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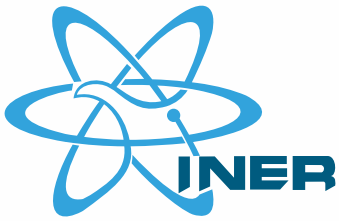
2016 Annual Report

Institute of Nuclear Energy Research

Automic Energy Council, Executive Yuan

Published in July, 2017

2016 Annual Report



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The advancing INER-

R&D for fostering the industries, we secure nuclear safety while striving for excellence in green energy

The Institute of Nuclear Energy Research (INER), established in 1968, is the sole government agency dedicated to research and development (R&D) on nuclear energy. Through transitions, INER has exploited the study of nuclear medicine and high-leveled medical instruments. In addition, based on the solid research foundation and systematic integration ability originated from the field of nuclear energy and radiation application, INER broadens itself to green energy related technologies and energy economic strategies. Now, INER is prominent in energy and nuclear medicine R&Ds, with impressive research achievements and many awards honored domestically and internationally.

Since 2002, we have devoted ourselves to the R&D works of new and renewable energy technologies. Years of hard work has yielded fruitful achievements in the fields of solar photovoltaics, wind power, biomass, smart grid and energy conservation. Currently, we are actively promoting these R&D achievements to industrial applications. In March and July 2016, Metal-supported SOFC Unit Production Technology and SOFC Stacks Technology, developed by INER, were respectively transferred to domestic enterprises in Taiwan, helping the industry in building up the integration capacity of producing SOFC units into stacks. The aims of transference are to form the industry chain further and to build business relationships worldwide. Moreover, in November 2016, Bio-refinery process technology, developed by INER, was transferred to a domestic enterprise, which was planning to construct a cellulosic alcohol full process plant in Chianan Plain with our collaboration. The plant was expected to utilize Pennisetum as its ingredient, and to yield three tons of xylooligosaccharide and 3000 litres of high concentration alcohol per day. By this model, the program is going to make Taiwan the demonstration area in Asia-Pacific for bio-energy technology, and to enhance localization of bio-energy related

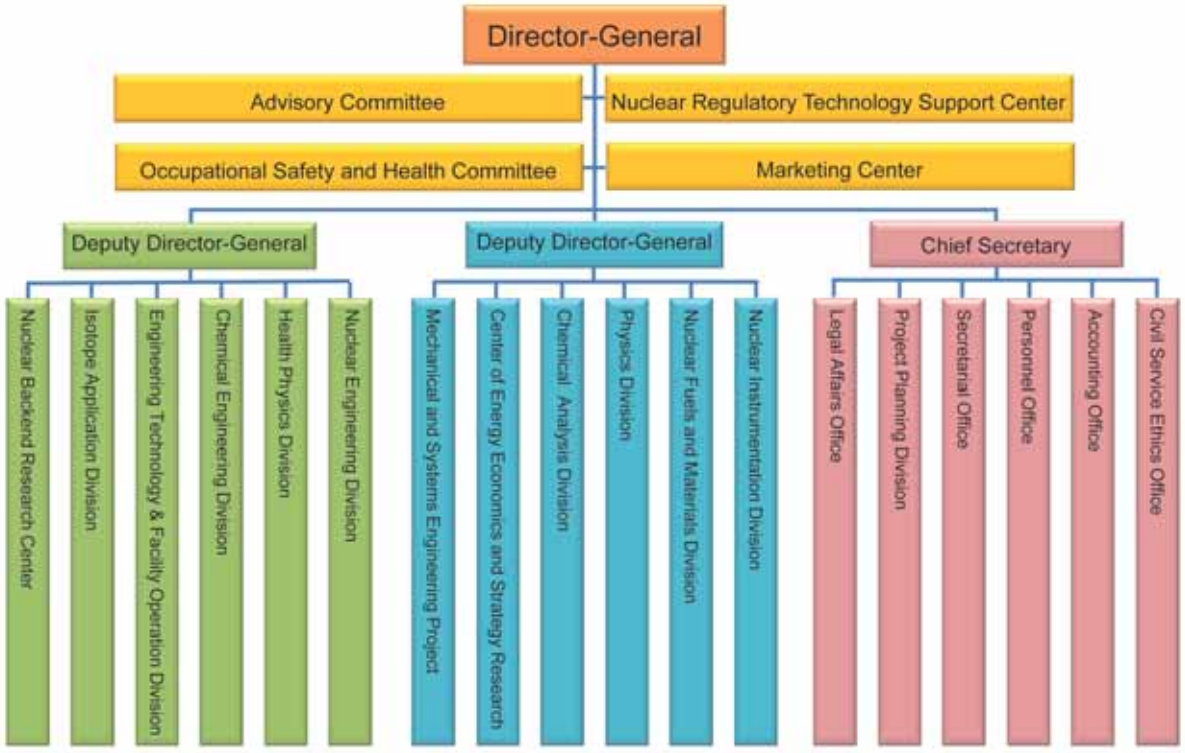
start-ups.

Indeed, in order to promote our R&D results, we have actively participated in international invention and technology trade shows. In September 2016, we won a total of 20 awards in the 2016 Taipei International Invention Show and Technomart, including one highest-honor platinum medal, seven gold medals, four silver medals, and eight bronze medals. Furthermore, INER was awarded two gold medal awards at the 2016 Germany Nürnberg International Trade Fair (IENA). Additionally, there were two technologies winning the National Innovation Awards, and an INER research team devoted in plasma coating energy-saving film R&D won 2016 Civil Service Outstanding Contribution Award.

Besides nuclear safety and green energy, we, INER, are devoted ourselves to R&Ds of nuclear medicine and high-leveled medical instruments. With 16 drug-license permits, two medical-instrument-license permits, and PIC/S GMP examination reassurance, INER is the only well-established government agency which legally produces and provides nuclear medicine services. Those high-quality radiopharmaceuticals provide diagnostic and therapeutic treatment for patients with Parkinson's disease, brain tumor, bone cancer, cardiovascular stenosis, and other tumors. More than 15,000 patients and 50 hospitals are benefited by our service annually.

Green energy technology is one of the five major governmental innovation R&D programs for technological industry. INER, as the only national agency integrating nuclear energy, nuclear backend, and green energy research, and with tremendous technological capacity and plenty of strategic experiences, is expected to become a comprehensive research agency in energy technology and strategy planning, and to achieve the mission of Nuclear-free Homeland with nuclear backend technologies. Today, we are diligently paving the way for the national nuclear safety, environmental protection, and civil health. Indeed, offering comprehensive strategies and technical solutions is our ultimate goal for which we continue to strive.

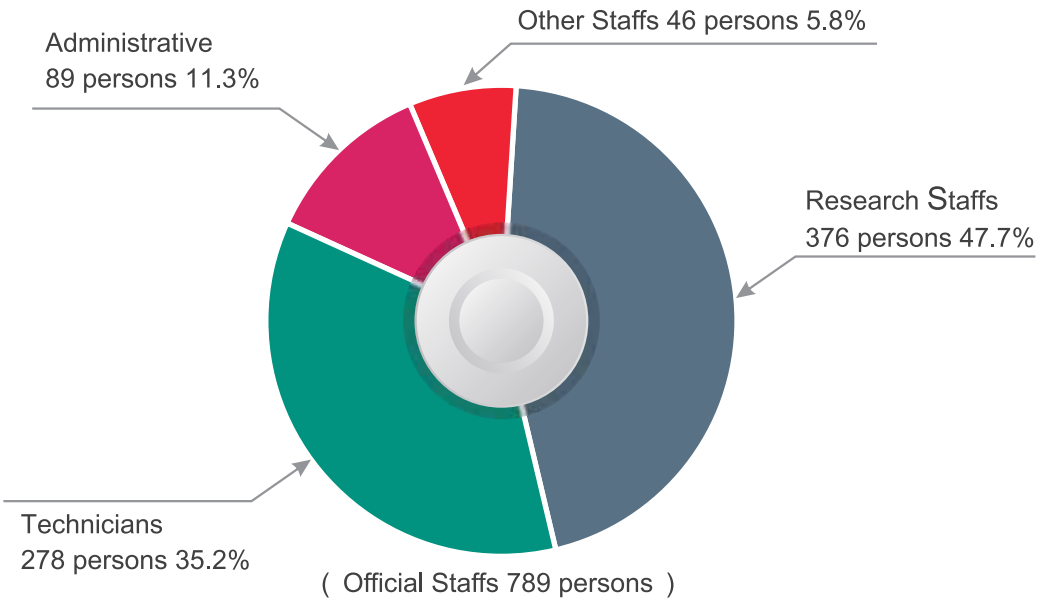
Organization Chart of INER



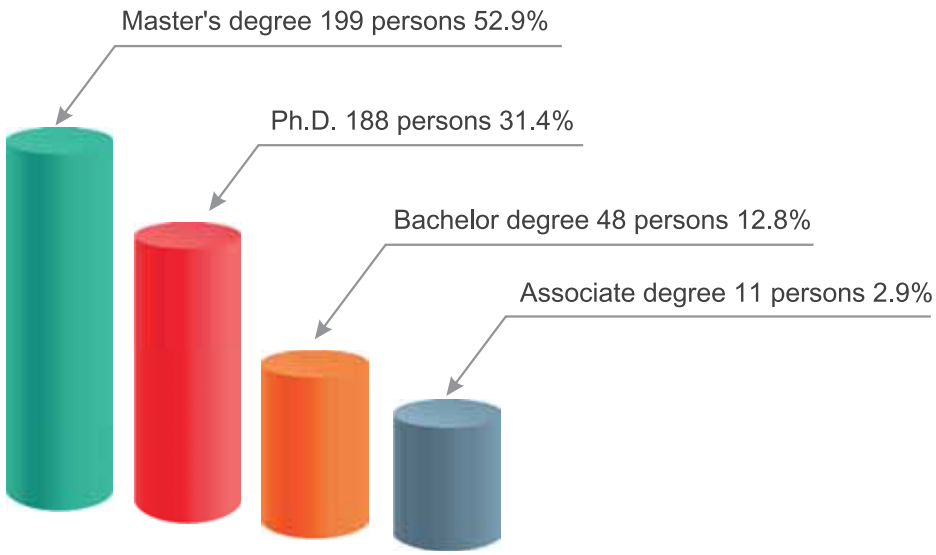
Human Resources and Badgets

■ (Time of data. December 2016)

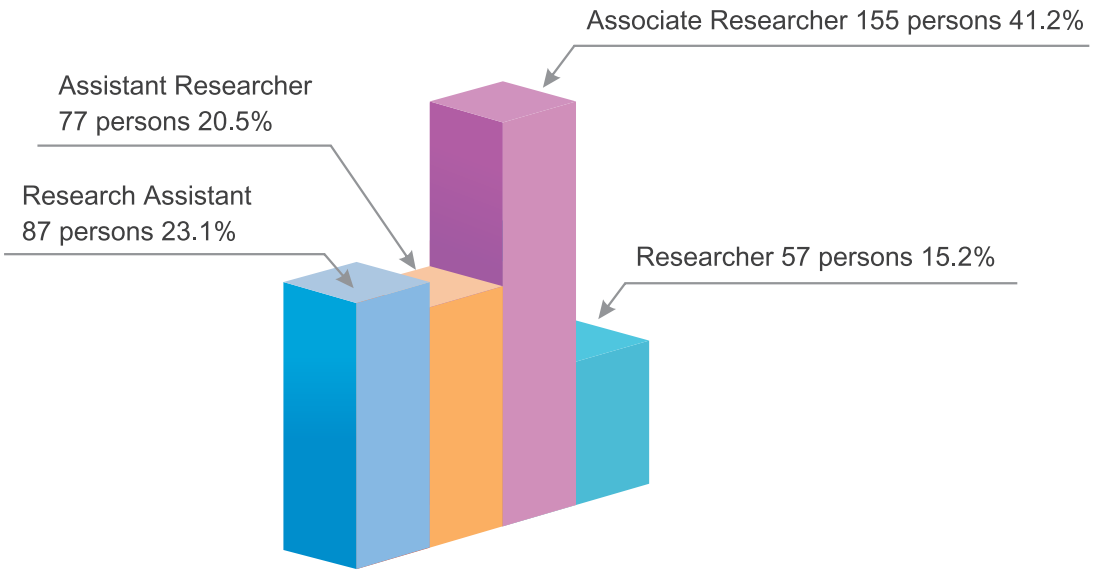
Manpower Distribution of INER



Statistics of Educational Background for Research Staffs



Statistics of Job Category for Organizational Research Staffs



2016 Annaal Budget

unit:Thousand NTD

Item	Number of Accounts	Percentage
Administration and Safety	1, 155, 953	54. 2%
Management, Operation and Maintenance	182, 874	8. 6%
R&D Projects	659, 748	30. 9%
Technology Promotion and Service	134, 791	6. 3%
Total	2, 133, 366	100. 00%

3 Current Major R&D Activities

Events of the Year

3-1 Research and Development of Radiation Applications

There are almost more than 40 years in the research and development of radiation applications in INER. Now the radiation applications have been deeply influence people's life, such as syringe radiation sterilization, spice radiation disinfection, foam material polymerization, weather resistant of cable insulator radiation, and the X-ray medical application. Recently, following the developing of science technologies like computer technology, molecular biology, semiconductor technology, new material development and environmental technology, cancer radiotherapy and nuclear medicine application have developed into a new generation, such as PET, SPECT combines with MRI, CT and with 3D tomographic technology. These develops can help doctor look inside the patient's sick foci clearly, and help doctor's micro surgery and precise therapy much easily. Radiation application in polymerization , crosslinking and grafting also produce a lot of new products for modern life, such as functional textile with wind resistant, moisture transferring and quick drying characters, and weather resistant automobile tire, and decoration material modification radiation. Now radiation application technology has become a very important item in people's living.

In nuclear medicine, INER has already developed and owned a mature value chain, including drugs discovery, optimization of lead compounds, preclinical study, clinical trials (IND), registration (NDA), PIC/S GMP manufacturing production facility (including raw materials and drugs), commercialization of products and technologies transfer etc. INER also has the experience in PET, micro CT and X-ray and CT. With the recent development of precise therapy and personalize medicine, INER chooses nuclear medicine and imaging technology as a priority research and developing items.

INER TRODAT-1 Kit was approved by Taiwan Department of Health in 2005. Over these years, INER TRODAT-1 Kit has reached the pharmaceutical industry PIC/S GMP level. INER has also broken the TRODAT-1 Kit synthesis bottlenecks to get 10 times more production yield than the original yield. In addition, INER TRODAT-1 Kit owns the spot light and internationally renowned by supplying to academic and medical field for research. It was license-out in 2016. We hope this drug will enter the highly competitive global biomedical market through industrial worldwide marketing channel.

In addition to the Rhenium-188 liposome, which is already in clinical trials phase 0 and phase 1 stage, there are two items on clinical trial applying and new drug approval from INER. They are, Rhenium-188-MN-16ET/Lipiodol injections, and INER iodine-123 MIBG injections. Especially INER iodine-123 MIBG is the best examples of a new use of an old drug. In recent years, iodine-123-MIBG used in diagnosis for the cardiac sympathetic nerve function is getting international attention. In 2015, we have obtained the registration trial wavier of iodine-123-MIBG on the diagnosis of neurogenic tumor and cardiac sympathetic nerve function from Taiwan Food and Drug Administration. We hope to get the medicinal license ASAP in the near future and to transfer this medicine to local industry for clinical application.

The global market of medical imaging devices was reached 800 million US Dollars (about 240 billion New Taiwan Dollars) in 2016. Our research and development of medical imaging

devices are focusing on improving the quality of medical imaging and decreasing absorbing dose as well as enhancing the measurement accuracy. There are several reports in this annual report related to the low dose 3D X-ray system, called Taiwan TOMO RD, developed by INER. These reports described some unique points of this system.

In nuclear medicine, INER also begin a lot of new research items. There are several related nuclear pharmaceutical research introductions in this annual report, such as galactose for the function imaging of liver and bile system, multiple function probe for tumor imaging, and generation system of Ga-68. These topics will be the major research and development items for INER in the near future.

With the purpose of precise therapy and personalize medicine, and enhancing the technical level of domestic pharmaceutical biotechnology and nuclear medicine industry. INER is trying to integration the energy of academy, research center and medical units through co-operation of those groups to achieve the industrialization and commercialization, to make a global high-competitive biomedical market distribution. To increasing the levels of Taiwan's pharmaceutical to be one of the best in the world, INER will like to create and fulfill these radiation medical applications, and make them as INERs sustainable development object.

3-1-1 How to assure nuclear power plants of safety
Severe Accident Safety Assessments for Nuclear Power Plants

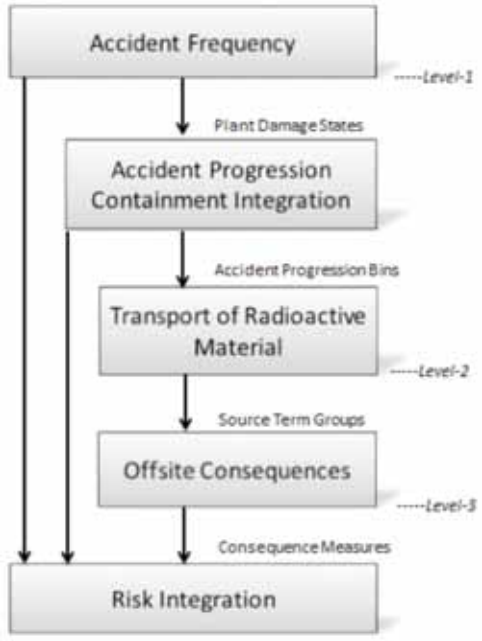
Even the probability of occurrence of a nuclear accident is very low, the consequence may be disastrous if it happens with the core severely damaged and a large amount of radioactive materials released to the outside environment. Therefore, the primary safety goal for the design, construction, and operation of a nuclear power plant is to mitigate the release of radioactive materials to the environment. Nuclear power plant safety assessment is the technology and tool used to achieve the safety goals.

Nuclear Power plants are designed with the concept of "Defense in Depth". Even in the worst case where core damage occurs the radioactive materials will not be released to the environment if the containment integrity is maintained. A full scope PRA comprises three parts of assessment, termed as Level-1, Level-2, and Level-3 PRA, respectively.

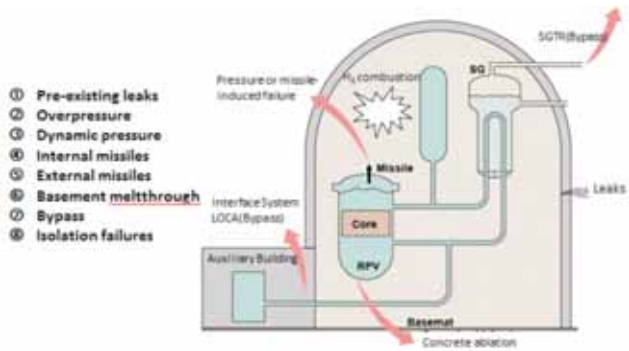
The Level-1 PRA identifies the event sequence and occurrence frequency with respect to the core damage, based on the results of event tree analysis and fault tree analysis for the reactor coolant system.

The Level-2 PRA performs the containment integrity evaluation and source terms calculation. The former assesses possible phenomena and failure mechanisms that may challenge the integrity of the containment during the progression of the accident and then estimates the failure probability of the containment structures. The latter analyzes the characteristics of the radiation source terms for the case that containment fails.

The Level-3 PRA deals with the transport and diffusion of radioactive material released to the atmosphere and evaluates the influence of its consequence on the risk of the public, considering various factors, such as the distance, meteorological conditions, terrain, population distribution, socio-economic activity, etc.

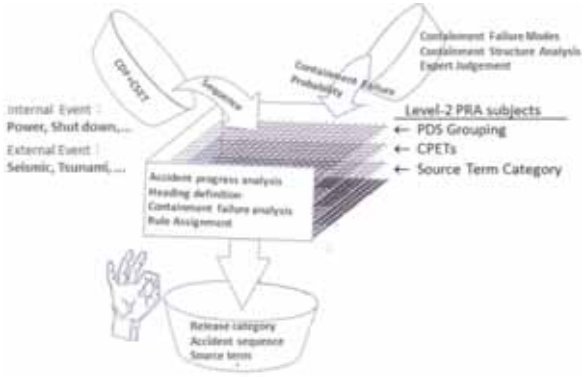


The frame of Full Scope PRA

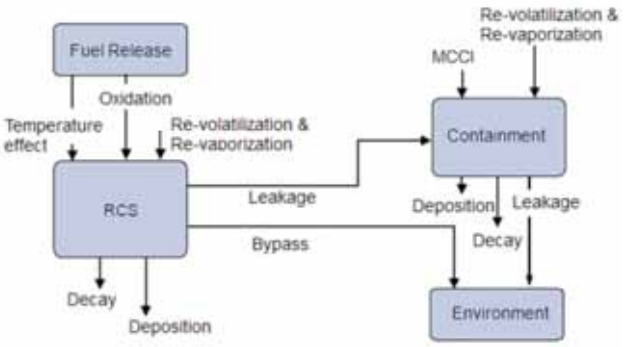


The containment failure mode

The Level-2 PRA begins with a re-examination of the Level-1 core damage sequences that considered the availabilities of the mitigation systems by employing the Containment System Event Tree (CSET). The combination of the core damage category and the associated CSET sequence defines a set of system operating conditions called plant damage state (PDS). Those accident sequences categorized as the same PDS bin have similar characteristics with respect to probable containment system responses during a severe accident. If the containment can be maintained intact under degraded core conditions, then the worst radionuclides release from the containment can be prevented or minimized. The level of release depends on various physical phenomena and mechanisms challenging the integrity of the containment in the progression of the accident. A containment phenomenological event tree (CPET) is implemented to delineate possible paths along which an accident sequence may progress. A CPET is a logical model with respect to timing and mode of containment failure that may lead to considerably different outcomes in terms of radionuclides release to the atmosphere. Key parameters include: (1) uncertainties in physical phenomena (e.g., direct containment heating etc.), (2) recovery and mitigation actions taken by the operator, or (3) system failure results in occurrence of specific physical phenomena (e.g., hydrogen burns). The steps following CPET sequence quantification is the source term binning in which a large quantity of containment sequence end points are grouped into a small quantity of source term categories (STCs). The source term categories are defined according to key radionuclide release characteristics, or factors affecting release, including timing, energy content, magnitude, etc. Finally, the severe accident simulation code, mainly MAAP5, is run to obtain the releasing source term data.



Methodology for Level-2 PRA



Radioactive materials release path

Fukushima nuclear accident reveals that beyond design basis accidents thought improbable may still occur (such as a Earthquake and Tsunami compound disaster). This urges the utility to develop the Level-2 PRA worldwide. After the Fukushima accident, a cooperation program between INER and TPC was established to improve the severe accident Level-2 PRA model, update the specific source terms data, and adequately use these results to strengthen the concept of defense in depth. One prominent achievement is to evaluate the Emergency Planning Zone (EPZ) using a more comprehensive approach.

3-1-2 Determination of Thermal and Radiation Conditions for Electrical Equipment Environmental Qualification in Nuclear Power Plant

A review and evaluation of the Equipment Environmental Qualification (EQ) Data Package, performed by the Architecture Engineering Inc., for the Kuosheng Plant units 1 and 2 reveal that the environmental thermal and radiation conditions of Design Basis Accident (DBA) specified in the Final Safety Analysis Report (FSAR) , used for qualifying the safety-related electrical and instrumental equipment installed in the Reactor Auxiliary Building (RAB), appears to be too restrictive to comply with. This may induce difficulty in the equipment procurement and may also constitute a safety concern. In view of this, INER accepts a two-year program from the owner, Taiwan Power Company, to proceed a study aimed at solving this difficult issue.

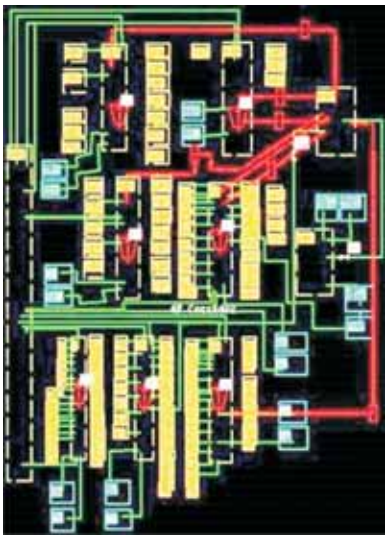
INER develops a methodology to determine the thermal and radiation conditions to be withstood by the equipment during DBA. The thermal conditions include the temperature, pressure, and humidity in the rooms and corridors. The radiation condition is focused on the absorbed dose in terms of RAD. The methodology employs the state-of-the-art computer codes together with the self-developed models. The calculation result demonstrates that the thermal and radiation conditions specified in the FSAR are actually too restrictive and can be relaxed reasonably. BY submitting the analysis report to ROCAEC for review and approval, it is expected that the issue can be solved effectively.

ESF Electrical Panel in RAB

Post-Accident hydrogen Monitor in RAB

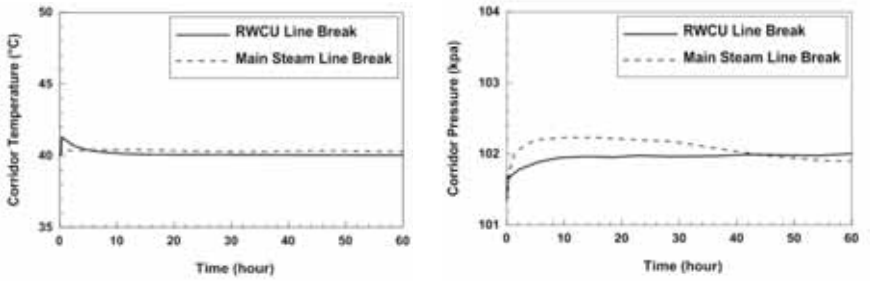
During the postulated DBA the safety-related electrical system and equipment are relied on to perform a rescue task, such as injecting water into the reactor, performing containment cooling etc. However, these system and equipment are themselves facing with harsh environmental conditions of high temperature, high pressure, and even high radiation. How to ensure the operability of these equipment thus becomes an important design and operation concern.

