to reassure it complied with the regulatory requirements. The QRA report has already been reviewed and approved by the Occupational Safety and Health Administration (OSHA).

(3) INER adopted inorganic ion-exchange adsorbent to replace traditional organic ion-exchange resin, and successfully developed the granulated inorganic adsorbent that can be applied to the treatment of high-level radioactive wastewater generated from the nuclear industry. INER has performed long-term on-site treatment of radioactive wastewater, and the adsorbent developed by INER showed better performance in terms of cost and treatment efficiency compared with other commercial adsorbents produced by international manufacturers.

(4) In order to promote the safety of decommissioning activities, INER has developed a remote control snake-type robotic arm for decommissioning and clean-up tasks of nuclear facilities, and has successfully performed functional tests of clamping and classification of radiation sources in the high activity underground waste storage facility of INER.

(5) Develop a container for low-level radioactive waste (INER-LRW-C2) suitable for higher radiation dose rates, which has been verified and tested to meet the requirements of regulations, and solves the dilemma of previous lack of suitable containers to effectively contain this type of waste, and improve the safety and efficiency of the packaging of related waste.

3-1-1 Increase in the CRE Inleakage Rate Acceptance Criteria to Improve the Safety Margin - Implementation of Nuclear Power Plant DBA Dose Assessment with AST Analysis Technology

Under almost all circumstances, operators of nuclear plant need to stay in the Control Room Envelope (CRE) to control the unit effectively during both normal operation and under accident conditions. Therefore, it is required to ensure the inleakage of unfiltered air into CRE does not exceed the inleakage acceptance criteria as specified in the operation technical specifications. The maximum allowable inleakage rate of the CRE based on the current licensing basis of the domestic nuclear power plants is quite stringent. After the power plant performed the tracer gas inleakage test, it was found that the safety margin between the actual inleakage rate and the acceptance criteria specified is too small. With the aim of further investigating into the possibility of raising the acceptance criteria of the CRE inleakage rate and the increase in the safety margin while not sacrificing the safety of the nuclear power plant, INER has successfully implemented the alternative source terms (AST) concepts into practices, by referring to the experiences of the nuclear power plants in the United States.

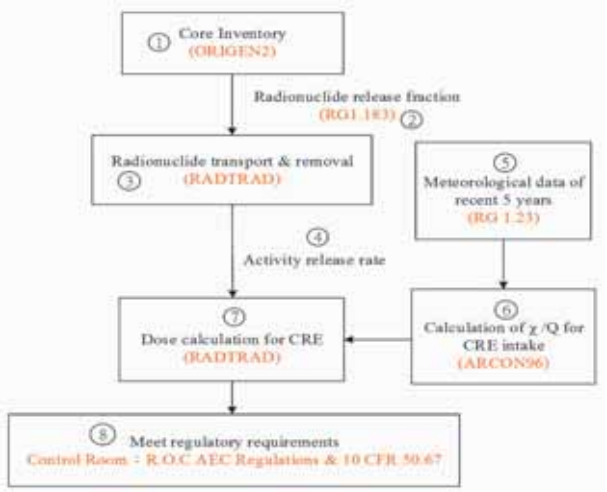


Fig.1. Flow chart of AST radiation dose analysis

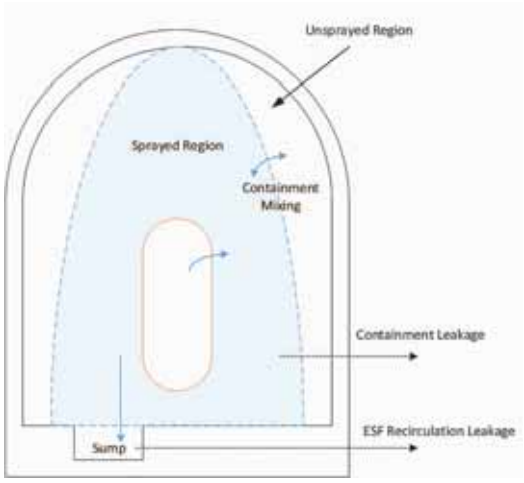


Fig.2. Removal mechanism and leakage path of radionuclides within containment for Maanshan plant

Through CRE Design Basis Accident radiation dose analysis, it is confirmed that each power plant in Taiwan meets the maximum allowable CRE inleakage rate required by regulations. The AST analysis methodology is based on U.S. Regulatory Guide (RG) 1.183, which is based on numerous publications on severe accidents over the past as well as considerable number of simulation results using advanced computer programs. The methodology used in RG 1.183 is more realistic comparing to TID-14844, and fully considers the possible radiation dose via various pathways. Figure 1 shows the flow chart of AST radiation dose analysis and Figure 2 shows the removal mechanism and leakage path of radionuclides within the containment in the AST analysis mode. Figure 3 illustrates the various possible pathways of causing radiation doses to personnel in the CRE in the analysis mode.

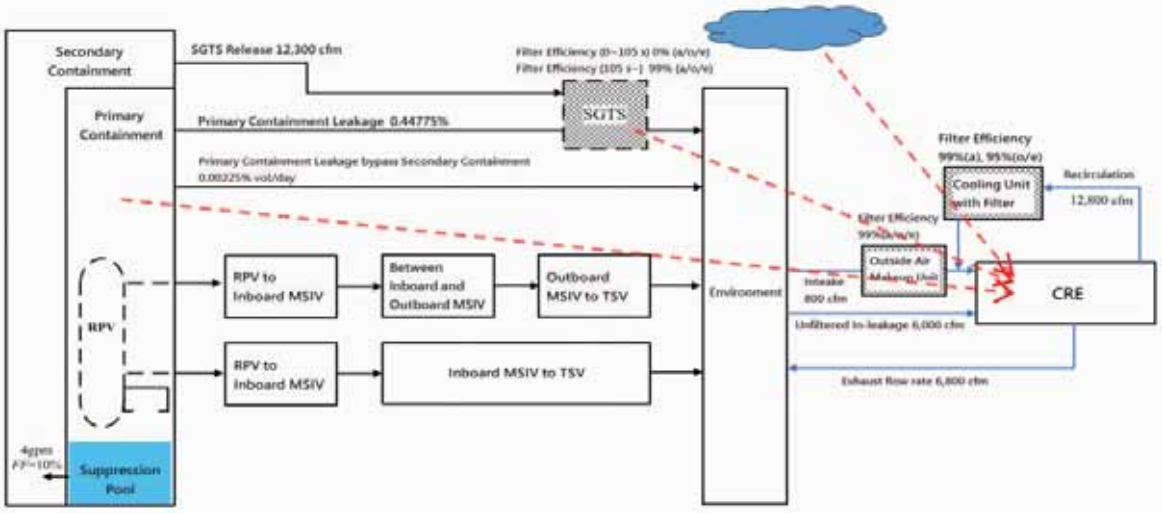


Fig.3. Various pathways of radiation exposure to personnel in the CRE as demonstrated in the analysis mode for Kuosheng plant

U.S. nuclear power plants use AST analysis methodology to increase the safety margin of accident dose analysis, and apply them to improve power plant operating performance or address the dose-related issues and requirements imposed by nuclear regulation authority, such as power uprate, control room habitability, and main steam isolation valve leakage rate limit relaxation, etc. Many application cases have been approved by U.S. regulatory authority. The AST methodology not only increases the safety margin of nuclear power plants, but also greatly improves the operating performance of the power plants in the United States. Similarly in Taiwan, INER developed AST analysis technology to raise the acceptance criteria of CRE inleakage rate and to increase the safety margin while not sacrificing the safety of the nuclear power plant as well as warranting the health and safety of the public. Table 1 summarizes the analysis results of the CRE unfiltered inleakage rate acceptance criteria and the measured value of domestic operating nuclear power plants. It is noticeably to see that the implementation of AST analysis methodology can greatly increase the margin between the inleakage rate acceptance criteria and the measured value.

Table 1. Analysis results of the CRE unfiltered inleakage rate acceptance criteria and the measured value of domestic operating nuclear power plants

Methodology	Unfiltered airinleakage rate acceptance criteria of radiation dose analysis (cfm)[2]	
	Kuosheng	Maanshan
TID-14844(Current licensing basis)	450	107
AST	5100	467
CRE inleakagerate measured value[1]	208±9	56±23

[1]The maximum value of all measured cases

[2]cfm：cubic feet per minute，volume flow rate unit

In Taiwan the AST analysis technology is used to perform radiation dose analysis in control rooms to address the requirements imposed by the authority accordingly. However, the analysis regarding the radiation source term determination, the radionuclides transport and removal in the containment, and the radionuclides leakage in the off-site dose calculation and the control room dose calculation are very similar. In addition, the AST analysis model for off-site dose calculation of domestic nuclear power plants had been established. The design basis accident radiation dose analyses such as the assessment of exclusion area boundary and the low population zone, DBA source term calculation for emergency planning zone evaluation and others are imperative. The AST analysis technology developed by INER is prospectively the methodology to be implemented with regard to design basis accident radiation dose analyses, of which using realistic methodology reducing unnecessary regulatory burdens without sacrificing the safety and health of the public.

3-1-2 Advance Deployment to Reduce the Risk - QRA for LNG Receiving Terminal Station


CPC LNG Storage Tank

Source：CPC Corporation,Taiwan eBook 2016.01

In real life, we usually rely on our past experiences to prevent risk from danger, like buying a cellular phone with a protective case. While proceeding the important engineering projects, we surely need to reduce the risk as much as we can. Therefore, we apply Quantitative Risk Assessment (QRA) to assess the risk of the important projects. Since 2019, INER has assisted CPC Corporation to determine the risk scope for the Liquefied Natural Gas (LNG) receiving terminal station and to reassure it complied with the regulatory requirements. QRA for the LNG receiving terminal station will include Initiating Events that provoke different accident scenarios, Facility Response Model, and Consequence Model as shown in Fig. 1 flowchart.

Initiating Events (IE)

For LNG storage facility, leaking natural gas may cause serious explosion and fire hazards, hence, the major Initiating Event is the failure of primary containment which causing the leakage of chemicals. The source of the LNG leaking may come from the rupture of the LNG storage tank or its belonging devices like pipelines, valves, or components. The rupture frequency of the tank is analyzed by the simulation of the tank structure. The leakage frequencies of the belonging components is calculated by Failure Mode and Effects Analysis. The occurrence of Initiating Event is the starting point of Facility Response Model which will list all possible events and assess each of the possible scenarios.

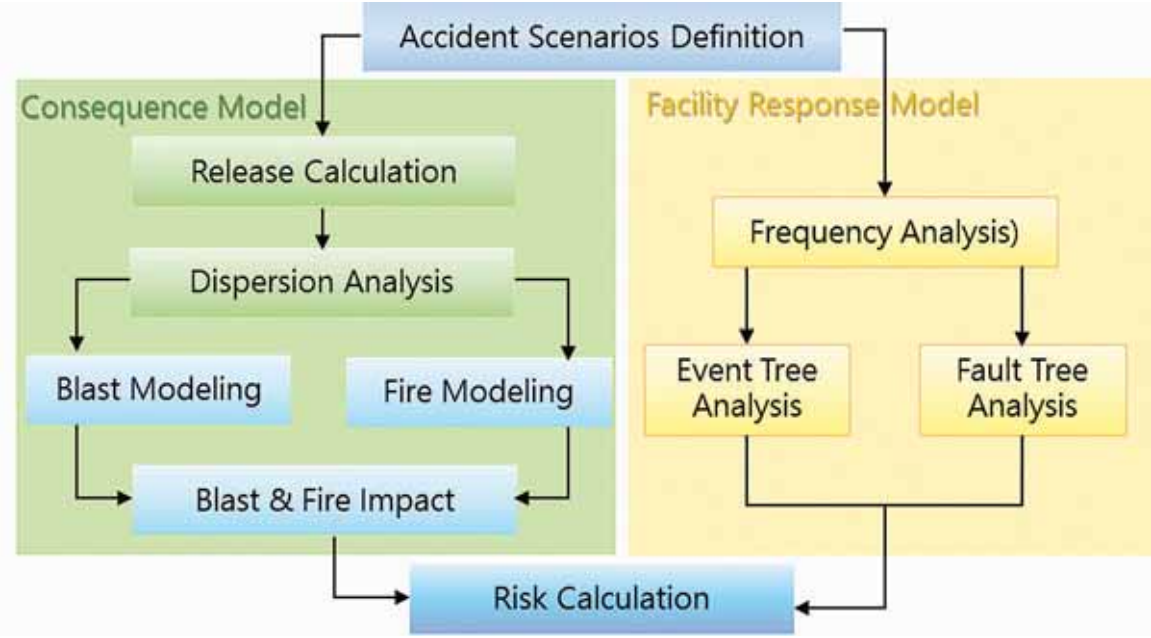


Fig.1. Flowchart of QRA for LNG receiving terminal station

Facility Response Model

In Facility Response Model, event tree is used to infer all possible leakage scenarios including all impacts on final consequences and setting some rescue actions up as event tree nodes. The failure probability of the event tree nodes is analyzed by the software INERFT developed by INER itself. It can make the accident scenario ratio closer to the reality by clarifying relationship of components.

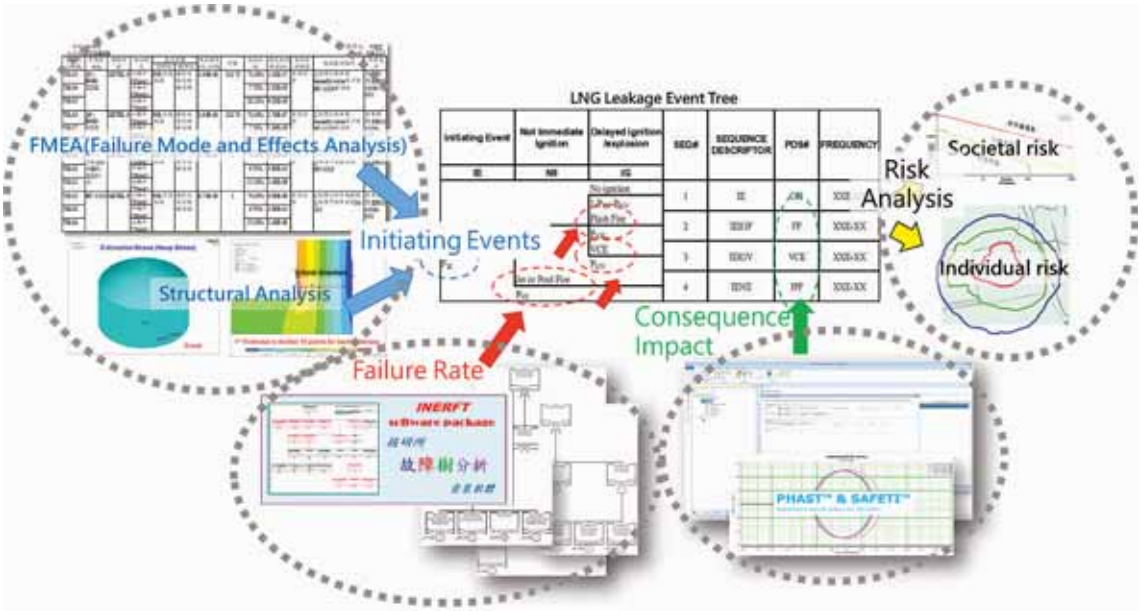


Fig.2. Relationship of quantification operation data

Consequence Model

After check of the parameters of event scenarios in Facility Response Model, the following fire and explosion simulations will be performed: Flash Fire, Pool Fire, Jet Fire, and Vapor Cloud Explosion (VCE). Consequence Model is implemented by SAFETI software of DNV GL and the results obtained include the leakage rate, vapor cloud dispersion footprint and the impact area of each event scenario.

Facility Response Model calculates the frequency of accident scenarios. Consequence Model analyzes the possible impact area. Risk is the product of those two (frequency and consequence). According to the results of QRA report, it indicates the major leak risk comes from the pipelines and valves, and the leakage of the storage tank contributes very little to the leak risk. The client have been suggested to strengthen the operation and maintenance of the discharge pipeline, and only a small increase in operating costs can effectively improve operational safety. The QRA report was reviewed and approved by Occupational Safety and Health Administration (OSHA) to comply with regulatory requirements. Therefore, the client can continue the follow-up construction work of the storage tank.

3-1-3 High-level radioactive wastewater treatment tool - Development and Application of Radionuclide adsorption technology

To develop the technology for treating radioactive waste, the Institute of Nuclear Energy Research (INER) has proposed the approach based on radioactive wastewater treatment, aiming to transform high-level radioactive wastewater into low- or medium-level radioactive wastewater. The resulting liquid waste can then be solidified for the subsequent shallow land disposal, minimizing its impact on the environment. Sr-90 and Cs-137 are the fission products of nuclear reaction that are abundant in high-level radioactive wastewater with long half-lives. Therefore, to convert high-level radioactive wastewater into low-level radioactive wastewater, the removal of Sr-90 and Cs-137 are essential. INER adopts inorganic ion-exchange adsorbent to replace traditional organic ion-exchange resin, which has the advantages of acid resistance, high radiation resistance, high temperature resistance, good selectivity, simple operation, using natural inorganic materials, and low cost, making inorganic ion-exchange adsorbent a more economical and appropriate technology for treating radioactive wastewater.

Fig.1. Working mechanism of inorganic ion-exchange adsorbent

The radionuclide adsorption technology developed by INER is based on the granulation of natural inorganic ion-exchange materials. A variety of highly selective inorganic adsorbents have been developed, which can avoid the shortcomings of high-temperature sintering in traditional granulation method, leading to the inactivation of adsorption capacity. The newly developed adsorbent have a radionuclide removal efficiency of greater than 99%, reaching an average adsorption capacity of more than 150 mg/g. The adsorbent can be applied to wastewater treatment in different pH ranges and has good mechanical strength as well as radiation resistance to meet the needs of final disposal. The adsorbents developed by INER have been continuously tested for a long period of time (more than 1,440 hours), demonstrating that the adsorbents can maintain their original performance and physical/chemical properties.

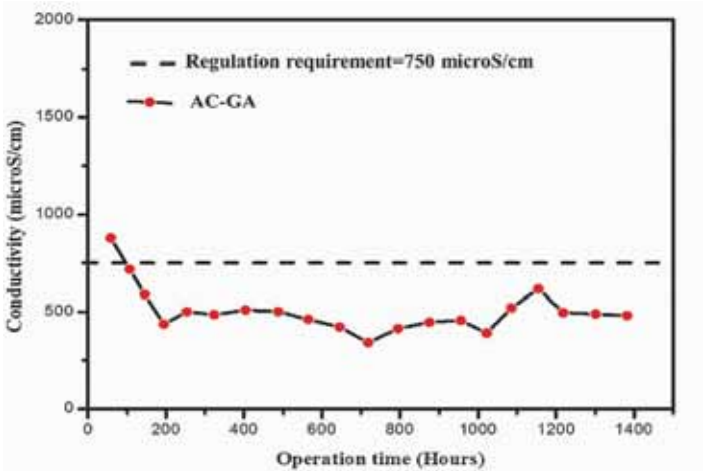


Fig.2. Conductivity test of wastewater after treatment

Fig.3. Sources of radioactive wastewater that can be treated by adsorbent

INER has performed the long-term on-site treatment tests of radioactive wastewater based on the developed absorbent. The granulated inorganic ion-exchange adsorbent was filled into a column with diameter of 26 cm and height of 100 cm. The retention time of the wastewater in the column was 12 minutes. The treatment capacity per hour is 26 L. After prolong operation to treat continuously 41,335 L of radioactive wastewater, the radioactivity in terms of Gross β/γ, Sr-90 and Cs-137 was reduced to meet the regulatory standards. During the treatment, the granulated inorganic ion-exchange adsorbent remained its integrity and was able to withstand a large pressure drop within the column, demonstrating good mechanical strength. Compared with other commercial adsorbents, the adsorbent developed by INER showed better performance in terms of cost and treatment efficiency.

The developed adsorbent technology has obtained 4 Patents and 1 under application.