Surveying in RAB Penetration Area

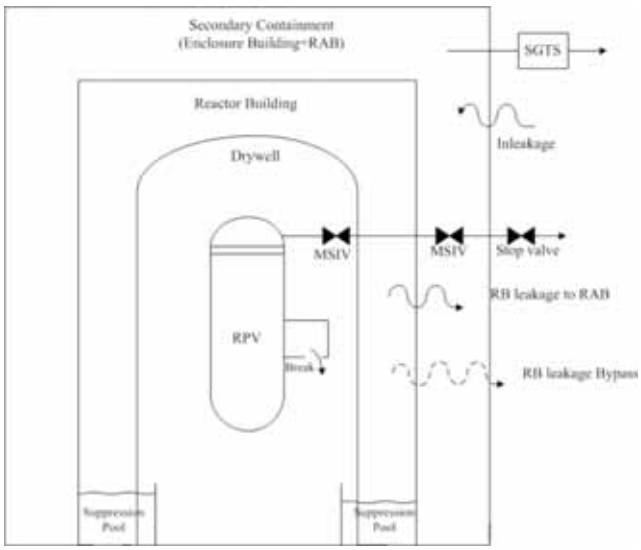


GOTHIC RAB Nodalization

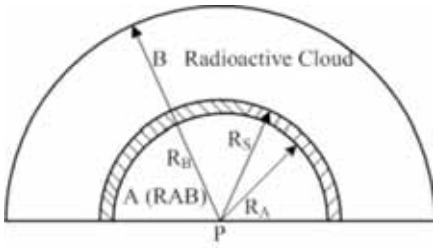
For the thermal calculation in this study, we develop an integral RELAP5 system model to determine the mass and energy blowdown conditions during the event. The blowdown conditions are then used as boundary conditions to drive the containment code GOTHIC to calculate the temperature, pressure, and humidity response of each compartment in the RAB, including the floor corridors. For the radiation calculation, we use the codes ORIGEN2 , RADTRAD, and ARGON96 to determine the core inventory, fission product transport and removal, and atmospheric dispersion factor, respectively. These are USNRC and ROCAEC-accepted codes. In addition, a self-developed finite radioactive cloud model is used to calculate the dose absorbed by the safety-related equipment at each compartment and corridor.



RAB Temperature and Pressure Response



Fission Product Transport and Removal Path during DBA



Finite Radioactive Cloud Model

The results show that the environmental conditions during the DBA, including temperature, pressure, humidity, and radiation, can be appropriately categorized as a mild condition in accordance with 10 CFR 50.49. This is justified based on the calculation that a low temperature rise (less than 5℃) and a low absorbed dose (less than equipment damage threshold of 1.0×10^4 rads) are observed.

The technology developed in this study is valuable to the country, since it not only improves the safety of the plant, but also produces an economic benefit. Further study is warranted to facilitate the methodology to be used in the determination of the EQ thermal and radiation conditions for other piping systems and building complex.

3-1-3 Fuel Lattice Design Automation Technique for BWR

Professor Paul J. Turinsky of North Carolina University viewed the optimization of fuel management as a decision making problem in which there is a very large decision space (up to 10^{100} discrete decisions). The optimization of fuel management is usually divided into several sub problems: lattice design optimization, single cycle loading pattern design optimization and multi-cycle loading pattern design optimization, etc. The purpose of this research is to develop a feasible method that can accomplish a high quality BWR lattice design while reducing the resolution time for the optimization. The results show that this technique has high potential for realistic application.

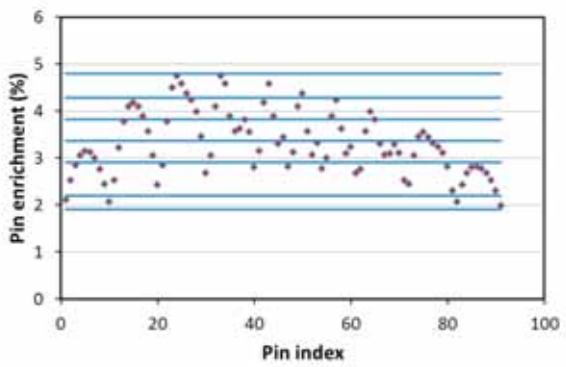


Fig. 1 Illustration of enrichment grouping

The basic concept for the design of a BWR fuel lattice is to deploy the enrichments of fuel rods within a lattice depending on the neutron moderation level of a fuel rod at its location, such that the local peaking factor (LPF) or F-eff can be minimized. The lattice design automation technique developed in this research utilized a method that divides the fuel rod enrichments of an ideal distribution into several enrichment groups and equalizes the peakings of these enrichment groups to optimize the design while taking into account the lattice design constraints for practical application.

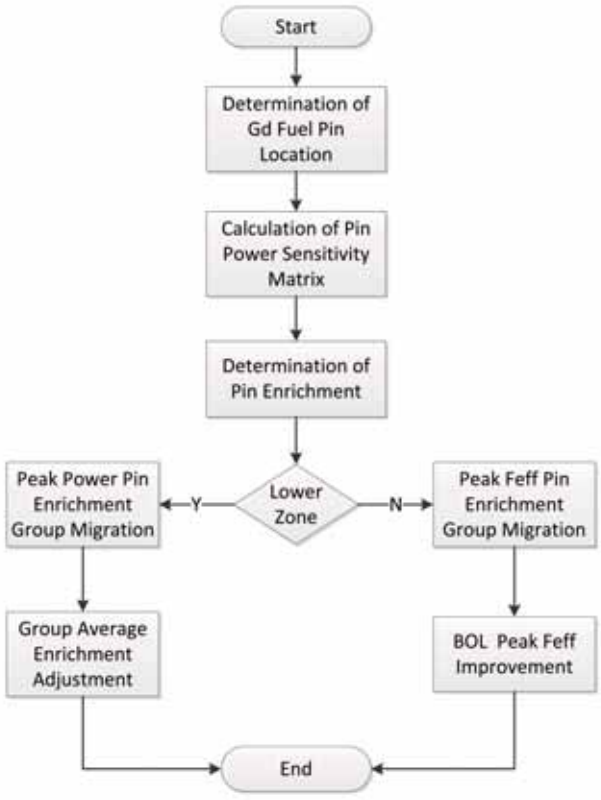


Fig. 2 Flow diagram of lattice design automation system

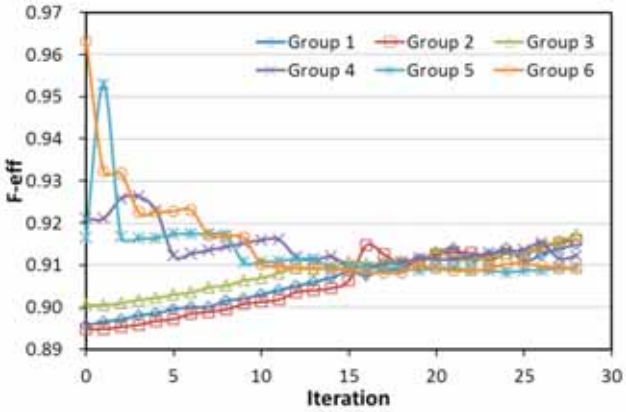


Fig. 3 F-effs of enrichment groups during optimization process

The research worldwide on BWR fuel lattice design optimization can be classified according to the methods used, which are mathematical method and heuristic algorithm. In comparison with these two types of method, our technique is more feasible, with shorter computational time and more flexible in terms of optimizing LPF and F-eff.

Comparing with the reference design, our optimization designs show better LPF performance at 0-15 GWD/MTU (Fig. 4) for the lattice located at the lower half of a fuel bundle and better F-eff at the exposures around 10 GWD/MTU (Fig. 5) for the lattice located at the upper half of a fuel bundle. The number of lattice calculation required for an optimization design is less than 40 using our technique, which is far less than the 1500 lattice calculations when using tabu search or ant colony algorithm for the optimization design.

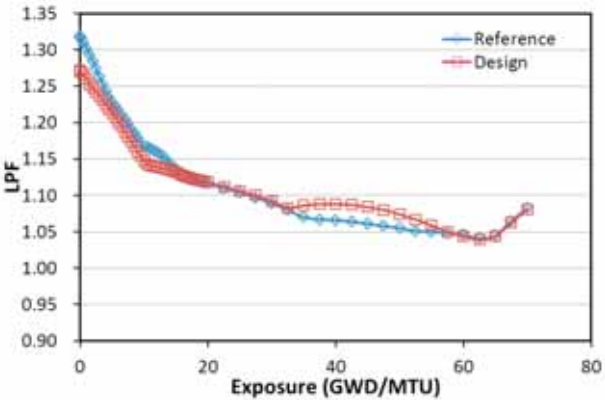


Fig. 4 Comparison of LPF between optimization and reference designs

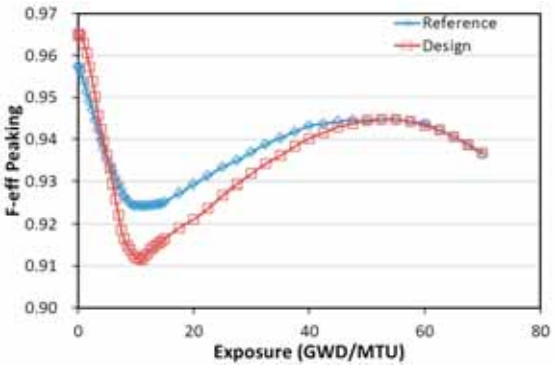
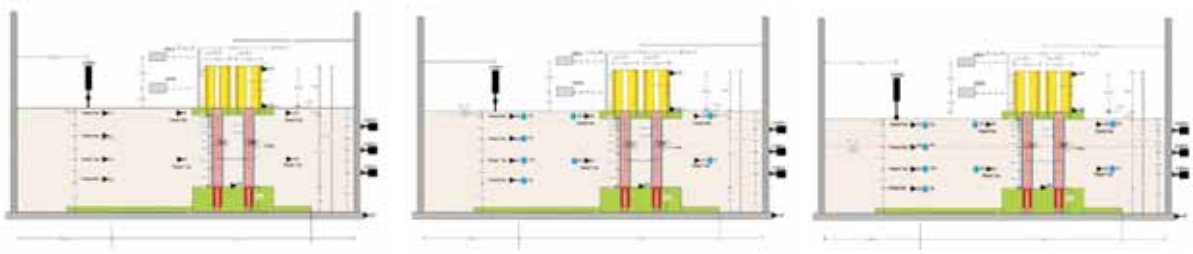


Fig. 5 Comparison of F-eff between optimization and reference designs

To further improve a lattice design, either using two types of Gd concentration or using two different enrichments for Gd rods can be considered. A reload core design involves several design processes, including lattice design, fuel bundle axial design, single cycle loading pattern design, etc. The next stage of research will focus on fuel bundle axial design, and the integration of lattice design and axial design methods to form a complete technique for fuel bundle design automation.

3-1-4 Experimental analysis of pile group in liquefying soil under a ground motion using centrifuge test

This study provides a solution to the likely earthquake disaster of pile foundation in soft ground, such as offshore wind turbine or anti-tsunami sea walls. Test and analysis methods are used to provide designers with reference data. The verification of pile group foundation is performed by centrifugal shaking table test, in which an accelerometer is embedded in soil layers to search the liquefaction of the soil layer and the seismic capacity of the pile foundation. Also, the numerical method is implemented to analyze the soil and pile group interaction during the earthquake based on this research data . The techniques can actually observe the seismic performance of the pile foundation in the liquefied soil layer, and provide understandable information for the public to see and to believe.



(a) dry sand with pile cap under the ground-Gtest1

(b) saturated sand with pile cap under the ground- Gtest2

(c) saturated sand with pile cap on the ground- Gtest5

Figure 1. The configuration of models

Three centrifuge shaking table tests were conducted . That were the dry sand which pile cap under the ground (Gtest1), the saturated sand with pile cap under the ground (Gtest2), and the saturated sand with pile cap on the ground (Gtest5) as shown in Figure 1. After the preparation of models, the centrifuge was accelerated at a 10 g per step until it reached the centrifugal acceleration of 80 g. Then, the shaker was invoked to excite the model with one-dimensional sinusoidal waves. A fine quartz sand with mean particle size of 0.19 mm was used to prepare the uniform sand deposit. An accelerometer is installed in the sand and pile head masses to measure the acceleration during vibration.

Pile cap exposed on the surface and in the saturated sand, as determined by the pre-vibration, subsequently each model was subjected to several shaking events. In the tests, the records are obtained for the response time of each sensor, including the acceleration at different elevations, the excess pore water pressure, the surface subsidence and the depth of the pile at different depths of the strain gauge voltage signal. Each earthquake event is ended, after the excess pore water pressure dissipation of test specimen is completed, and then the additional seismic events are applied.

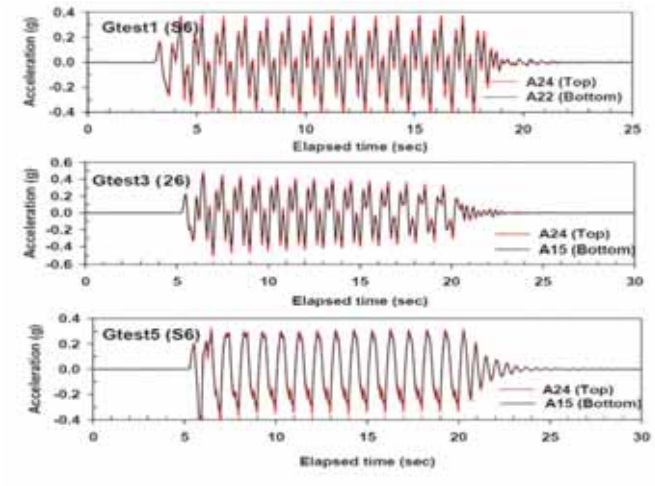


Figure 2. Time histories of dry storage tank acceleration (Gtest1, Gtest2 and Gtest5)

Observing the amplification of seismic waves and the level of soil liquefaction is to provide a reference for designers. The input earquake PGA of base shaking is about 0.3 g, and measurement of the acceleration time history in the pile head and bottom from Gtest1, Gtest2 and Gtest5 are shown in Figure 2. During the earthquake it shows Gtest 2 and Gtest5 (the saturated sand) have been liquefied, the accelerations at the top and bottom of dry storage tank are almost the same , and in Gtest1 the acceleration at the dry storage tank is much larger than that of other tests at the bottom

In order to understand the effect of liquefaction and the settlement of adjacent structures, several seismic tests with different maximum accelerations were carried out. Figure 3 shows the relationships between settlement and acceleration of Gtest1, Gtest2 and Gtest5. Gtest1 embedded in dry sand, there is no liquefaction phenomenon induced by the earthquake so the amount of settlement and acceleration is only slightly related. For Gtest2 and Gtest5 embedded in the saturated sand, liquefied level vibration increases with the acceleration, and the liquefaction causes a large settlement. The results meet the expectation from the theory of soil mechanics.

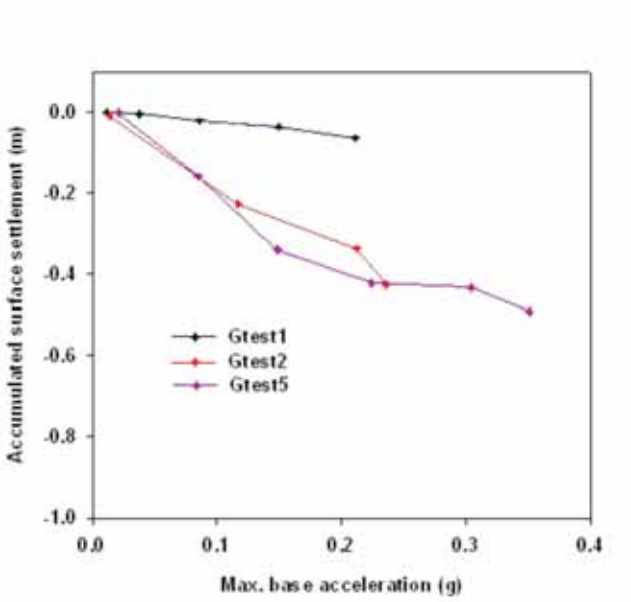


Figure 3. The relationship between settlement and acceleration of Gtest1, Gtest2 and Gtest5

The results of all tests show that the seismic performance of pile groups can be predicted by this test method. The test results can also be used to validate the results derived from the numerical simulation. For the more complicated pile group structure, besides the test condition can be modified to evaluate the seismic behavior of the structure, and the severity of settlement caused by liquefaction, it can also be combined with numerical simulation tools to make more accurate quantitative assessment. It is helpful to make the pile foundation structure safety confirmation, reduces the worry of the public about the earthquake disaster.

3-1-5 Numerical simulation in thermo-mechanical coupling of EBS of SNF

We use the finite difference method (FDM) to simulate the thermo-mechanical coupling of the EBS by FLAC3D under the heating effect(Fig. 1) of the canisters. The objectives are to explore the temperature and stress field during the operation period of the SNF disposal site until re-saturation, to provide reference basis for the authorities to conduct safety analysis of SNF disposal sites in Taiwan, and to enhance public awareness of HLW without affecting human life.

The 3-D numerical model(Fig. 2) developed in this study that modeled with T-M coupling is compared with the international case studies. The results(Fig. 6) are very close to ensure the effectiveness of the model.

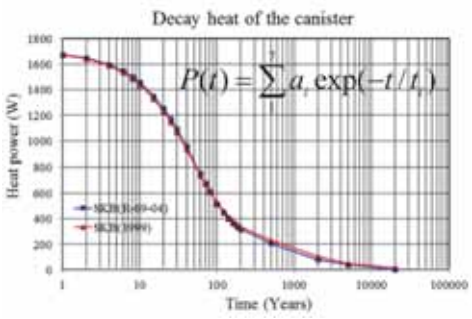


Fig. 1 : Decay heat of the canister

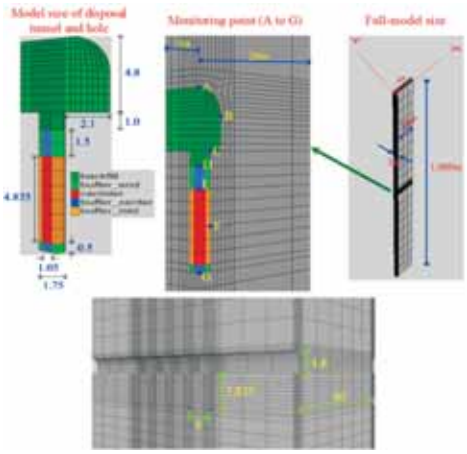


Fig. 2 : Local numerical model

Temperature (Fig. 4): The buffer will reach the max. temperature of 93.4 ℃ in the 15th years after disposal, while the rock wall is 74.2 ℃ after 58 years.

Stress(Fig. 3): The max. pressure of the rock wall is about 50.5 MPa, which is about 16 years after disposal(same as max. temperature). The max. tension is about 0.035 MPa at the arch crown.

Displacement(Fig. 5): The max. displacement of the near field is about 7 mm, indicating that the rock is still in elastic stability.

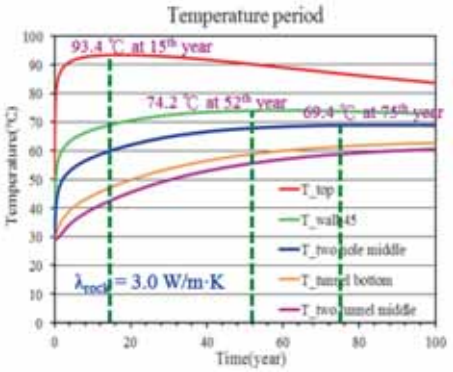


Fig. 4 : Temperature period

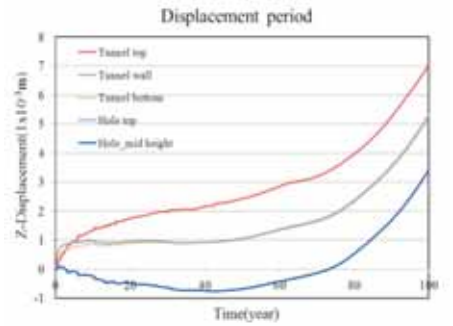


Fig. 5 : Displacement period

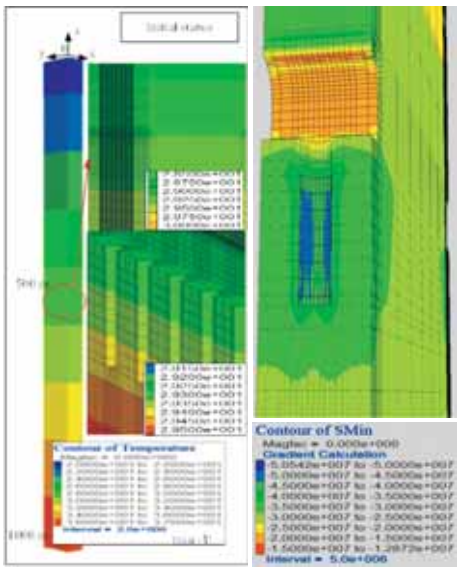


Fig. 3 : Initial mechanical balance (including geothermal gradient) and stress distribution after 16 years of disposal

	INER	SKB
Temp. at the top of canister(℃)	71.74	71.26
Temp. at the rock wall(℃)	40.00	39.00
Time of occurrence(year)	10	10

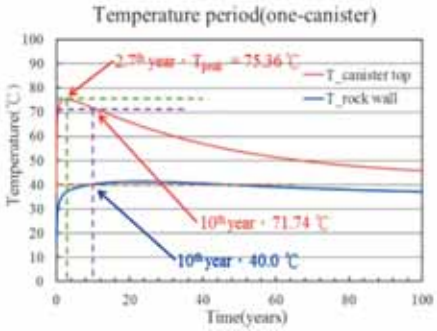
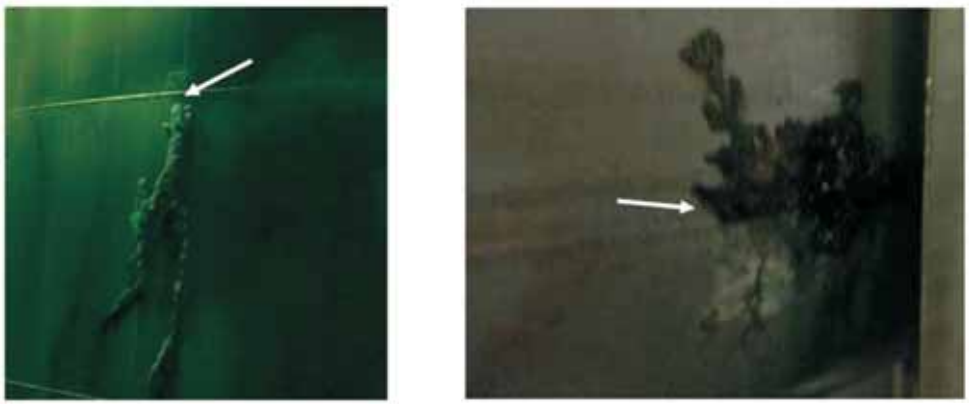


Fig. 6 : Comparison of temperature distribution of one-canister with SKB

The influence of groundwater on heat transfer and stress is crucial while both the buffer and backfill are re-saturated during disposal. Thermo-hydro-mechanical coupling analysis will be carried out in the future to understand the reaction of EBS under thermal effect.

3-1-6 The safety improvement on the storage components of petrochemical industry by integrating the welding technologies

For the benefits of good mechanical properties and corrosion resistance, 2205 duplex stainless steel (DSS) and Hastelloy C-276 have been used for the acid solution storage components in petrochemical industries. Despite their excellent corrosion resistance, these components can only sustain for about a year in such a highly corrosive environment. The continuous production line in the petrochemical industries has to be interrupted from time to time to repair the failed components imperatively. It causes not only significant economic losses but also serious concerns about the operation safety.

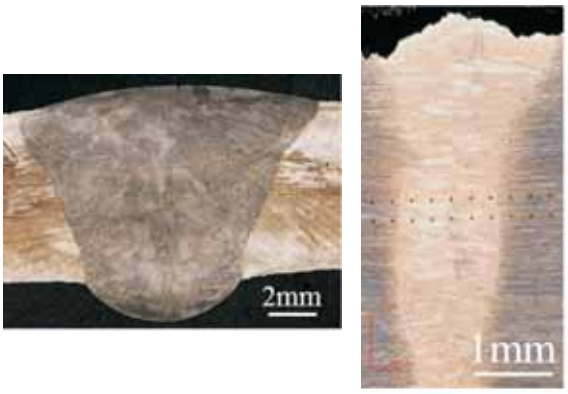


The visual test indicates the leakage around the fusion zone.

The root causes show that the corrosions mainly initiate in the heat affected zones (HAZs) of these components, where serious sensitization and high residual stress were induced by welding procedures. To solve these problems, an integrated welding process of gas tungsten arc welding (GTAW) and laser beam welding (LBW) was investigated. In the first phase of this study, the influence on the welding processes, the shielding gas compositions, and the GTAW pulsed frequency were investigated. Mechanical GTAW and LBW were individually employed for the two weldments, 2205 DSS and Hastelloy C-276, with their relevant weld metals, ER2209 and ERNiCrMo-4, respectively. Their properties were evaluated by the results of microstructure characterization and mechanical tests.

Auto GTA welding system

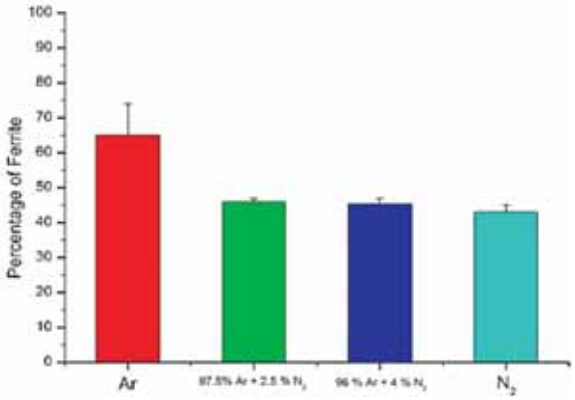
High power laser beam welding system



The marcostructure of the weldments:
(1)GTAW; (2)LBW

It is more time-consuming to finish the weld by a multi-passes GTAW in comparison to LBW process. LBW could generate a higher post-weld cooling rate and induce a lower heat input. For this reason, it would result in less brittle phases to improve the corrosion resistance. In order to solve this problem, the pulsed mode has been used to improve the GTAW process by decreasing the welding current.

Nitrogen is an austenite forming element, which could increase the ferrite transformation temperature, so as to improve the ratio of ferrite/austenite (F/A) in the fusion zone. In this study, the shielding gas was adjusted with various levels of N_2. The ferrite/austenite (F/A) ratio of GTAW welds was measured to be about 68/38 with a pure Ar shielding gas, while that was about 35/65 using a shielding gas of N_2. The ferrite/austenite (F/A) ratio of LBW welds were about 65/35 to 54/46 by changing pure Ar shielding gas to N_2.