1. Method for preparing granulated inorganic adsorbent for radionuclides · US14/527,941
2. Method for preparing granular inorganic adsorbent for treating radionuclides, Patent No. 6059306 (Japan)
3. Method for preparing granular inorganic adsorbent for treating radionuclide, Patent No. I510286
4. The application and method of using silica-alumina compound as a solidification agent for treating radioactive phosphoric acid phosphoric, under application
5. Granulation method for preparing adsorbent and the adsorbent prepared by such method, Invention No. I457173

Table 1. Long-term on-site operation results for the treatment of radioactive wastewater

Volume flow rate (Lh^{-1})	Monitored item	Before treatment (BqL^{-1})	After treatment (BqL^{-1})	Clearance standard (BqL^{-1})	Kd ($10^3 Lkg^{-1}$)	Total volume treated(L)
262	Gross β/γ	613	26.7	--	20.2	41,335
	Sr-90	279	24.5	32.6	9.6	
	Cs-137	178	<1.8	70.2	180	

The granulated inorganic adsorbent developed by INER is formed by mixing mainly aluminosilicate and inorganic polymers at room temperature. It can be applied to the treatment of radioactive wastewater generated from the nuclear industry, the petrochemical industry, the steel industry, academic research institutes and hospitals. INER will continue to develop and improve the formulation of adsorbent based on the current achievements in order to increase the applicability and the versatility of the product. By applying the adsorbent to treat the radioactive wastewater stored in INER, the experiences gained can serve as useful reference for promoting the technology or transferring the technology to related industries, fulfilling their needs. In the future, the technology can also benefit industries worldwide that are in need of radioactive wastewater treatment.

3-1-4 Development of a remote control snake-type robotic arm for decommissioning and clean-up tasks of nuclear facilities

The robots or tele-operated manipulators can be used to assist workers to remove contaminated components for reducing the radioactive exposure risk on personnel, therefore they can promote the working safety during the decommissioning of nuclear power plants. In order to promote the safety of decommissioning activities, INER took the lead in the development of a remote control snake-type robotic arm for decommissioning and clean-up tasks of nuclear facilities and conducted cold tests in the high activity underground waste storage facility (015D) of INER.

Fig.1. Remote control snake-type robotic arm

Kinematic control of robotic arm

Each link of the snake-type robotic arm includes a base and end plate, supporting structure, and a vertex. Through the coordinate of each vertex, the rotation angle of each link can be conducted to reach the desired position. Each link of this robotic arm is driven by three motors through the steel cables, and fifteen motors are controlled by the controlling system so the five joints of this arm can be operated synchronously. Besides, one more motor is controlled and used to drive the base to move whole robotic arm horizontally. Forward kinematics and synchronization algorithm are used to calculate the precise position of each link and make all joints move smoothly without intervention.

Mechanical design and configuration

The functions of the developed snake-type robotic arm include remote control, multi-degrees of freedom, self-lifting, and 5 kg maximum payload. It is composed of six links and an end-effector. The first link, the base of the robot, can translate for 100 cm, and the end-effector can rotate for 180 degrees. The rest of the links are consecutively connected by universal joints which have 2 degree of freedoms for each. Therefore, this robotic arm has a total of 12 degrees of freedom. It can be accurately positioned and operated in the pipeline and free space. When using different types of end-effectors, the snake-type robotic arm can perform various tasks, such as cutting remote pipes and reactors or gripping and taking radiation sources.

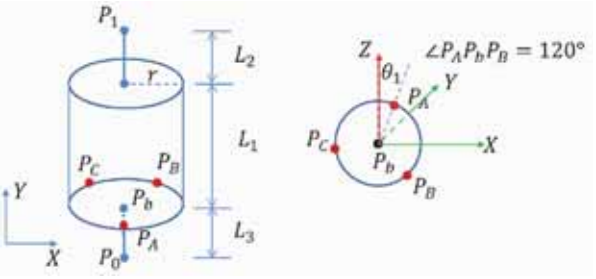


Fig.2. The coordinate systems of the snake-type robotic arm

Simulation and analysis of the robotic arm motion

When the base point position of the robotic arm is set to (0, 0, 0), the cylinder length of the snake-type robotic arm (L1) is 20 cm, the length of the joint connection column (L2) is 4 cm, and 6 joints are in total, the motion simulation results of this snake-type robotic arm is shown as the figure. These simulation results prove that this snake-type robotic arm can swing freely in the vertical and horizontal directions, and the swing angle can reach 180 degree.

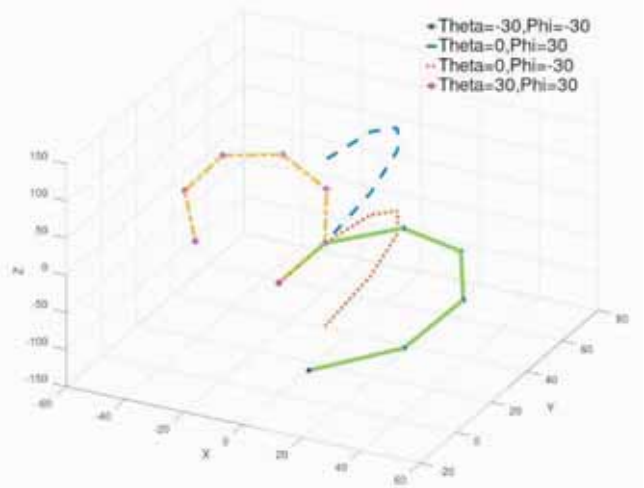


Fig.3. Simulation results of the robotic arm motion

The experiments of the end-effector gripping

In order to verify the function of end-effector gripping, INER manually and remotely controlled the robotic arm to avoid obstacles and clamped objects with the end-effector. Through the test results, it is proven that the robotic arm can be accurately positioned and operated in the pipeline and free space. This feature shows that this robotic arm can work in various tasks, such as cutting remote pipes and reactors or gripping and taking radiation sources.

Fig.4. Cross to dodge the obstacle

Fig.5. Fly to dodge the obstacle

Fig.6. Turn to dodge the obstacle

The trials in the high activity underground waste storage facility

Solid radioactive wastes with high radiation produced from Taiwan Research Reactor (TRR) and other laboratories are stored in the underground waste storage facility (015D) of INER. For the purpose of cleaning and decommissioning 015D, INER developed this snake-type robotic arm to perform clamping and classification of radiation sources. These clamping and classification functions have been tested and validated through the trials performed in that site.

Fig.7. Radioactive wastes in 015D

Fig.8. Remotely controlled the robotic arm

Fig.9. Cold tests in 015D

3-1-5 INER-LRW-C2 Low Level Radioactive Waste Container: Redeem the Insufficiency of the Prior Approved Waste Containers in Taiwan

No-nuke homeland is part of the energy policy in Taiwan. Therefore, all of the nuclear power plants in Taiwan will be permanently shut down in 2025. Besides, the dismantling tasks of Taiwan Research Reactor (TRR) will be embarked in 2021. Dismantling nuclear facilities will produce lots of low-level radioactive wastes (LLWs) which shall be stored in containers, and some of them are with higher radiation. However, there was no proper LLW container that can efficiently store these kinds of wastes in Taiwan. Hence, Institute of Nuclear Energy Research (INER) developed INER-LRW-C2 LLW container to redeem such insufficiency.

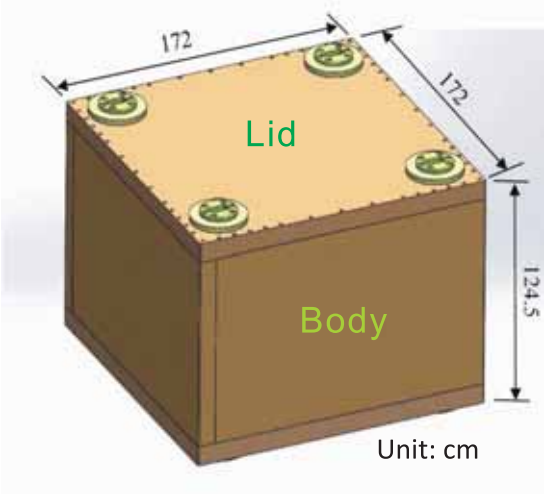


Fig.1. Dimensions

Design specification

INER-LRW-C2 LLW container is devised to store LLWs with higher radiation and fulfills the requirements of Industrial Package Type II. Its gross weight is 21.6 MT, and it has 75-year design service life. This container is mainly constructed by 10 cm thick steel plates, and the exterior of the plate surfaces is coated with hot dip galvanization and epoxy. 56 bolts are utilized to fasten the lid and container body, and two EPDM O-rings are installed between the lid and body to achieve the confinement function.

Analysis

To verify the design validation of INER-LRW-C2 LLW container, three analysis scenarios, lifting, stacking, and dropping, were evaluated to meet the requirements of the associated regulations. The evaluation results show the container design satisfies all of the corresponding requirements in the regulations.

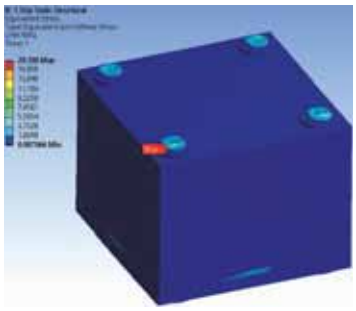


Fig.2. Lifting analysis

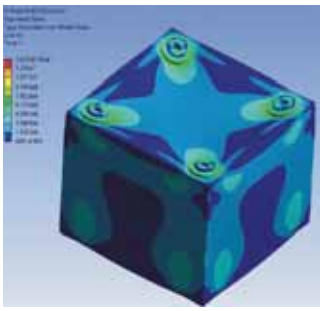


Fig.3. Stacking analysis

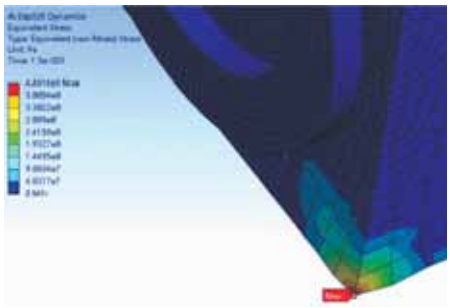


Fig.4. Dropping analysis

Fabrication

INER entrusted a domestic vendor to produce a prototype of INER-LRW-C2 LLW container. The fabrication processes are consisted of steel plate machining and welding, hot dip galvanization, and epoxy coating. After the fabrication, the producibility of the container is verified.

Fig.5. Hot dip

Fig.6. Epoxy coating

Fig.7. Welding

Test

Based on the regulations, spray, vibration, lifting, penetration, stacking, and dropping tests must be conducted before applying the usage permit. Here, the dropping tests include side dropping and corner dropping tests. After all the tests were performed, the test results show that INER-LRW-C2 LLW container satisfies all of the associated regulatory requirements.

Fig.8. Spray test

Fig.9. Vibration test

Fig.10. Lifting test

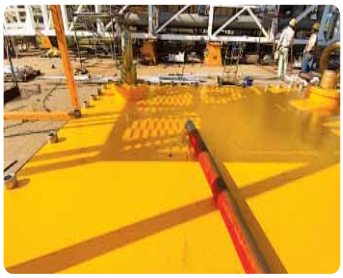


Fig.11. Penetration test

Fig.12. Stacking test

Fig.13. Side dropping test

Fig.14. Corner dropping test

There was no proper LLW container that can efficiently store LLWs with higher radiation in Taiwan. To redeem this, INER develops INER-LRW-C2 LLW container which is suitable to store such LLWs and passes all of the corresponding requirements specified in the storage and transportation regulations. Its application of the usage permit was approved on 13th November 2020, and it can be applied to the future dismantling tasks of nuclear facilities.

3-2 2020 Research on Green Energy & System Integration Technologies

The promotion of "Six Core Strategic Industries" was announced in the presidential inauguration on May 20, 2020. By building on the foundations of the 5+2 Innovative Industries Program, it is hoped that Taiwan will play a key role in future global economy. Especially, in green and renewable energy industry, as well as strategic stockpile industries, the strategies are closely complied with the "Energy Transition" policy launched since 2016, and would be beneficial to realize the designated goal. The Institute of Nuclear Energy Research (INER), with the status as National Laboratories, aims to develop multiple energy technologies, and hopefully promotes industrial applications as well as competitive capability.

To match up national policy, INER has devoted to R&D on environmental and energy technologies, for which the major achievements in 2020 are categorized in five dimensions and summarized in the following sections.

1.Energy Saving: In various basic processes for industrial and household purpose, energy-saving dehumidification technology with low environmental impact creates a win-win situation for energy conservation and economy.

INER developed indigenous "integrated drying technology of environment-friendly dehumidifier and heat pump," which was applied in a field test for drying agricultural product (e.g., garlic), and resulted in lower operating cost and improved environmental quality. Furthermore, domestic energy-saving industry can be upgraded, through know-how authorization, technical service and investment promotion. In the future, INER will continue to develop high-efficiency **energy-saving drying system integration** and green desiccant drum with adsorption materials, and forge diversified implementation.

2.Energy Storage: Energy storage units have been widely deployed in mobile platforms, green energy systems, etc. Capacity, cost and safety, as well as the stability of power supply would be crucial for future energy storage systems.

(1)Gel polymer lithium-ion batteries (LIBs): Safety issues still exist in the application of conventional LIBs technology. Therefore, INER has developed a new **gel polymer electrolyte (GPE) technology** to solve the present problems, and to optimize the LIBs with high performance indices. In the future, INER will continue to concurrently proceed the LIB related safety standard and material property tests to further accelerate the transfer of the new low-cost GPE technology to domestic LIB industry.

(2)Vanadium redox flow battery **(VRFB)**: To cope with large portfolio of renewable energy, energy storage systems can improve the stability of electric grid system. INER has focused on indigenous flow battery technology and developed key materials and components of VRFB; moreover, platforms for field tests of single cell, battery stack, and system are commissioned at INER, to provide technical support for domestic industry. INER establishes key technology capability, so that the technological and economic competitiveness can be enhanced.

3.Clean Energy: Renewable energy features low carbon footprints, while solid oxide fuel cells can provide high efficiency, low emission (HELE) energy options, which would be beneficial to mitigate climate change and promote sustainable development goals.

(1)Organic solar cell modules: Organic photovoltaics **(OPVs)** feature thin, flexible, transparent, and higher efficiency in dim-light environments, so enable niches in both indoor and outdoor applications. INER developed a roll-to-roll continuous coating process for flexible organic solar cells in an ambient environment, from which the modules exhibit good efficiency. Looking forwards, INER will play a key role in the mid-stream position of the flexible OPV module in Taiwan, integrating upstream and downstream, so that Taiwan will seize the opportunity and competitive advantage in future international market.

(2)Solid oxide fuel cell (SOFC): INER developed indigenous metal-supported cells (MSC) by plasma spray, designed new interconnect and assembled kW-level stacks, to build up a 5 kW power

generating system. In addition, an automatic stack assembling platform has been set up and successfully passed the performance tests. Moreover, low-temperature MSC and ceramic-based anode-supported cells (ASC) show great power characteristics at 550°C and 800°C, respectively. Through technology transfer and collaboration, INER assists domestic manufacturers to establish indigenous **SOFC** core fabrication technologies, for both industrial development and environmental protection.

(3)Wind power: Wind power is the most practicable option for electricity generation applications among various types of the renewable energy, and one of the important items among the "Six Core Strategic Industries." INER has devoted to the development of offshore wind turbine technologies, commissioned a **scaled floating wind turbine**, which can be employed for the development and verification of key technologies for the anti-typhoon floating offshore wind turbine system.

4.Smart System Integration: Visualization of Distribution Network Management can enhance the decision-making strategies on load transfer, and system integration with geospatial information, to effectively increase the penetration of renewable energy into electric grids.

As environmental sustainability issues gradually received attention, more renewable energy will be incorporated into future distribution feeders. Hence, INER develops the **Visual Distribution Network Management and Application System**, consisting of Supervisory Control and Data Acquisition (SCADA), geographic information system (GIS), and distribution dispatching applications, to help a dispatcher make decision with the aid of geospatial information. This outcome won the Platinum Award in the 2020 Taiwan Innotech Expo (TIE), and has been licensed to a domestic SCADA company. By technology transfer, it is hoped to enhance technology basis and inspire more innovative applications.

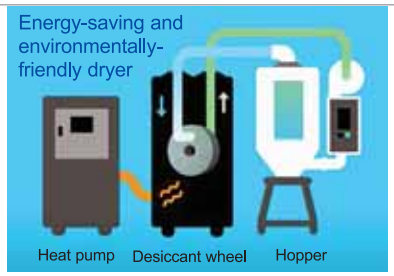
5.Circular Economy: Reutilizing resources through circular economy, it is hoped to accomplish the vision of sustainable development and environment rehabilitation, in which application of the potential of biomass and waste would be beneficial to enhancing the establishment of energy resources independence.

(1)Bioplastic Technology: PolyLactic Acid (PLA) is produced via low-carbon, non-toxic fermentation and synthesizing processes with lower carbon footprints. The characteristic of biodegradability in a specific environment is the key to making PLA recycling and reuse with more options. INER developed a high-temperature depolymerization technology, while these regenerated lactic acid can be polymerized again into a brand new PLA. In the future, INER will continue to promote the industrial application of **environmentally friendly PLA technology**, and biorefinery industry toward sustainable environmental development.

(2)Waste reutilization: The "dehumidification drum" commissioned at INER is made of aluminum hydroxide from natural bauxite. The refining process requires a large amount of energy and increases carbon dioxide emissions. INER has developed a green process for desiccant wheel. The aluminum hydroxide and aluminum oxide materials are extracted from purified aluminum smelting slag, and then, form the porous drum with high moisture absorption capacity. Moreover, VRFB utilizes Vanadium ions at different oxidation state to store chemical potential, and results in a type of rechargeable flow battery. The electrolyte can be prepared from Vanadium-containing industrial waste. INER assists domestic industry to establish indigenous resources reutilization technologies, for both industrial development and environmental protection.

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

3-2-1 Energy-saving and environmentally-friendly drying technology applied to garlic drying



Dehumidification and drying are the basic equipment functions necessary for industrial and household purposes. After collecting of commercially available adsorption dryer information, the analysis shows that there is room for improvement in commercially available drying equipment, mainly in energy consumption and cost. In addition, the garlic after harvesting in Taiwan is mostly dried and conditioned with diesel combustion hot air dryer to reduce the moisture content by 20-30% before storage. Diesel combustion dryer is cheap, but it has the following disadvantages: time-consuming, energy-consuming, noise and air pollution. Thus, the Institute of Nuclear Energy Research (INER) has focused on the problems of high power consumption and high cost, established the local technology of desiccant wheel, which is the core of an adsorption dryer, and developed the desiccant wheel and heat pump integrated drying technology. The advantages of the technologies are quietness, energy-saving and no air pollution. Hence, they are very suitable for garlic drying and creating a win-win situation for energy saving and economy.

Fig.1. The problems of conventional garlic dryer and the advantages of energy-saving and environmentally-friendly drying technology

The raw material of the desiccant wheel is aluminum hydroxide from natural bauxite. The refining process requires a large amount of energy and thus increases carbon dioxide emissions. Since there are no domestic mines and the main raw materials rely on imports Thus, the Institute of Nuclear Energy Research (INER) has developed a green and environmentally-friendly manufacturing method for desiccant wheel. The aluminum hydroxide and aluminum oxide materials are extracted from purified aluminum smelting slag, then they were added to a 3D mesh structure foam carrier. After sintering, it becomes a porous ceramic wheel body with an open three-dimensional network skeleton structure, then is added with activated alumina, and forms a green and environmentally friendly desiccant wheel with high moisture absorption capacity. Because the process air needs to be cooled in advance during the desiccant wheel adsorption while the regeneration air needs to be heated during desiccant wheel desorption process, a heat pump is implemented to recycle thermal energy to improve the energy efficiency. Finally, the environmentally-friendly desiccant wheel and the heat pump are combined into an energy-saving and environmentally-friendly drying system, which can be used in the food, plastics, and semiconductor industries.

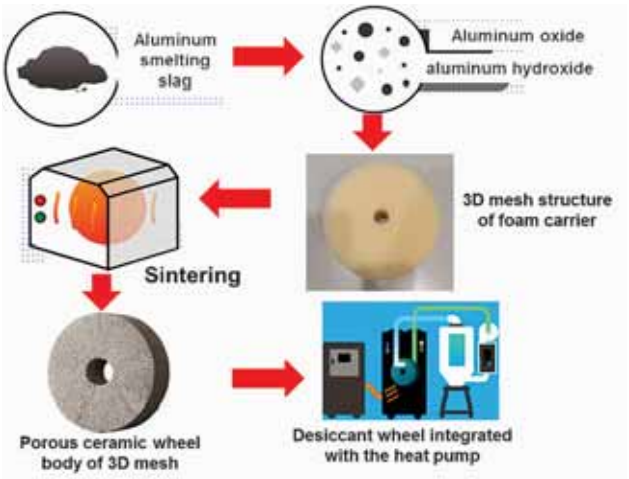


Fig.2. The flow diagram of energy-saving and environmentally-friendly drying technology

Fig.3. Investment of porous ceramic production process equipment by Jasico corporation

In 2020, Shiang Ying Refractory corporation was given authorization of "Plasma Auxiliary Material Refining and Porous Ceramic Technology" with payment of 1 million NT$. Tse Jie Enterprise corporation asked INER to perform "Feasibility Evaluation of Waste Tire Plasma Pyrolysis" for recovery carbon as Desiccant Material, with payment of NT$400,000. In addition, Juncheng Thermal corporation requires a technical service to perform "Design of Auxiliary Boiler Exhaust Cooling and Energy-saving Improvement" with an amount of NT$200,000. Jasico corporation invests 1.2 million NT$ to set up production equipment.

In 2020, a garlic drying field test of 540kg scale was completed at a garlic farmhouse in Yunlin County. The air flow rate for the drying process was magnified by 5 times, from 40 m^3/h (2019) to 200 m^3/h (2020) . During the test, the heat pump completely replaced the electric heater as the heat source for the regeneration of the desiccant wheel, and operated continuously without failure. Over 30% water of garlic was removed, and the drying energy factor exceeded 0.6 kg/kWh. The drying time of garlic was shortened from 25 days to 12 days. No diesel was used at all, and so no derivative air pollutant emissions were produced. The noise level was alleviated from the 92 dB to 55 dB.

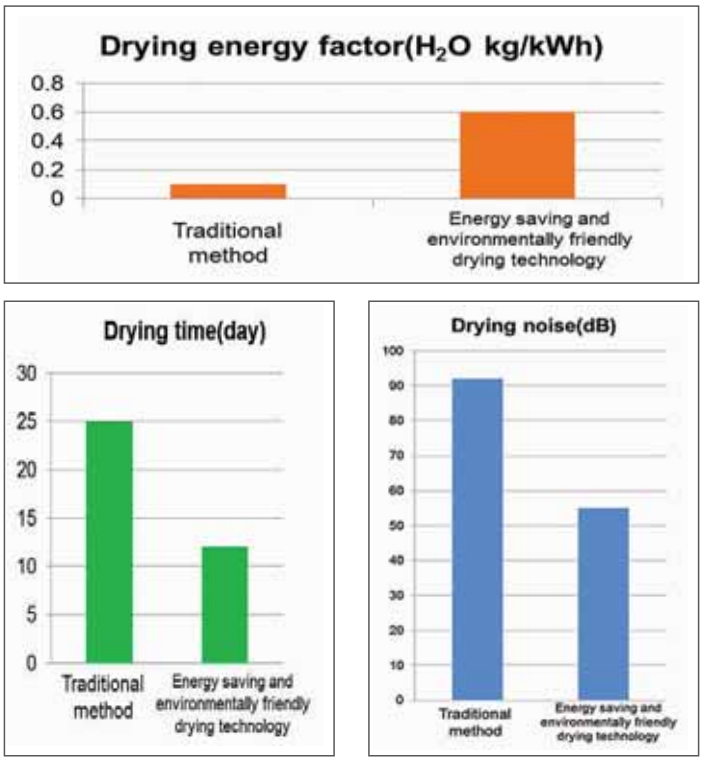


Fig.4. The comparison of conventional garlic dryer and the energy-saving and environmentally-friendly drying technology

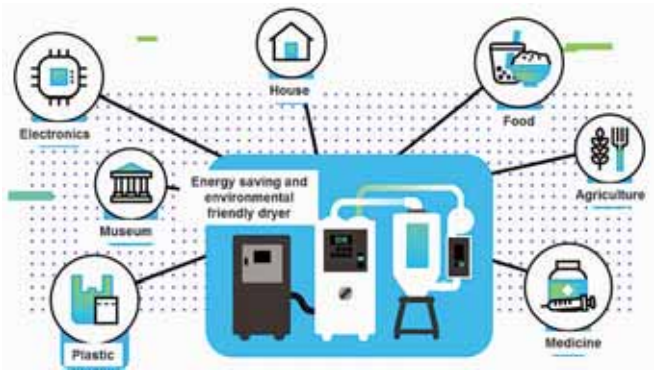
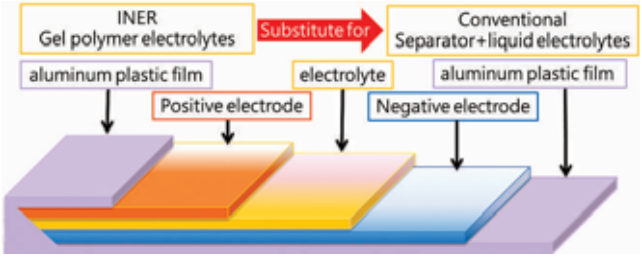


Fig.5. The application future of the energy-saving and environmentally-friendly drying technology

In 2021, INER will continue to develop the energy-saving drying system integration and the green circular desiccant wheel with adsorption materials. Advanced recovery of desiccant wheel regeneration waste heat and reduction of heat energy loss will be implemented to increase the drying energy factor to 0.8 kg/kWh. The manufacturing process will be optimized to increase the yield rate to 90%. The scale of the garlic drying field test will be increased to 1,000 kg. The technology will be extended to other industries such as the food industry, plastic industry, semiconductor, paper industry, ceramics industry, etc.

3-2-2 Research and development of a low-cost gel polymer electrolyte technology for improving the safety of lithium-ion batteries

Rechargeable lithium-ion batteries (LIBs) are important power sources in our daily life. They are widely used in 3C electronics, wearable devices, electric vehicles, and green energy storage. However, commercial batteries containing liquid electrolytes are subject to considerable risk of fire or explosion. As a result, the trend of LIB improvements is toward replacing the liquid electrolyte by polymer or solid-state electrolyte for the sake of product safety, and higher energy density. Table 1 shows a detailed comparison of different technologies. According to a report by a renowned research unit, the market size of the solid-state electrolyte industry is predicted to reach over US$7 billion in 2030. Among those technologies, gel polymer electrolyte (GPE) LIB has demonstrated the potential for high safety, and, its production cost is similar to that of commercial liquid electrolyte LIBs. Although safe, high-energy-density and flexible polymer electrolyte lithium batteries have been investigated for nearly four decades, their poor ionic conductivity at room temperature is still a problem that needs to be solved for many applications. Therefore, the Institute of Nuclear Energy Research (INER) has developed a new GPE technology to solve the problem of present commercial liquid electrolyte LIBs and to optimize them with high safety, high-energy density, and low production cost.



Lithium-ion battery structure

Table 1. Comparison of LIB technologies

Technology Classification /characteristic	Liquid LIBs (Market existing technology)	Gel polymer LIBs	All solid-state LIBs
Safety	Low safety (Organic solvent)	high safety (polymer materials+Flame retardant)	Highest safety (No organic materials and solvent)
Mass production technology	Mature	Can technology integration with liquid LIBs	Semiconductor-level manufacturing technology, low coating rate
Battery capacity	high (more than hundreds of mAh)	A little lower than liquid LIBs (hundreds of mAh)	Lowest (μAh~mAh)
Process cost	lowest (average $USD 137/kWh)	With Technological development can close to liquid LIBs (close to $USD 137/kWh)	Highest cost (about $USD 1,500/kWh)
Main application areas	Energy storage and wearable device (medium and large battery capacity application)	Energy storage and wearable device (medium and large battery capacity application)	IOT sensing module (small battery capacity application)
Difference	Positive and negative electrodes of the battery are fabricated on different substrates, and the battery structure (a few hundred μm) is a stacking combination of two substrates.	Positive and negative electrodes of the battery are fabricated on different substrates, and the battery structure (a few hundred μm) is a stacking combination of two substrates.	The positive and negative electrode (< 1 μm) of the battery structure is completed by coating on a single substrate.

Source: Steve LeVine, "Batteries Are Advancing According to Their Own Little-Known Moore's Law," The Mobilist, extracted from https://themobilist.medium.com/batteries-are-advancing-according-to-their-own-little-known-moores-law-5a17c1d141d5.

The new GPE developed by INER has demonstrated ionic conductivity greater than 10^{-4} S/cm, even at room temperature, which is better than that of traditional GPE technologies. INER has recently cooperated with local battery and cell companies to accelerate the commercialization and industrialization of the new GPE technology. Furthermore, a roll-to-roll production process for a high-quality GPE thin film has been verified on a roller that is 15 cm in width. Figure 1 shows the products of the GPE thin films with different thicknesses.

One advantage of this new GPE technology is that both the preparation and thin film formation steps can be operated in an atmospheric environment. In addition, the precursor of the as-prepared GPE is in its solid phase at room temperature, and it is transformed into a liquid phase by a heating process. As a result, the GPEs can easily form thin films with different thicknesses and shapes. Furthermore, the GPE films can be easily and quickly assembled with commercial cathodes and anodes into sandwich structures to produce GPE LIBs. Figure 2 illustrates the GPE membrane specification.

Fig. 1. Samples of roll-to-roll GPE membrane

GPE membrane specification	
Membrane thickness	50μm~150μm
Ionic conductivity(room temp.)	~ 10^{-4}S/cm
Mechanical properties	bendable
Material characteristics	Flame retardant

Fig. 2. GPE membrane specification

By the end of 2020, fourteen LIB-related patents have been granted to INER, and the characteristics and cell performances of the GPE membranes have been verified by domestic companies. An aluminum plastic film battery having electrode area of 960 cm^2 was fabricated with a commercial lithium nickel cobalt manganese (NCM) positive electrode and a graphite negative electrode. A battery capacity greater than 1800 mAh was obtained, as shown in Figure 3. The energy density is close to the counterpart of current liquid LIB products.

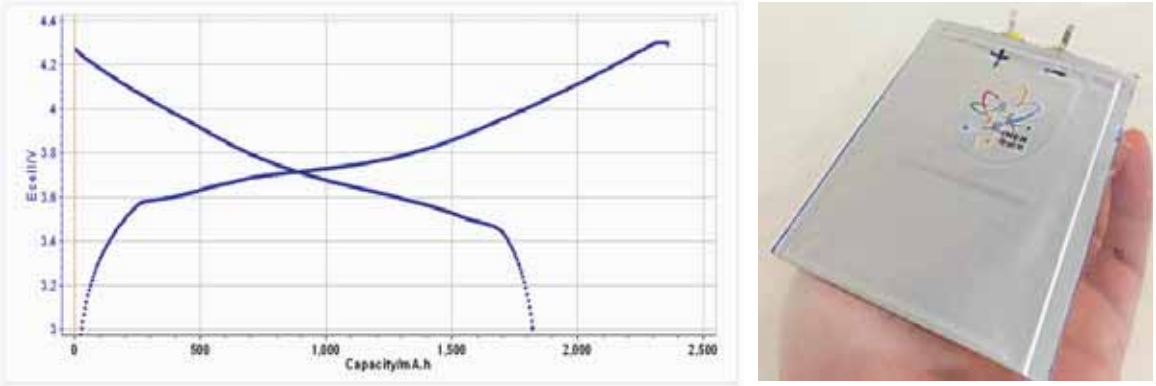


Fig. 3. Left: Charge and discharge curves of the aluminum plastic film battery. Right: A GPE LIB sample.

The new low-cost GPE technology has presently undergone several kilogram-level and small-scale electrolyte membrane fabrication tests. Moreover, some preliminary tests of the GPE LIBs with a capacity greater than 1.8 Ah assembled by commercial LIB positive and negative electrodes have been carried out. In the future, INER will continue to conduct small-scale trial production and high-capacity battery tests with domestic companies and simultaneously proceed with LIB-related safety standard and material property tests to further accelerate the transfer of the new low-cost GPE technology to the LIB industry.

3-2-3 Indigenous flow battery technology for promoting domestic energy storage industry

To achieve the 2025 green energy goal (20% renewable energy), and to improve the stability of the grid system, the government plans to set up a 590 MW energy storage system by 2025. Flow battery features the characteristics of high safety, long lifetime, high design flexibility (storage power and capacity designed separately), easily recycled material, no fire or explosion probability (non-flammable water-based electrolyte), and development potential of large-scale energy storage.

Energy storage can improve the controllability of power grid and the penetration of renewable energy, which help promote green energy policies. Establishing operation and maintenance technologies for flow battery energy storage would be beneficial to achieving the policy goal of maximizing the renewable energy portfolio, and serve as a prerequisite for commissioning a demonstration system to verify the feasibility of future energy storage application.

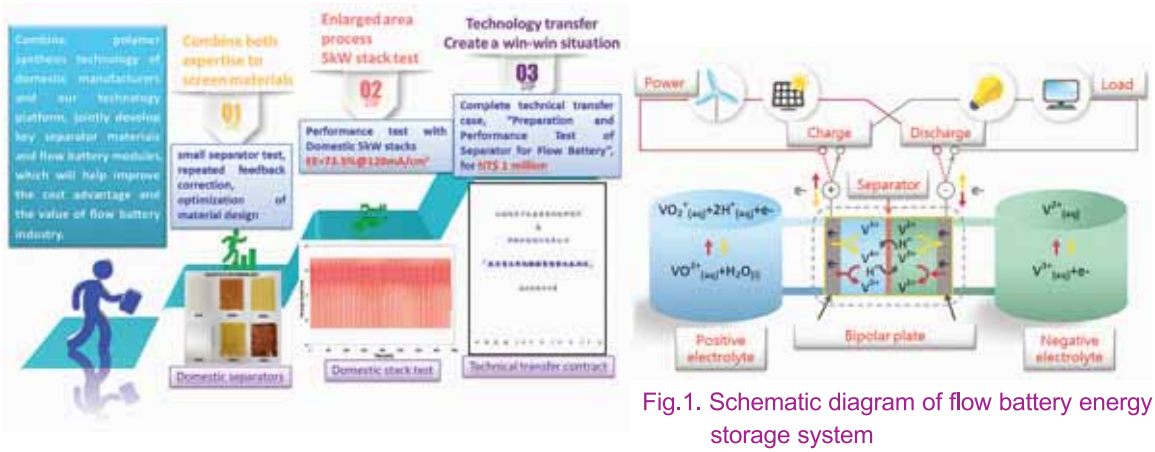


Fig.1. Schematic diagram of flow battery energy storage system

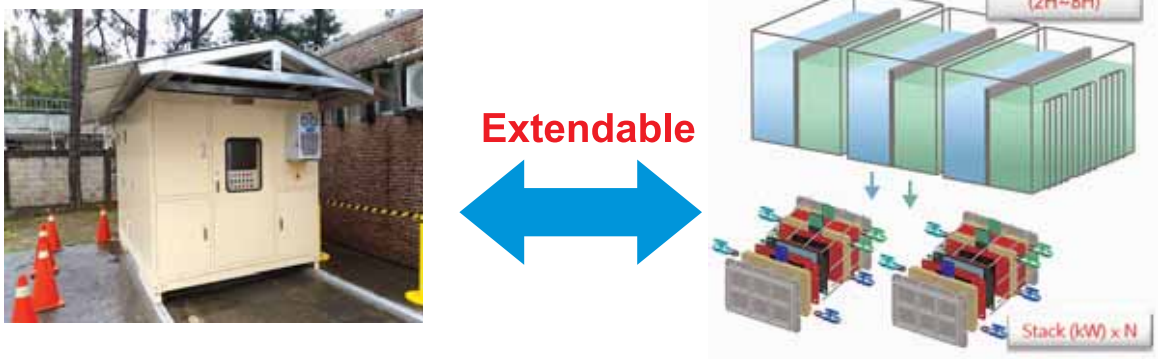


Fig.2. Domestic flow battery energy storage system

The main key materials and components of flow batteries include electrolytes, electrode materials, separators and bipolar plates, each with its own mechanism and improvement plans. It is necessary to test different material combinations, adopt the optimal operating conditions to evaluate the best performance, and further clarify the limits of the materials and components. The aim is to enhance the reliability and stability of flow batteries, raise the cost-performance ratio of energy storage systems, and become the basis for the industrialization of flow batteries.

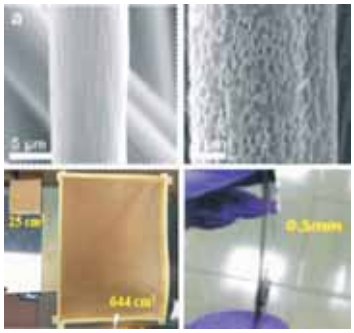


Fig.3. Key materials for domestic flow battery

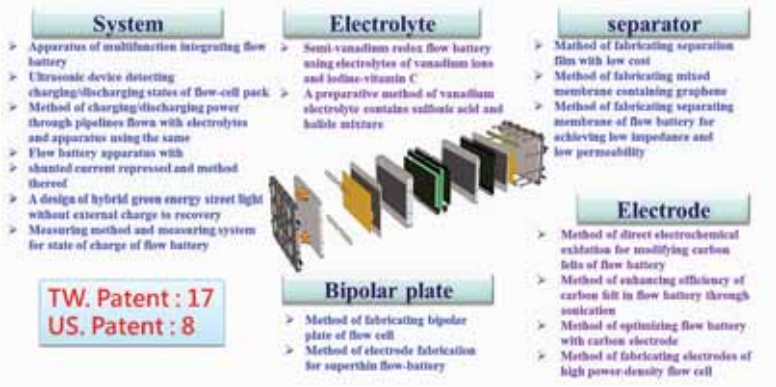


Fig.4. Institute of Nuclear Energy Research flow battery patent

The Institute of Nuclear Energy Research (INER) is actively engaged in patent layout, breaking through the patent barriers of international manufacturers, and fostering domestic enterprises to establish indigenous flow battery brands. Presently, several patents have been granted, including battery systems (9 items, 1 item for technical service this year), carbon felt electrodes (7 items), bipolar plates/flow field plates (4 items), and separators (3 items, 1 item for technical transfer this year), and electrolyte (2 items).

Platforms for field tests of laboratory-scale (3-6 W) single cell, kW-class battery stack, and energy storage system are commissioned at INER, and provide technical support for the development of energy storage technology.

Domestic manufacturers required a technical service to perform the "Bipolar plate and electrode combination performance tests," for energy efficiency and capacitance decay rate of the components developed by the company, to evaluate future mass production technologies and feasibility.

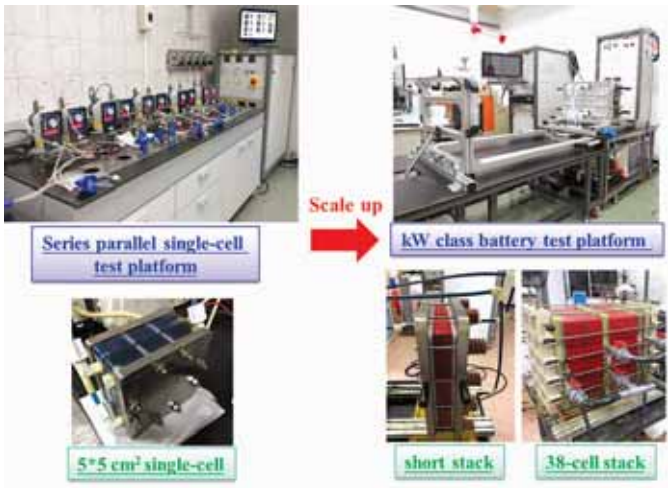


Fig.5. Verifying performance with flow battery test platform

INER establishes the design capability as well as operation and maintenance technology for the modular system of vanadium redox flow battery, which improve the lifetime of the system. Furthermore, the technological competitiveness and economic value can be enhanced, through the development of key materials and the improvement of the efficiency of the battery stack system.

Assembling battery module independent technology

Domestic battery module

Fig.6. Domestic flow battery module made by Institute of Nuclear Energy Research

3-2-4 Environmentally Friendly Bioplastic Technology-Polylactic acid(PLA)

Low carbon • Non-toxic • Multiple recycling methods

Have you heard of PLA? As long as you look carefully at the bottom of the transparent egg box, you should often find PLA printed on it, which means that the box is made from PLA. PLA is actually the abbreviation of PolyLactic Acid. It is one of very common type of bioplastics on the market, widely used in tableware, straws, food packaging materials, agricultural mulch, 3D printing wire and biomedical materials, etc. Therefore, it has already existed in our daily lives. As the name indicated implies, PLA is a bioplastic manufactured by artificially synthesized technology using common lactic acid as raw material, while lactic acid can be produced by biological fermentation with sugar in various biomass, such as starch, sucrose, and lignocellulosic materials. Thus, it is a substitute for plastic to replace petroleum with plants as the raw material. Almost all of the PLA products on the market are made from corn starch and sucrose. There has not yet been a mass production plant in the world to produce PLA using lignocellulosic materials.