Improve the shielding gas in 2205 weldments

C276 base metal

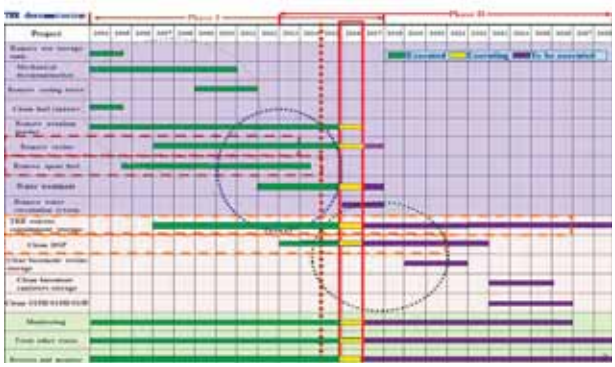
1.C276 weld metal
2. The interface between weld and base metal

The preliminary results of this work showed that the precipitation of the detrimental phases and the content of the austenitic phase in the 2205DSS welds were changed. The former could be reduced by lowering the welding heat input, and the later could be increased with variations of the shielding gas compositions. Both pulsed GTAW and LBW processes could decrease the Mo segregation along the subgrain boundaries of the C-276 welds.

Through the process improvement and appropriate personnel training, it could shorten the production time of the storage components, enhance the self-made capabilities of components and maintenance capacity, and increase the production efficiency and operational safety.

3-1-7 TRR Decommissioning Plan - Foundation of Domestic Decommissioning Technology

"Taiwan Research Reactor (TRR) decommissioning plan" was approved by Atomic Energy Council R.O.C in 2004. The major missions in Phase 1 (2004 - 2017) were to dismantle auxiliary facilities, to clean the spent fuel pool, and to enhance safety management of the remained system. In Phase 2 (2013 - 2028), major activities include the cleaning of the dry storage pits(DSP) and the decommissioning of the waste conditioning and storage facilities. In addition, the reactor vessel had been one piece removed to building 074 under safe store; recently, the process of dismantling TRR vessel was assessed. Major tasks in the Phase 1 have been successfully completed at present, including the dismantling of wet storage tank and emergency cooling tower, the cleaning of miscellaneous radioactive sources and the water in spent fuel pool. INER not only successfully develops techniques, but also effectively performs the nuclear facilities decommissioning plan and establishes the domestic technology of nuclear facility decommissioning.



TRR decommission schedule

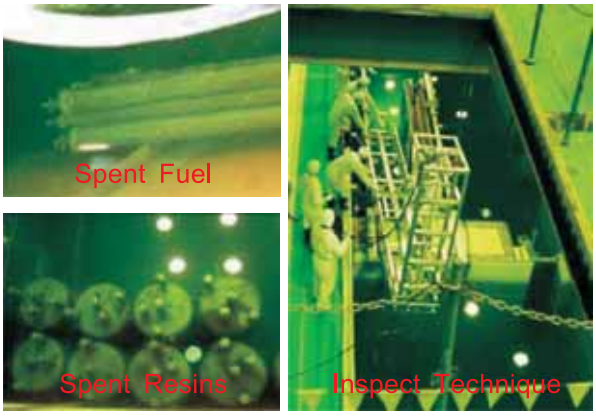
TRR reactor waste safe storage

Wet storage tank and emergency cooling tower dismantling

The function of the wet storage tank was to temporarily store spent fuel. Emergency cooling tower was a backup system when TRR in operation. Both of them were concrete structure . Before the demolition, the investigation of the radiation characteristics and the removal of internal contaminated part was performed to ensure radiation safety. With the characteristics and classification data, INER adopted dismantling equipment such as diamond wire saw, drill machine, designed cutting procedure, and plotted wastes process procedure. Concrete structure was dismantled into blocks level by level. After the wet storage tank was demolished, a metal waste decontamination facility has been set up in situ.

Wet storage tank dismantling

Emergency cooling water tower dismantling



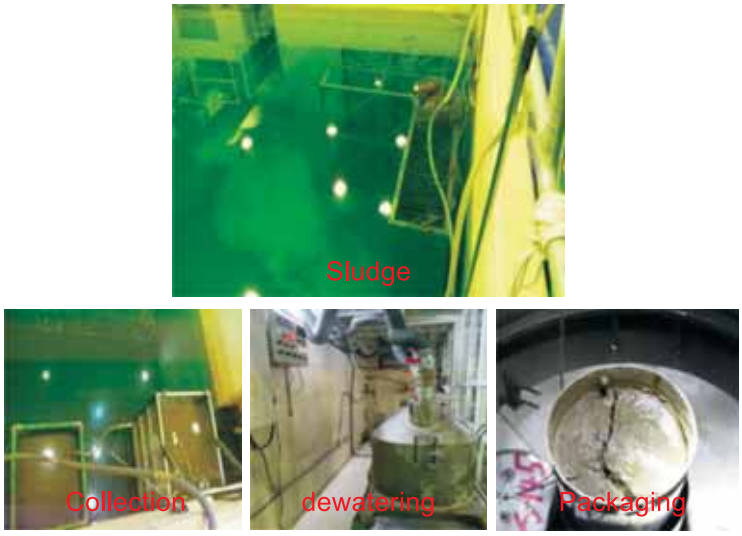
wastes in the pool

Spent fuel and resin clean-up

Spent fuel, fuel canister and spent resin stored in the TRR spent fuel pool are difficult and important items in TRR decommissioning project. INER established techniques such as underwater handling, dewatering, packaging and loading methodology for the clean-up of those items. An non-invasive inspection techniques (Plutonium Coincidence Counter(PCC)) was developed with cooperation of Los Alamos National laboratory via Taiwan-US nuclear cooperation platform. Hence, all of the spent fuel rods and spent resins have been safely removed from the pool.

Sludge clean-up

After years of operation, amount of sludge was deposited on the bottom of the pool. They spread widely in pool water and were difficult to remove. Considering to minimize the secondary waste, a process of natural precipitation collecting method was developed. With self-designed underwater suction devices and flexible collection system the difficulties , such as depth of the pool, limited working space, radiation environment , were overcome the sludge in pool was collected, dewatered, packaged, and removed from the spent fuel pool successfully.



Sludge Clean

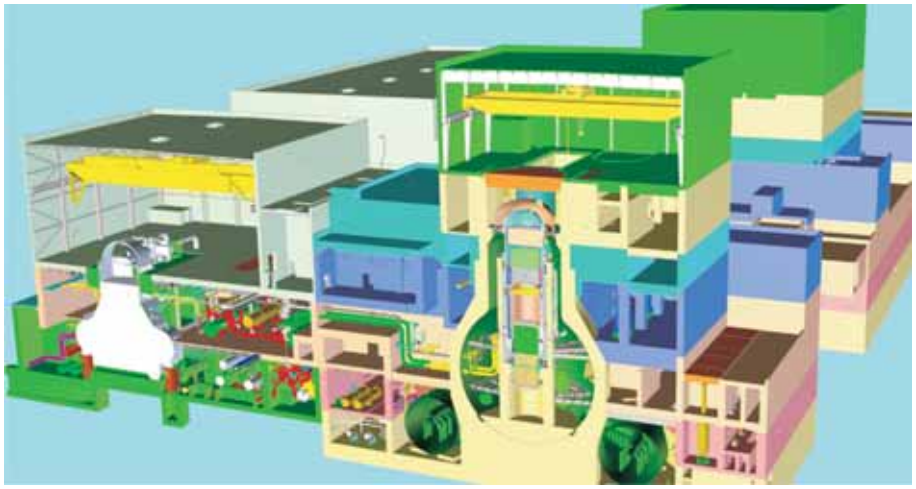
Pool Water treatment

Pool water treatment

The pool water provides shielding and cooling function. However, it was muddy due to operating for years , and it was contaminated. Considering operation safety and secondary waste minimization, INER developed an unique in-pool treatment process ,including water purification, ion adsorption, filtering, coagulating and depositing techniques. All water in the pool was successfully treated to fit the acceptance specifications of the radioactive liquid waste treatment facility.

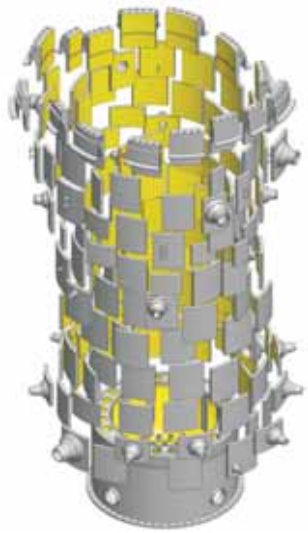
3-1-8 Development of the 3D engineering simulation technology - The solid technical support on nuclear power plant decommissioning

This engineering simulation technology based on computerized 3D digital model has been developed in many fields application including the decommissioning of nuclear power plants. When this technology is utilized in the field of nuclear power plant decommissioning, it can integrate and process the original 2D design drawings and transform them into a visualized 3D digital model which includes the building structures, pipeline systems and components. It can be implemented in the decommissioning applications, such as segmentation, waste inventory and packing, radioactive dose distribution and staff training to get a real visualized understanding of the nuclear power plant without any speculation .



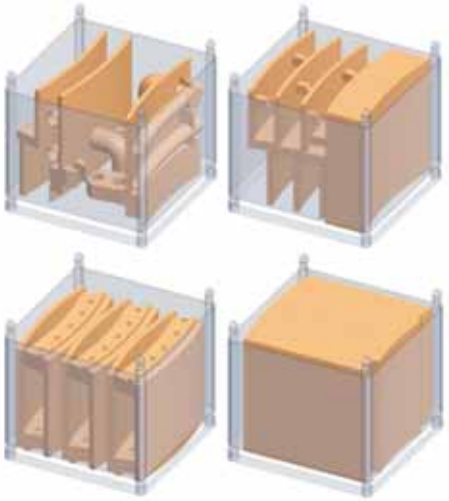
3D model of the nuclear power plant (section view)

Take the reactor pressure vessel (RPV) and its internals as an example to explain how the segmentation simulation works. Because RPV is complex in shape and has high radiation dose, comprehensive evaluation and simulation are necessary before performing the segmentation task. The 3D model can not only accurately depict the geometry and layouts of the RPV components but also provide the information about the constraints in space. Based upon the information that the 3D model provides, the segmentation procedures can be planned, and the tools can also be designed. Besides, the 3D model can be utilized to plan the cutting trajectories and the optimal size of each segmented piece in accordance with the constraints in space and the requirements of waste containers respectively. With these plans and information, the frequency of tools replacement, worker dose and man-hours can be evaluated and specified. The establishment of engineering simulation technology will be useful to promote the safety and reliability of the segmenting task.

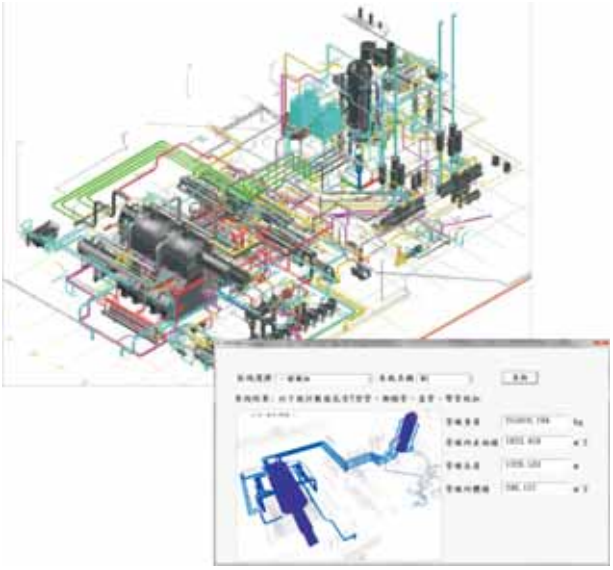


Cutting planning of reactor pressure vessel

During the segmentation process, each segmented piece can be depicted through the 3D model to show how it is placed and stacked in the waste container. Based on the simulation, waste package arrangements inside containers can be evaluated and planned in advance of the real segmentation task. With the help of 3D model, the packaging efficiency can be optimized, and the quantity of the waste containers needed will be significantly reduced. By the 3D model integrates the information of the dose rates, numbers, and properties of the segmented pieces in the waste containers, an effective waste tracking and management will be achievable.

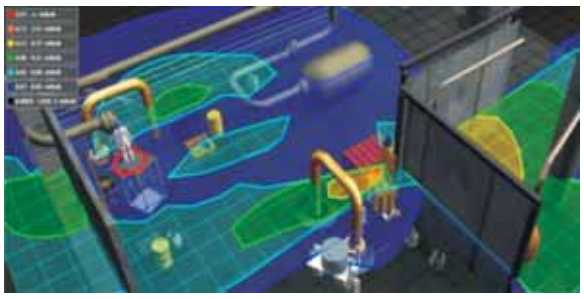


Packaging simulation of core shroud segmentation



Decommissioning waste inventory

The traditional waste inventory is based on 2D design drawings and document records. It would spend too much manpower, and the accuracy is poor. When the 3D model of the pipeline system and the building is completed, the length and weight of each pipeline can be easily calculated according to the characteristics of the 3D model, and the data such as the volume, weight and floor area of the building structure can be easily calculated and the statistical error is greatly reduced.



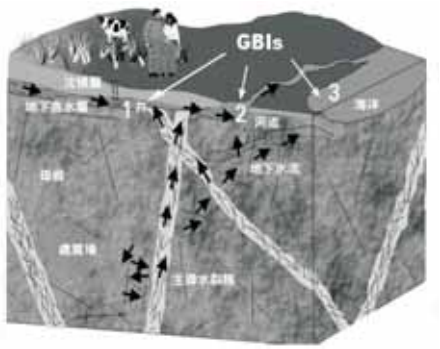
Color block display for site characterization survey

After the 3D model integrates the information of the site characterization survey, the staff can get the visualized understanding about which places have higher dose rate. If this model integrates the visual reality technology further, the staff can get an almost real environment of the site even in a classroom training. It can make the staff more familiar with the site they will work on to reduce the unnecessary exposure they would receive.

The goal of 3D engineering simulation implemented in the nuclear power plant decommissioning is to reduce radiation dose and risks the workers would get, promote the work safety, and optimize the efficiency. INER will continue to study the 3D engineering simulation technologies and establish the localized technical capacity used in nuclear power plant decommissioning to meet the government policy, domestic demand and operation safety.

3-1-9 Biosphere Dose Assessment for Spent Nuclear Fuel Disposal

In this study, we have adopted the reference biosphere concept which has been developed as part of IAEA BIOASS research project to make reasonable estimates of radiological impacts based on future environments and lifestyles. Furthermore, dataset for biosphere dose assessment will also be investigated to assess exposure doses among different exposure groups with modelling software AMBER.



The long-term R&D program for safe disposal of SFs has been conducted at Institute of Nuclear Energy Research (INER) since early 1986. After reviewing disposal systems under developments in the world, at this stage we adopt the disposal concept which is similar to that of Swedish KBS-3.

The objective of this study is to construct a biosphere conceptual model for Taiwan, by which dose to the individuals due to long-term radionuclides release from repository can be evaluated. However, this does not constitute a candidate site but that the information is used purely to provide a real basis for the safety assessment of a reference case.

Due to a long time period of safety assessment for SFs disposal, it is difficult to predict the future human behaviors and lifestyles. To address this issue, the BIOMASS proposes a complete procedure outlined in Fig. 1 to develop the biosphere model, providing a systematic methodology based on key steps by which conceptual and mathematical modeling can be introduced. The long-term R&D program for safe disposal of SFs has been conducted at Institute of Nuclear Energy Research (INER) since early 1986. After reviewing disposal systems under developments in the world, at this stage we adopt the disposal concept which is similar to that of Swedish KBS-3.

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The first step in this approach is to determine the assessment context that provides the scope of modeling. Description of environment and lifestyle in the future is compiled as the biosphere system and potentially exposed groups. Once the first step was completed, FEPs (Features, Events and Processes) to be taken into consideration in the biosphere assessment were selected from the biosphere FEP list of BIOMOVS II. Because the FEP list of BIOMOVS II covers only inland regions, a new FEP list for Taiwan (an island) is prepared referred to both H12 and BIOMOVS II.

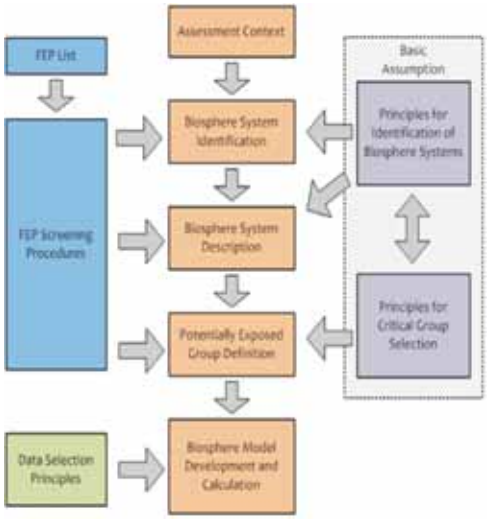


Fig. 1. Schematic illustration of the r eference biosphere methodology.

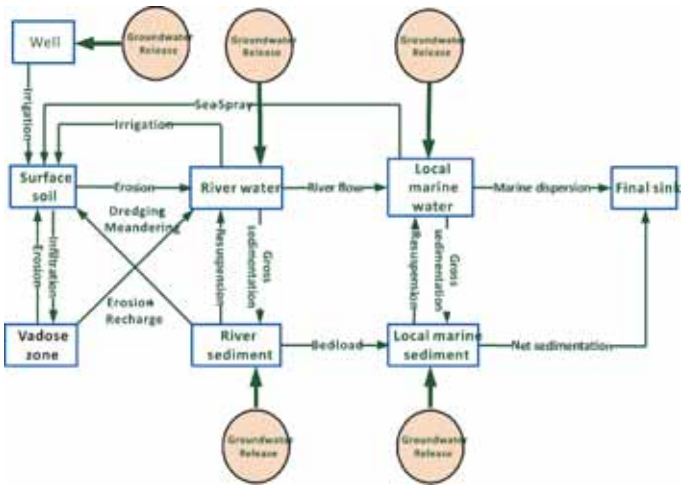


Fig. 2. Conceptual model for the biosphere assessment.

The researchers use the interaction matrix as mentioned in the previous section to identify and understand the processes of nuclide transport. They further complete the development of a biosphere conceptual model that reflects the conditions for the initial period of temperate climate after closure and the glacial climate period (see Fig. 2). The conceptual model also includes five geosphere-biosphere interfaces (GBIs) through which the radionuclide is likely to be released to the biosphere. In addition, three critically exposed groups (agriculture, freshwater fishing and ocean fishing) are identified(see Fig. 3).

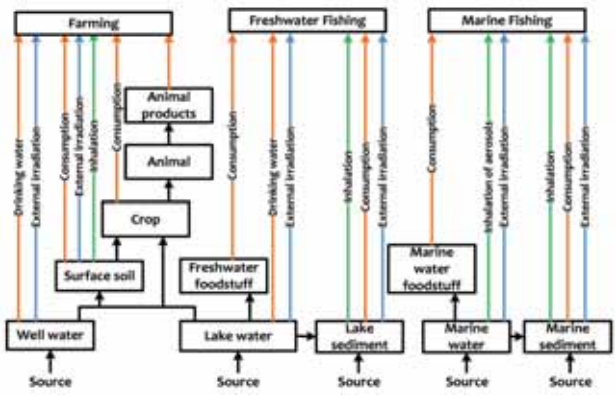


Fig. 3. Exposure pathways for the initial period of temperate climate after closure and the glacial climate period .

Typically, appearance of nuclides in the biosphere will take place in GBIs where groundwater finally discharges. In this report, well is selected for the reference case. The calculation of transport in the biosphere assumes that release of each nuclide of 1 Bq/y is maintained until steady-state biosphere doses are obtained. In Fig.4, the dose rate seems to remain constant after breakthroughs are reached their peaks. Therefore, once reached at peaks, these values are used as biosphere dose conversion factors (BDCFs) to generate annual individual dose rate. BDCFs for parent nuclides are calculated to account for all daughter nuclides that will be produced by radioactive decay and ingrowth in the biosphere.

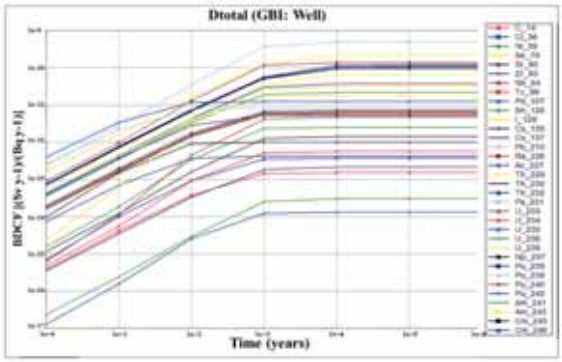
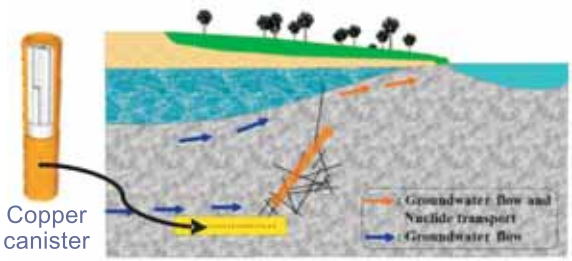


Fig. 4. BDCF variation of different radionuclides in the following time slots.

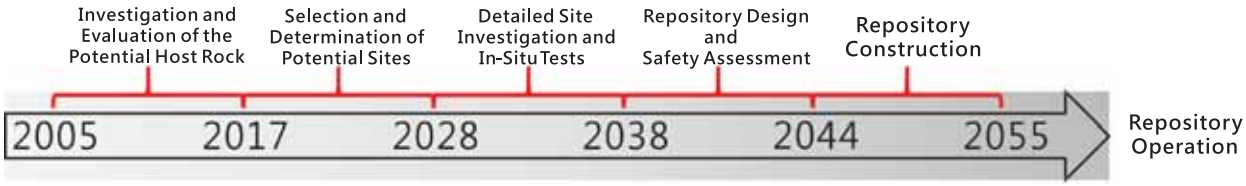
In this study, the IAEA BIOMASS methodology has been adopted to construct the biosphere conceptual model for Taiwan to preliminarily assess the radionuclides transport in the biosphere. The FEP lists and an interaction matrix were also used to identify the exposure pathways and groups. Furthermore, dataset for biosphere dose assessment was investigated to assess exposure doses among different exposure groups with modelling software AMBER

3-1-10 Safety Assessment Methodologies for the Reference Case of the High Level Waste Final Disposal

For the management of the spent nuclear fuel, the final disposal of it is set into action based on the Spent Nuclear Fuel Final Disposal Program. The program is divided into five stages and is currently in stage one which is Potential Host Rocks Characterization and Evaluation stage. There are two main objectives in this stage: (1)To complete the survey, characterization and evaluation of the potential host rocks in Taiwan and (2)To develop the potential host rock performance/safety assessment technologies. The safety assessment for the spent nuclear fuel final disposal of a reference case has been done. The dose risk to the critical group is compared with the regulation requirements.



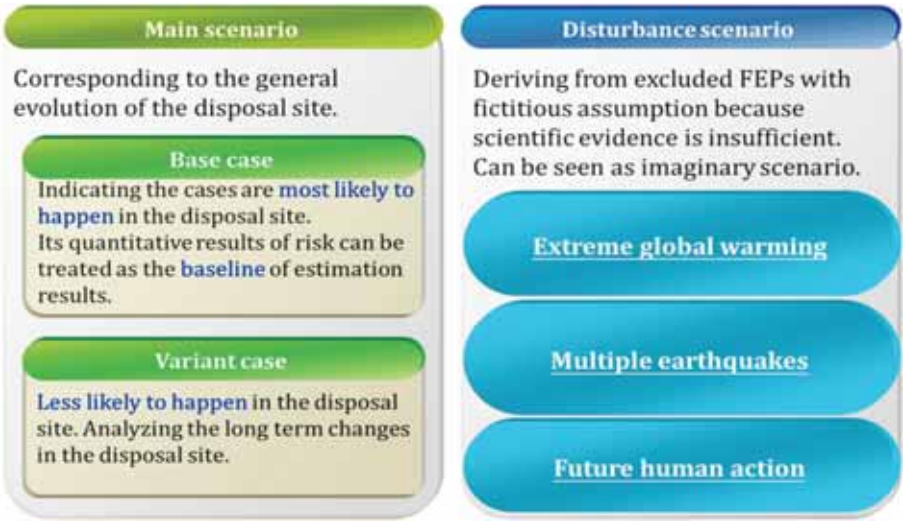
By referring to KBS-3 vertical disposal concept in Sweden, the HLW will be put into copper canisters and be disposed in the crystalline rocks at the depth of 500 meters in order the there will be isolation and retardation for the spent nuclear fuel.



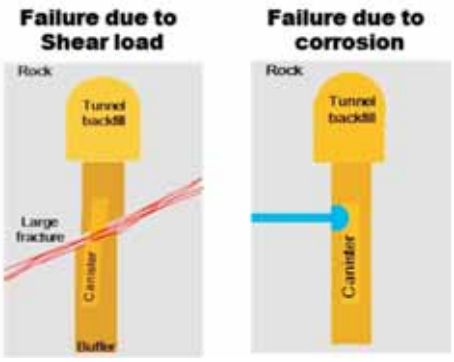
The Proposed Schedule of the Spent Nuclear Fuel Final Disposal Program

The main scenario of safety assessment can be divided as base cases and variant cases. The base cases are based on the internal and external conditions in the repository. Under the million year time-scale, the canisters will fail probably due to (1) the corrosion and (2) the shear load. So it is necessary to assess the nuclides released in each scenario and the dose risk to the critical group. The variant cases are to assess the consequence by changing the variables in the reasonable ranges.

The disturbance scenario has taken account of other features, events and processes (FEPs) and could be divided as the phenomenon caused by natural factor and the phenomenon caused by human factor. The disturbance scenario could robust the study of the safety assessment.

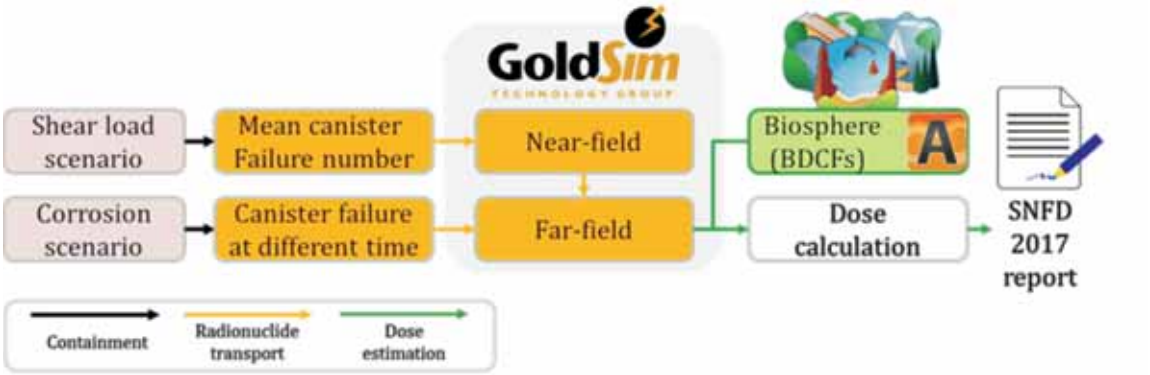


For the analysis for the containment function of th canister, the erosion time of the buffer material aroun the canister by the groundwater has been assessed i the corrosion scenario. When the groundwater contac with the copper shell of the canisters, the corrosic begins and the time for penetrating the thickness copper shell has also been assessed. In the shear loa scenario, the canister could be failed by the shear loa arising from the movement of the fracture of the rock du to the earthquake. The amount of the failed canister caused by the shear load of an earthquake has also be estimated.