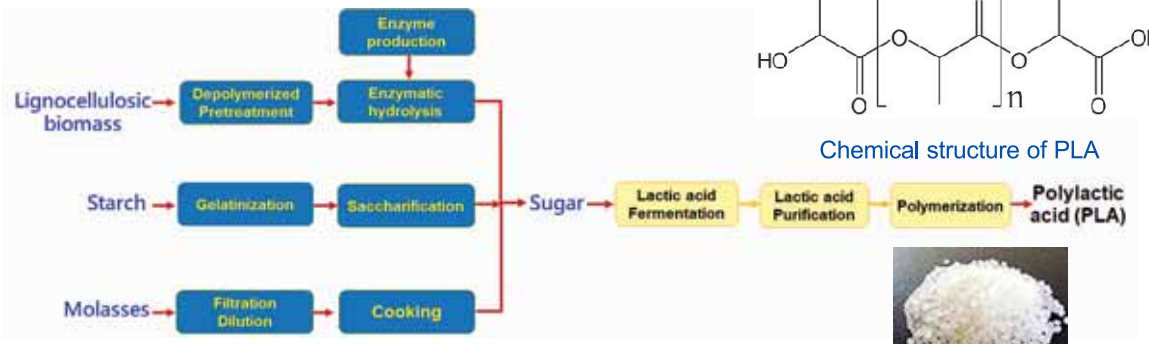


Fig.1. The process of producing PLA with different biomass

Chemical structure of PLA

PLA granules

Low-carbon, non-toxic PLA production technology

PLA production technology has been known as a low-carbon, non-toxic plastic production method. Taking the PLA production technology developed by the Institute of Nuclear Energy Research (INER) as an example, the fermentation temperature of lactic acid production is about 37°C. and is regarded as a relatively mild operating temperature, compared with that in the petrochemical plastics manufacturing process. Therefore, it requires less fossil fuels, and produces relatively lower greenhouse gas emissions; so lactic acid fermentation is known as a production technology with low carbon footprint. As for the process of synthesizing Polylactic acid from lactic acid, although it is a chemical process with medium-to-high temperature, no toxic or carcinogenic substances are released during the process, while the operating temperature and pressure are still lower than the counterparts in the synthetic process of petrochemical plastics.

Table 1. Low-carbon and non-toxic properties of PLA production technology

Items	PLA production technology
Feedstock	Corn, sucrose, and lignocellulosic materials are all natural and non-toxic
Lactic acid production	Using microbial fermentation technology, the reaction temperature is between 30-40°C, relatively less petrochemical energy-consuming and has a lower carbon footprint
Intermediate product	Lactic acid solution produced by fermentation, non-toxic (for example, the composition of Yakult is mainly lactic acid)
Polylactic acid Synthesis from lactic acid	Mid-range operating temperature (150~200°C), no toxic substances emission
Operating pressure in the process	Normal pressure, less energy consumption
Risk from Process	Low risk, the raw materials or intermediate products are non-toxic and not easy to emit, friendly to the environment

The value of PLA's biodegradability showing multiple recycling paths

In general, PLA can be completely decomposed in an environment with 50-60°C, high humidity and bacteria. The decomposition time varies with the thickness and molecular weight of PLA products. However, PLA is almost impossible to degrade in seawater. In fact, almost of all plastics cannot be degraded in seawater environment; but intrinsically, it should not be discarded into the ocean. The key to solving marine pollution still depends on human countermeasures. The characteristic of PLA's biodegradability is the key to making PLA recycling and reuse with more options. Since PLA is repeatedly reused, its physical properties will gradually deteriorate and still require final disposal. Therefore, INER has recently developed a high-temperature depolymerization technology that can decompose PLA into lactic acid without adding chemicals. These regenerated lactic acid can be polymerized again into a brand new PLA. In addition, PLA has been regarded in the current EU composting standard (EN13432) as organic waste, and it is recommended to use composting and biogas production as the final disposal. Therefore, INER also carried out appropriate pretreatment for waste PLA and then mixed it with rice straw to produce biogas. It is found that the biogas production can be increased by 70% compared with rice straw alone. And if PLA is treated by incineration for power generation, it can also be regarded as a bioenergy.

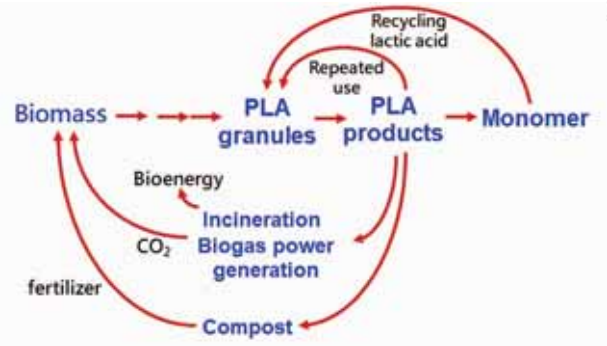


Fig.2. Polylactic acid has multiple recycling paths

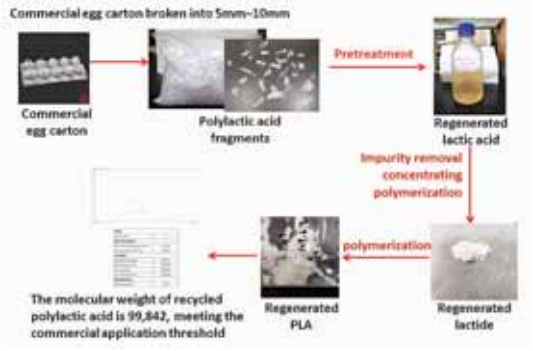


Fig.3. Process for preparing regenerated lactic acid and synthesizing PLA

INER's PLA technology booming

Using non-grain and diversified biomass as the feedstock is the key feature of INER's PLA technology. In addition to starch and sucrose, lignocellulsic biomass can also be used as the feedstock with more complex technologies to produce high purity L-lactic acid and D-lactic acid, and further polymerized into PLA. Recently, INER has cooperated with several domestic and foreign companies to promote the industrial application of PLA production technology. For example, INER has currently cooperated with a New Zealand's company, to integrate local afforestation and plywood factories, and then use the waste wood chips from the plywood factory to produce PLA, which facilitates the development of wood biorefinery industry chain.

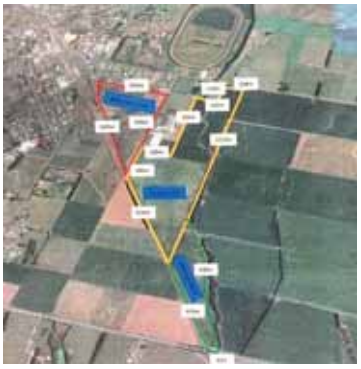


Fig.4. Scheduled site for New Zealand PLA production plant

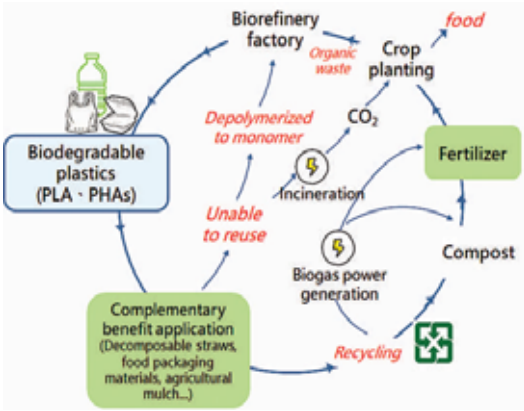


Fig.5. Schematic diagram of integrating PLA production and reuse

Light up the prospects of PLA technology

Looking forward to the future, INER will not only continue to promote the industrial application of environmentally friendly PLA technology, but also further develop the production technology of marine biodegradable plastic PHAs (Polyhydroxyalkanoates), which is complementary to each other with the PLA production technology and assist in creating indigenous upstream supply industry of bioplastics. So that manufacturers of bio-plastic products will have more diversified PLA import sources. INER will also evaluate the technologies for recycling PLA to produce biogas and convert it into regenerated lactic acid. It is promising to further show the benefits and values of PLA production.

3-2-5 Flexible organic solar cell modules for indoor and outdoor applications

Traditional silicon solar cells, which currently dominate the market, feature good power efficiency under sunny outdoor environments, and are suitable for rooftop or ground-based solar photovoltaic systems. However, the shortcomings of silicon solar cells, including thick, fragile, inflexible, opaque, and the poor efficiency in cloudy or indoor light, make them unable to be applied indoors and in some outdoor fields.

Unlike silicon solar cells that require high-temperature and vacuum processes, organic photovoltaics (OPVs) are prepared by solution coating in an ambient environment feature thin, flexible, transparent, and much higher efficiency in dim-light environments, and enable niches in both indoor and outdoor applications .

The Institute of Nuclear Energy Research (INER) has established the process technology service platform for roll-to-roll (R&R) mass production of OPVs, and is cooperating with industrial companies to develop various prototype products in indoor and outdoor applications.

Fig.1. The roll-to-roll organic solar cell process equipment and the flexible organic solar cell modules prepared by INER

INER developed a roll-to-roll continuous coating process for flexible organic solar cells in an ambient environment, combining slit-die coating with roll-type continuous coating process, and successfully implemented a fast and universal process to coat each film layer on a flexible PET substrate.

For indoor applications, the large-area ($100cm^2$) flexible organic solar cell modules prepared by INER exhibit efficiency of ~16% in a 500 lux TL84 light source environment, corresponding to electrical power densities of about $27\mu W/cm^2$. For outdoor applications, the large-area flexible transparent organic solar cell module developed by INER accomplishes efficiency up to 5.6% and transparency of 50%; so, it can be fully attached to the transparent plastic agricultural greenhouse to achieve the vision of agrivoltaics.

Fig.2. Flexible transparent organic solar cell modules developed by INER

Fig.3. The flexible and transparent OPV module technology developed by INER won the gold medal of the invention competition in the "2020 Taiwan Innotech Expo "

The flexible and transparent OPV module technology developed by using grid-like electrodes combined with high-conductivity polymer PEDOT:PSS as the hole transport layer exhibit efficiency almost equal to that of the opaque OPV module. This R&D achievement is honored the gold medal in the "2020 Taiwan Innotech Expo". Currently, the industry-academia cooperation project is being carried out to conduct the field tests of the transparent OPVs, in order to achieve the win-win policy goal of agriculture and green energy.

Besides efficiency, stability is the most critical factor for the commercialization of flexible organic solar cell modules. The key to improving stability lies on encapsulation technology. The encapsulation technology for flexible large-area organic solar cell modules developed by INER strengthens the resistance of the flexible modules to the intrusion of water vapor and oxygen in the external environment, thereby improving the behavior of accelerated damp and heat testing, and the T_{80} lifetime can exceed 1400 hours at 65°C/65% RH accelerated life test. This R & D result was published in the international SCI journal (Solar Energy (2021), Vol. 213, pp. 136-144) in 110.

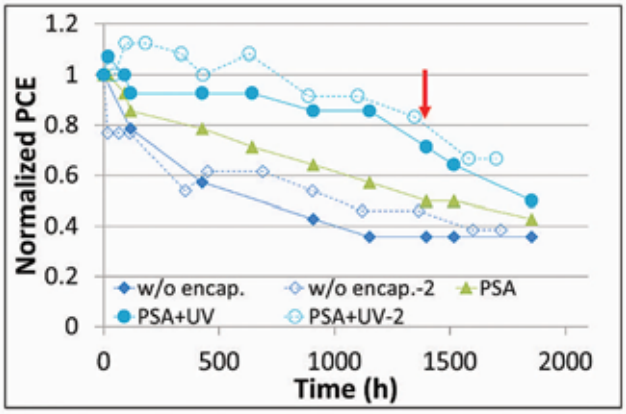


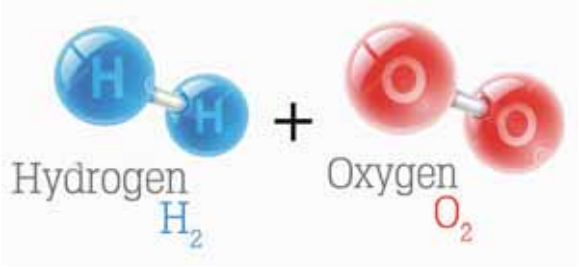
Fig.4. The large-area flexible organic solar cell module developed by INER has a T_{80} life of over 1400 hours at 65°C/65% RH conditions

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

Looking forward to the future, INER will play a key role in the mid-stream position of the flexible OPV module in Taiwan, vertically integrating upstream academia/materials vendors and downstream industrial manufacturers, in order to establish localized key technology patents and have an international market competitive advantage. So that Taiwan will seize the opportunity and competitive advantage in the future international market of flexible OPV module industry.

3-2-6

A wonderful journey of hydrogen and oxygen - the technology of solid oxide fuel cell



Working on the advancement of solid oxide fuel cell (SOFC) technology, the Institute of Nuclear Energy Research (INER) co-operated with domestic companies for interconnect manufacture and protective coating spray, and applied the newly designed interconnect in metal-support-cell (MSC) stacks. INER has built up a 5 kW power generating system and executed a pilot run with four 10-cell MSC stacks. An automatic stack assembling platform has been set up and successfully passed the test for assembling short stacks. Four kW-level MSC stacks were prepared and performance testing was conducted with satisfactory results, confirming the stacking processes. Under the frame of patent licensing for manufacturing cells, INER has assisted the licensee in massively producing anode substrate tapes and manufacturing commercial cells with performance evaluation, for the establishment of an integral domestic supply chain.

Fig.1. INER 36-cell MSC stack

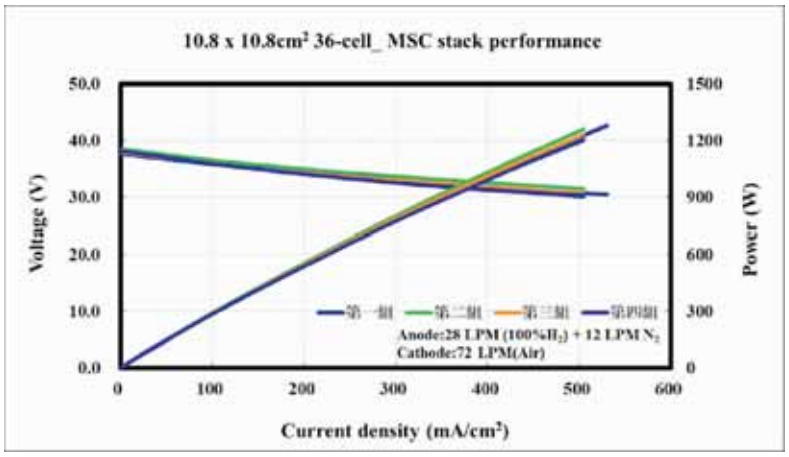


Fig.2. Stack performance test curves

KW-level new type stack

Four stacks, each assembled with 36 self-made metal-supported cells (MSC) by plasma spray, were tested. Tafel testing was conducted after pure hydrogen gas was fueled. For one of the stacks, the maximum power output reached 1.23 kW at current intensity 40 A with average power 34.2 W/cell. Other stacks demonstrated similar results, verifying the reproducibility of the stacking process.

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

Metal-supported SOFCs with 1.2 mm in thickness and 10x10cm^2 in size are produced. The single cell can deliver 28.8 W (power density 356 mW/cm^2) at 0.7 V and 550°C. This cell shows a great power performance at operating temperatures lower than 600°C.

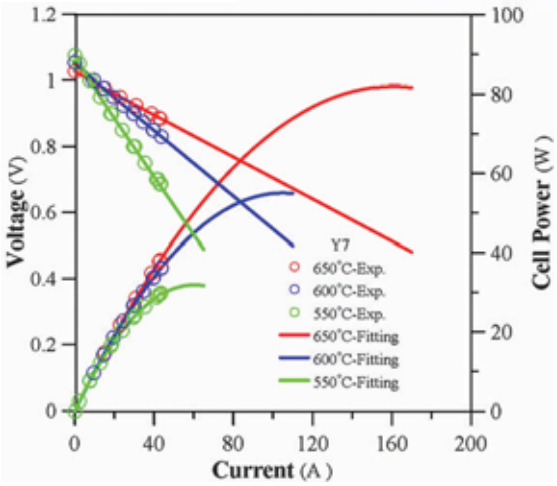


Fig.3. Performance of plasma-sprayed metal-supported SOFC

Ceramic based anode-supported solid oxide fuel cell

Cell product performance is improved for the anode-supported SOFC (thickness:~430μm) with introducing gradient anode cermet composition and increased substrate porosity. Cell product exhibits process and performance reproducibility for commercial available specs.

The cell product with YSZ electrolyte exhibits enhanced OCV of 1.13 V and the cell output power ~ 30 W (power density 370 mW/cm^2) at 800°C (0.7 V) for further stacking / system application.

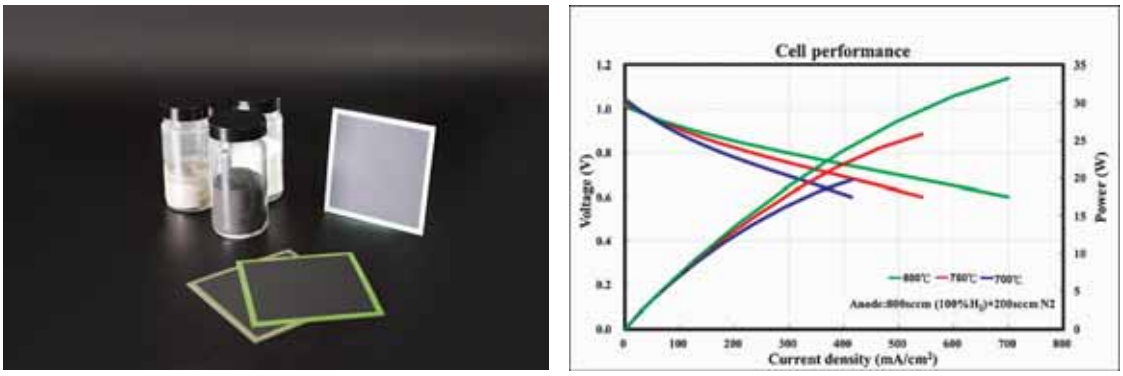


Fig.4. Ceramics-based anode supported SOFC and performance enhancement results

Fuel reforming honeycomb catalyst

Novel honeycomb catalyst exhibits high activity over a range of reforming reactions and demonstrates resistance to carbon deposition for longer.

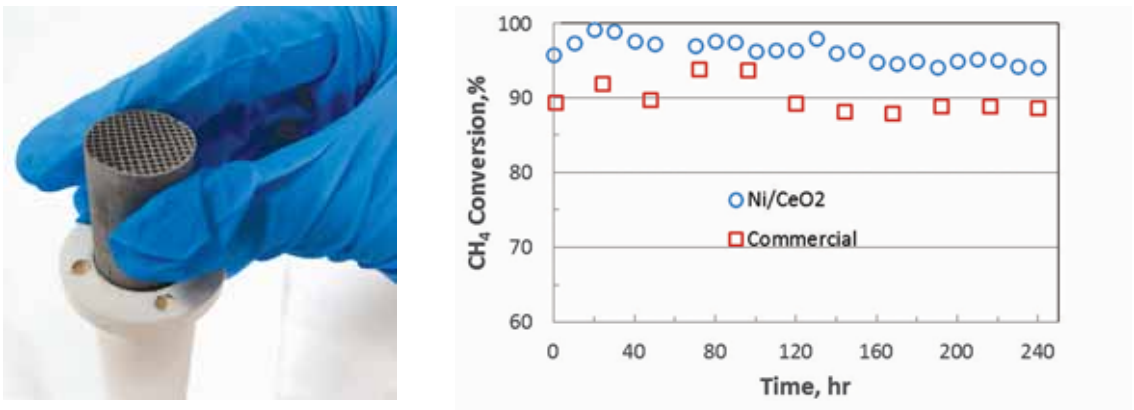


Fig.5. Fuel reforming honeycomb catalyst

Awards

2020 National Innovation Award:

Excelsior award : 【Plasma-sprayed metal-supported solid oxide fuel cell and its manufacturing method thereof】

3-2-7 Visual Distribution Network Management and Application System

In recent years, as environmental sustainability issues have received high attention, the green energy industry has also developed vigorously. As the result, it is expected that a large amount of renewable energy will be incorporated into distribution feeders in the future. Practically, dispatchers supervise real-time operation status of feeders by Supervisory Control and Data Acquisition (SCADA), which presents feeders' topologies in single-line-diagram style without geospatial information. Therefore, in power outage, it is necessary for a dispatcher to query maps on Outage Management System (OMS) to confirm the fault region, which might increase delay of power recovery. To address the issue, the Institute of Nuclear Energy Research (INER) develops the Visual Distribution Network Management and Application System, consisting of SCADA, geographic information system (GIS), and distribution dispatching applications, to help a dispatcher make decision with aid of the geospatial information. It won the Platinum Award in the 2020 Taiwan Innotech Expo (TIE) honorably (Figure 1).