The canister failure scenario

Using the contaminant transport module in the GoldSim computer code, the corrosion scenario and the shear load scenario have been established for the analysis of nuclide transport and radiation dose. In order to calculate the risk to the critical group, the spent nuclear fuel inventory, the process of the nuclear fuel dissolution, the model of the canister failure, the transportation parameter in the buffer material and in the fracture of the rock, all need to be combined together with the biosphere model.



The safety assessment model is established by the GoldSim and combined with the biosphere model.

For international technology exchange, the INER safety assessment team went to Stockholms, Sweden in 2016 to have communicate with the experts in the Swedish Nuclear Fuel and Waste Management Company (SKB), and gained a lot of feedback and recommendation. By the comparison of the cases study from both team, the same trend could be shown and the SKB experts have given INER team a nice expectancy and provided many suggestions for the cases study. The suggestions are valuable to INER.

The communication with the experts in the Swedish Nuclear Fuel and Waste Management Company (SKB) for the technological purpose in Stockholms, Sweden

INER safety assessment team has established the technology of the safety assessment of the HLW disposal program. This could help to assess the risk based on the science foundation. Also by the analysis of parameter sensitivity, the priority items for the future R&D could be identified. To robust the disposal technology for the back end of the nuclear industry and to contribute to the non-nuclear policy will be the focuses of next stage program.

3-1-11 A Rapid Safety Assessment Method for Cylindrical Shell Weldments with Multiple Through-Wall Cracks

The core shroud, which is the stainless steel cylindrical shell surrounding the reactor core, is one of the important safety components of the nuclear power plant (NPP) and should be constructed in accordance with ASME B & PV Codes, Section XI and GL 94-03. However, the manners and calculation processes provided by ASME code are very complicated and time consumed. In order to seek both safety goal and evaluation efficiency, we developed a graphic user interface program (GUI) (Fig. 1) that can assist the engineers to evaluate core shroud rapidly only by using the examination data associated with stress conditions under different service conditions.

Fig. 1. Shroud evaluation program(Left) and shroud support model generating program(Right)

The GUI program facilitates complicated calculations of core shroud evaluation. It not only reduces the large amount of judgments time, but also ensure the correctness of the results. Besides the core shroud, we also developed a Windows program (Fig. 1) for shroud support that can directly build the finite element model which covers the whole shroud assembly from top to bottom.

For domestic BWR, this program can quickly establish the numerical simulation model of shroud support plate according to the detected degradation information (Fig. 2), and then evaluate the structural safety margin.

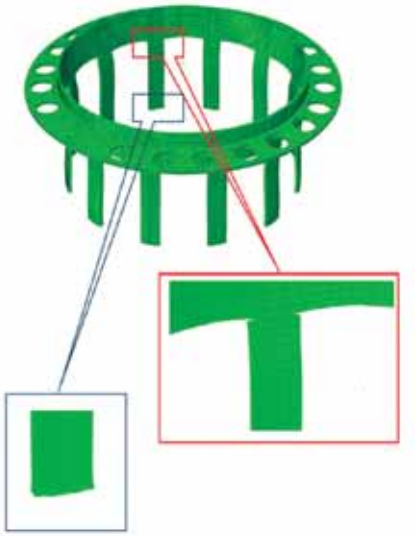


Fig. 2. Core shroud support model

Weldment No.	Operation Condition	Results from ASME Codes		Results from GUI program	
		Plastic collapse bending stress (psi)	Safety Factor	Plastic collapse bending stress (psi)	Safety Factor
H1	Normal	40615.97	84.40	40618	84.4030
H2	Upset	47364.17	99.07	47364	99.0720
H3	Emergency	16823.13	29.51	16824	29.5120
H4	Faulted	9450.39	5.83	9451.6	5.8300
H5	Normal	17271.49	12.91	17265	12.9050
H6A	Upset	5477.44	4.41	5461.3	4.3993
H6B	Emergency	2279.74	1.61	2265.2	1.6006
H7	Faulted	2355.64	0.72	2341.7	0.7152

Table 1. Program verification by following ASME Codes

This program has been validated and applied practically many times to domestic NPP (Table 1). In terms of innovation, the program which integrates regulatory assessment and finite element analysis provide great benefits in safety assessment for important components of NPP.

The technology transfer of the program has also been completed, and many reviews and evaluations have been performed. This shows that the development and application of this program has been paid more attention to the operation and maintenance of domestic NPPs.

The development of this program is to meet the safety requirement of NPP. Some foreign researchers have developed DOS and WIN95 versions of the crack evaluation softwares many years ago, but no further version was issued.

Comparing with foreign programs which only consider symmetrical model, our program can establish a global analysis model with the actual crack (Fig. 3), which is more practical and accurate (Fig. 4).

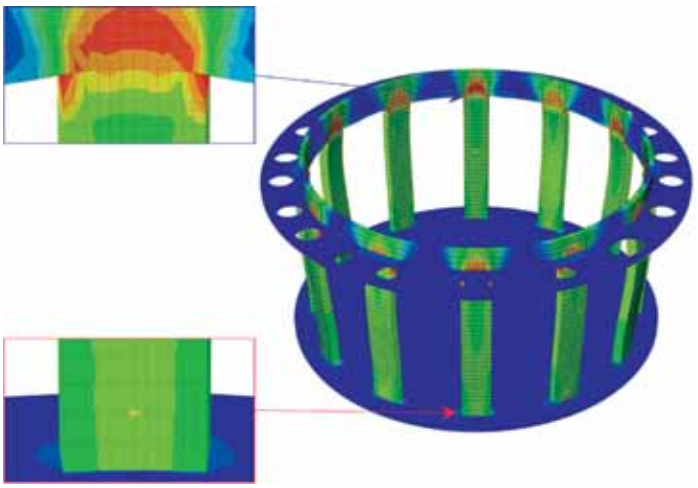


Fig. 3. A global analysis model with the actual crack distribution

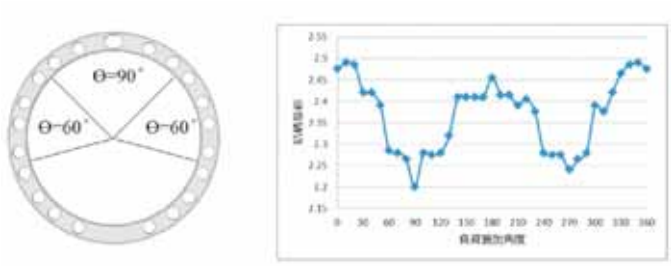


Fig. 4. Model verification

In the future, more modules will be involved in the program, such as fatigue and stress corrosion crack growth calculations to improve the function. Also, we will update the code requirements to meet the demands of NPPs. Using the program, the engineers of NPP can easily implement the evaluation for core shroud components with multiple cracks instead of complicated evaluation process of codes or standards.

3-1-12 Nuclear Safety!! Equipment Seismic Qualification Watcher - Seismic Testing Laboratory

Seismic qualification for safety related equipment used in nuclear power plants is one of most important measures to assure safe operation of NPPs. the qualified equipment can maintain its structural integrity and safety function during/after design earthquake, and achieve the goal of nuclear safety. The Seismic Testing Laboratory of INER has dedicated on the areas for years, through their efforts, hundreds of commercial grade items are qualified and used in NPPs, quality of these replaced equipment were watched and granted.


TAF

財團法人全國認證基金會
Taiwan Accreditation Foundation

Certificate of Accreditation

Institute of Nuclear Energy Research
Seismic Test Laboratory

is accredited in respect of laboratory

Seismic Testing Laboratory of INER

The Seismic Testing Laboratory (STL) is working under the Mechanical and System Engineering Program of the Institute of Nuclear Energy Research (INER) with emphases on advanced seismic engineering based testing and modeling for small to medium nuclear power plant equipment. STL was founded in 1994 for the demand of seismic dedication of the commercial grade items used in the existing nuclear plants.

• Certification

(1)Recognized by ROCAEC as : a seismic dedication organization in 1995.

(2)Accredited as a TAF test laboratory-TAF (Taiwan Accreditation Foundation) in 2003.

Seismic Qualification Process

In STL, testing of seismic qualification is conducted deliberately. All the test steps strictly followed the requirements of IEEE Std. 344, “IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations”, as well as other specific specification if required, also tests are performed according to QA procedures of the laboratory to control the quality of test results and reports.

Before testing, there are a lot of preceding work shall be accomplished, such as field inspection to make sure the installation of test specimen and fixture design, discussion with customer to confirm the Required Response Spectrum, and pretest to determine test wave, etc. The Seismic Qualification Process chart is shown in Fig. 1.

Projects in 2016

•Seismic Qualification-

(1)Accomplished：Printed Circuit Boards of SSILS system and Diesel Generator(shown in Fig. 2 and Fig. 3)，battery module and host cabinet of seismic monitoring system.

(2)Undergoing：shaft of screen wash pump、4”and 16”butterfly valve (by analysis)，MCC，air breaker.

•Pattern Appling-Rotatable fixture for shake table Test (Fig. 4), apply file No. 105140122, R.O.C.

•TAF Certified Test Laboratory Sustain-Completion through audit by TAF on May.

Fig. 1：SQ process Chart

Fig. 2：PCB of D/G in field

Fig. 3：PCB SQ Test on Shake Table

Fig. 4：Rotatable Fixture

Fig. 5： Certificate

Pattern-acquired

• 「Accelerometer insulation seat」, No.I510785, Republic of China, 2015. (Certificate shown in Fig. 5)

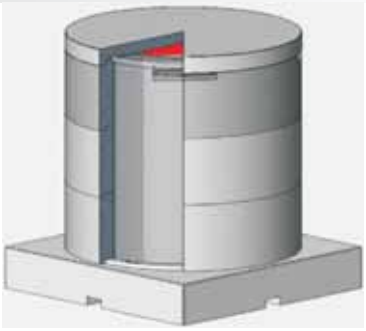
Collateral Contribution

In addition to nuclear safety, the STL promote the opportunity of choosing local industrial products as replace items by domestic nuclear power plants, since it is more cost-effective and time saving. This benefit will give the domestic industry has other growing space.

Other Seismic Related Research

Test and analysis are two major methods of seismic qualification, so not only the test skills but also the analysis technology are developed by the STL. In 2016, a computing program using MatLab software to calculate In-Cabinet Response Spectrum was developed. And a PWR containment model was built for soil structure interaction reanalysis by using SASSI program.

3-1-13 Apparatus for Verifying the Integrity of the Confinement Boundary of a Spent Nuclear Fuel Dry Storage Canister in Operation



Because of the stress corrosion cracking (SCC), the confinement boundary of the transportable storage canister (TSC) would be damaged and lose its integrity. Due to the structure of the dry storage system, no existing inspection method can be used to verify its integrity in storage operation.

The proposed method can effectively verify the integrity of the confinement boundary without affecting the storage safety and costing too much resource. With proper inspection span, the proposed method can detect the damage of the confinement boundary in the early phase and prevent the degradation of the nuclear spent fuel cladding and the leakage of the radioactive materials to assure the storage safety.

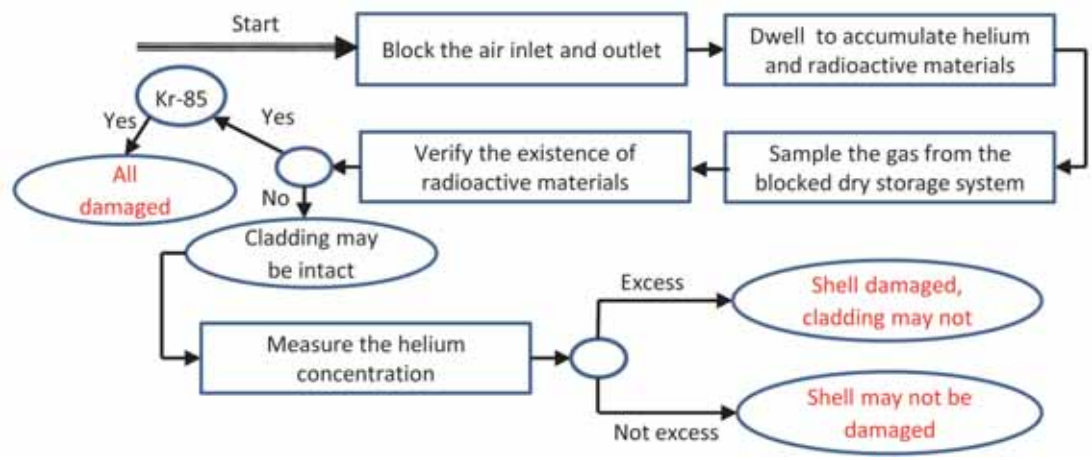


Fig. 1 Flowchart of the proposed inspection method

The proposed method blocks the air inlets and outlets of a dry storage system to stop the natural convection to raise the temperature of TSC and force the helium and fissile gases (if existing) inside the TSC to leak out through the damage (if existing). Then, sample the gas inside the dry storage system and examine whether it contains fissile gases and measure the helium concentration to verify the integrity of the confinement boundary. Fig. 1 and Fig. 2 are the flowchart of the proposed method and the depiction of how to block the natural convection of a dry storage system respectively.

Fig. 2 Blocking the natural convection

Electronic Acknowledgement Receipt	
EFS ID:	23830921
Application Number:	14887498
Confirmation Number:	1480
Title of Invention:	Apparatus for Verifying the Integrity of the Confinement Boundary of a Spent Nuclear Fuel Dry Storage Canister in Operation

Fig.3 The patent information

Based on the reports issued by US NRC, there is no creditable test and inspection method can be utilized to verify the integrity of the confinement boundary. The proposed method not only can solve this problem but also has great potential in profit. Currently, the proposed method is patent granted (patent number: I 572854) in Taiwan and patent pending in the US. The patent information are shown in Fig. 3. Besides, the proposed method was granted the INER R&D reward in 2016.

The proposed method can effectively detect the damage of the confinement boundary caused by SCC in four-hour testing. Even the dry storage system has operated for 120 years, this would not reduce its effectiveness. Fig. 4 is used to explain why its effectiveness would not be damaged.

Current existing methods or the ones in developing cannot detect the damage of the confinement boundary caused by SCC in its early phase, but the proposed one does. Its effectiveness has been confirmed through a verification test. The verification test result is shown in Fig. 5.

	Storage duration (year) Reference value:5.2						
Residual helium in TSC(%)		20	40	60	80	100	120
	100	32.60	27.70	21.47	19.58	17.91	16.47
	80	27.12	23.20	18.22	16.71	15.36	14.21
	60	21.64	18.70	14.96	13.83	12.82	11.96
	40	16.16	14.20	11.71	10.95	10.28	9.71
	20	10.68	9.70	8.45	8.08	7.74	7.45

Fig. 4 Helium concentration of the sampled gas

The effectiveness of the proposed method has been confirmed. Making it easier to use and promoting it to the users, vendors, and authority agents will be the efforts in the future.

Reference value: 5.2

Test item	Test method / instrument	Test result	Detection limit	Unit
Helium	Gas chromatograph	32	10	ppmv

Fig. 5 Verification test result

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

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

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

In the energy saving technology, in order to take the NIR-blocking effect, the Ag-doped transparent conductive oxide (TCO) is applied in the structure of energy-saving electrochromic glass. Electrochromic glass reduce energy consumption up to 20%, and often reduce the size of the HVAC system required for the building. We have also integrated the wireless control function to the electrochromic glass. Occupants can remotely use the mobile app to fine tune tint zones for specific lighting effects from anywhere in the building—so they can control the status of the glass no matter where they are. Customized light-zoning strategies can be developed through the use of dynamic control following the climate conditions so that occupants can always strike the ideal balance between comfort and interior lighting.

The CO_2 reduction technology has been developed for several years in INER . Furthermore, the CO_2 capture systems with different kW level were investigated to fit for varied conditions of CO_2 capture. In 2016, the INER's CO_2 capture system have applied on the recycling industry of plastic waste. The result indicates the CO_2 removal efficiency can be achieve above 90% of international indicator, under the stream condition with CO_2 concentration 10-40%. The "CO_2 capture techniques" in INER have been planed to cooperate with domestic environmental industry, and develop the technologies of recycling and reusing of the coal, bio-mass and organic waste. The gas stream resulted from the gasification of organic waste can be used for CO_2 capture and be separated/purified to produce the syngas with high economic value. However, the "CO_2 capture techniques" have actually been used for the cycling of organic waste, the efficiency of resource reuse can be remarkably enhanced and beneficial to environment sustainability.

Moreover, we have long committed to develop biorefinery technologies. Cellulosic ethanol and cellulosic lactic acid production have reached the leading-edge of technology globally. Currently, we have signed a technology authorization agreement with domestic industry. It is planned to build the first biorefinery plant in Taiwan to approach the vision of localizing this innovative industry in the homeland. The plant will be located in the Chianan Plain, southwest part of Taiwan. Meanwhile, our institute is planning to assist domestic start-up companies to develop cellulosic biorefinery industry in ASEAN (Association of Southeast Asian Nations) region, strengthen along with our previous technology patent layout in Southeast Asia. We were proud that the biomass depolymerization technology and its various applications of INER's biorefinery process had been awarded the 13th National Innovation Award months ago. It demonstrates our biorefinery technology possessed innovative contribution and strong economic competitiveness.

In the aspect of developing distributed power systems and intelligent control technologies, we had helped Taipower Company(TPC), Penhu County Government, etc. to plan and build intelligent

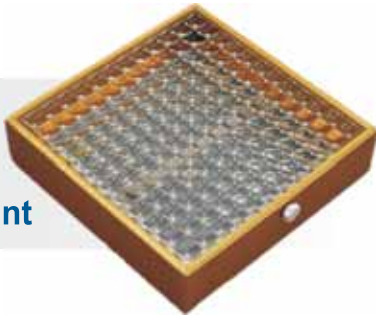
microgrid in 2016, including: (1)to transfer the management and control technology of intelligent energy source to Controlnet Co., as well as to cooperate with TPC to build a "preventative microgrid " in Fushan Community of Wulai, New Taipei City; (2)to cooperate with Tatung Co. to build an "18kW preventative microgrid " in Wulai District Office; (3)to cooperate with Chung-Hsin Electric and Machinery Mtg. Corp. to build an off-shore islanded microgrid in Dongji, Penghu. The patent, cascaded battery energy storage system technology, won the gold medal in the 2016 Taipei International Invention Show & Technomart, and the excellence award of the Research and Development Result Show and Business Innovation Competition in 2016 INER anniversary celebration. Moreover, the paper entitled "Design of Resiliency Control and Reliability Analysis of Microgrid" won the best paper award in the 37th Electrical Power Engineering Seminar.

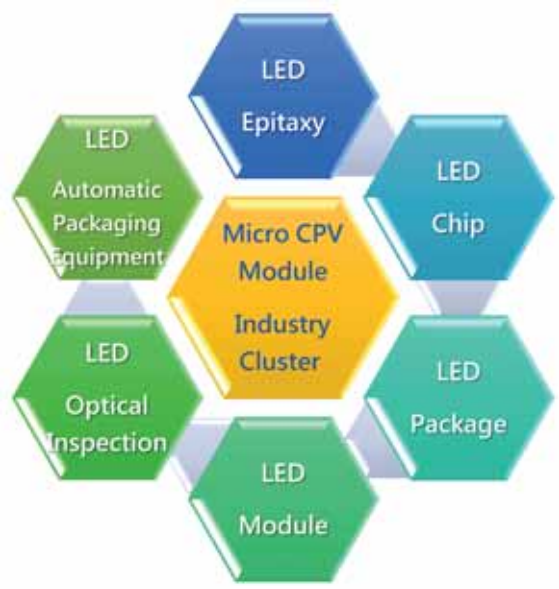
Currently, there is no public available tool for energy security and risk analysis in Taiwan, INER establishes an energy security information platform. The Energy Security Web provides an online energy security information platform for professionals or interested users, and provide flexible combinations of index and weighting. The Energy Security Information Platform is designed to provide a flexible index combinations and weight assignments that allow users to define and establish their own energy security index. Energy Security Information Platform has built a set of major energy, economic and environmental data of Taiwan, which will be regularly updated. In the future, the energy security risk index data analysis, energy model, economic model and social intentions survey will be integrated for providing energy and economic strategy recommendations.

In addition to the energy security information platform, our institute and the MIT JP (MIT Joint Program on the Science and Policy of Global Change) jointly develop the first global CGE model for environmental-policy simulating purpose in Taiwan since 2016, which was named Projection and Policy Analysis (EPPA) -Taiwan. At the same time, INER cultivates human resources for CGE-modeling capabilities that are valuable and rare in Taiwan.

The United Nations raised Sustainable Development Goals(SDGs) to integrate the efforts from member states and organizations to deal with desperate issues we are facing with. Most of them linked to the advanced development and use of energy to preserve a sustainable future. We, as a national research institute, are in a position taking the responsibility to catch the international focuses and trend in both energy and environment, helping our country get involved the global effort in resolving the mutual and imminent critical problems.

3-2-1 Micro-CPV Module Process Technology with Cross-cutting Integrating LED Packaging Technology for Low Carbon Footprint





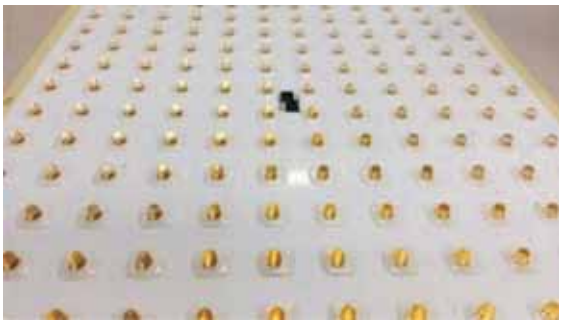
Micro-CPV Module
Combined with LED Industrial Settlement

In view of increasing global warming and serious air pollution, renewable energy has become the focus of recent energy development, in which solar photovoltaic is one of the most important renewable energy options.

Institute of Nuclear Energy Research (INER) has long been committed to dig into III-V solar energy (Concentration Photovoltaic, CPV) power generation technology. At present, the innovative micro-CPV module is invented with advantage of light weight by improving modular components and reducing the usage of materials to cut transportation and system construction costs. In addition, automated LED packaging process is introduced in order to establish the mass production line to facilitate quality control and achieve three high benefits: high productivity, high repeatability and high reliability. In particular, Taiwan has the world-class LED industry with matured LED manufacturing technology which will implement the goals of reducing the micro-CPV module production costs and carbon emissions.

INER micro-CPV module is featured with the indoor photoelectric conversion efficiency 35.15%, optical zoom ratio 1,100 times, the optical angle tolerance±0.7° carbon footprint 24.47g/kWh in the life cycle, which is the lowest in all kinds of photovoltaic modules.

At present, the energy recovery period of micro-CPV module is about 0.5 years, which is less than half of the silicon solar panel, and the module cost is about 0.6 USD / W, which can compete with the traditional silicon products in short term.



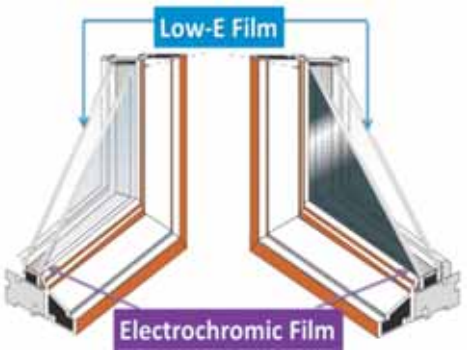
Module Receivers with Highly
Automated Packaging Technology

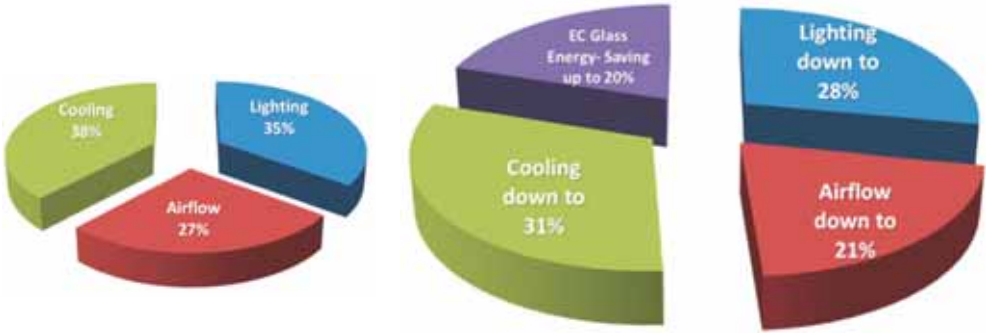
INER is in efforts to get on the industrial promotion, hoping to help Taiwan develop CPV local industrial settlement and endow the LED industry with new opportunities for the ultimate goal of creating job opportunities and raise the domestic energy self-sufficiency.

- The technology derived from the invention has a total of four patents, of which two have already acquired the invention patents from the United States ;
- Awards granted in 2016 Taipei International Invention Exhibition.

3-2-2 Energy-saving electrochromic glass with the NIR rejection function even in the bleached state

To increase the efficiency of energy use for buildings is one of the key factors to facilitate the transition to an era of renewable energy. The implementation of electrochromic glass in the form of smart windows that dynamically modulate solar light and heat flux penetrating through it could significantly decrease the energy consumption of buildings. According to previous studies, electrochromic glass reduce energy consumption up to 20%, and often reduce the size of the HVAC system required for the building.

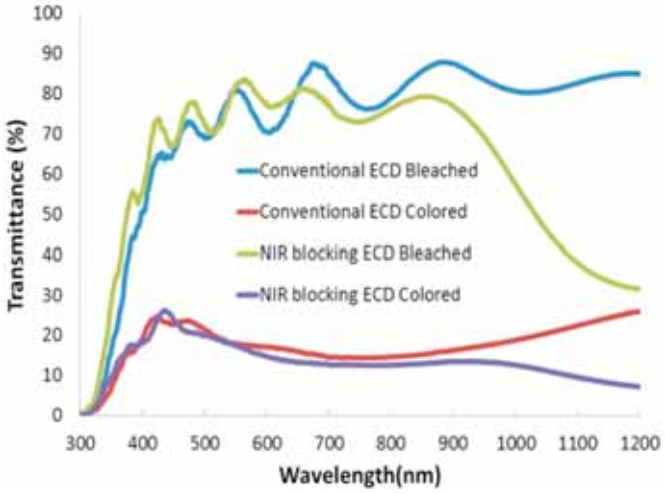




Electrochromic glasses reduce energy consumption up to 20%

Regarding the previous research of energy-saving electrochromic glass, spectral selectivity, that is, independent modulation of visibility and near-infrared (NIR) radiation, is still considered the key factor for reducing the energy needed to light up and regulate building interior temperature.

In order to take the NIR-blocking effect, the Ag-doped transparent conductive oxide (TCO) is applied in the structure of energy-saving electrochromic glass. The all-solid-state ECD could potentially modulate the optical transmittance between 81.9% and 17.5% at 550 nm in the visible region and between 38.0% and 9.5% at the NIR wavelength longer than 1100 nm.

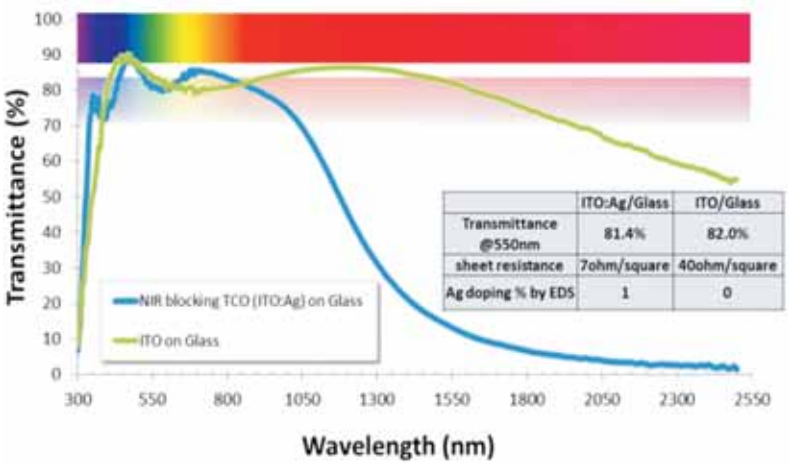


Energy-saving electro chromic glass with the NIR rejection function even in the bleached state.

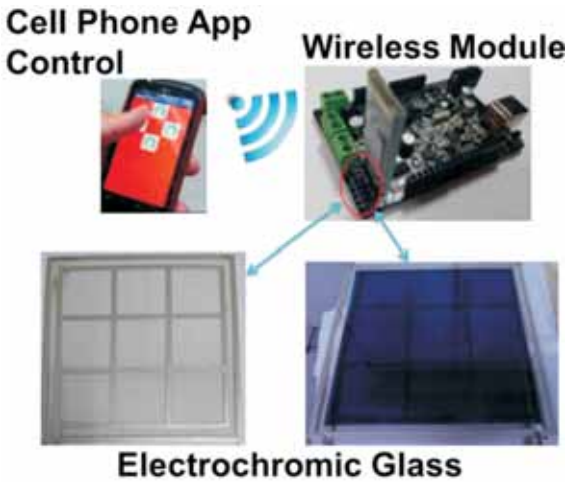
Structure	SHGC	Transmittance (at 550nm)			Transmittance (at 1100nm)		
		colored	bleached	ΔT	colored	bleached	ΔT
Conventional ECD	0.82 0.27	18.0%	80.6%	62.6%	22.5%	82.7%	60.2%
NIR blocking ECD	0.61 0.26	17.5%	81.9%	63.4%	9.5%	38.0%	28.4%

Detailed comparison of the conventional and NIR –blocking ECD devices performance.

With the application of ECDs, it is possible to directly apply the device onto energy-saving glass with the NIR rejection function even in the bleached state. The resultant energy-saving electrochromic glass demonstrates an unrecognized optical switching behavior that will enable the dynamic control of solar radiation penetrating through the glass and further achieve higher energy-saving efficiency. Furthermore, the NIR-blocking TCO with the low sheet resistance and high transparency characteristics also provides the lower power consumption for large area applications in the switching cycle.



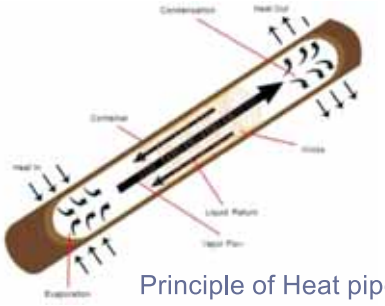
Comparison of transmittance spectra and sheet resistance between ITO and NIR blocking TCO coated on glass substrate



Mobile app to fine-tune tint electrochromic glass for specific lighting effects from anywhere in the building.

For the application of smart energy-saving buildings, INER has also integrated the wireless control function to the electrochromic glass. Occupants can remotely use the mobile app to fine tune tint zones for specific lighting effects from anywhere in the building—so they can control the status of the glass no matter where they are. Customized light-zoning strategies can be developed through the use of dynamic control following the climate conditions so that occupants can always strike the ideal balance between comfort and interior lighting.

3-2-3 Development of Heat Pipe Technology for Industrial Waste Heat Recovery



Principle of Heat pipe

According to the survey of waste heat by TIER for various industries, there are about 1.66 million kiloliters oil equivalent of heat discharged totally in Taiwan. Around 46% of them is from 150 to 300 °C and worth to recover. However, 40% of them is below 150 °C and mainly exists in the flue gas from the industrial furnace. It is difficult to recover and may result in a dew point corrosion problem. To recover the available energy from waste heat, INER has developed a smart heat pipe waste heat recovery system for incinerators and furnaces. The system is compact, highly efficient, anti-corrosive, anti-ash-blocking, with smart thermal management ability and manufactured locally. Hence, the problems of recovering low-grade waste heat below 300 °C faced by industries are solved and the goals of energy saving and carbon reducing are achieved.

	Chemical industry	Basic Metals industry	Non-metallic mining	Food industry	Textile industry	Paper industry	Electric industry	Others	Total
<150°C	401,939	21,006	111,153	7,038	31,707	34,603	50,015	2,966	660,428
151°C to 200°C	159,198	35,723	287,73	42,441	21,807	85,413	20,714	3,574	397,643
201°C to 250°C	55,721	4,150	113,933	7,483	-	-	1,697	806	183,789
251°C to 300°C	10,909	150,159	-	-	-	-	-	32,626	193,693
301°C to 400°C	0	94,847	-	-	-	-	-	-	94,847
>400°C	9,106	119,209	-	-	-	-	-	1,275	129,590
Sub-total of industry	636,874	425,094	253,859	56,962	53,514	120,016	72,425	41,247	1,659,990
Industrial waste heat accounted for	38.4%	25.6%	15.3%	3.4%	3.2%	7.2%	4.4%	2.5%	100.00%

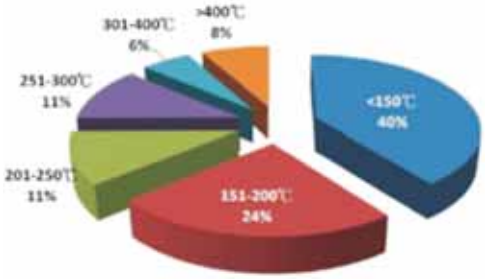
Unit: Kiloliter oil equivalent

Source: "Investigation of District Energy Integration and Suggestion about Policy", Taiwan Institute of Economic Research (TIER), 2011

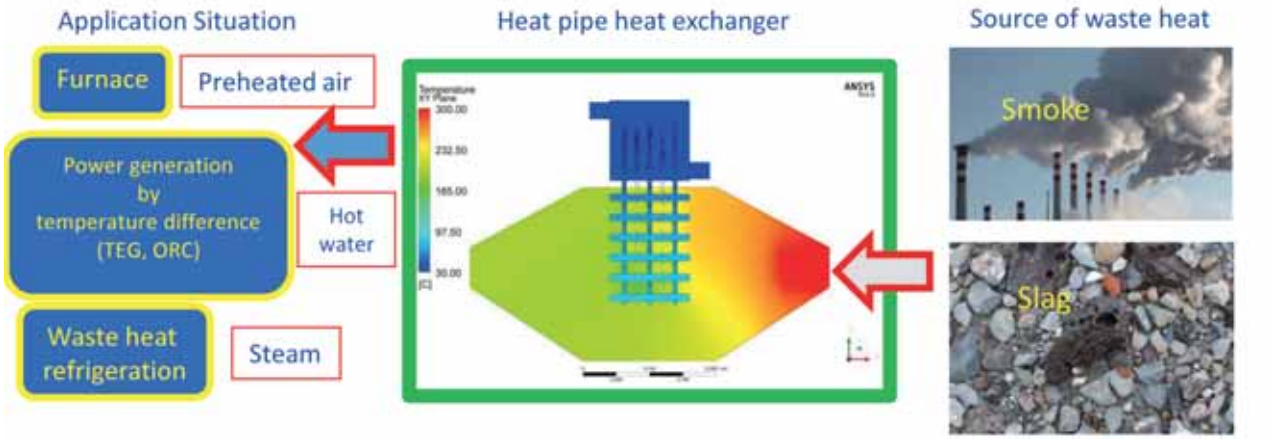
Waste heat of various industry for different temperature ranges in Taiwan

For the development of highly efficient heat pipe heat recovery technology by INER, SUS316L is used for the shell material and deionized water for the working fluid. The outer surface of the heat pipe is coated with corrosion-resistant film by plasma to enhance the protection against dew-point corrosion and reduce corrosion current. Furthermore, the porous zeolite film in the inner surface of heat pipe stronger the capillary force and boiling heat transfer. The thermal resistance is lower to 0.07 K / W, so the equivalent thermal conductivity is better than copper nearly 380 times. Heat transfer coefficient> 19 kW / (m^2· K), and heat flux> 190 kW / m^2. They are better than the industry standard.

The heat from 150 to 300 °C accounted for 46 % of total is worthy recovery. Below 150 °C accounted for 40%, is difficult to recover.

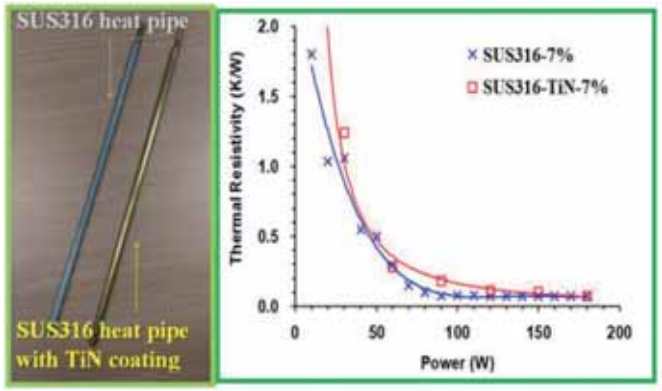


The portions of industrial waste heat in different temperature range

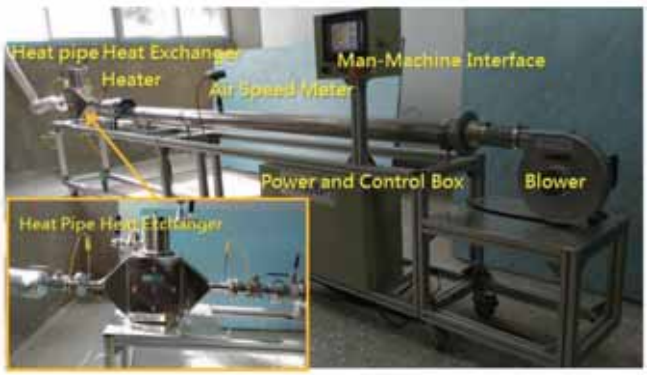


Smart heat pipe waste heat recovery energy saving system

INER develops the heat pipe heat exchanger to recovery a large amount of industrial waste heat. For effective utilization, the waste heat is adopted for preheating the air of combustion furnace, or generating hot water to supply thermoelectric generator or organic Rankine cycle system for electric power, or producing low pressure steam to drive absorption refrigerator for chilling water. For the case that waste heat refrigeration technology is used in waste plastic cracking system, the condenser chilling water is produced with waste heat and without additional power so the temperature of oil vapor condensation is lowered and the production capacity is increased effectively. The economic analysis results show that the production capacity is improved at least 10%, and the capital investment can be paid back in one year.



Heat pipe and performance curve



Heat pipe heat exchangers and testing platform

Future Work

- Further Development of Smart Heat Pipe Energy Saving Key Technology for Waste Heat Recovery.
- Field Verification Test of Heat Pipe Heat Exchanger Technology for Waste Heat Recovery .
- Development of Sorption Refrigeration Technology, Refrigeration Temperature 7~12 ° C.
- Development of Microencapsulated Phase Change Thermal Storage Building Material Technology.
- Research and Development of High Efficiency Active Controlled Air Heat Exchange Technology for Improving Air Heat Transfer by Plasma Drive Technology.
- Development of High Efficiency Low Temperature Drying Technology for Energy Saving and Environmental Protection.

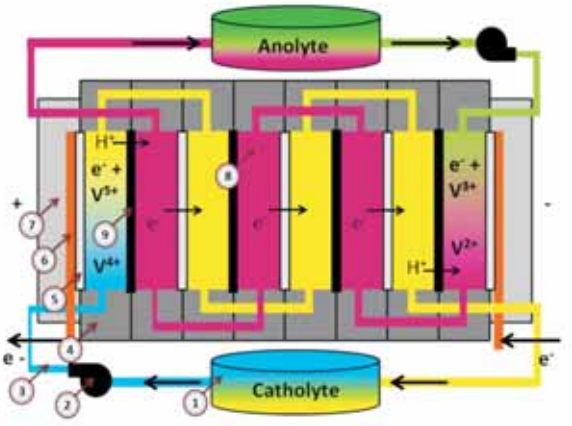
3-2-4 Develop the key technologies of VRBF to build up Taiwan's energy storage industry

Development of renewable energy is the major solution to respond our energy policy. Government has set the mix power generation targets in 2025 with the constitution of 50% from gas, 30% from coal, and 20% from renewable energy where the solar photovoltaic(70%) and offshore wind power(15%) play the two major pillars. However, the electricity generated from these renewable sources is intermittent and unstable. Therefore, the efficient electrical energy storage(ESS) devices are needed for effective delivery of uninterrupted electricity and load leveling as well as grid energy storage. To fit the needs, a design of vanadium redox flow battery(VRFB) has been investigated as an ideal and effective electrical energy storage device for renewable energy for its superb performance in energy efficiency, storage capability, safety and lifetime. Its cell consists of proton exchange membranes, electrodes, bipolar plates and flow channels on each end. Groups of cells are stacked up that can be connected to make systems, and then integrated to become a network.

Development of vanadium redox flow Battery at INER.

This research focuses on electrode, separator, and electrolyte advancements with an attempt to improve power density and lower stack cost of the VRFB. The design and engineering of the cell stack and the whole system in general is critical to improve the performance and economy of redox flow battery technologies.

The operational efficiency of the battery determines the operating cost of the system. On the other hand, lower cost membranes are under development and will soon be available for further improvement.

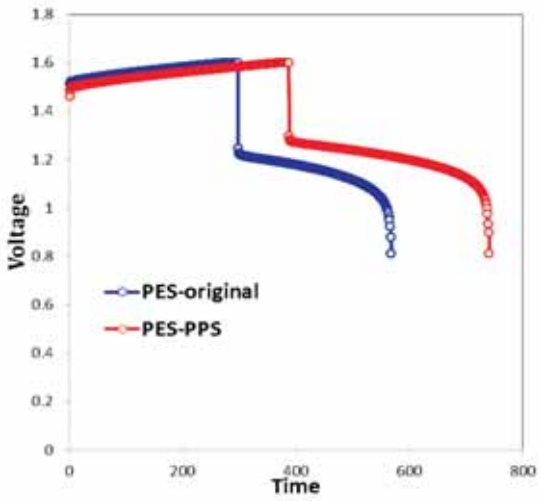


VRFB Charging Schematic Diagram.
(Li et al., Adv. Energy Mater. 1, 394–400, 2011)

2016 Flow Battery Technology Development Forum.

The "2016 Flow Battery Technology Development Forum" hosted by INER and Bureau of Energy, Ministry of Economic Affairs, was held in November, 2016. This Forum created a new opportunity for Taiwan's energy storage industry and to concentrate on the R&D of key components. It was for the development of related industries to cope with the target of national energy policy in stressing the role of renewable energy.

To look into the process, Polystyrene sulfonate (PSS) with sulfonate is reacted with the polyethersulfone (PES) porous film by atom transfer radical polymerization. The $-SO_3^-$ groups are grown on the PES film surface and pores to increase hydrophilicity and conductivity, thereby improve the charge-discharge energy efficiency. The Coulumbic efficiency, voltage efficiency and energy efficiency of the VRFB with hydrophilically modified PES porous films are 7, 4.6 and 9.5 % higher than with the pristine PES membrane, respectively. Hydrophilic groups can reduce the vanadium ion permeation due to cover the pores of PES porous films to increase the Coulombic efficiency and voltage efficiency.



Charge-discharge curves for VRFB with PES and modified PES membrane.

Fig 5. Projection of 5 kW VRFB system installation process until June 2018.

The design of the system is optimized so as to minimize the shunt current that is created as a result of the voltage difference over different cells and to improve other performance parameters in order to reduce the overall system cost. The differences between components in operational and self-discharge characteristics have been studied. In the future, a battery module will be operated through an optimized 3D peripheral system planning to monitor the impacts of various experimental parameters on the battery performances.

3-2-5 To mitigate the global warming: finding treasure from carbon reduction-CO2capture technology

Since the industrial revolution in the eighteenth century, the concentration of carbon dioxide(CO_2) increases gradually, leading to greenhouse effect risk that is an important issue for human being. To reduce CO_2 emission is the only resolution to mitigate the greenhouse effect. Recently, the government claims fully support the "innovative green energy technology". Except for the alternative energy(eg. wind, solar power, bioenergy et al.), the reduction and recycling of carbon also are parts of "green technology". Many advantages of "carbon recycling aspect"can be expected, including enhancing autonomous energy, in dealing with climate change, CO_2 emission reduction, recycling and waste source reusing. The "CO_2 capture techniques"of INER have been planed to cooperate with domestic environmental industry, and develop the technologies of recycling and reusing of the coal, bio-mass and organic waste. The gas stream resulted from the gasification of organic waste can be used for CO_2 capture and be separated/purified to produce the syngas with high economic value. However, the "CO_2 capture techniques"have actually been used for the cycling of organic waste, the efficiency of resource reuse can be remarkably enhanced and beneficial to environment sustainability.

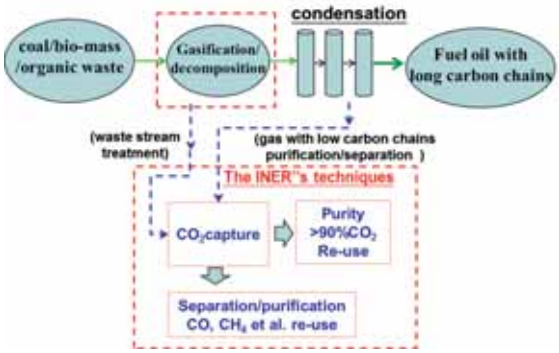
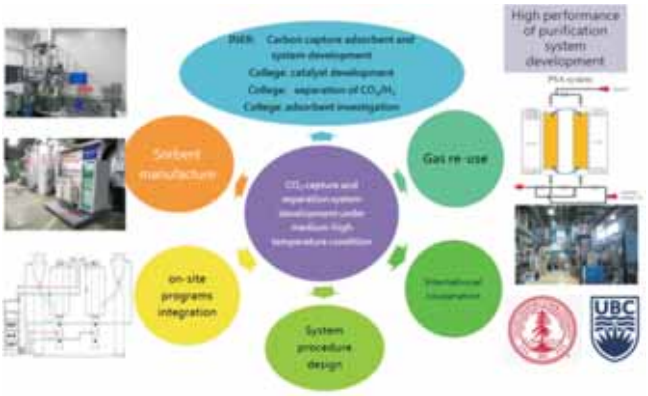
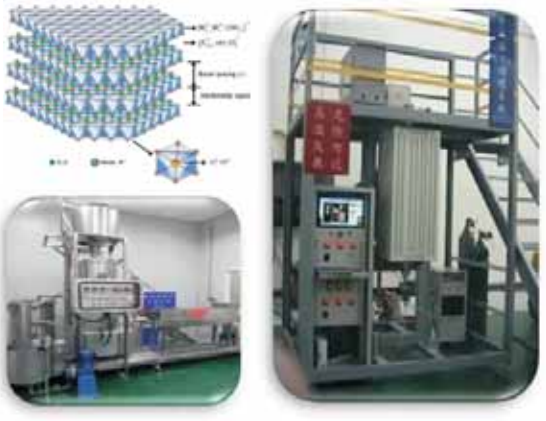


Fig.1 Schematic diagram of carbon capture and recycling.



The INER-led strategic alliance of carbon reduction.

The INER's CO_2 capture technique develops simple co-precipitation manufacture to synthesize novel Ca/Mg/Al nano-layered structure with high ionic dispersion. The novel carbon capture sorbent with nano-layered structure can obtain excellent stability under CO_2 capture looping, that is the carbon capture programs most needed (the"stability"denotes the performance of sorbent under the cyclic looping of CO_2 adsorption/desorption) . Furthermore, the CO_2 capture systems with different kW level were investigated to fit for varied conditions of CO_2 capture. In 2016, the INER's CO_2 capture system have applied on the recycling industry of plastic waste. The result indicates the CO_2 removal efficiency can be achieve above 90% of international indicator, under the stream condition with CO_2 concentration 10-40%.



Manufacture technique　　Carbon capture system

The kg-grade CO_2 sorbents manufacturing system and the CO_2 capture reaction platform developed by INER.

A short list of the CO2 capture-related patents and certificates of merit owned and acquired by INER.

The Ca/Mg/Al nano-layered structure has high stability for carbon capture looping, as compared to other Ca-series sorbent. For long term test of 100 hour capture cycling, the performance of Ca/Mg/Al sorbent can keep the removal ratio above 90%, obviously higher than other Ca-series sorbent. The sintering of structure results in the decline. The Ca/Mg/Al sorbent overcomes the sintering problem, leading to the stable capture performance. Recently, our group devotes to share the carbon reduction technology to industries. The integrated system consisting of Ca/Mg/Al sorbent and capture reactor have been applied on the bio-mass gas, simulated syngas and flue gas. The result indicated most of CO_2 can be removed under different stream conditions.

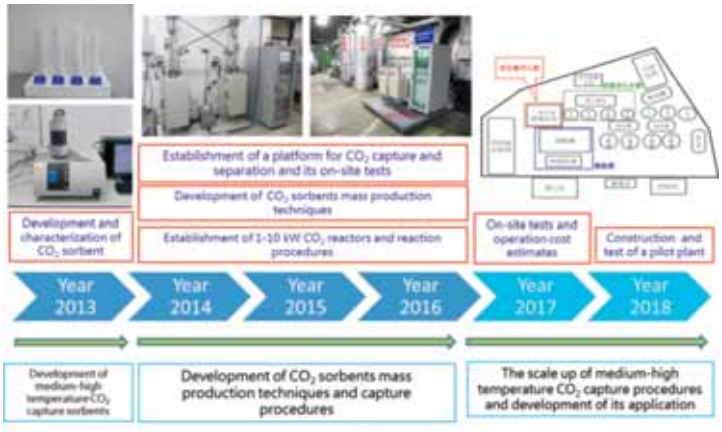
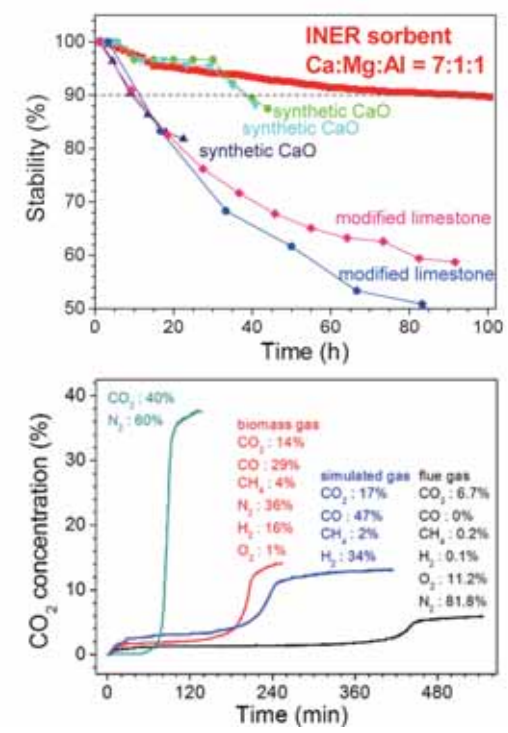


Fig. 6 The road map of development of CO_2 capture technology by INER.

The CO_2 reduction technology has been developed for several years in INER. We possessed several patents of Taiwan and USA related to CO_2 capture materials. In addition, we won a silver award in Taipei int'l invention show & technomart and an award for outstanding performance in 2015 International Symposium on Carbon Reduction Technology that had promoted global partnerships and indicating our research achievements being influential.

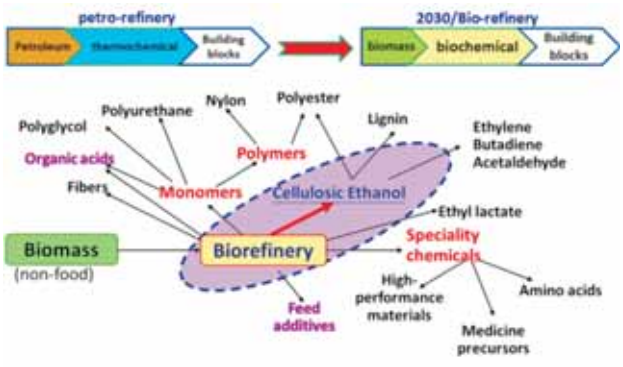


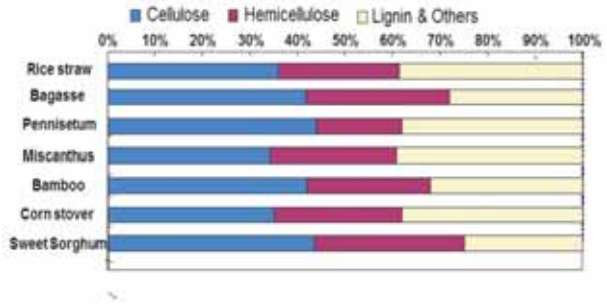
Comparison of long term stabilities of CO_2 sorbents invented by INER and other groups; and the CO_2 removal ratio of our sorbents in various atmosphere.

Since 2014, our group have actively interacted with domestic industry to discuss the possibility of carbon capture application on the established process. The cooperation between INER and industry is ongoing till today. We plan to help industry building the prototype of carbon capture module. The test model would be beneficial to the development of carbon capture technology. In the future, industries using coal boiler and fuel gas boiler will be encouraged to apply INER's carbon capture technique.

3-2-6 Biorefinery development rooted in Taiwan shed the light on green innovation industry!