Fig.1. 2020 Taiwan Innotech Expo (TIE) Award Ceremony

In our research, it is focused on enhancing information integration mechanism between SCADA and GIS. By making the equipment information monitored by SCADA, the distribution network operation status visualization function can be further developed on GIS. Besides, with the graph tracing algorithm and equipment connectivity relationship, once a switch action occurs, such as on/off status of switches, the algorithm can automatically determine the power source and service status (normally supplies power or not) of every segment on feeders, followed by display them with different colors to indicate different status. Therefore, when a accident occurs in feeder and needs conducting fault detection, isolation, and power restoration (FDIR) process, dispatchers can quickly grasp the range of power failure, recovery, and load transfer region of the incident feeder on GIS (Figure 2). In addition, the power source indication function is also developed on GIS. The arrows indicating power supply direction marked on feeders can be changed dynamically with the switch on/off action (Figure 3). The function can also be applied to mark the reverse power flows phenomenon when the power generation of renewable energy increases. The function provides great convenience for dispatchers to clarify the power source of each segment on feeders and realize the power generation status of renewable energy.

Fig.2. After SCADA (left) finishes FDIR process, GIS (right) visualizes the feeder operation status on the map.

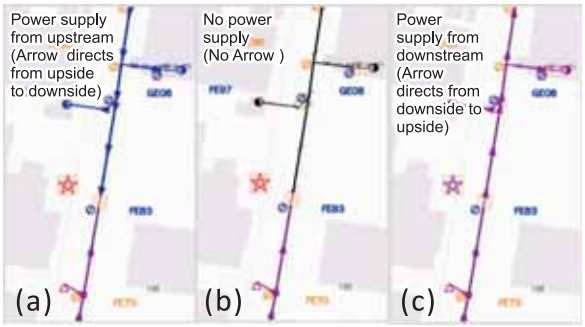


Fig.3. GIS changes the direction of arrows on feeders depending on operation status (a) supply power normally (b) outage (c) power transfer.

The aforementioned GIS is developed on the basis of open-source GeoServer; furthermore, the feasibility and system performance of distribution management and application system on commercial open-system GIS are also under study. Therefore, commercial GISs are employed to develop our Visual Distribution Network Management and Application System, as shown in Figure 4. Through a series of functional development and testing, it is proven that commercial GISs can extensively display the geospatial information of feeders, and also be fully integrated with SCADA to achieve system operation status visualization function. Besides, compared to open-source GeoServer, commercial GISs provide richer line style, color style, and more delicate user interfaces. All of these merits are added up to result in a system with more satisfying visual effect. Commercial GISs also provide convenient Application Program Interface (API) for developers, which can make development process much more efficient. Another significant advantage of commercial GIS is the support of 3D display mode to present 3D structures of facilities on feeders, such as the profile of underground distribution lines (Figure 5), which can provide comprehensive information for dispatchers, designers and inspectors to make decision.

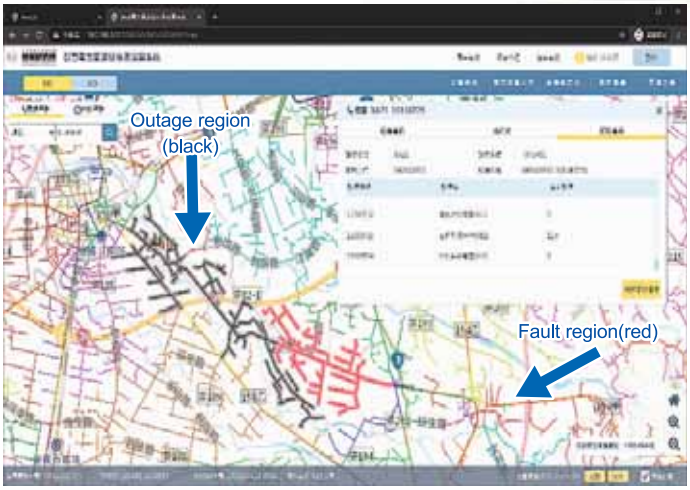


Fig.4. Developing distribution network geospatial information publication service and system operation status

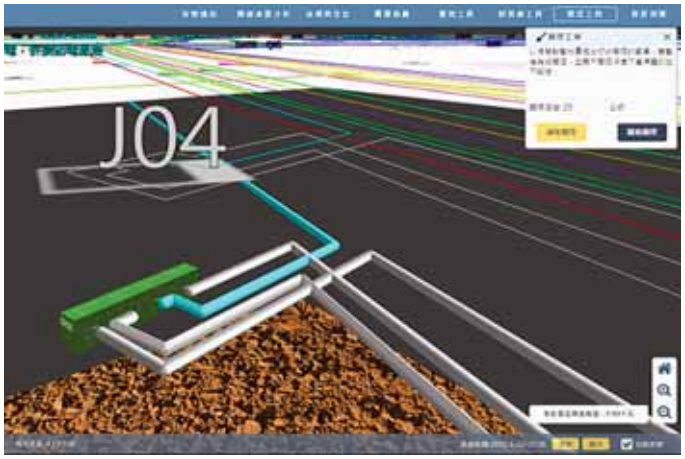


Fig.5. Presenting 3D profile of underground distribution feeders on commercial GIS

Our research has been granted as ROC patent entitled "Method of Transfer Supply containing Green Energy for Distribution feeder", and licensed to a domestic SCADA company. By transferring our technologies, it is hoped to help and foster domestic SCADA companies to strengthen their FDIR function, especially about decision-making strategies on load transfer, and increase their system integration level with geospatial information of distribution networks. Moreover, it is hoped that these technologies can be further promoted in relevant fields at home and abroad, to accelerate the development of power distribution systems and renewable energy industries.

Fig.6. ROC patent certificate

In response to the trend of more and more renewable energy being integrated into distribution networks, INER will continue to develop various distribution management applications such as that for optimizing feeder configuration with taking renewable energy into account, state estimation, and distribution network diagram correctness inspection. By dedicating our effort to make technology breakthroughs, INER aims at creating value-added applications and cross-domain benefits in domestic industries. It will finally lead to an environment beneficial to power companies in both operation and maintenance aspects. At same time, it will also enhance industrial technology basis and inspire more innovative applications.

3-2-8 Construction of Scaled Floating Wind Turbine - Sea Test

The 5 kW commercial wind turbine is selected as the reduced-scale model of the NREL 5 MW reference wind turbine. For this work, the pitch and yaw control systems are incorporated into the scaled wind turbine.

The mechanism design and control system are two primary parts of this study. The mechanism part includes the design of blade pitch, yaw system, tower and assembly frame, etc. The control system establishes the logic of the overall control system of the wind turbine, and configures the power box, control box, wiring, etc. The sea test floating wind turbine is a small 5 kW wind turbine that features the same active pitch and yaw control systems as the large offshore counterpart. It can be used as a scaled model of the floating wind turbine for related sea tests.

Table 1. 5 kW Commercial Wind Turbine and Scaled Wind Turbine Redesigned

5 kW Commercial Wind Turbine Specifications	
Rated Power	5 kW
Rated Wind Speed	10 m/s
Rated Rotational Speed	270 rpm
Design Maximum Rotational Speed	540 rpm
Number of Blades	3
Rotor Diameter	5 m
Swept Area	20.7 m^2
Wind Turbine Type	Horizontal, Upwind
Pitch System	N/A
Yaw System	Furling Tail
Drive Transmission	Direct-drive
Generator Type	Permanent Magnet Generator
Scaled Wind Turbine Redesigned Specifications	
Testing Max Wind Speed	10 m/s
Testing Rotational Speed	Below 200 rpm
Rotor Diameter	5.34 m
Swept Area	22.4 m^2
Pitch System	Activity Pitch
Yaw System	Activity Yaw

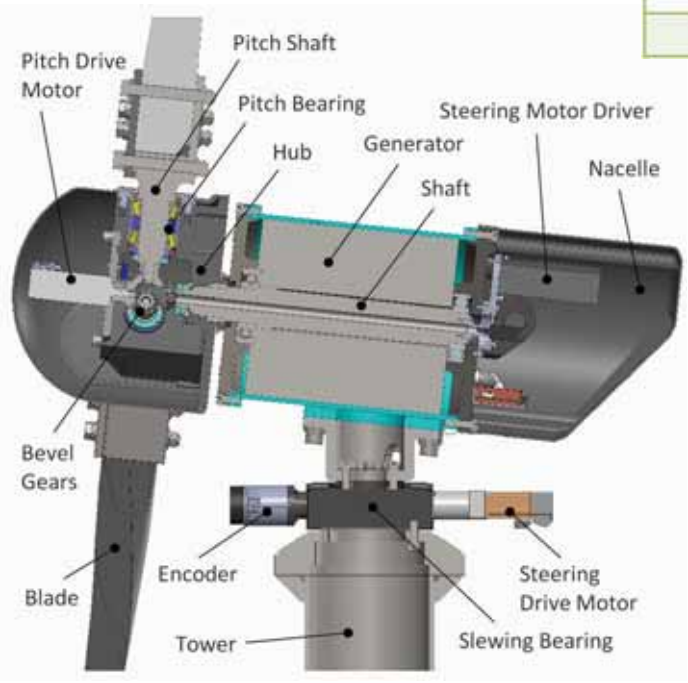


Fig.1. The sectional drawing of scaled floating wind turbine mechanism

The design of the scaled wind turbine mechanism includes the active pitch and yaw.

As shown in Figure 1, the pitch mechanism design includes: pitch drive motor, bevel gear, pitch bearing, pitch shaft and hub, etc. The pitch angle of the three blades are manipulated by a servo motor with bevel gears to achieve the functional requirements of synchronous drive. The yaw mechanism design includes: steering drive motor, slewing bearing, encoder, steering motor driver, etc. The steering motor and the nacelle end are rotating and moving simultaneously, which can avoid the possibility that the steering motor collides with the blades during steering.

The wind turbine control system is programmed through LabVIEW, which integrates motors, sensors, controllers and monitoring hardware devices to establish an online system. The system integrates dual-frequency outdoor high-power wireless APs to carry out relevant experimental data transmission and collection to facilitate continuous monitoring of the operating status.

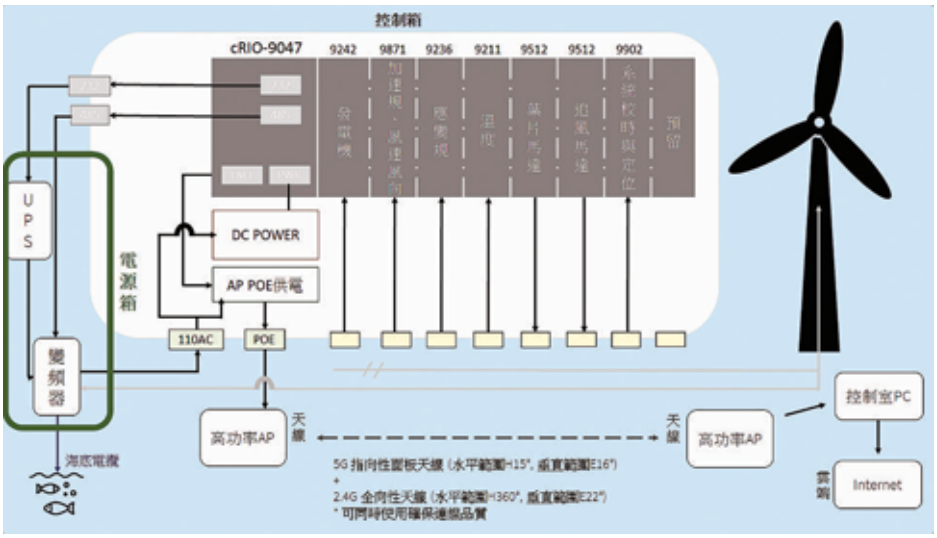


Fig.2. The overall planning of scaled floating wind turbine control system

The actual power generation characteristics of the scaled floating wind turbine tested in the sea area are shown in Figure 3. At the same wind speed, better efficiency of power generation is observed with smaller pitch angle.

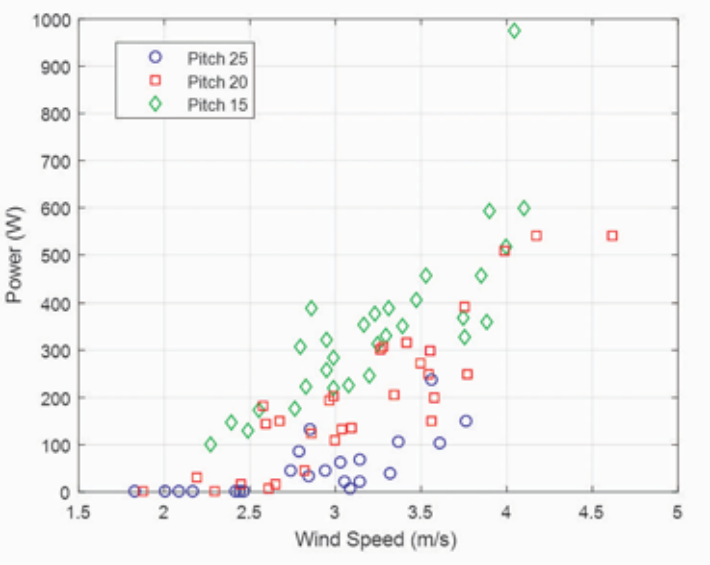


Fig.3. The power generation of wind turbine

Fig.4. The field test of scaled floating wind turbine at Anping Port

Wind power is the most practicable option for electricity generation applications among various types of the renewable energy. Therefore, the Institute of Nuclear Energy Research (INER) has devoted to the development of offshore wind turbine technologies since 2010. The redesign of the 5 kW commercial wind turbine integrated the active blade rotation and steering control systems. The mechanism design and control system of the scaled floating wind turbine have been developed. The ground test and water tank test have also been completed successfully.

As shown in Figure 4, the proposed scaled model can be employed for the development and verification of key technologies for the anti-typhoon floating offshore wind turbine system.

3-3 2020 Research on Civil Application of Radiation

The cross-domain integration of atomic energy technology and modern science has specifically developed into various innovative technologies and high-quality products. The important results of this year's radiation application in human livelihood will introduce the application of artificial intelligence in the fields of API synthesis, intelligent rehabilitation and neuroimaging medicine; In the application research of medical instrument and radiopharmaceuticals, the low-dose three-dimensional X-ray digital radiography (Taiwan TomoDR) has been clinically verified for its high resolution, and INER Dolacga Gallium liver function imaging agent won the silver medal of the National Invention Award, and dual-targeted tumor hypoxia therapeutic agents showed their efficacy through the animal model of colorectal cancer.

(1) Apply new artificial intelligence technology to promote the application of atomic energy to the people's livelihood

INER has promoted the research and development of artificial intelligence (AI) technology in radiological imaging medical materials, using artificial intelligence deep learning technology to establish convolution of nuclear medicine three-dimensional image spatial information The neural network model has been trained and tested to distinguish between the brains of normal people and patients with Alzheimer's disease. In the future, it will be further integrated with the clinical Tc-99m-ECD single-photon tomographic imaging technology to improve the accuracy of nuclear medicine imaging in determining Alzheimer's disease, and achieve the goal of early diagnosis and symptomatic treatment of the elderly.

INER has been engaged in the research and development of radiopharmaceuticals for many years. Recently, we invested in the application of artificial intelligence to drug synthesis. Since the outbreak of COVID-19, Remdesivir has been urgently needed as the first choice for this pandemic treatment in the world. However, due to the shortage of raw materials, the research team at INER used AI chemical reverse synthesis to retrospectively disassemble, and only starting materials can be. Remdesivir is successfully synthesized with easily obtained raw material via eight steps, which is simpler than the original process and obtains a higher total yield. During the research and development period, the optimal reaction conditions for each synthetic step are also established, and standard operating procedures are formulated to facilitate the expansion of production and contribute to the national epidemic prevention work.

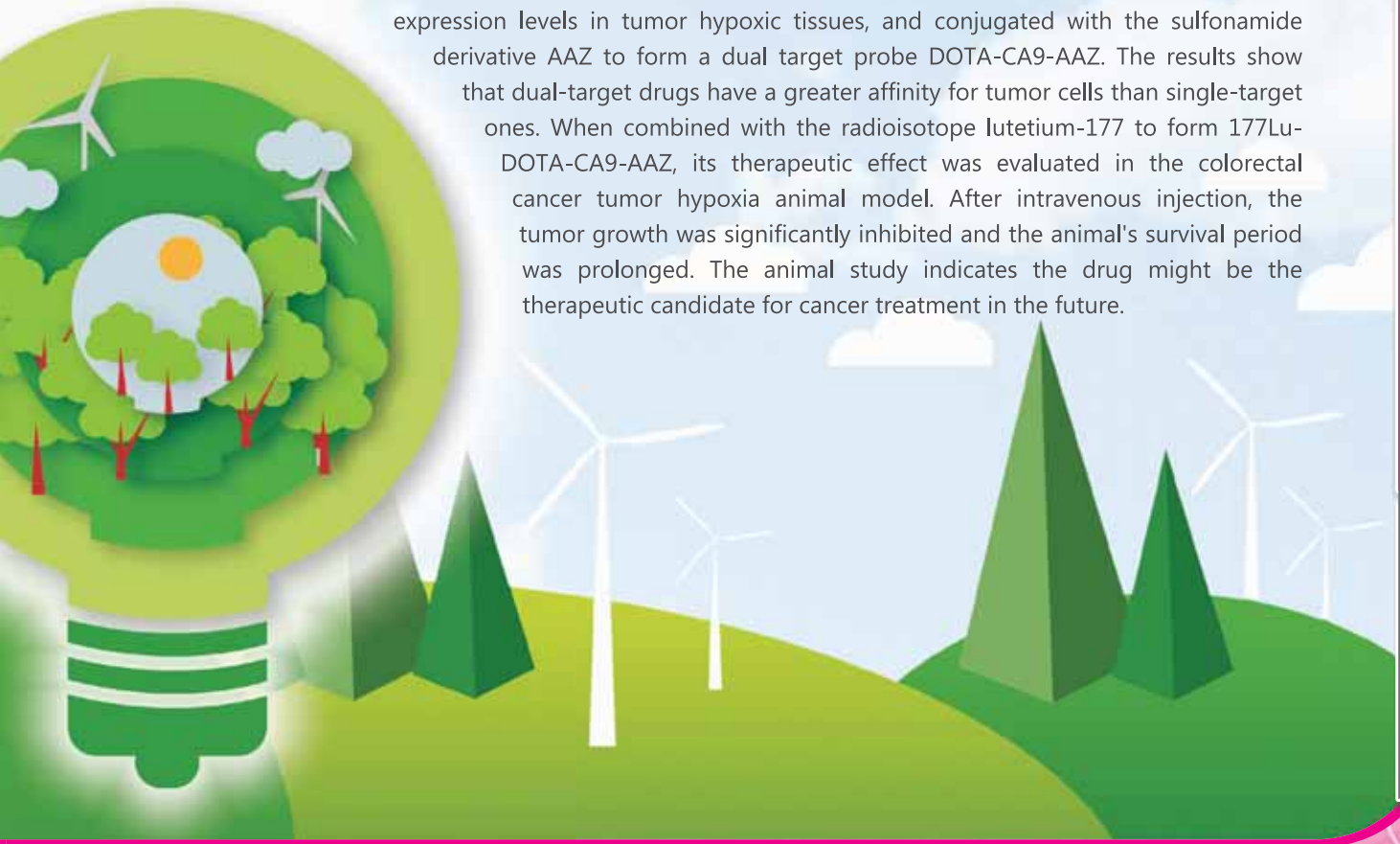
In response to the future trend of an increase in the elderly population and a decline in the labor force, INER uses the applied optoelectronics technologies to combine with optical pressure sensing technology and artificial intelligence judgments to develop "intelligent rehabilitation devices". It is demonstrated with excellent stretch and flexibility characteristics. This technology can be combined with existing rehabilitation devices to provide quantitative data and intelligent judgment capabilities for medical staff as a reference to improve the effectiveness of rehabilitation.