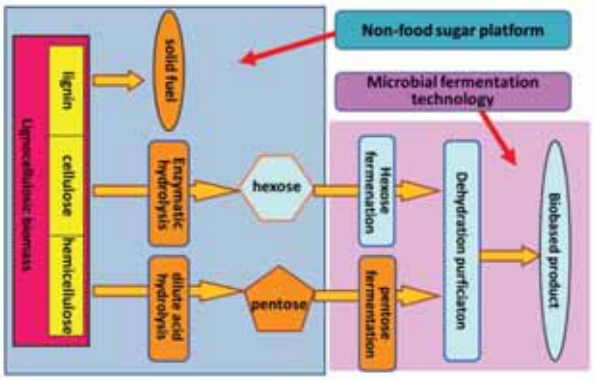
Under the impact of global climate change, world's major economies have been promoting initiatives to promote bio-economy development, aiming to improve human health and promote environmentally sustainable growth by making full use of green processes and renewable resources. Instead of petro-chemical refinery, biorefinery utilizes sustainable biomass as resources to produce bio-based chemicals and bioenergy, such as biofuels, power, chemicals, and foodstuffs of similar use. Because of the potential benefits on the reduction of oil dependence and greenhouse gas (GHG) emissions, biorefinery is considered to be the core industry and the future of bioeconomy. To avoid the competition with food crops, non-food lignocellulosic biomass such as rice straw, sugarcane bagasse, napiergrass and woody residues are preferably used, these are some of the domestic natural resource like wind and solar power that can be mastered and ought to be utilized to its greatest potential. In order to pursue the security of energy independence, sustainable environmental and economic growth, our research team has dedicated to the development of nonfood-based biorefinery technology in recent years. Significant achievement has been reached and it helped to accelerate the commercialization of innovative technologies and the maturity of domestic biorefinery industry.





The concept of biorefinery and the typical of non-food lignocellulosic biomass

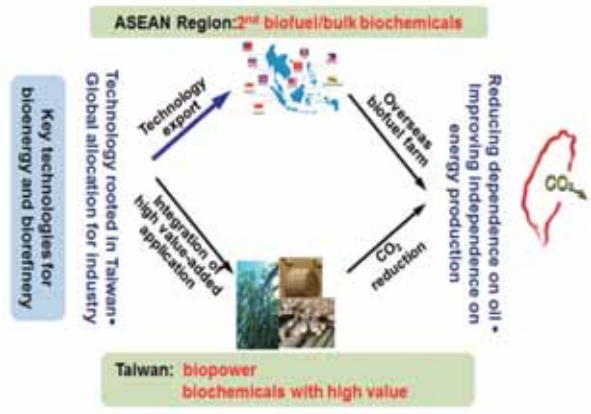
The biorefinery technology of INER is based on mild condition of chemical and biochemical process. In this typical process, tough structure of biomass material is first subjected to dilute-acid catalytic depolymerization and enzymatic hydrolysis to release the glucose and xylose from cellulose and hemicellulose. Recombinant micro-organism and product purification technology are then applied to convert sugars into various products of biofuel or bio-based chemicals with different applications, such as bioethanol, lactic acid, fatty acid and xylitol. The remaining lignin residue can further be used for electricity generation or other byproduct production. Clearly, INER's biorefinery technology is a green process that can make full use of each composition of lignocellulosic material.



Biorefinery technology at INER

The biorefinery team members of INER in the scene of the 13th National Innovation Award

INER has long committed to developing biorefinery technologies. Cellulosic ethanol and cellulosic lactic acid production have reached the leading-edge of technology globally. Moreover, by using the biorefinery pilot plant facilities, INER has established the cellulosic lactic acid production process,and the production yield and optical activity of both L-form and D-form of lactic acid can be up to 90% and 99% respectively. This result has met the threshold of commercialization application. In addition, synthesis technology of lactide and polylactic acid(PLA) polymerization of molecular weight above 100 thousand have also been developed in order to provide assistance to related domestic industry for establishing self-owned technology with different specifications production. Hence this will be able to enhance competitiveness of domestic PLA bioplastic industry。



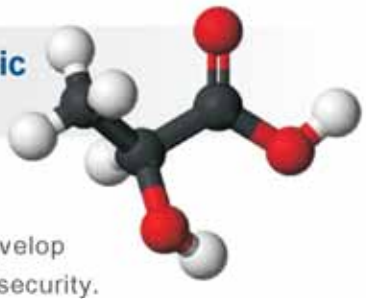
Biorefinery industry promotion strategy by INER

Currently, INER has signed a technology authorization agreement with domestic industry. It is planned to build the first biorefinery plant in Taiwan to approach the vision of localizing this innovative industry in the homeland. The plant will be located in the Chianan Plain, southwest part of Taiwan. Meanwhile, INER is planning to assist domestic start-up companies to develop cellulosic biorefinery industry in ASEAN (Association of Southeast Asian Nations) along with INER previous technology patent portfolio in Southeast Asia. We are proud that the biomass depolymerization technology and its various applications of INER's biorefinery process had been awarded the 13th National Innovation Award a few months ago. It demonstrates INER's biorefinery technology possessed innovative contribution and strong economic competitiveness.

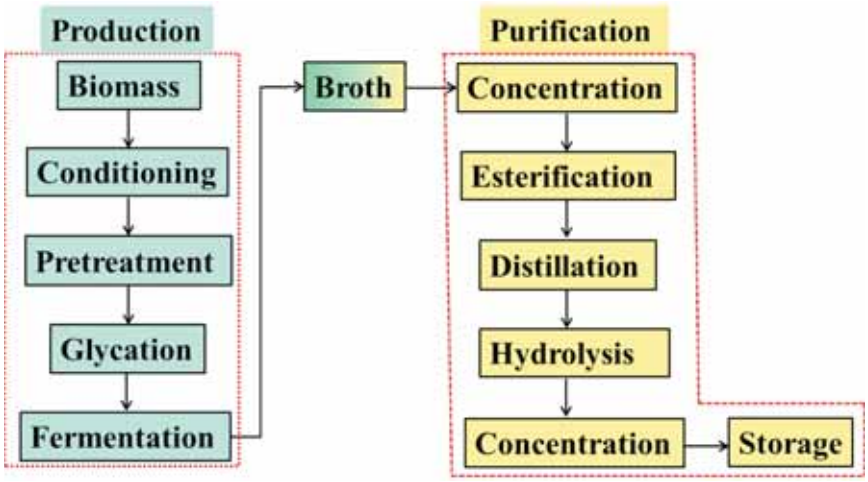
The finished and semi-finished products in the process of PLA production from lignocellulosic biomass

The biorefinery technology is now at the stage of technology transfer, in addition to the promotion of industrial development based on the principle of domestic priority but not limited to. INER will keep putting effort in assistance of domestic biorefinery demo-plant construction and hope to shed some light on local green innovation industry development. On the other hand, INER is also planning to assist domestic industry to enter the ASEAN region for biorefinery project participation, in correspondence with government' s New Southbound Policy. This could bring the benefit to domestic industry on the experience accumulation and offer the opportunities to the new market, achieving the ultimate goal of technology commercialization and industry globalization.

3-2-7 Process design for an efficient Lignocellulosic Lactic Acid purification procedure

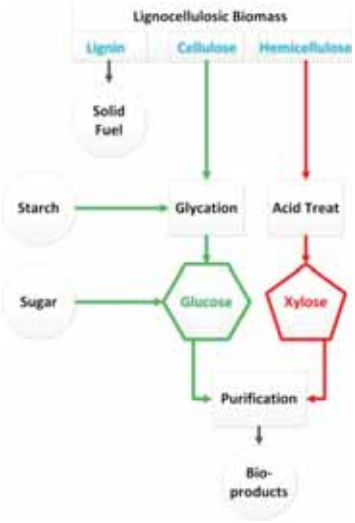


Nowadays, the main feedstock of bio-materials as one of the sources for renewable energy is starch and sugar. It is important to develop non-edible biomass feedstock bio-refinery process to improve the food security. Lactic acid is the product of the metabolic process. It is utilized as the ingredient in the cosmetic and food industries. Polylactide (PLA) is the polymer with lactic acid building block. PLA has the excellent mechanical properties and is biodegradable. We developed the lactic acid purification pilot plant with the capacity of 30 tons/day of wood feeding rate. The feasibility of the process has been demonstrated.



Production of Lignocellulosic Lactic Acid

The commercial lactic acid is produced by the fermentation process. During fermentation, the pH level of the fermentation broth is controlled by the calcium carbonate addition. After fermentation, the broth is mixed with the sulfuric acid to form the calcium sulfate precipitate. The precipitate is removed by the filtration. The solution with various content of lactic acid is produced by evaporation or distillation. Our team use the ammonia as the pH level adjusting agent and recycle the ammonia after the fermentation process.

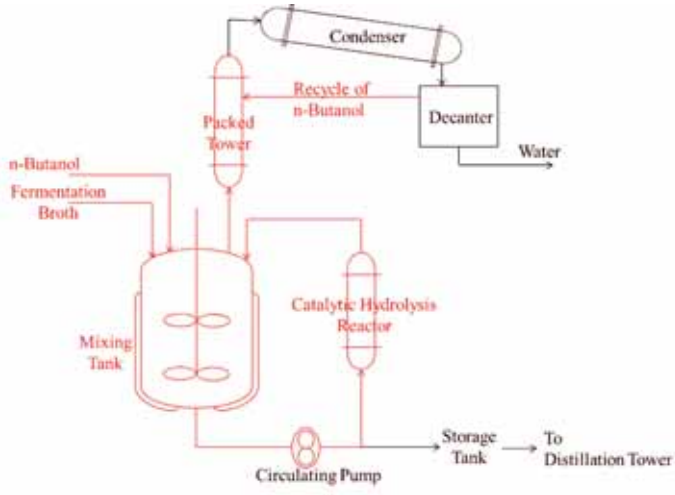


The Lactic Acid Production from Lignocellulose and Starch/Sugar Raw Materials (source: Chem. Div., INER.)

Esterification :
Lactic acid + Alkyl alcohol =
Alkyl lactate + Water
Hydrolysis :
Alky lactate + Water =
Lactic acid + Alkyl alcohol

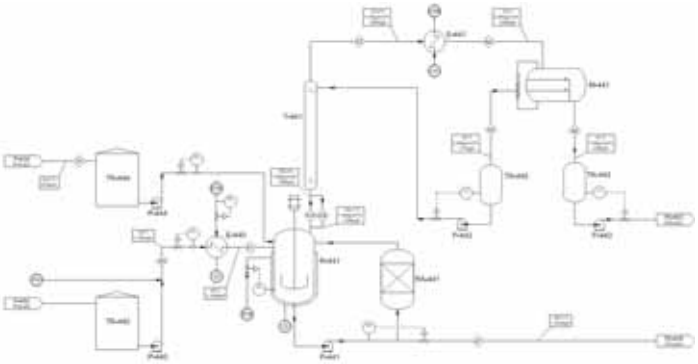
Esterifiction and Hydrolysis of Lactic Acid

With the improvement, the issue of the solid by-product disposal can be avoided. Lactic acid is the thermal sensitive material and is difficult to purify. We implement the esterification-distillation-hydrolysis procedure to overcome the issue. Lactic acid is esterified with n-butanol to form n-butyl lactate. The lactate is more stable than lactic acid. Therefore, the lactate can be separated from the broth by distillation. Furthermore, the specific product (water of the esterification or alcohol of the hydrolysis) is removed during the reaction by distillation. So the chemical equilibrium is toward the product end and the reactant conversion ratio is increased. The high concentration (> 90%) lactic acid can be obtained by this method.



Esterification Process of Lactic Acid and n-Butanol

The research team has devoted effort in the bio-ethanol technology development since 2005. In 2007, we carried out the bench-scale system with 10 kg biomass batch feeding capacity for the bio-ethanol process validation. In 2010, a pilot plant with 1 tons/day capacity was built up to demonstrate the feasibility. In 2016, a technology licensing agreement was signed between INER and a company from Malaysia.

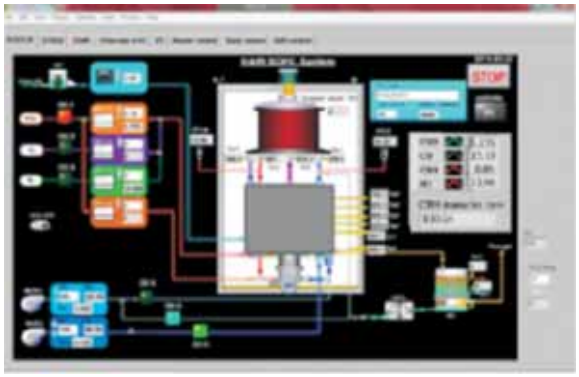


Hydrolysis Process of n-Butyl Lactate

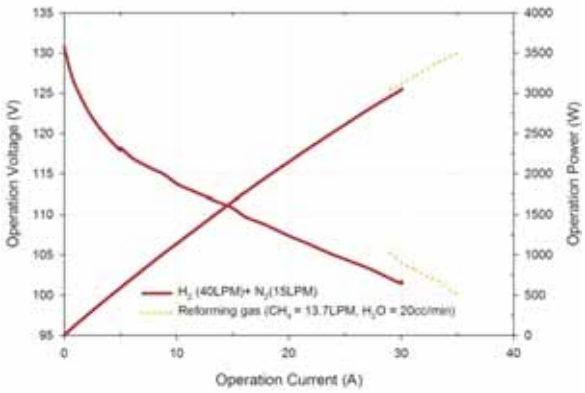
Now, the main driving force of the research in lignocelluloscic lactic acid is the rapid growth of demand from the market for PLA plastic. In addition, the domestic industries will be more competitive if they could manufacture the polymerization grade lactic acid and the local research institutes could provide the novel polymerization process for lactic acid. Therefore, we will extend the lactic acid related research to the field of PLA and fill the gap between results from the lab and the products the market needs with the associated knowledge for the process of scale-up.

3-2-8 Progress of SOFC technology development at INER

Solid oxide fuel cell (SOFC) technologies developed at the Institute of Nuclear Energy Research (INER) are being transferred to domestic companies. The events include (1) technology transfer for the fabrication of ceramic anode substrate supported membrane electrode assembly; (2) licensing the power system technology to increase the capability and broaden renewable energy spectrum; (3) technology transfer for the SOFC stack assembly; (4) technology transfer for the fabrication of metal supported cells.



Man-machine interface of a SOFC power system



I-V-P curves for a 3-kW SOFC power system

SOFC Power System

INER is currently developing a 3 kW SOFC power system. A pilot test indicates that temperatures on the stack and at the anode and the cathode inlets all exceed 700°C, sufficing the requirement of high-temperature operation conditions. Power output of the stack is higher than 3.5 kW with the fuel utilization rate about 58% and electrical efficiency over 40%.

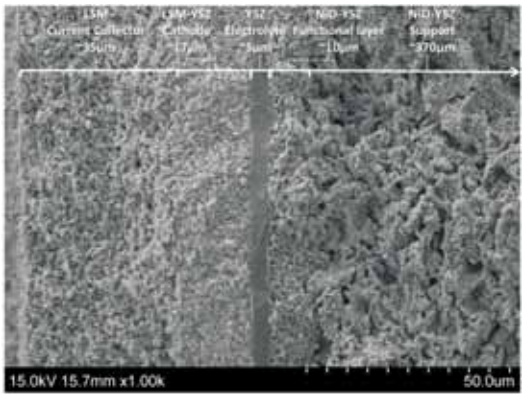
SOFC power system	Electrical power (kW)	Electrical efficiency (%)	Volume (cm^3)
INER	3	≥ 40	65×65×188
Solid Power-BlueGEN	1.5	60	60×66×101
Hexis-Galileo	1	30~35	62×56×160

Comparison of SOFC system performance

Plasma sprayed metal-supported solid oxide fuel cell:

The 10 x10 cm^2 cell reaches a power density 510 mW/cm^2(@700ºC) with fast startup capability and redox stability. This cell tested at 400 mA/cm^2 constant current density and 700ºC has a long term low degradation rate 1%/khr. This improvement will accelerate the popularization of SOFC power generation technology.

Metal-supported solid oxide fuel cell



Microstructure of YSZ-based solid oxide fuel cell

Ceramic-supported solid oxide fuel cell:

(1)Introducing high mechanical strength YSZ and sub-micron NiO in the anode cermet structure for thinner anode support substrate with rigidity and improved homogeneity of porosity.

(2)Optimizing the elemental ratio in cermet with proper tape casting additives as pore formers to reach a peak output power density in 771 mW/cm^2 (@800℃) for the (NiO-YSZ|YSZ|YSZ-LSM|LSM) system.

Nano-catalyst for fuel-reforming:

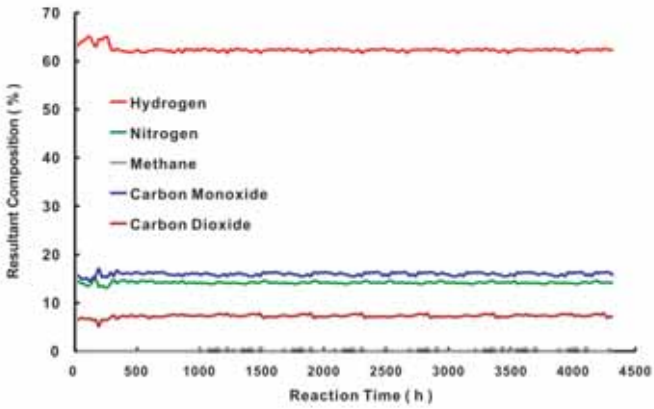
(1)High durability >4000 hours

(2)High natural gas conversion > 95%

(3)High thermal stability >1000ºC

(4)Interaction of Pt and Ce oxide inhibits Pt sintering by surface diffusion

(5)Innovative nano-catalyst design helps in the retention of surface area and prevents the migration and coalescence of the metal crystallites



Composition of reformed gas from methane

Awards:

(1) 2016 Taipei International Invention Show & Technomart --3 gold awards:

(i)A fabrication process for production of SOFC-MEA with a pore array anode structure for improving output power density

(ii)A high permeable porous substrate for a solid oxide fuel cell and the production method thereof

(iii)Method of fabricating catalyst carrier for generating hydrogen through methane reformation

(2) 2016 iENA Nuremberg-- gold award:

Solid oxide fuel cell and manufacturing method thereof

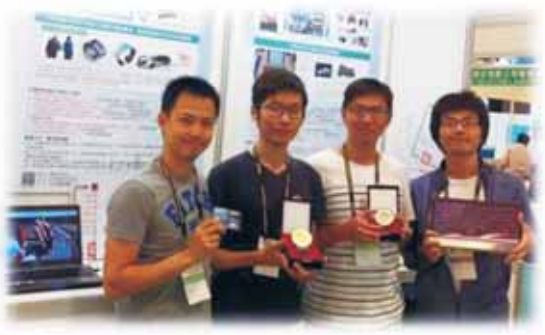
3-2-9 Development of Polymer Solar Cell Modules Technology

The rise of alternative renewable energy sources, including wind, water, geothermal, tidal, biomass and solar energy, provides not only the diverse options in the use of energy but also mitigates the risk of ecological catastrophe and global warming caused by the use of fossil fuels. Among these renewable energy sources, solar energy is one of the most competitive renewable energies because the solar energy is unlimited by region. INER has developed the modularization technology for large-area Polymer Solar Cells (PSCs). The level of its capacity is approaching the international advancement. Unlike traditionally inorganic solar cells, PSCs can be easily combined with wearable smart electronic products, such as smart watches, bluetooth headsets and google glasses, because of the advantages of light weight, transparency, flexibility, printability, low cost, and high power conversion efficiency under dim light. Moreover, PSCs can even replace the disposable battery and apply to low-power-consuming electronics for indoor applications, such as the Internet of Things sensors coming into focus recently.

Grasp the pulsation of renewable energy: Polymer solar cells

The short energy-pay-back time is one of the major niches for PSCs. In the development strategy of PSCs modularization, our research team adopted a low-energy consuming, non-vacuum and fully-solution-printing process for PSC modules manufacturing where the associated technologies in inkjet printing, ultrasonic spray coating, screen printing, and sheet-to-sheet/roll-to-roll slot-die coating processes were developed. PSC modules can be fabricated on flexible substrates, and the PSC modules can be cut into arbitrary shapes according to the demand of application. Besides, high power conversion efficiency of PSCs under dim light circumstances extends its applications into the indoor activities and broadens the feasibility of PSC modules to cover different scenarios.

Low-energy consuming and fully-solution printing process: Taking roll-to-roll process for example

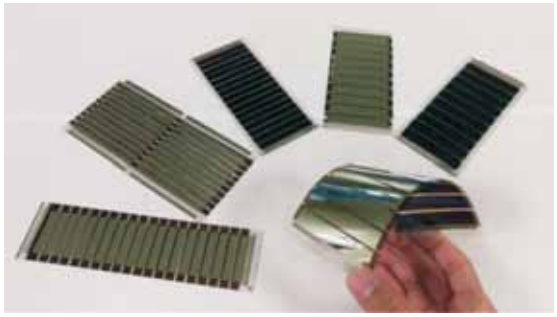


2016 Taipei Int'l Invention Show & Technomart: Silver Medal

The PSC modules offer a fully freedom of design thus it can be suitable for any product specifications by choosing materials, geometric sizes, and programming the circuit. The mini module combined with the smart card has a module area of 4.8 cm^2 and a maximum power conversion efficiency of 6.4% (the highest efficiency of module with the area of 4 cm^2 is 7.4% reported in the literature). In addition, we also develop large area module comprised 24 large cells(1x7 cm^2 for each cell) in which 12 cells are in series into a subpart, and two subparts are in parallel connection. The efficiency is up to 5.04% (there is no similar module size with such a performance reported in the literature). The production of large-area PSC module can examine the capability of large area coating processing of INER. These results demonstrate that our coating technique is well developed and capable in line with the mass production process.

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

In 2016, our team participated in Taipei Int'l Invention Show & Technomart, and won the Silver Medal by the invention of "Soft and mini power module integrated with energy storage devices". The power module is successfully combined with the smart card released by the company of "Foongtone Technology". The power module can not only drive the display directly outdoors, but also supply electricity indoors via integrated with energy storage device. We currently focus on the performance improvement of the power module by optimizing the materials and durability. The smart card can yield about 8,000 million US dollars in output value each year; therefore, the advent of the prototype products based on PSC modules as independent power source in near future is of indicative significance for the relevant industries.



The Beginning of Mass-Production Printing Technology: Large-area module validation

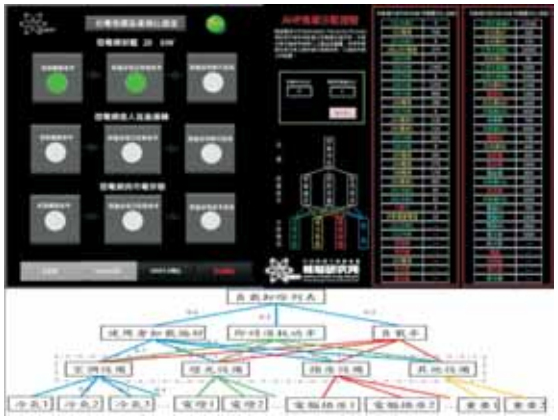
INER is the only national research institute which has the capability of mass production and modularization of PSCs in Taiwan. We cooperate with the academic community and material developers (upstream) for designing the novel and high-efficient polymer materials, and develop mass production technologies being transferred to industries for the installation of mass production line. INER will be a backstage driving force to accelerate the advent of PSC module-based products, and link up the academic community with industry to form a PSC industrial chain. The development of PSC industrial chain would become the foundation of setting up our indigenous industry and reinforce their competitiveness in the global market.

3-2-10 A tool to maximizes the availability of green energy to support the utility grid

INER has dedicated to develop the control and management technologies of autonomous regional distributed electricity to increase the capacity of renewable energy a regional grid can accommodate. In addition, all these technologies could be transferred to domestic professional manufacturers to explore domestic and international businesses. In 2016, a research team in INER had helped Taiwan Power Company(TPC), Penhu County Government, etc. to plan and build intelligent microgrids, including: (1)to transfer the management and control technology of intelligent energy source to Controlnet Co., as well as to cooperate with Taiwan Power Company to build a "preventative microgrid " in Fushan Community of Wulai, New Taipei City; (2)to cooperate with Tatung Co. to build an "18kW preventative microgrid " in Wulai District Office; (3) to cooperate with Chung-Hsin Electric and Machinery Mtg. Corp. to build an off-shore islanded microgrid in Dongji, Penghu. The patent, cascaded battery energy storage system technology, won the gold medal in the 2016 Taipei International Invention Show & Technomart, and the excellence award of the Research and Development Result Show and Business Innovation Competition in 2016 INER anniversary celebration. Moveover, the paper entitled "Design of Resiliency Control and Reliability Analysis of Microgrid" won the best paper award in the 37th Electrical Power Engineering Seminar.

INER microgrid demonstration site

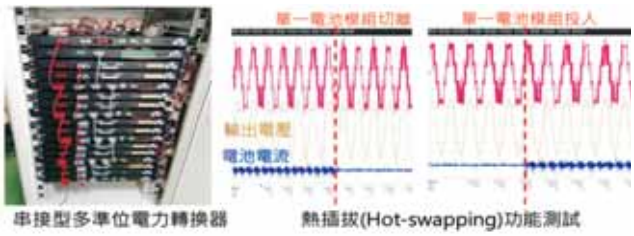
In the aspect of developing distributed power systems and intelligent control technologies, the first high-voltage microgrid SCADA workstation was created with the FDCS platform in TPC to proceed analog power dispatch. The EMS load shedding strategy based on analytic hierarchy process (AHP) was developed to dynamically rank the load shedding propriety, real-time consumed power, and hourly load usage rate. When receiving load shedding command from TPC, EMS would shed loads sequentially until their total amount satisfies the command. Currently, the EMS of INER microgrid could execute load shedding more than 50kW by AHP. The active power compensation program was also developed, which can stabilize voltage by modulating the battery energy storage system. After 168-hour practical test, it showed that the voltage flicker ΔV10 can be suppressed to 0.242, which is complied with the voltage flicker specification in IEEE519.



EMS load shedding strategy development based on analytic hierarchy process

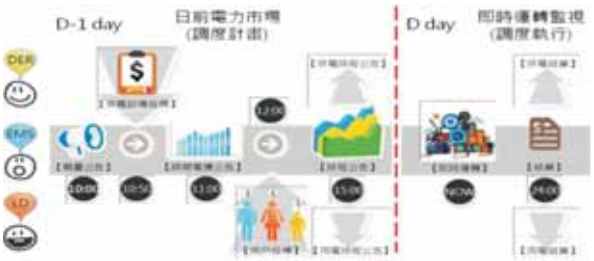
In the aspect of developing distributed power electronics technologies, a static switch system of hundred-kW scale was developed. After numerous tests, its switching time is 5 ms, which characterizes its accurate controllability and rapid response. Meanwhile, it also passed through the following tests in INER microgrid: continuous operation, bi-directional power transmission, and islanded mode switching. In addition, the hot-swapping function of cascaded multi-level converter was verified both in islanded mode and grid-connecting mode. When one battery module is out of order, it can be removed or replaced without shutting down the system and continue its operation, which substantially increases the power supply stability for energy storage converter.