(2) Promote the application of innovative medical instruments and radiopharmaceuticals to provide new tools for disease diagnosis and treatment

INER has successfully developed the digital radiography(Taiwan TomoDR). In order to verify its performance, we cooperated with NTU hospitals to explore its clinical value on the diagnosis of spinal compression fractures in the elderly. The results showed that the performance of Taiwan TomoDR is significantly better than traditional two-dimensional X-ray machine on the identification of different depths under limited angle and low-dose imaging condition. Taiwan TomoDR can clearly show the anatomy of the spine, and has great potential to develop into a powerful tool for assisting compression fracture diagnosis, surgical evaluation and follow-up.

The development of hexa-lactopeptide technology in "INER Dolacga Liver Imaging Agent" has already verified its safety and liver target characteristics in the phase I clinical trials. The Phase II clinical trials is planned to be carried out in 2021-2022 to evaluate the accuracy and reliability of Gallium 68-Dolacga as a preoperative assessment of residual liver function. As a result of continuing to promote clinical research to verify the accuracy of liver function evaluation, the drug won the "National Invention and Creation Award" Silver Medal Award and the "New Innovation Award" and other affirmations in 2020.

In terms of innovative research and development of new drugs, INER actively invests in the development and clinical application of diagnosis and treatment drugs for cancer diseases. The target peptide was designed for carbonic anhydrase IX (CA9 for short), which has high expression levels in tumor hypoxic tissues, and conjugated with the sulfonamide derivative AAZ to form a dual target probe DOTA-CA9-AAZ. The results show that dual-target drugs have a greater affinity for tumor cells than single-target ones. When combined with the radioisotope lutetium-177 to form 177Lu-DOTA-CA9-AAZ, its therapeutic effect was evaluated in the colorectal cancer tumor hypoxia animal model. After intravenous injection, the tumor growth was significantly inhibited and the animal's survival period was prolonged. The animal study indicates the drug might be the therapeutic candidate for cancer treatment in the future.



3-3-1 Novel Weapon of Precision Medicine for Liver Disease- Dolacga Won 2020 National Invention and Creation Award- Silver Medal Award

Important contribution of R & D achievements

The key for survival is to maintain enough functional mass of liver. The asialoglycoprotein receptor (ASGPR) is liver specific. The less ASGPR a liver has, the more serious the hepatopathy is. Therefore, ASGPR imaging has been developed for evaluation of functional mass of liver (Fig 1 & 2). Dolacga, a liver function imaging agent innovated by INER, has got the approval of clinical trials by FDA and TFDA to enroll 12 evaluable healthy volunteers (including 7 males and 5 females) for phase I study, which includes studies of the biodistribution, dosimetry and pharmacological safety at National Taiwan University Hospital (NTUH). The results indicated its highly liver-targeting characteristic. Besides, the safety pharmacology study indicated its highly safety usage. In 2020, Dolacga has applied the FDA phase II clinical trial with the title of "An Open-Label, Comparative Phase II Clinical Trial to Assess the Accuracy and Reliability of the Ga-68 Dolacga Positron Emission Tomography Compared to Computer Tomography Volumetry and Indocyanine Green Retention Test for Measurement of Liver Reserve among Scheduled Operation Patients".

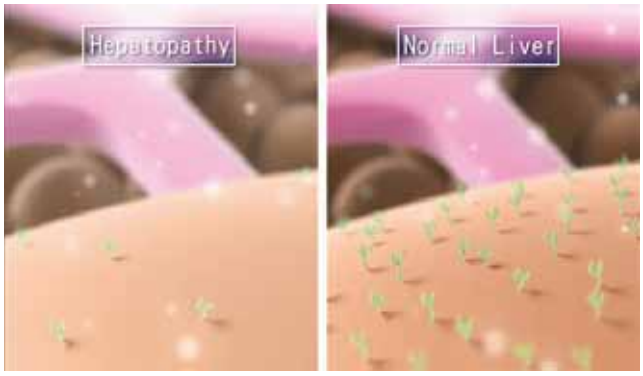


Fig. 1. There is statistical difference of asialoglycoprotein receptors on hepatocyte surface membrane between normal liver and diseased liver.

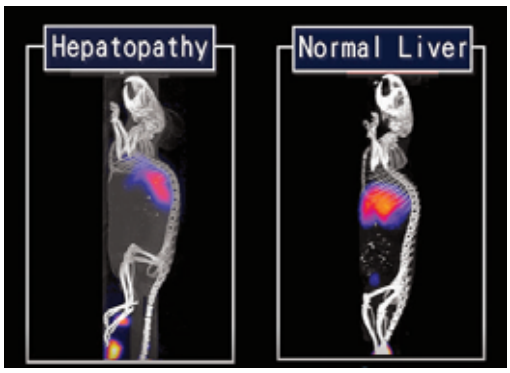


Fig. 2. By asialoglycoprotein receptor imaging technique, there is statistical difference of image between normal liver and diseased liver.

Lyophilized Design with Global Marketing Advantage

Dolacga is a Taiwan brand innovation and has been a commercial product with a trade name as Dolacga for clinical trials. The lyophilized formulation takes advantage of instantly soluble convenience, 15 min quick preparation, short half-life, and good stability for global marketing.

Fig. 3. Figure of Dolacga Product

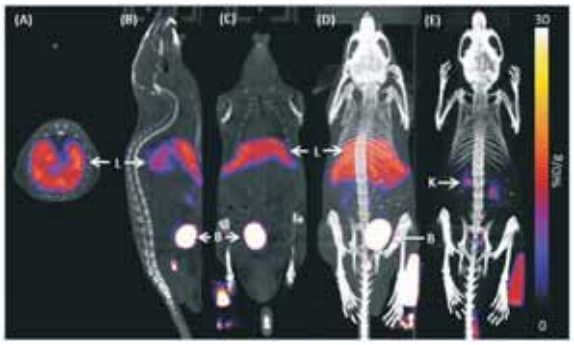


Fig. 4. Representative images (A–C) and anterior 3D volume-rendering projections (D, E) of fused PET/CT scans of normal Balb/c mice at 60-min after injection of [^{18}F]AlF-NOTA-hexa-lactoside. Mice in (E) pre-injected with a blocking dose of NOTA-hexa lactoside (25 mg/kg). L, liver; B, bladder; K, kidney. (Applied Radiation and Isotopes 2020; 162: 109-199.)

Drug Design Concept and Imaging Specificity

Asialoglycoprotein receptor, ASGPR is liver specific and resides on hepatocyte surface membrane. It has functions of adsorption, metabolization and excretion to maintain the hemostasis of serum glycoprotein. It is well known that all natural asialoglycoproteins have several galactose termini. Therefore, a hexa-lactopeptide is designed to conjugate with a chelator for Gallium-68 labeling. The Gallium-68 hexa-lactoside can be used as an imaging predictor for functional mass of liver. The liver-targeting characteristic comes from hexa-lactoside. Either In-111, Ga-68, or F-18 labelling did not change its liver specific property. The animal imaging results indicated F-18 labeled hexa-lactoside has highly liver-targeting characteristic (Fig. 4).

Innovation Awards

Dolacga won the 10th National Innovation Award in 2013 and won the Excelsior Award in 2019 and 2020 due to the continuous innovation and development process. Dolacga is the first glycopeptide for evaluation of liver reserve in the world. INER has obtained the patents of "Hexa-Lactoside-Triazanonane Triacetic acid (NOTA) Derivative, Method for Radiolabelling Hexa-Lactoside Positron Emission Tomography" in countries of Taiwan, Japan and USA. INER won 2020 National Invention and Creation Award-Silver Medal Award from Ministry of Economic Affairs by the patent "Hexa-Lactoside-Triazanonane Triacetic acid (NOTA) Derivative, Method for Radiolabelling Hexa-Lactoside Positron Emission Tomography". The winning rate is only 7.4% that is the lowest over the years. INER will present the invention at 2021 Taiwan Innotech Expo to show these innovatiion achievements.

Fig. 5. Innovation Patents and Awards

Future development and expectations

We have applied the US phase II clinical study for evaluation of the safety and efficacy of Dolacage among the scheduled operation patients. The clinical trials will be performed in 2021-2022 to confirm the diagnostic value of Dolacga and to clearly define its indication for clinical usage.

3-3-2 The terminator of hypoxic colorectal cancer-a multifunctional nuclear medicine diagnosis and treatment agent

The number of occurrences and deaths of colorectal cancer (CRC) worldwide is increasing year by year. It predicts that it will increase by 13-15% in 2035 (Fig. 1). Twenty-five percent of newly diagnosed CRC cases are in the terminal stage. The remaining 50% of cases will eventually develop distant organ metastases. Even if the treatment technology continues to improve, the mortality rate is still rising. At present, patients with terminal colorectal cancer are treated with surgery combined with chemotherapy or radiation therapy. The tumor's hypoxic characteristics (Fig. 2) contribute to chemotherapy or radiation therapy resistance, resulting in a poor prognosis of surgery, with a five-year survival rate of about 10%. Therefore, it is necessary to develop new therapeutic drugs to assist surgical treatment in prolonging patients' life and quality of life with late-stage colorectal cancer. Traditional radiotherapy is invasive and can only treat the rectal area, not the colon area. Besides, patients often feel uncomfortable in the course of treatment. Therefore, the Institute of Nuclear Research developed dual-target tumor hypoxia therapeutic agents, enabling the drug to reach the hypoxic site of colorectal cancer tumors quickly and accurately through intravenous injection. The radiopharmaceutical also provides imaging data to physicians for efficacy evaluation.

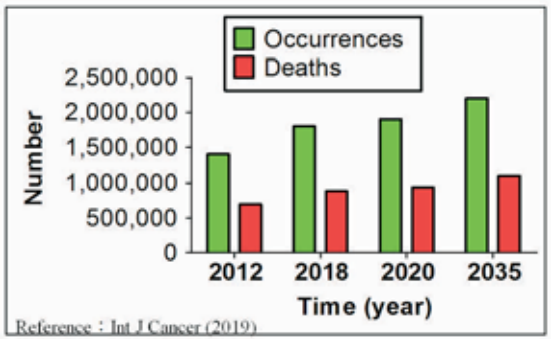


Fig.1. The global number of occurrences and deaths of CRC

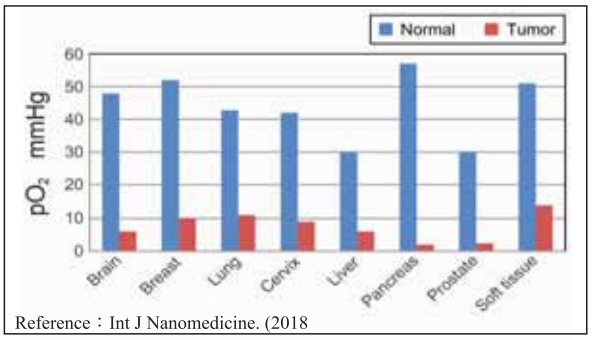


Fig.2. The oxygen levels between tumor tissue and normal tissue

Most target drugs use antibodies, peptide fragments, or small molecule inhibitors as probes to carry the drugs to the tumor site for treatment. This study's drug is peptide-based, which has a faster blood clearance rate than antibodies and can effectively reduce side effects. The protein of carbonic anhydrase IX (CA9) overexpressed in hypoxic tumor sites as a best tumor hypoxia biomarker. The dual CA9-targeted probe is developed, composing of CA9-targeted peptides and acetazolamide (AAZ). AAZ is a CA9 inhibitor with a high affinity for CA9. It has been clinically used as a treatment for high altitude disease or glaucoma. Finally, the dual CA9-targeted probe is labeled with a radioactive isotope (Lutetium-177) to become a tumor hypoxic treatment agent (^{177}Lu-DOTA-CA9-AAZ) (Fig. 3). This multi-targeted drug can improve the affinity for target locations (such as hypoxic locations) more than single-targeting (Fig. 4).

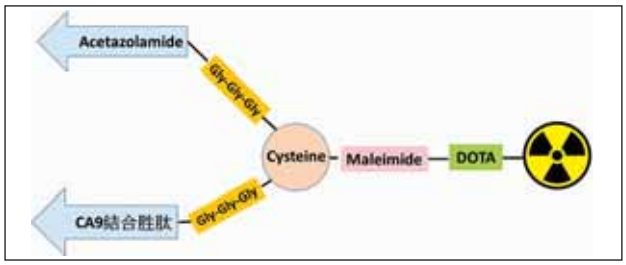


Fig.3. The structure of dual-targeted tumor hypoxic therapeutic agent

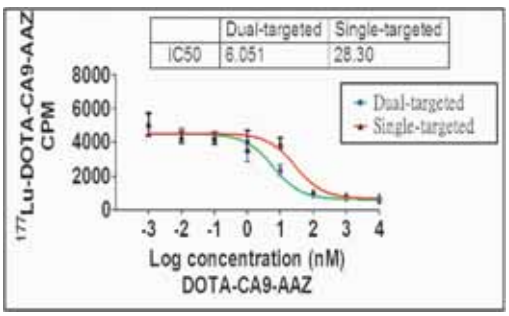


Fig.4. Drug competitive binding assay

The results showed that the dual-targeted tumor hypoxic therapeutic agent (^{111}In-DOTA-CA9-AAZ) is highly stable in serum and still has a radiopurity of more than 90% after 144 hours (Fig. 5). The tumor hypoxic animal model confirmed that ^{177}Lu-DOTA-CA9-AAZ significantly accumulated at the tumor site for 72 hours (Fig. 6). After a single dose of drug treatment, animals' tumor growth was significantly inhibited (Fig. 7). Life span prolongs by about 1.3 times (Fig. 8), and there was no significant change in animal body weight (Fig. 9). The above results indicate that the low-toxicity drug enhances the therapeutic ability and improves the side effects.

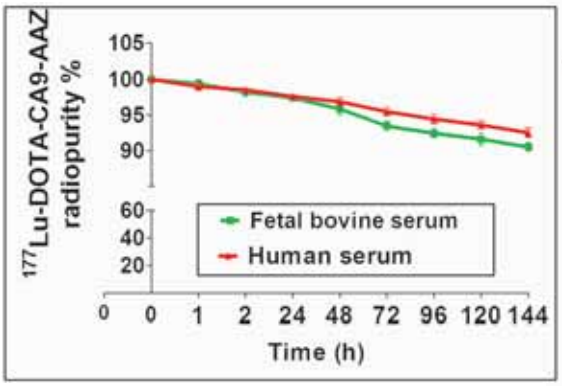


Fig. 5. Drug stability assay

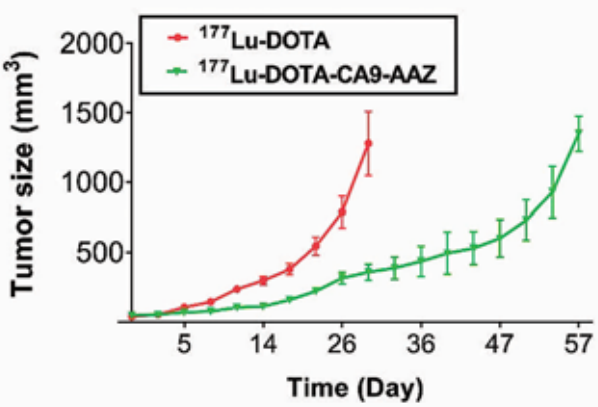


Fig. 7. Drug for CRC tumor therapy

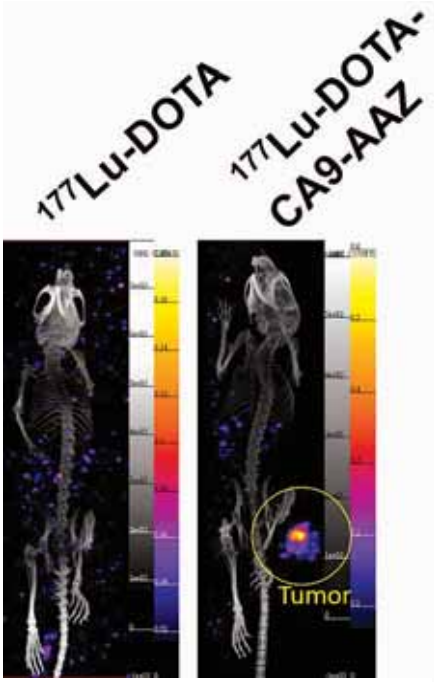


Fig. 6. NanoSPECT/CT detection

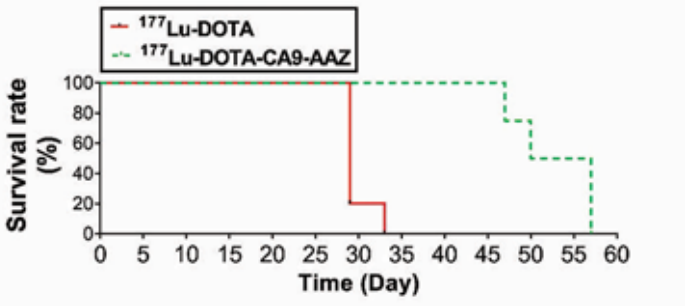


Fig. 8. Survival rate of drug-treated CRC animals

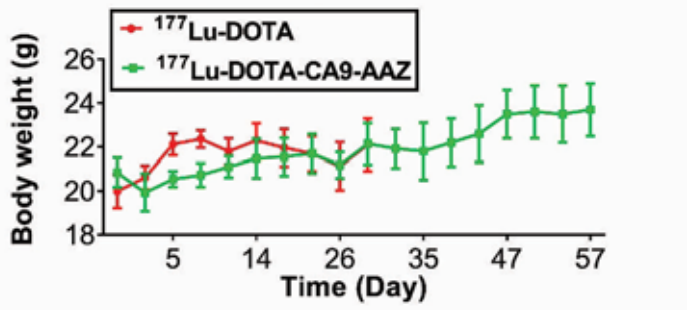


Fig. 9. Body weighto f drug-treated CRC animals

The above results confirmed that the novel dual-targeted tumor hypoxic therapeutic agent developed by the Institute of Nuclear Research Institute has the potential for clinical application. In addition to colorectal cancer, the drug can also apply to the treatment of various tumor hypoxic sites. In the future, a pre-clinical assay of drugs, including pharmacokinetic tests and animal toxicity tests, will be conducted to provide information for human clinical trials. We hope that the radiopharmaceutical drug can completely cure late-stage colorectal cancer after cooperating with surgical treatment.

3-3-3

The academic clinical trial results of Taiwan TomoDR used in the diagnosis of vertebral compression fractures

Institute of Nuclear Energy Research (INER) has spent more than 40 years on doing R&D of radiation application that upgrades the quality of healthcare. INER has successfully developed a low-dose 3D X-ray imaging system (Taiwan TomoDR, as shown in Figure 1) that produces 3D sectional information and eliminates tissue overlap problem using digital tomosynthesis (DT) at much lower radiation dose than computed tomography (CT) scans.

In order to verify the function of TomoDR, INER collaborated with teaching hospitals to apply for academic clinical trials. The vertebral compression fractures (VCFs) of the elderly were chosen as the topic. The results of clinical trials showed that the performance of TomoDR was significantly better than that of two-dimensional X-ray machines. It showed the spine anatomy in detail, and has the potential to be a powerful tool for assisting compression fracture diagnosis, surgical evaluation, and follow-up.