Development of hundred kW static switch



Development of cascaded multi-level converter with hot-swapping function

In the aspect of developing the multi-agent system (MAS) integrated platform for distributed energy resources (DER's), a power dispatching system was created, which adopts MAS technique to proceed power dispatch in 4 zones, including 3 entities within the microgrid and a virtual zone (Zone 0) integrating the power information of 3 entities. A microgrid electricity trading simulation platform was created, which could perform power dispatch auction and scheduling. It also can coordinate with microgrid controllers to simulate the electricity trading and scheduling in a microgrid. The electricity trading process includes demand announcement, DER's bidding, time of use rates announcement, consumers bidding, scheduling results announcement, scheduling operation autonomously and billing. Furthermore, a 10-second decision making subsystem was invented, which can mate electricity supply and demand rapidly.



Electricity trading simulation platform

Real-time operation interface

INER will continue to develop the control and management technologies of autonomous regional distributed electricity, replenish the INER microgrid, and promote the associated key technologies. Meanwhile, INER will cooperate with domestic manufacturers related to electricity system, and coordinate with Penghu government and TPC in building the practical microgrids at Tongpan and Hujing to enlarge the renewable energy penetration for more than 40%. We anticipate our works will be beneficial for carbon reduction and helpful for domestic professional manufacturers to explore domestic and international businesses in the future.

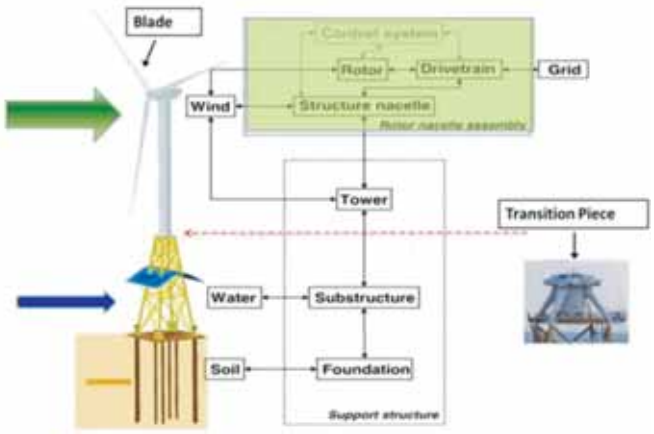
3-2-11 Surging of wind power The cooporation with industries to develop local wind turbine technologies

During the past decade, the R&D in INER has shared some efforts in developing small wind turbines, such as 400W, 25kW to 150kW. INER is a national laboratory, specialized in design and integration of the wind turbine system. For advocating domestic techniques, we also participated in the offshore wind turbine project supported by Ministry of Science and Technology (MOST). We are responsible for the verification of the offshore wind turbine with support structures.

Gold medal pattern "Passive Pitch Angle Control Mechanism for Small Vertical Axis Wind Turbines"

A new pattern of "Passive Pitch Angle Control Mechanism for Small Vertical Axis Wind Turbines" won the gold medal on the 2016 Taipei International Invention Show & Technomart. With this mechanism, the turbine blades can be operated with positive angle for low wind speed, yielding higher torque for better start-up. As the wind speed exceed the rated value, the blades turn to negative angle, yielding smaller torque while maintaining rated output power. This will enlarge the operable range of the implemented wind turbine, and increase the overall power output.

With the subsidy from MOST, INER and China Steel Corporation (CSC) teamed up to develop the engineering technique for the jacket-type support structure of the offshore wind turbine. INER and Taiwan Generations Corp. signed the Letter of Intent for the communication of the design and verification technique for the offshore wind turbine and support structure. Via the cooperation among industries, academic and research institutes, the efficient, safe and reliable domestic offshore wind farm will be developed.



Integrated structure system for the offshore wind turbine and support structure

Hosted the IEA Task 27 2016 with BSMI in Taiwan

INER and Bureau of Standard, Metrology & Inspection (BSMI) co-hosted the IEA Task 27 2016 meeting in Taiwan. In this conference, INER presented the development of the VAWT SLM and latest wind turbine industrial status in Taiwan, and promoted the international recognition of the technologies on small-and-medium scale wind turbines which can be extended to the offshore wind application in the following future.

Using the construction experience of the 150 kW wind turbine, we assisted CSC to develop the analysis and system integration methodology for the wind turbine system. As a result, CSC built up the capability on the design, manufacture, operation and maintenance of the wind turbine, making them able to conduct the Engineering, Procurement and Construction (EPC) project and wind turbine procurement.

Technical communications at China Steel Corporation

The domestic industry of the small wind turbine system is still in developing stage and there is no 5 to 10 kW level commercial product. Therefore, the design of small wind turbine generator and the mechanical safety require further investigations. The gap in related technologies could be filled through the small-and-medium scale wind turbine project. The development will proceed toward the medium-and-large scale wind turbine, enhancing the competitiveness of local industry.

The implemented international standards for large and offshore wind turbines are based on the environmental conditions in Europe. For countries with different environmental conditions, such as the U.S.A., the evaluation of the offshore wind turbine safety with the effect of hurricane was conducted by American Bureau of Shipping (ABS). Similarly, the ongoing project at INER evaluated the threat of local typhoons and earthquakes to the safety of wind turbine. The applicability of design standards on Taiwan regional circumstances will then be verified, which is beneficial to improve the reliability and safety for the domestic offshore wind farm in the future.

The evaluation of design, operational stability and causes analysis of malfunction will be conducted by the fault diagnostic technology developed in the research projects. This is especially useful for rotational components and offshore wind farms. The development of relevant technologies will be a reference for the offshore wind turbine with the effects of Taiwan's unique environment. It is also very useful for the development of the offshore demo wind farm in Taiwan.

3-2-12 Energy Security Information Platform Master Your understanding in energy security

Center of Energy Economics and Strategy Research Institute of Nuclear Energy Research

Currently, there is no public available tool for energy security and risk analysis in Taiwan, Center of Energy Economics and Strategy Research (CEESR) establishes an energy security information platform which is based on clear, local and international purposes. It provides an online website for professionals or interested users. The Energy Security Information Platform is designed to provide a flexible index combinations and weight assignments that allow users to define and establish their own energy security index.

This platform collects 27 sets of energy index built by international organizations and classifies them into three initial index groups. With a filter process based on the following criteria: "name and meaning", "calculation process or description", and "statistical information in Taiwan", only Asia Pacific Energy Research Center (APERC) and Asia-Pacific Economic Cooperation (APEC) are in preliminary group; Economic Research Institute for ASEAN and East Asia (ERIA) and Bureau of Energy (BOE) are in mid-level group; U.S. Chamber of Commerce(USCC) international version and International Energy Agency(IEA) are in High-end level group. Finally, APEC, BOE, and USCC international version are chosen for Preliminary, Mid-level, and High-end level indexes(see Table). This tool, implemented with EXCEL, can be carried out under different needs of energy security .

Comparison of 3 Energy Security Index

Index	Preliminary: APEC	Mid-level: BOE	High-end level: USCC
Advantages	➢ Simple and requires less information ➢ Quickly reflects the impact	➢ Localization index ➢ Easy to get data	➢ Provide calculation process and weight ➢ Data for international comparisons
Dis-advantages	➢ Can not reflect the impact of other levels on energy security ➢ No weighting	➢ Data only, no calculation process ➢ No weighting	➢ Require complex data input ➢ professional

The Energy Security Web provides an online energy security information platform for professionals or interested users, and also provide flexible combinations of index and weighting. Users can calculate their own energy security index from the above 3 sets of tools. It also completes the data required for the operation of the index in Taiwan from 1990 to 2014 and provides functions of online calculation, search and download. The information and operational procedures are as follows:

While using Energy Security Information Platform, users can choose the index according to individual needs, and set the weighting factor. After obtaining the result, we can compare it with existing data and use it as a reference for future strategy recommendations.

The following process uses the "Natural Gas Import Exposure" in the USCC indicator as an example of the operation of the Energy Security Platform (see Figure on the right):

Step1:

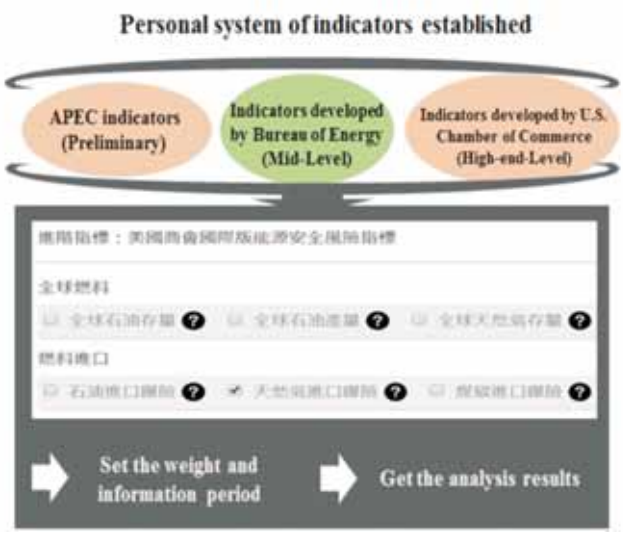
Enter the index system establishment, select "natural gas import exposure", click the next step.

Step2:

Set the weighting factor (100% total), the data period (the duration and base year), and the benchmark score.

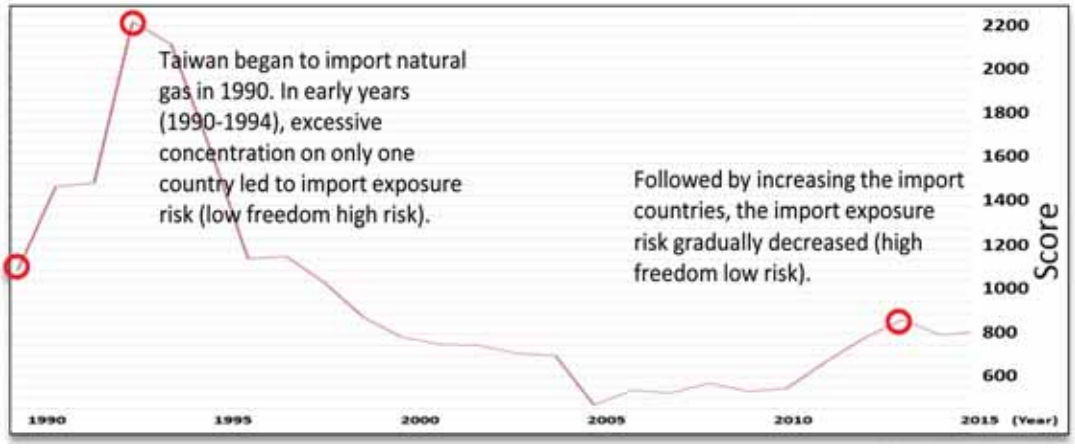
Step3:

Obtain the analysis results (see Figure below).



Analysis process of Energy Security Information Platform

Analysis results
(ex. Natural Gas Import exposure)

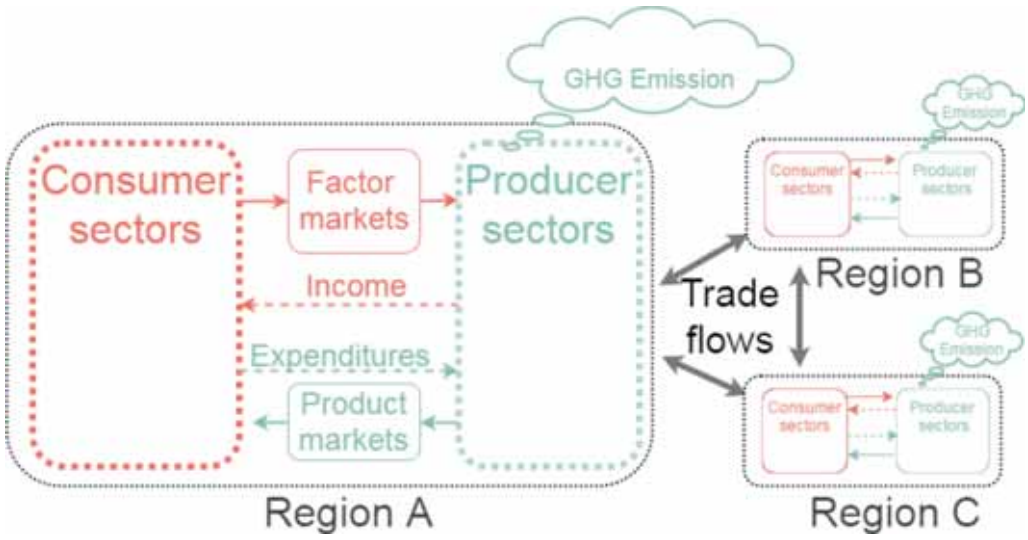


Exposure risk of natural gas import

Energy Security Information Platform has built a set of major energy, economic and environmental data of Taiwan, which will be regularly updated. In the future, the energy security risk index data analysis, energy model, economic model and social intentions survey will be integrated for providing energy and economic strategy recommendations

3-2-13 Development of the Economic Projection and Policy Analysis (EPPA) -Taiwan

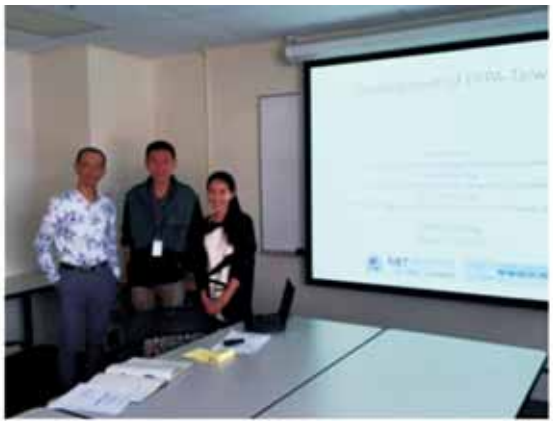
The economy of Taiwan is highly dependent on international trade. Furthermore, Taiwan relies heavily on imports of fossil fuels which currently account for around 98% of Taiwan's energy supply. Either Taiwan-only CO_2 reduction policy or global greenhouse gas (GHG) emission cut could have crucial implications on Taiwan's economy due to the trade effect. The main advantage of a global Computable General Equilibrium (CGE) model is that it captures interactions among markets across countries (see Figure below). Thus, a global CGE model is suitable for analysis of trans-boundary pollution problems, such as carbon leakage. In the context of global efforts to cut greenhouse gas (GHG) emissions, a global CGE model with energy use and emissions details where Taiwan is explicitly represented is essential for the analyses of policy impacts. Therefore, INER and the MIT JP (MIT Joint Program on the Science and Policy of Global Change) jointly develop the first global CGE model for environmental-policy simulating purpose in Taiwan since 2016, which was named Projection and Policy Analysis (EPPA) -Taiwan.



The circular flow in the in the EPPA-Taiwan

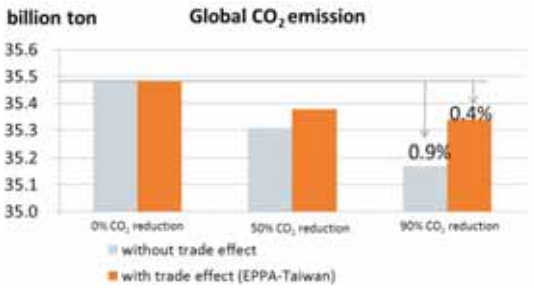
Our strategy is to conduct the model based on the standard MIT EPPA model, a reliable and well-known tool for energy and climate policy analyses. Therefore, the EPPA-Taiwan inherited strength from the MIT EPPA model, such as it has elaborated settings of energy and electricity sectors, explicit treatment of the relation between the fossil fuels and various GHG emissions. However, adjusting the regions and sectors is very time-consuming in many CGE models. The EPPA-Taiwan extend the aggregation procedure provided in GTAP9inGAMS to produce a database for the base-year. Consequently, the EPPA-Taiwan provides high flexibility for modelers.

In general, it costs considerably to construct and maintain a global CGE model. INER built the EPPA-Taiwan by joint development relationship with the MIT JP rather than simply technology transfers. Through being long-term visiting scholars at MIT JP, researchers from INER were trained by a series Learning-by-doing processes (see Figures below). Our team got the know-how of constructing a global CGE model, which will bring the long-term benefit beyond simply technology transfers. At the same time, INER cultivates human resources for CGE-modeling capabilities that are valuable and rare in Taiwan.



MIT EPPA model workshop in INER and EPPA meeting in MIT

Most of the current CO_2 emission reduction relevant studies in Taiwan are essentially based on a single-country modeling framework. Under this framework which is ill-equipped for representing international trade, it's difficult to identify the fact that the carbon leakage makes the Taiwan-only policy less effective. CO_2 emissions of Taiwan accounted for around 1% of the world. According to the projection from the EPPA-Taiwan shown in the Figure below, global CO_2 emission decreases only 0.4% under a very stringent Taiwan-only policy (90% CO_2 reduction). The total CO_2 reduction is much less than the naively expected number - 0.9%



Global CO_2 emission under Taiwan-only reduction policy

The continuous effort is required to extend and improve the model, including introducing the dynamic mechanism, considering backstop technology for energy-related sectors. In addition, CGE analyses are sometimes perceived as a black box to non-expert readers. We would like to increase the transparency of the models because it is the best way to relieve doubts of outsiders. In a long run, our targets include bringing to light the details of the EPPA-Taiwan, publishing research results based on the EPPA-Taiwan, and providing an open version of the EPPA-Taiwan.

3-3 A Prelude on Nuclear Safety Research Report- Envision a Nuclear-Free Homeland

Our government's current energy policy is to develop green energies, mitigate the release of greenhouse gases and gradually build the environment of nuclear-free homeland. It takes steps to implement the policy. We have to make sure the integration of any infrastructures of nuclear power plant before and after stopping running, to develop techniques needed for the safe decommissioning procedure, and to plan the radioactive wastes intermediate storage and final disposal strategies. All these efforts aim at reaching the expected target of planned energy policy. Therefore, in the fiscal year of 2016, INER had engaged in research including the safety issues about the operation and maintenance of nuclear power plant, the technologies to execute the TRR decommissioning project, and the optimum spent nuclear fuel storage strategy and its final disposal safety assessment method. Valuable results have been achieved.

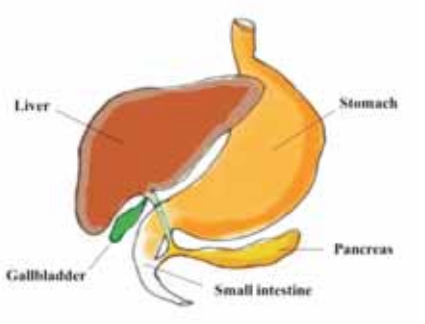
In the aspect of increasing the operational safety of nuclear power plant, an evaluation method, named as Level-2 PRA, has been established to assure the nuclear facilities safety when it comes to the severe accident condition. This method updated the specific source term data and adequately used these results to strengthen the component of defense in depth and to evaluate the Emergency Planning Zone (EPZ) much comprehensively. Furthermore, a fuel lattice design automation technique for BWR has been improved. This is a feasible method that can accomplish a high quality BWR lattice design at the same times reducing the resolution time for the optimization. In the aspect of enhancing the equipment maintenance convenience, INER developed a methodology to determine the extreme thermal and radiation conditions in case that during the Design Basis Accident (DBA) equipment should be survived. This technology has been applied to the Kuosheng Nuclear Power Plant to qualify the safety-related electrical and instrumental equipment installed in the Reactor Auxiliary Building. The parameters are revised reasonably to facilitate the equipment maintenance in time and economically. In addition, INER used centrifuge test to understand the phenomena of pile group in liquefying soil under a ground motion. This technique helps us deploy solutions to construction work, such as anti-tsunami walls and offshore wind turbine, to prevent from the possible demolition of pile foundation in soft ground caused by earthquake. Furtherly, the weld quality is also an important issue for the equipment maintenance. INER has established a rapid safety assessment method for cylindrical shell weldments with multiples through-wall cracks. It can assist the engineers to evaluate core shroud rapidly with limited data. In another case about the weld, INER has integrated welding process of gas tungsten arc welding (GTAW) and laser beam welding to solve the problems of induced cracks. This technology can be widely applied to nuclear and petrochemical industries to increase the operational safety and production efficiency. INER also keeps Seismic Testing Laboratory on the cutting edge of innovation. Not only the test skills are used to elevate the opportunity of choosing local industrial products as replacing items, but also the analysis technology about the seismic research is developed.

With regard to nuclear facility decommissioning, INER has acquired plenty knowledge and techniques through the implementation of TRR decommissioning. The major missions in phase I (2004~2017) have been achieved mostly, including the dismantling of wet storage tank, emergency cooling tower, and the cleaning of spent fuel pool. In order to improve the feasibility and safety of nuclear facilities decommissioning, a computerized 3D digital model has been

developed in INER. It can offer a visualized 3D digital model for the work, such as segmentation, waste inventory, radiation dose distribution etc. During the fulfilment of a decommissioning project, the spent fuel usually shall be removed to another storage site with either wet storage or dry storage. INER has developed an apparatus for verifying the integrity of the confinement boundary of spent nuclear fuel dry storage canister in operation. With this apparatus and the proposed method, it can effectively verify the integrity of the confinement boundary and detect the damage of the confinement boundary in early phase to avoid the leakage of any radionuclides.

Besides, in the aspect of spent nuclear fuel disposal, INER is developing safety assessment methods. With a set of reference case information and referring to KBS-3 vertical disposal concept of Sweden, a safety case was documented through the international technology exchange with SKB. Also, in order to understand the evolution of engineered barrier system (EBS), INER used the finite difference method to simulate the thermo-mechanical coupling effect to EBS by FLAC3D under the heating effect of the canister. The result helps to develop a three dimensional numerical method that modeled with T-M coupling, which the calculation results were compared with the international case study to verify its correctness. This technology will be used to understand the stability under the thermal effect furtherly. Furthermore, in order to construct a specific biosphere concept model in Taiwan for the long-term safety assessment of spent nuclear fuel disposal, INER adopted the reference biosphere concept which has been developed as part of IAEA BIOMASS. FEPs list and international interaction matrix were also used to identify the exposure pathways and groups. Last but not the least, a stage dataset for biosphere dose assessment was established, which will be beneficial to the work of engineering design of the disposal facility and the safety assessment.

3-3-1 Novel Gall Bladder Image Agent



Based on statistics, there are 120 infants died with biliary atresia due to late diagnosis and surgery every year.

The clinical symptom of gall bladder obstruction is very similar to that of hepatitis, but their therapy strategy are quite different. Early and accurate diagnosis for gall bladder obstruction is essential and emergent to determine the patients'outcome. Since now we do not have any gall bladder image agent in our country, INER developed Tc-99m DISIDA and Tc-99m MTG. The former has been used in clinic and is well known for gall bladder image. It is the analog of bilirubin, absorbed by liver and excreted by gall bladder. However, it often developed false positive due to bad liver function. For patient with bad liver function, Tc-99m TriGalNAc is another choice, because it is specific to liver receptor, and metabolizes quickly in liver, and passed through gall bladder in 15 min.

Tc-99m-DISIDA can accumulate at a gall bladder and is mostly used to estimate whether a cystic duct is unobstructed. It is used to diagnose an infant with biliary atresia in an early period. However, Tc-99m-DISIDA is not suitable for patients with liver dysfunctions. Patients with liver dysfunctions absorb Tc-99m DISIDA drugs very slowly and drugs cannot accumulate at the gall bladder easily, so it is very difficult to judge if bile duct is obstructed or not. Patients with liver dysfunctions need to seek other methods.

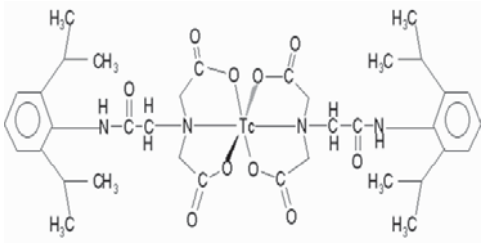


Fig1. Structure of Tc-99m DISIDA

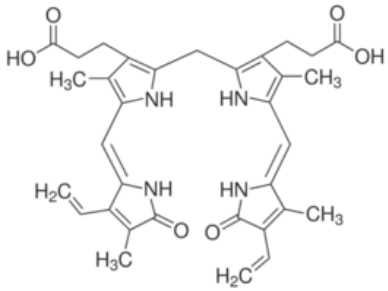


Fig2. Structure of bilirubin

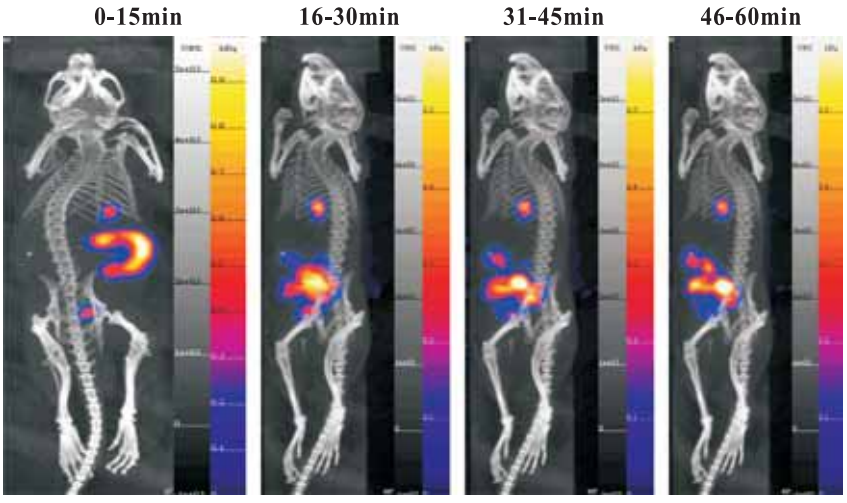


Fig3. Dynamic Imaging of Tc-99m DISIDA

A trivalent-GalNAc glycosides was synthesized and conjugated with mercaptoacetyltriglycine and further radiolabeled with the technetium-99m radionuclide for further SPECT imaging study. The imaging data indicated Tc-99m MAG3 -tri-galactosamine can reach the gall bladder in 15 minutes.