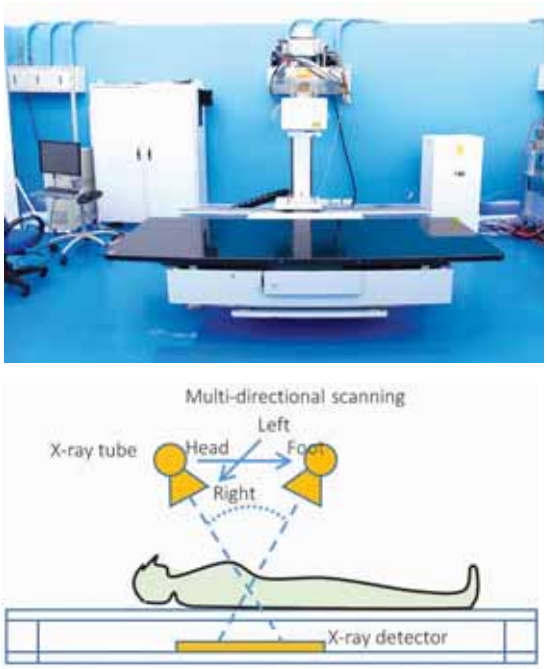


Fig.1. Low dose 3D imaging system - Taiwan TomoDR

DT is one of the important technologies of radiology imaging. In addition to DT, INER used self-developed new technologies to apply to the TomoDR (Figure 2): (1) Multi-directional scanning - Scanning can be performed in various directions, such as head-to-foot, left-right directions, etc.; (2) Retractable bed Design - In addition to lying radiography mode, standing scanning mode can also be realized; (3) A number of innovative 3D rapid image reconstruction technologies developed by INER provide the good image quality, while reducing the radiation dose received by the patient, and shortening the overall imaging process time. TomoDR also won the 16th National Innovation Award (Figure 3).

Fig. 2. Patents obtained of TomoDR

Fig. 3. The 16th National Innovation Award Ceremony

INER collaborated with the of National Taiwan University Hospital, Hsinchu Branch to conduct academic clinical trials. The results of clinical trials showed that the TomoDR can give more information in the images of patients with osteoporosis, and greatly reduce the blurring of the thoracic spine influenced by other soft tissues around it. Therefore, the edge of the thoracic spine is clearly discernible (Figure 4, left). For the more complex three-dimensional structure of the spine, such as the pedicle and facet joint, which can be clearly displayed by switching to the appropriate slice of TomoDR images, the planar X-ray image is susceptible to the overlap of surrounding tissues. In addition, the compression fracture of the thoracic and lumbar spine at the diaphragm position can also be clearly seen in TomoDR images (Figure 4, right).

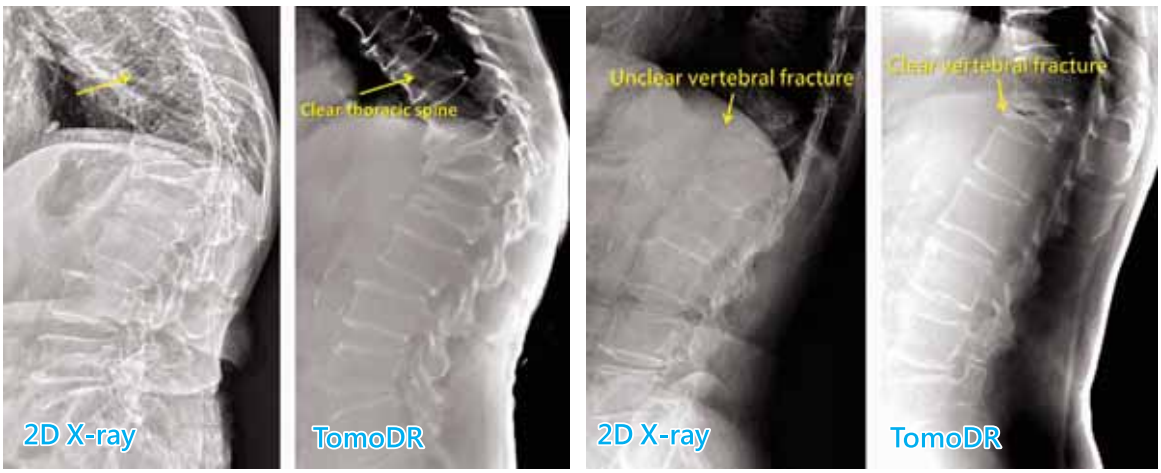


Fig.4. Comparison of spine image quality between Taiwan TomoDR and planar X-ray images

In order to quantify the image quality, visual grading characteristics analysis (VGA) was used to compare planar X-ray and TomoDR tomosynthesis spine images. After the TomoDR and the planar X-ray images of the academic clinical trial were scored by three physicians, the visual grading characteristics (VGC) curve and the area under the curve (AUC_{VGC}) were calculated as a measure of difference of image quality between the two devices. AUC_{VGC} equal to 0.5 means that the two devices have the same quality. If AUC_{VGC} is greater than 0.5, it means that TomDR is better than planar X-ray. The closer the value is to 1, the greater the degree of difference. The analysis results show that the AUC_{VGC} values of each part of the spine are far greater than 0.5(Figure 5). Therefore, according to the VGA, the image quality of TomoDR is much better than that of planar X-ray.

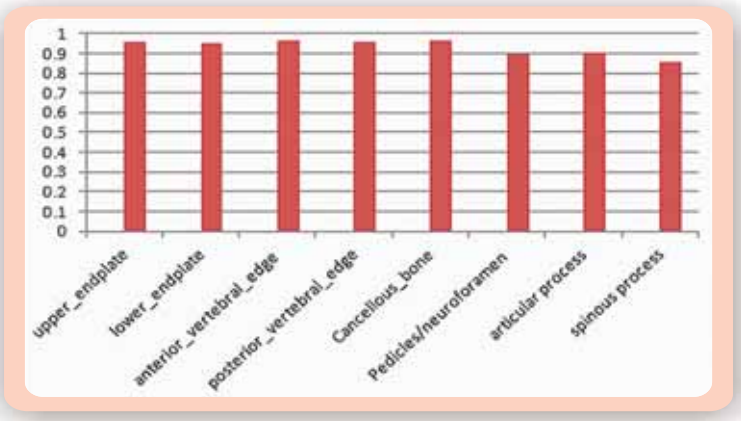


Fig. 5. AUC_{VGC} values of the spine

Based on the results of the clinical trial, bone fractures that are not visible in the planar X-ray images can be seen clearly in the TomoDR images, and for patients with osteoporosis, the thoracic spine that is unclear in planar X-ray images becomes clear in TomoDR images. Using VGA for quantitative statistical analysis, the TomoDR image is compared with the image of the planar X-ray machine. The image quality of TomoDR is significantly better than that of planar X-ray, which shows that TomoDR can help orthopedists diagnose VCFs. The academic clinical trial results can strengthen clinicians' confidence in the quality of domestic medical devices, and is helpful to promote the effectiveness of TomoDR's clinical application.

3-3-4 Using deep learning 3D imaging models to discriminate Alzheimer's disease

Dementia is a major cause of disability and inability to live independently for the elderly and is an important social issue. According to statistics, about 8% of the dementia population in Taiwan is over the age of 65, and about 1 in 5 people over the age of 80 suffer from dementia, as shown in Fig.1, of which Alzheimer's disease is the type that accounts for the highest percentage. In clinical neuroimaging, magnetic resonance imaging and single-photon computed tomography are powerful tools for the diagnosis of Alzheimer's disease.

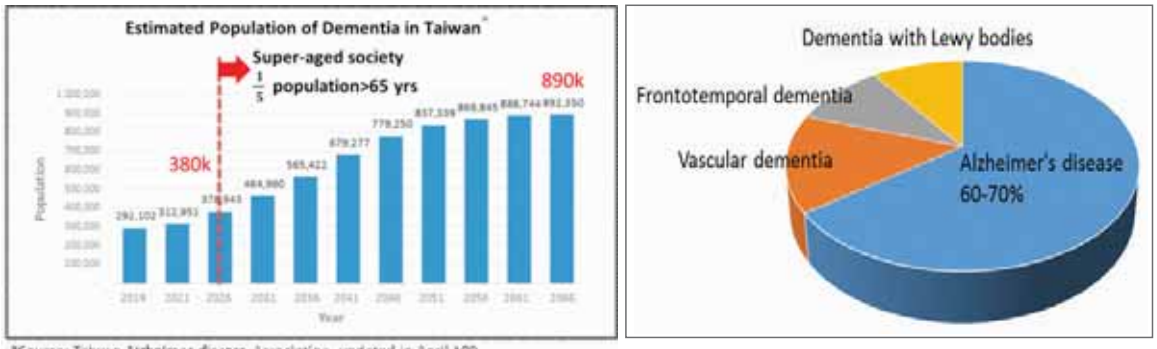


Fig.1. Demographic and clinical proportions of dementia

The Institute of Nuclear Energy Research (INER) is dedicated to the development of nuclear medicine and image technology and has established software for the display and analysis of abnormal cerebral blood flow, as shown in Fig.2. It can assist the interpretation of Tc-99m-ECD single photon computed tomography images.

In this study, the deep learning technology of artificial intelligence provides inferential results of disease classification and improves the performance of medical image-assisted software.

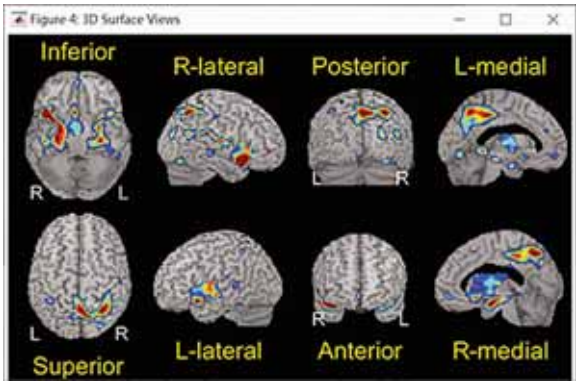


Fig.2. Abnormal cerebral blood flow display and analysis software

Deep learning models are very powerful tools when sufficient data is available. It can learn image features and textures directly from the data and build pre-trained model from external databases. The pre-trained models can be used to transfer image texture experience to Tc-99m-ECD single-photon computed tomography image by transfer learning.

INER uses an image public database called ADNI (Alzheimer's Disease Neuroimaging Initiative) to develop a three-dimensional convolutional neural network model algorithm for nuclear medicine. Model training and validation using a standard training process (shown in Fig.3) with 2,000 ^{18}F-FDG PET images.

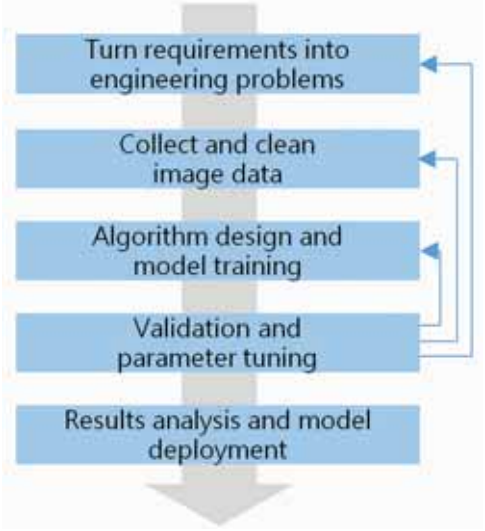


Fig.3. Deep learning model training process

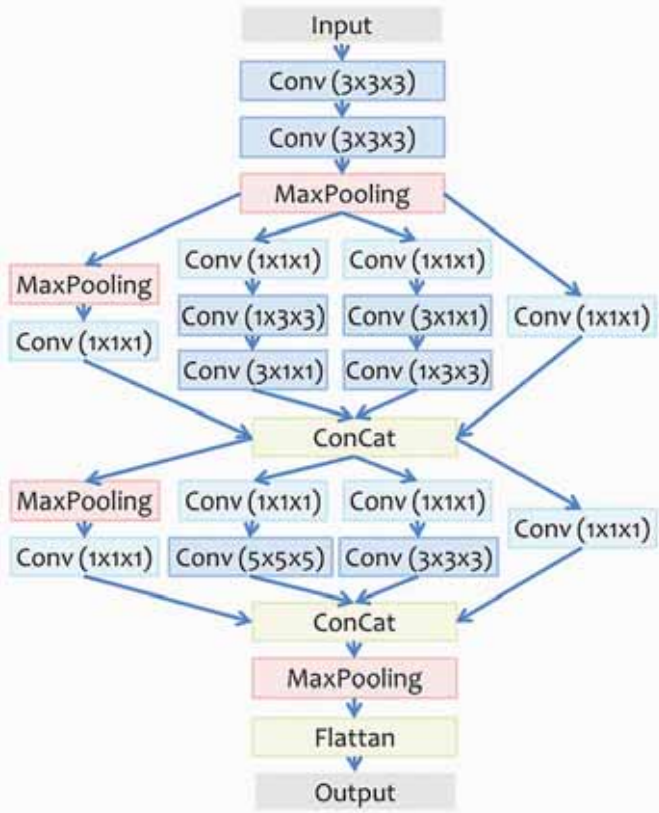


Fig.4. 3D convolutional neural network model design

In our implementation, the convolutional neural network model designed is shown in Fig.4. The first block uses the traditional method for the extraction of low-level features. The second block and the third block correspond to middle-level features and high-level features. Both are used with 1x1x1 convolutional layers for dimensionality reduction on the channel.

Considering that the property of nuclear medicine instruments on the Z-axis is different from the X-Y axis, middle-level features use 1x3x3 and 3x1x1 convolutional layer to design the separable convolution. High-level features still use a 5x5x5 convolutional layer to see the macro view.

This algorithm design can fully consider the spatial information of the three-dimensional image and extract features of nuclear medicine. In the case of fewer images, the model can still be trained stably.

The performance of the three-dimensional convolutional neural network is evaluated by the ROC curve. The ^{18}F-FDG PET validation results of normal (class 0), Alzheimer's disease (class 1), and mild cognitive impairment (class 2) are shown in Fig.5. The sensitivity of Alzheimer's disease classification is 80.3%, the specificity is 93.3%, the accuracy is 85.5%, the accuracy is 89%, and the F1 score is 82.8%. It has achieved good results in distinguishing between normal and Alzheimer's disease.

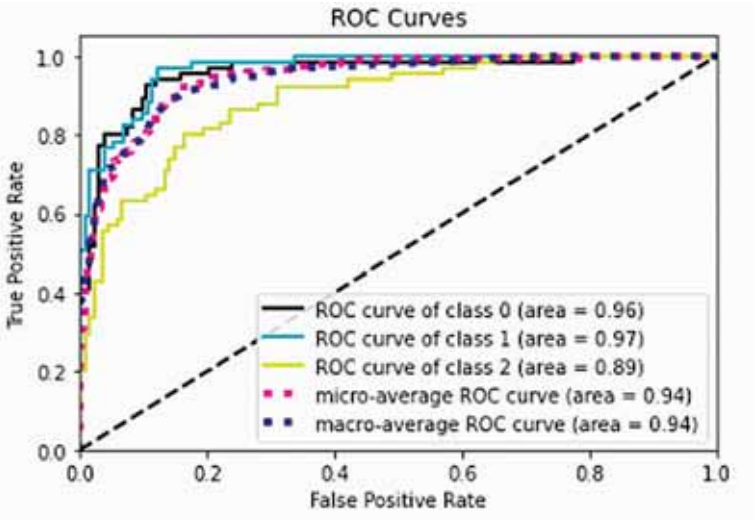
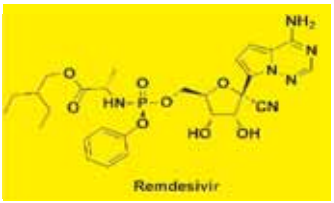


Fig.5. ROC curve: normal (class 0), Alzheimer's disease (class 1) and mild cognitive impairment (class 2)

In view of the high demand and cost of dementia care services, it is necessary to develop new technologies to enhance the primary prevention of dementia and to assist in accurate diagnosis. The three-dimensional image deep learning model developed by the INER can be transferred to clinical Tc-99m-ECD single photon tomography, which is expected to improve the accuracy of Alzheimer's disease diagnosis by nuclear imaging in Taiwan, and achieve the goal of early diagnosis, early treatment, care planning, and lifestyle changes of optimal living the goal of old age.

3-3-5

Applying AI optimization process in synthesize Remdesivir: a robust support for the nation's epidemic prevention



COVID-19 is a disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). As to the end in 2020, more than 68.25 million cases have been confirmed and approximately 1.55 million people have died of COVID-19 in 191 countries and territories around the world. Remdesivir is a new experimental antiviral drug developed by Gilead Sciences Inc. in the United States and is considered the most ideal treatment for patients with severe COVID-19.

The INER has been engaged in the research and development of nuclear medicine for many years. Over the years, it has developed and received 17 drug permit licenses for diagnostic or therapeutic nuclear medicine, and in recent years it has also invested in research on the application of artificial intelligence (AI) to drug synthesis. Due to the lack of raw materials of Remdesivir, the commonly used starting materials cannot be obtained. The research team then resorted to using AI for chemical retrosynthesis to retrospectively dismantle and subsequently propose new steps for synthesis. The research team carried out processes for screening and performed judgments based on its robust experiences accumulated over the years, as well as conducting chemical validation, and successfully synthesized Remdesivir. Using optimized selective protection and deprotection strategies and starting from a simple raw material, D-Ribose, Remdesivir can be synthesized in only eight steps, which are two steps fewer than the original process, with a higher overall yield.

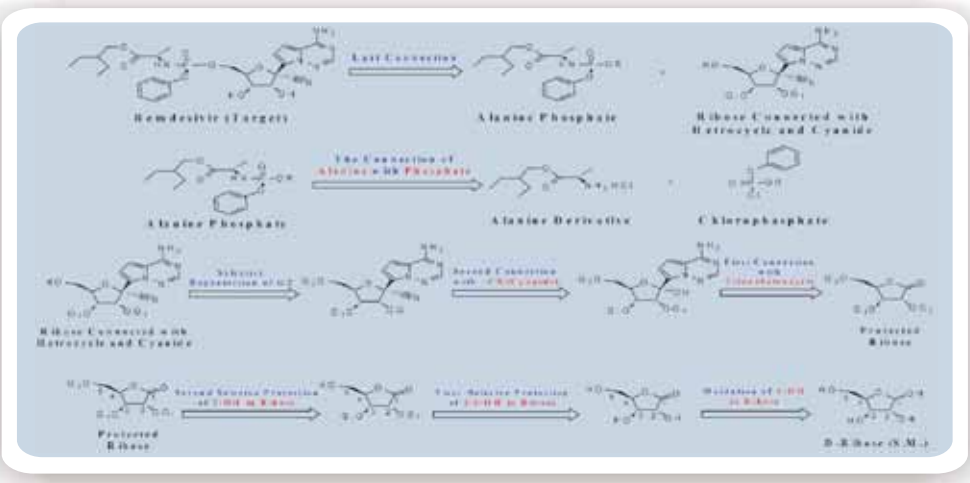


Fig. 1. AI Applied to the Chemical Retrosynthesis Plan for Remdesivir

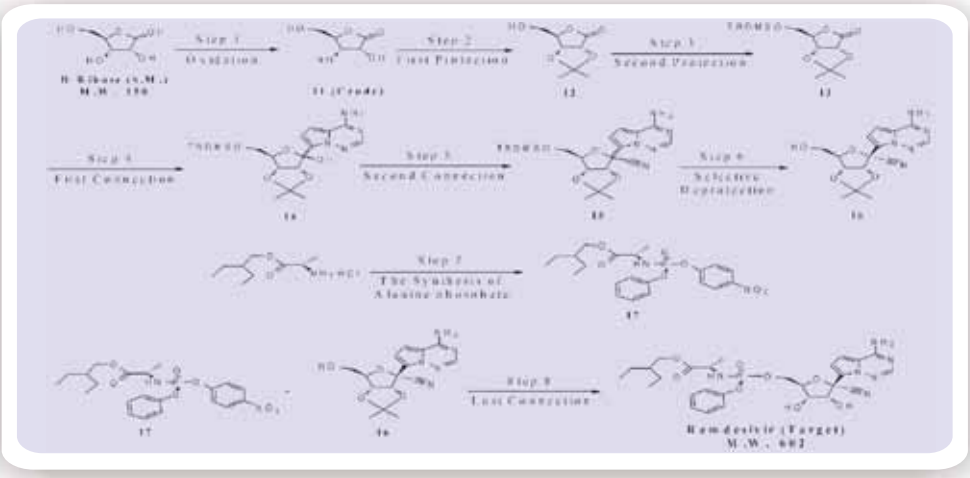


Fig. 2. The INER Synthetic Process for Remdesivir (eight steps in total)

In implementing the innovation process, the INER also tried to construct optimal reaction conditions for each step which may be favorable to scale up production, and to develop standard operating procedures (SOPs). In addition, the intermediate and final products of each synthesis step also underwent various molecular structure identification. For example, a nuclear magnetic resonance (NMR) spectrometer was used to identify the surrounding molecular and skeletal structures of the products; Fourier transform infrared (FTIR) spectrometer to analyze the polar functional groups of the products; mass spectrometer (MS) to confirm molecular weight. These efforts were made to ensure the correctness of each intermediate product and the final pharmaceutical product, as well as to comply with the essence of chemistry, manufacturing and controls (CMC) for pharmaceutical research and development in realizing the possibility of drug commercialization.

After two months of research and development, the INER successfully synthesized two batches of Remdesivir. Data collected from ^{1}H- and ^{13}C-NMR spectrometer, FTIR spectrometer, and mass spectrometer were confirmed to perfectly match data from the extant literature. Demonstrate the research team's ability to apply AI in drug synthesis.

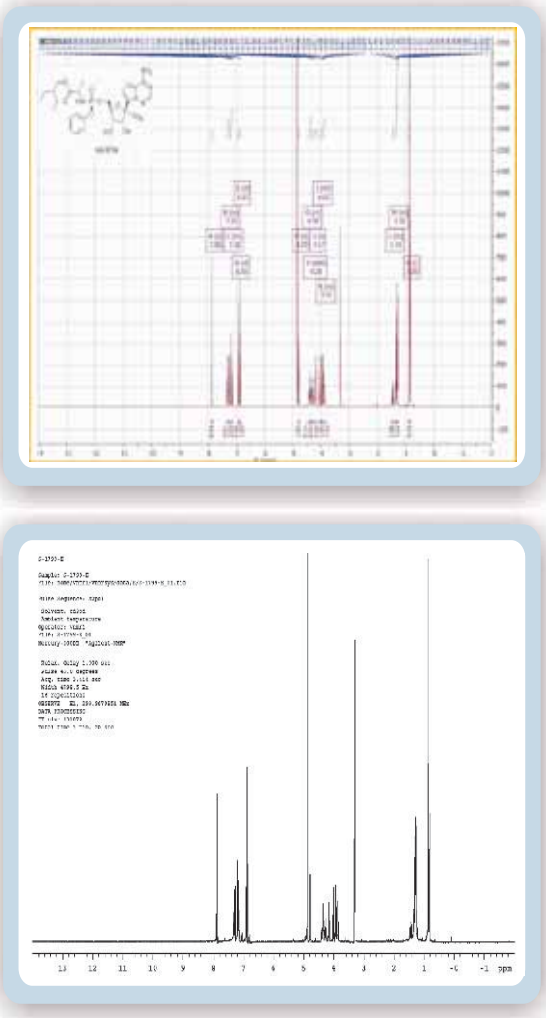


Fig. 3. The ^{1}H-NMR Spectra of the Remdesivi literature (top) and INER (bottom), which are consistent with each other.

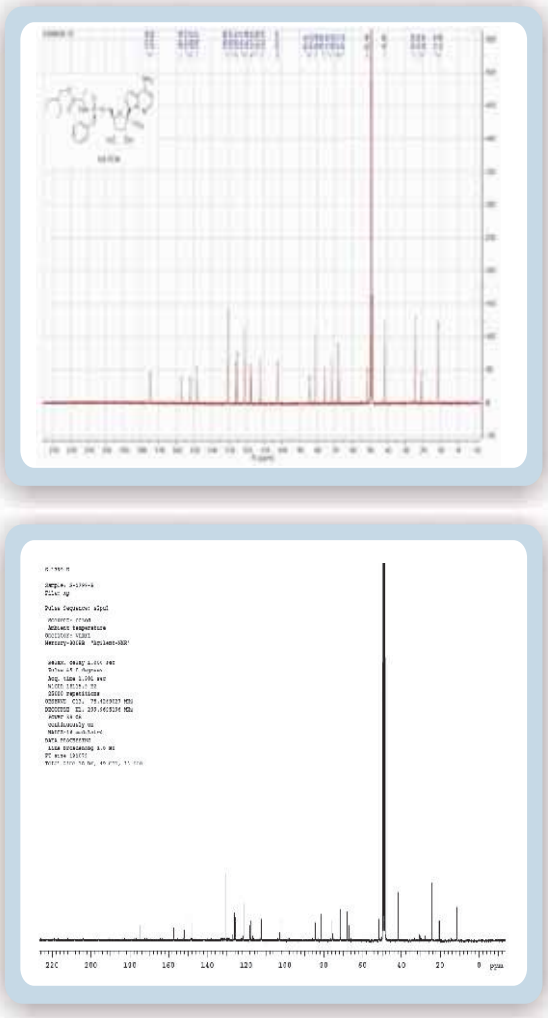
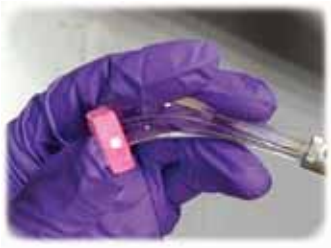


Fig. 4. The ^{13}C-NMR Spectra of the Remdesivi literature (top) and INER (bottom), which are consistent with each other.

The INER's innovative process, with simpler and more concise reaction steps, differs from that of the previous literature. In response to the increasing threat of the second wave of the pandemic, the INER will submit a patent application for the process and propose cross-licensing with the proprietary patent to facilitate technology transfer to domestic pharmaceutical production, so as to contribute to the nation's epidemic prevention efforts, and even start innovative research in the development of other drugs.

3-3-6 Optical pressure sensing technology for devices of leg rehabilitation



The project is devoted to developing intelligent rehabilitation devices for the coming issues on increasing elderly populations and declining labor forces. The specific works include the developments of the AI diagnosis and the optical-based pressure sensing technologies, by means of derivative photoelectric designs. The project goals are set on the work assistance for the rehabilitation personnel, the resolution of the difficulties in the insufficient rehabilitation manpower, and the enhancement of effectiveness of rehabilitation.

The development of optical tactile sensors can be extended to the field of medical technology. The Institute of Nuclear Energy Research (INER) designs add-on appliances to conventional rehabilitation equipment for supplementary functionalities, e.g. the sensing of muscle force and the joint angle. By analyzing the sensing/collecting information, INER further capacitates the device with AI-diagnosis functionalities, and enables the recording and data-delivering functions to medical personnel for high-quality medical services.

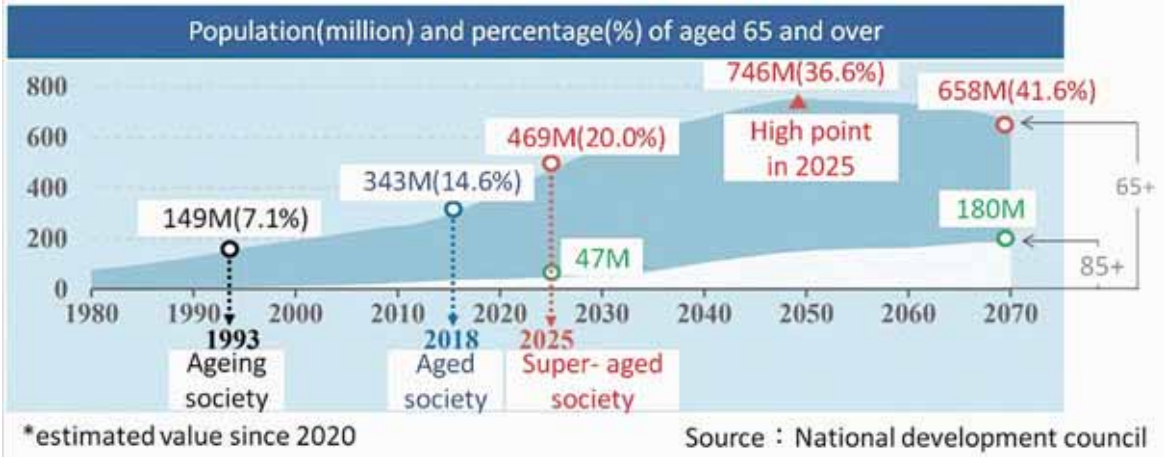


Fig. 1. Trend chart of the proportion of the elderly population

Optical pressure sensor

On the basis of silicone-waveguide, INER develops optical pressure sensors. This sensor works on the fact that reduction of the cross-sectional area of the squeezed waveguide causes the decrease of the light energy transferred to the photoresistor. Experimental tests show that the linear correlation coefficient between the signal (resistance value) and the applied pressure reaches 0.95. It demonstrates that the developed sensor can provide good pressure sensing characteristics.

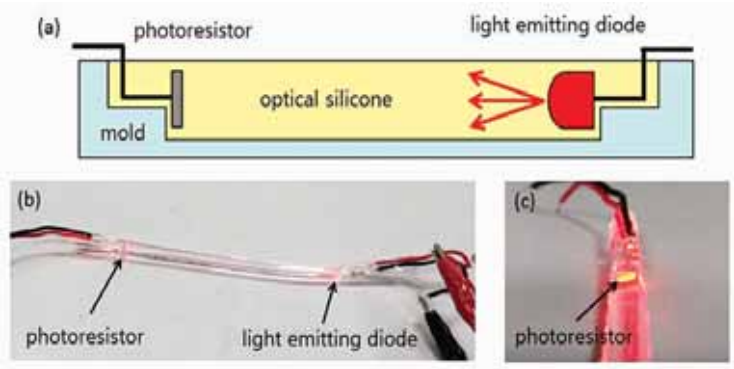


Fig. 2. Integrated elastic waveguide. (a) schematic of waveguide ; (b)picture of waveguide ; (c) light energy transferred to the photoresistor.

Compared with electrical pressure sensors, the optical sensors exhibit excellent stretchability and flexibility, and are more in line with the requirements for sensing human body. The patent applications associated with this technology have been filed.

Fig.3. Elastic waveguide integrated with elbow pads

Joint-angle measurement technology

The developed elastic waveguide is integrated with commercially-available elbow pads. The bending degree of the joint can be determined via the quantitative relation between the resistance of the photoresistor and the waveguide length. The technology is also applied to the assessment of knee flexion, providing necessary reference information for medical personnel.

Leg rehabilitation and pressure measurement platform

Considering the absence of perception functions in commercial rehabilitation equipment, INER develops an advanced leg rehabilitation platform. Besides the essential rehabilitation and fitness function, the platform equips perception functionality, allowing the quantification of the sensing data. The patient hence can recognize the real-time rehabilitation situation about legs, and encourages oneself for further rehabilitation treatments during rehabilitation processes. The data with analysis can regarded as criteria for the assessment of rehabilitation effectiveness. The significant features of this platform are as follows：

- Provide measurement and data analysis for physiological information.
- Provide functional testing and verifications of analytical methods for rehabilitation equipment.
- Provide real-time pressure sensing of legs, and enable tunable resistances of the equipment pedals. The sensing data after analysis can help assessment of leg rehabilitation.

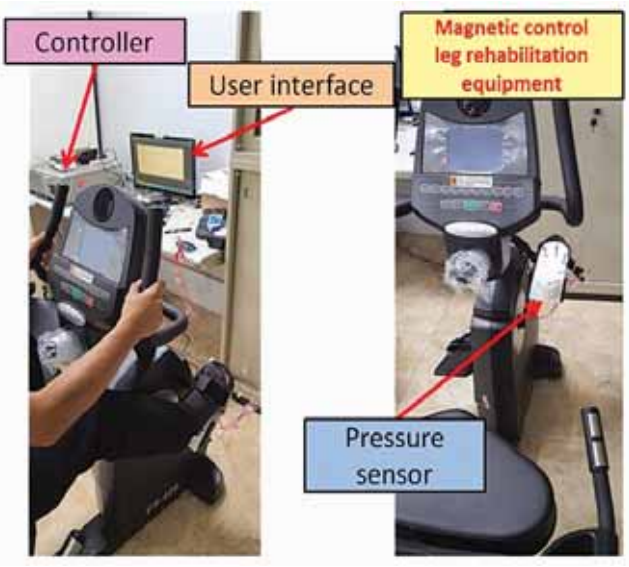


Fig.4. Leg rehabilitation and pressure measurement platform

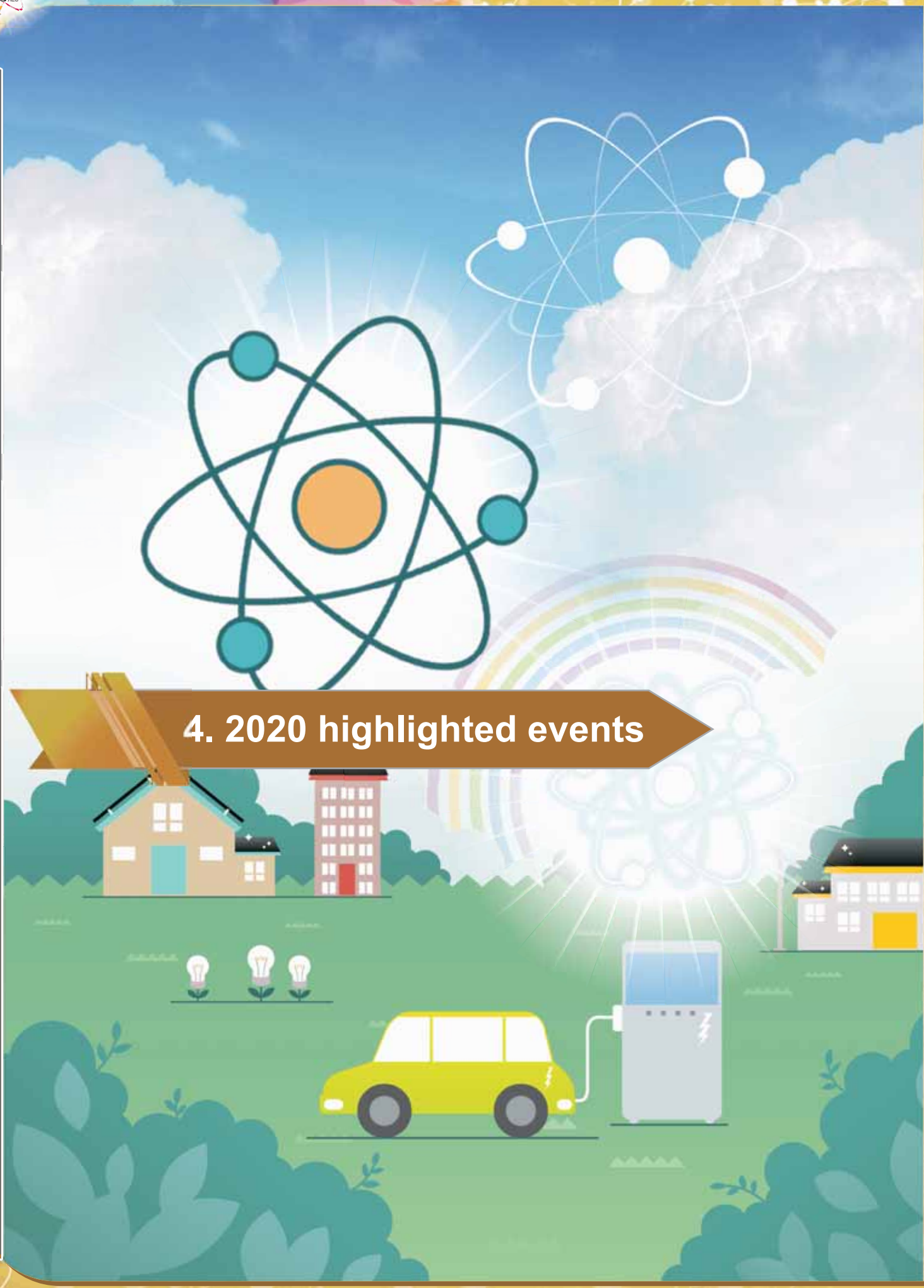
Fig.5. Screen shot of platform

Source：Renren Medical Instruments Ltd.

Fig.6. Happy Life Smarc

Conclusion and outlook

INER developed the optical pressure sensing technology and the Leg rehabilitation & pressure measurement platform this year. In the future, our group will establish the technology of fiber Bragg grating to improve capabilities of spatial resolution of optical pressure sensors. By the available sensing database, our group also plan to cooperated with medical equipment companies for developing of the value-added intelligent rehabilitation device.



4. 2020 highlighted events

4-1 2020 highlighted events

1. ***2020.03.26-04.27*** Two batches of "cellulosic ethanol" developed by INER, totaling 700 liters of 75% alcohol, were put into Taiwan's national team for COVID-19 prevention.

2. ***2020.04.18-11.30*** In response to the shortage of imported nuclear medicines during the pandemic, INER launched an emergency production of nuclear medicines: "Thallous Chloride (Tl-201) Injection" and "Gallium Citrate (Ga-67) Injection", which were used in imaging procedures for 25,700 patients.

3. ***2020.06.04-05*** INER organized an annual training course for the Radiation Emergency Response Technical Team, with participation by 40 persons from the AEC, the RMC, and the INER.

4. ***2020.06.12*** INER successfully synthesized remdesivir by applying the latest AI technology on chemical retrosynthesis to optimize synthesis steps.

5. ***2020.07.02*** Two inspectors from IAEA conducted design information verification (DIV) of the Zero Power Reactor (TWK-) at INER to ensure that the reactor is housed in a containment structure. No anomalies were found during the verification.

6. ***2020.07.23*** INER has actively participated in the "Taiwan Space Radiation Environment Verification & Testing Alliance." A memorandum of cooperation was signed by seven participating units at the National Space Organization of the National Applied Research Laboratories, which is a major step toward refining the testing capabilities of Taiwan's space environment.

7. ***2020.08.06*** INER carried out the "Regional Power (Distribution) Grid Enhanced Resiliency Research and Development" of the MOST, and was recognized as a 2020 MOST "Highlight Program." The program team subsequently received an interview by CommonWealth Magazine.

8. ***2020.08.19*** Era TV conducted an interview with Director-General of INER and filmed the R&D outcome of a microgrid on site. A special program on the R&D outcome of the "Microgrid and Localized Power Distribution Management System" was broadcasted on Era Much TV's "Discovering New Taiwan" program.

9. **2020.09.01** Marek Ruščák, division head of the National Radiation Protection Institute (NRPI) of the Czech Republic, visited INER with a delegation led by the president of the Czech Senate to discuss cooperation and exchange matters relating to atomic energy.

10. **2020.09.03** INER and National Cheng Kung University jointly conducted the "Key Technological Development of a Typhoon-Resistant Floating Wind Turbine and Real-Sea Verification Program"; it was recognized as a 2020 MOST "Highlight Program." The program team subsequently received an interview by CommonWealth Magazine.

11. **2020.09.11** INER successfully conducted a "Full Participation Exercise at the Northern Radiation Monitoring Center as part of the 2020 Nuclear Emergency Exercise (No. 26)."

12. **2020.09.22** INER's vanadium flow battery, presented at the "2020 Flow Battery Key Materials and Energy Storage Applications Conference", can be used in combination with renewable energy for grid integration.

13. **2020.09.24-26** INER participated in the 2020 Taiwan Innotech Expo, having exhibitions in all three themed areas. It also submitted 15 technologies in the competition and won eight awards (two platinum medal awards, three gold medal awards, one silver medal award, and two bronze medal award), for its best performance in four years.

14. **2020.10.06-08 10.12-14** IAEA inspectors conducted an inspection on the nuclear fuel contents of INER TRR-II cask, which went smoothly.

15. **2020.10.21** INER hosted the "2020 Nuclear Facility Decommissioning Technology Conference", with participation by 120 experts and scholars in related fields from National Tsing-Hua University, Taipower, and engineering consulting firms.

16. **2020.11.02** INER's patented invention: "Hexamer Lactose NOTA Derivatives, Hexamer Lactose Positron Liver Receptor Contrast Agent Ga-68 Radiolabeled Method, and Hexamer Lactose Positron Liver Receptor Contrast Agent" won the silver medal of the "2020 National Invention and Creation Award" sponsored by the Ministry of Economic Affairs.

17. **2020.12.01** INER won three "2020 Renewal Awards" in the 17th National Innovation Award organized by the Research Center for Biotechnology and Medicine Policy, and received the awards at the Taipei Nangang Exhibition Center.

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