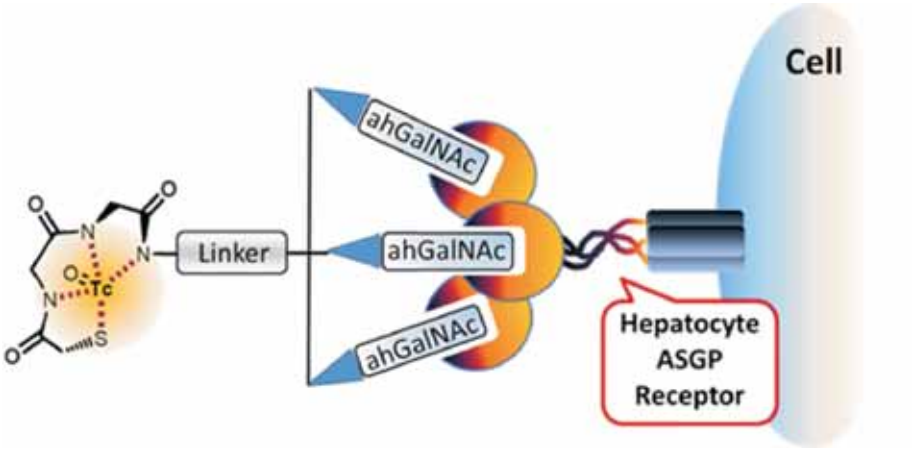


Fig4. Diagram of Tc-99m MAG3 -tri-galactosamine

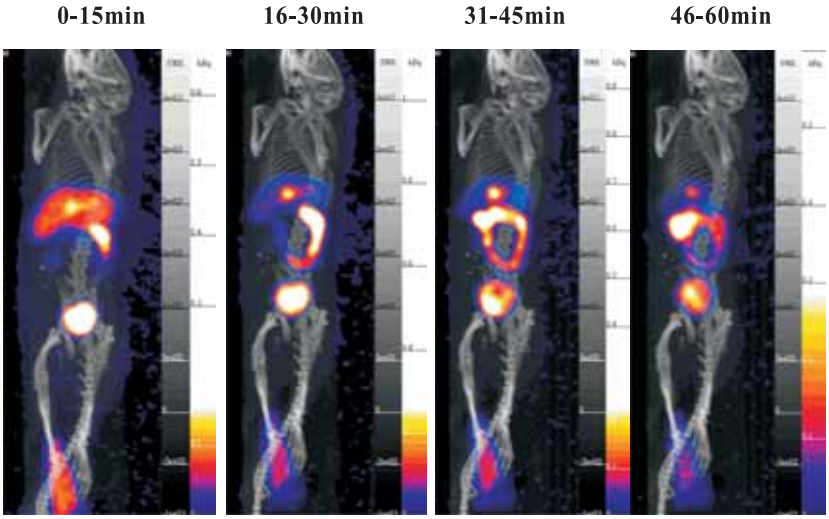


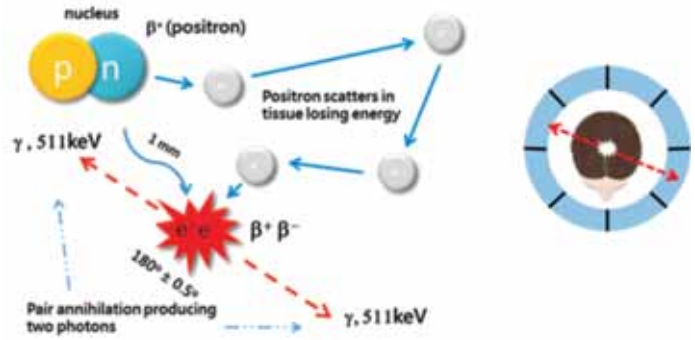
Fig5. Dynamic Imaging of Tc-99m MAG3-tri-galactosamine

We have the US and Taiwan patents and one prize award for Tc-99m MAG3-tri-galactosamine. Through further toxicity tests and clinical trials, it would be used for diagnosis application in bile duct obstruction.

3-3-2 A New Model of Ge-68/Ga-68 Generator

Because the half-life of Ga-68 is short, a huge amount of Ga-68 is lost in the transformation process. As regards Zinc oxide, When it is filled in the absorption tube, the eluent for the nuclide Ga-68 has to be 1N hydrochloric acid and the product has to be processed with neutralization reaction before further application. It is hard to prevent environment contamination and damage resulting from a leakage of inorganic metal ions dissolved in the hydro chloric acid.

Therefore, a Ga-68 radioisotope generator With high production rate and low pollution has been desired. In addition, the Ga-68 radioisotope generator is preferably simple configured and easy to use for hospitals and research institutes to reduce loadings and costs.



Application of clinical research

50 mCi Ga-68 generator	
Test parameter	Specification
Activitive (mCi)	50
Content (%)	< 60
Radionuclidic purity (%)	$< 1.0 \times 10^{-3}$ %
pH	1.0

Technical Specifications

With the amount of the added citrate eluent is sufficient, such as 10 ml, the 0.1 or 0.2M citrate eluent or the 0.1 or 0.2M citrate eluent at specific pH value (pH 9) can perform a high level of the Ga-68 elutriation rate (at least close to 50%). It proves that the citrate eluent indeed desorbs the Ga-68 radioisotope from the resin filled in the generating column. More importantly, in the elutriation process, the elutriation rate of the Ge-68 radioisotope, which indicates that the ratio of the Ge-68 radioisotope desorbed with the Ga-68 radioisotope to the Ge-68 radioisotope reminded, is considerably low. It proves that the purity of the Ga-68 radioisotope contained in the solution is considerably high. Taking the 0.2M citrate eluent 10 ml as an example, its elutriation rate is 4.5×10-3 %. Oppositely, the elutriation rate of the Ga-68 radioisotope is up to 70%.

Taiwan & US patent

GALLIUM-68 RADIOISOTOPE GENERATOR AND GENERATING METHOD THEREOF

A Gallium-68(Ga-68) radioisotope generator includes a generating column and a citrate eluent. The generating column is at least partially filled with ion-exchange resin with glucamine groups to absorb Ge-68 and Ga-68 radioisotopes. The citrate eluent is conducted to the generating column to desorb the Ga-68 radioisotope and thereby generate an eluent containing the Ga-68 radioisotope in the form of citrate gallium. A Ga-68 radioisotope generating method is also disclosed.

However, there are a few defects in the conventional Ge-68/Ga-68 nuclide generator. Consequentially, the product, Ga-68-EDTA, is a type of consider ably stable complex. Which must to be proceeded with other complicated treatments to transform Ga-68 into radiopharmaceuticals. Unfortunately, because the half-life of Ga-68 is short, a huge amount of Ga-68 is lost in the transformation process. As regards Zinc oxide, when it is filled in the absorption tube, the eluent for the nuclide Ga-68 has to be 1N hydrochloric acid and the product has to be processed With neutralization reaction before further application. It is hard to prevent environment contamination and damage resulting from a leakage of inorganic metal ions dissolved in the hydrochloric acid. Therefore, a Ga-68 radioisotope generator with high production rate and low pollution has been desired.

	INER	Cyclotron Co Ltd.	Eckert & Ziegler IPL	Eckert & Ziegler IPL	Eckert & Ziegler IPL	I.D.B. Holland B.V.	Isotope Technologie s Garching
Origin	Taiwan	Russia	Germany	Germany	Germany	South Africa	Germany
Resin	TiO_2	TiO_2	TiO_2	TiO_2	TiO_2	SnO_2	Organic Material
Eluent	0.1 M HCl	0.1 M HCl	0.1 M HCl	0.1 M HCl	0.1 M HCl	0.6 M HCl	0.05 M HCl
Elution Yield	66~73 %	60~75 %	70~75 %	70 %	95 %	80 %	> 80 %
Break-through	$<8\times10^{-4}$ %	$<10^{-3}$ %	$<5\times10^{-4}$ %	$<10^{-3}$ %	$<10^{-3}$ %	$<2\times10^{-3}$ %	$<10^{-4}$ %

Comparative evaluation Ga-68 generator

The Ga-68 radioisotope in the form of Ga-68 citrate can be transformed into that form of Ga-68 hydrochloride, which is more generally used, by combining the generator with a transforming column. It prevents further complication to users from the non-regular product. The apparatus in accordance with the present invention is simple designed, easily operated and suitable for various hospitals and research institutes to provide the publics better clinic diagnosis in the field of nuclear medicine and increase social welfare.

3-3-3 Multifunctional probe (DOTA-NIR790) for cancer nuclear and NIR fluorescence imaging, and photothermal therapy

Cancer-targeted multifunctional probe labeled with the radionuclide has been developed to provide multi-modalities for NIR fluorescence and nuclear imaging and for photothermal therapy (PTT) of cancer. In this study, we synthesized NIR dye-based probe (DOTA-NIR790), which could be chelated with In-111, Tc-99m, Ga-68, Cu-64 for nuclear imaging (SPECT, PET), Lu-177、Y-90、Re-188 for tumor brachytherapy, or Gd for MRI imaging. In addition, the NIR dye allowed the probe to have multi-functions in NIR imaging and photothermal therapy (PTT) (Figure 1). This probe can provide cancer patients more effective diagnosis and treatment of cancer, create the pharmaceutical industry's output value, and enhance the competition of pharmaceutical in our country.

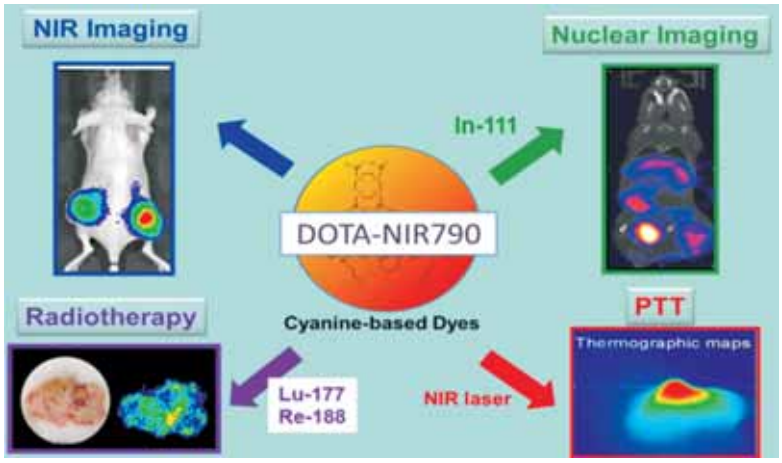


Figure 1. Development potential of multifunctional theranostic probe (DOTA-NIR 790).

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

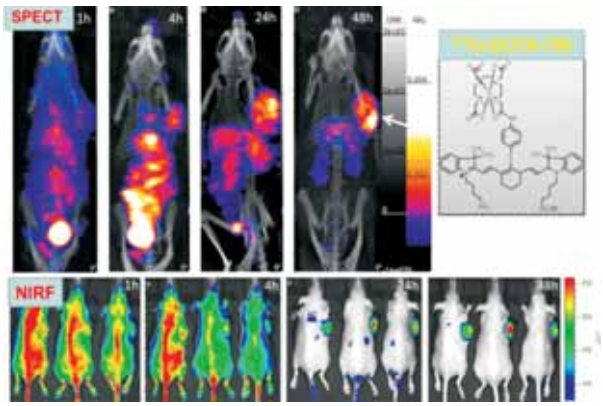


Figure 2. SPECT/CT and NIRF imaging of multifunctional probe (^{111}In-DOTA-NIR790) in tumor-bearing mice.

Multifunctional probe were used for photothermal therapy of tumor. After irradiation with a wavelength of 808 nm (1.5 w / cm^2), the thermal images were acquired to measure the tumor temperature by a thermal imaging instrument (Figure 3) The results show that it can effectively enhance the tumor temperature to about 48.6 ℃. As shown in Figure 4, the result of tumor growth also show that the photothermal effect caused the tumor temperature to rise, resulting in effective tumor ablation.

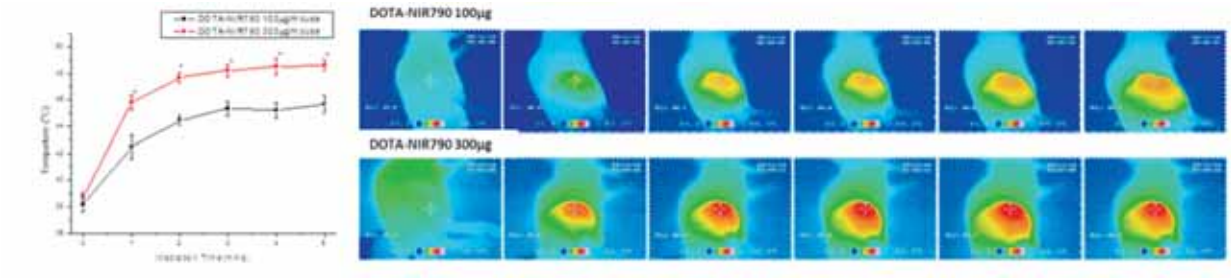


Figure 3. Photothermal property of multifunctional probe (DOTA-NIR790) in tumor-bearing mice. The tumor temperature measurement and thermal imaging during laser irradiation.

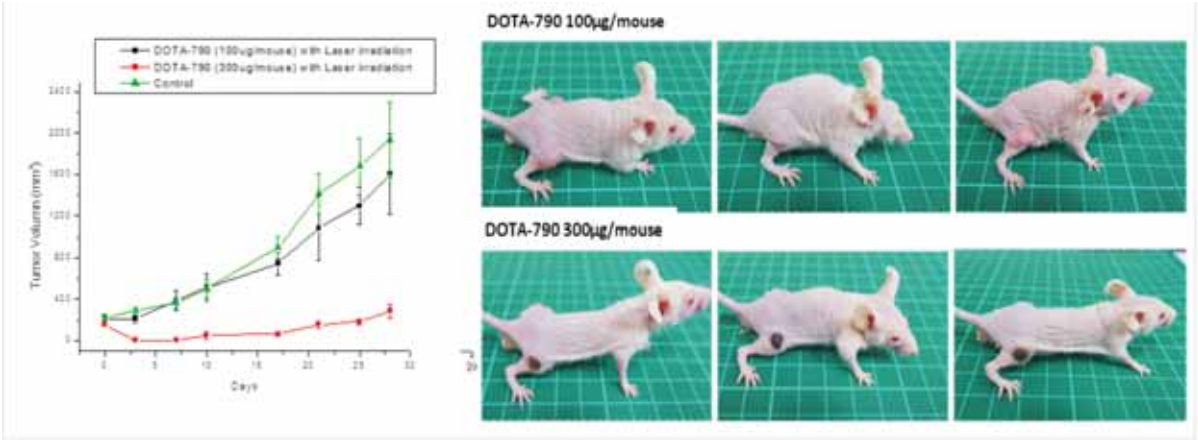


Figure 4. The anti-tumor efficacy of multifunctional probe (DOTA-NIR790) after laser irradiation in tumor-bearing mice.

The cancer-targeted multifunctional probe had been developed to provide multi-modalities for NIR fluorescence and nuclear imaging (PET, SPECT) and for photothermal therapy (PTT) and radiotherapy of tumor. In this study, we synthesized NIR dye-based multifunctional probe(DOTA-NIR790), which could be chelated with isotopes for nuclear imaging (PET, SPECT) and acquired for tumor infrared fluorescence (NIRF) imaging. The NIR dye allowed the probe to have multi-functions in cancer NIRF imaging and photoththermal therapy (PTT). In addition, this multifunctional probe can be conjugated with chemotherapeutic drug for the synergistic combination of tumor imaging and photo-chemotherapy in the future.

3-3-4 Taiwan TomoDR—New Generation 3D Digital Radiography, Accurate Diagnostic Quality

Figure 1: Photograph of the prototype Taiwan TomoDR scanner

Taiwan TomoDR, a new generation 3D imaging modality, has been developed in Institute of Nuclear Energy Research (INER) to improve medical imaging application in diagnostic radiology (Figure 1). Taiwan TomoDR is a digital tomosynthesis imaging modality that produces 3D sectional information and eliminates tissue overlap problem. Digital tomosynthesis improves the image resolution to detect small lesions and at much lower radiation dose than computed tomography (CT) scans.

Three important techniques developed by INER are applied to Taiwan TomoDR: (1) Multi-directional scanning function, (2) optimal scanning protocol, and (3) innovated and fast 3D image reconstruction algorithms.

Taiwan TomoDR vs. Conventional X-ray Digital Radiography

Conventional X-ray digital radiography (DR) is commonly used as a first-line imaging modality in diagnostic radiology. The radiation dose to a patient is low (0.02 to 0.1 mSv for chest radiography*). The cost of imaging equipment and inspection charge is low. However, the conventional X-ray DR provides only 2D image information. The tissue overlapping problem interferes in detection of small lesion. Computed tomography (CT) is used as a second-line imaging modality for advanced diagnostic radiology. CT images provide high resolution 3D information at each imaged location and can be post-reconstructed in three axes. Higher radiation dose to patients (~7 mSv for chest CT*) is the drawback of CT examinations. The radiation risk from CT scans is of concern. The cost of CT scanner and inspection charge are higher than conventional X-ray DR (Table 1).

	Digital Radiography (DR)	Computed Tomography (CT)
Imagedimension	2D	3D
Tissueovelap	Yes	No
Radiationdose	Low	High
Equipmentcost	Low	High
Inspectioncharge	Low	High

(Table 1: Diagnostic imaging modality comparison)

Taiwan TomoDR provides precise 3D imaging information better than conventional X-ray DR and lower radiation dose to patients than CT scans. Taiwan TomoDR is ready to be the alternative for the first-line medical imaging modality.

Figure 2 demonstrates the comparison of chest image quality and lesion detectability between 2D X-ray DR and Taiwan TomoDR. Three sizes of lesion mimic objects were imbedded in the chest phantom. The results indicated that Taiwan TomoDR provides excellent image resolution for lesion detection. The smallest lesion size (3 mm diameter) could be detected. The high resolution image can provide detailed information for diagnosis of lung cancer. The lesions were difficult to identify in the conventional X-ray 2D image. Furthermore, the lesion boundaries were blurry.

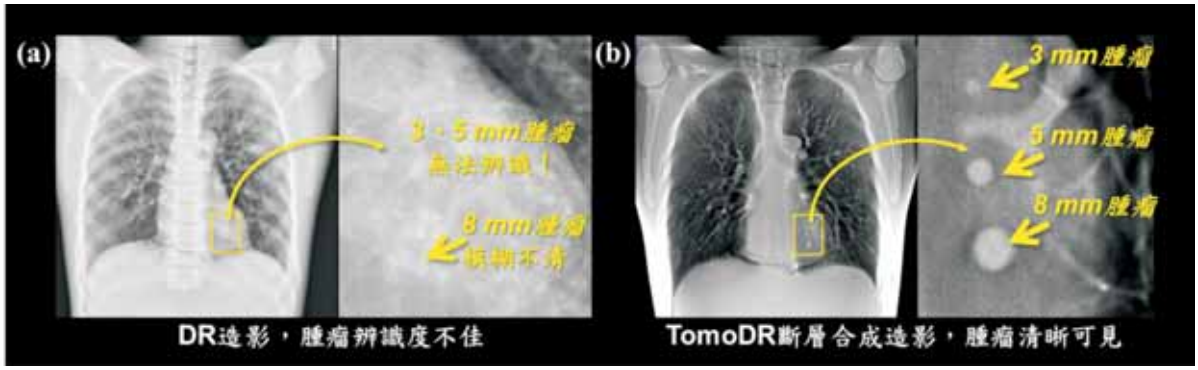


Figure 2: The comparison of chest image quality for lesion detection between the conventional X-ray digital radiography and Taiwan TomoDR

Taiwan TomoDR provides high resolution image for lesion detection. It also provides perfect image quality for detecting carpal bone structure (Figure 3). Pisiform bone, triquetrum bone, capitate bone, and unciform bone can be identified clearly in different depth of reconstructed tomosynthesis images.

Figure 3: The comparison of image quality for carpal bone identification between the conventional X-ray digital radiography and Taiwan TomoDR

Future Perspective

Taiwan TomoDR provides lower radiation dose to patients than CT scans. The digital tomosynthesis image resolution is better than conventional X-ray digital radiography. Taiwan TomoDR is an advanced digital tomosynthesis imaging modality. It can provide more detailed diagnostic information for radiologists and wide applications to clinical examinations, such as chest, head and neck, bone, and emergency radiology. Taiwan TomoDR is a good choice to be the first-line imaging modality for patient healthcare.

Reference:
*Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M (2008) Effective doses in radiology and diagnostic nuclear medicine: a catalog 1. Radiology 248:254. doi: 10.1148/radiol.2481071451

3-3-5 TomoDR limited-angle 3D imaging technology

In order to restrain the high dose received in the process of CT and reduce the risk of misdiagnosis due to the overlapping of organs and tissues imaged by the traditional 2D X-ray radiography, INER develop a limited-angle 3D imaging technique for the exclusive use of TomoDR. It has the advantage of slightly higher dose than 2D X-ray radiography. Besides, it can reconstruct CT-like images by a few angles of scan of the object. Usually, some artifacts are found for much fewer scan of the object in order to achieve the low-dose intent. The low-dose limited-angle 3D imaging technique has the capability to overcome this problem and can be applied to first-line screening and lesion tracking. It can not only effectively reduce the radiation dose but also provide doctors and patients with improved medical imaging information.

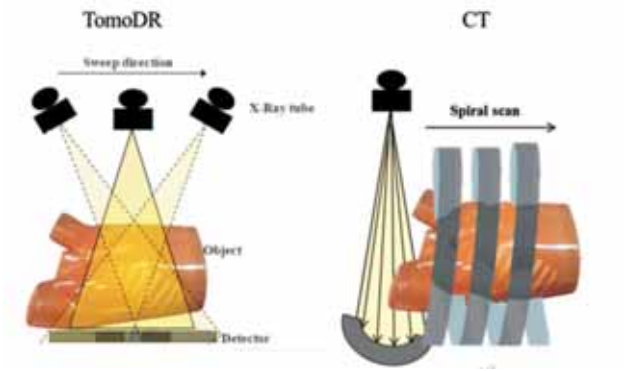
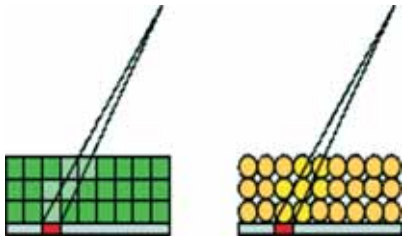


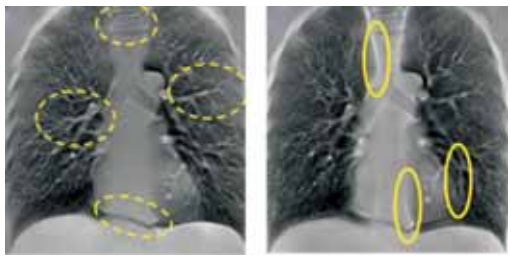
Fig. 1: The comparison between TomoDR and CT



(a)Box voxels (b)Sphere voxels

Fig. 2: 3D imaging projection method

The range of scan angle of TomoDR is significantly different from the counterpart of CT. CT scans over 180°, by contrast the TomoDR scans only 30°~40°"3D Imaging Projection Method"patent which employs the isotropic property of sphere voxels(Fig. 2(b)) so as to improve the efficiency of 3D imaging reconstruction algorithm. Also, using only one direction scanning information will affect the depth resolution of images, resulting in the blurring of the organs and blood vessels paralleling to the scan direction(Fig. 3(a):the result of head-feet direction). This technique provides multi-axis scanning imaging capabilities. By combining with the information of different scanning direction, the organs in different directions can be seen clearly as shown in Fig. 3(b). Apart from those problems described above, there are edge artifacts if we would like to shoot fewer slices in the same range of scan in order to reduce the dose further. We develop the "Edge Artifacts Repression Algorithm"patent against the problem. The combination of limited-angle 3D imaging technique and algorithms developed above improve the sensitivity of low-dose medical diagnoses.

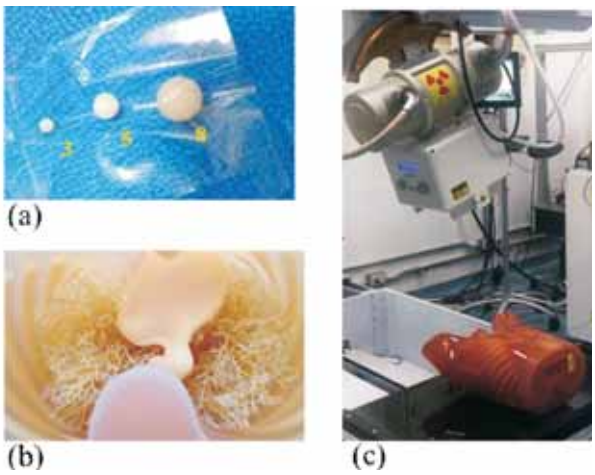


(a)Head-feet imaging (b)Multi-axis imaging

Fig. 3: Results of reconstruction

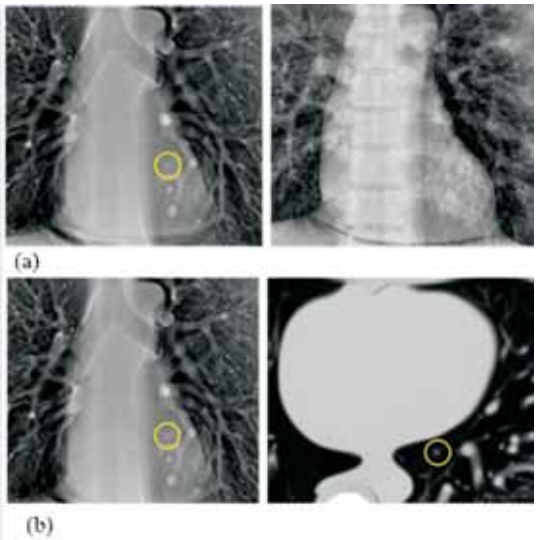
(a)Edge artifacts (b)After repression

Fig. 4: Edge artifacts repression algorithm



(a)Homogenous tumor phantoms(diameter 3、5、8mm)
(b)Tumor phantoms were placed in the chest phantom
(c)The imaging experiment of TomoDR
Fig. 5: The imaging experiment aims at chest phantom

For the purpose of comparing the performance of existing imaging techniques, we did an experiment that aims at a chest phantom and homogenous tumor phantoms. The tumor phantoms were placed in the chest phantom(Fig. 5). The limited-angle 3D imaging technique can not only solve the difficulty in identifying the tumor size below 3 mm when using the 2D X-ray radiography but also reconstruct CT-like slice images as shown in Fig. 6. In addition, Fig. 7 shows the locations easy to crack including the xiphoid, the leading, side, back edge of the ribs, the intervertebral disk, and the scapula. This technique makes these places observed clearly at different depth of slices.



(a)Comparison between low-dose 3D TomoDR and 2D radiography
(b)Comparison between low-dose 3D TomoDR and CT
Fig. 6: The results of imaging experiment

The TomoDR limited-angle 3D imaging technique was acquired the award for excellence of the 2016 SMIRS international symposium.

The “3D Imaging Projection Method” has been not only broken through the commercial bottleneck of the time-consuming iterative problem, but was patented for China, America, Japan, and Europe.

The “Edge Artifacts Repression Algorithm” has been proved effective repression of artifacts found in low-dose imaging, and it is patent pending for China and America at present.

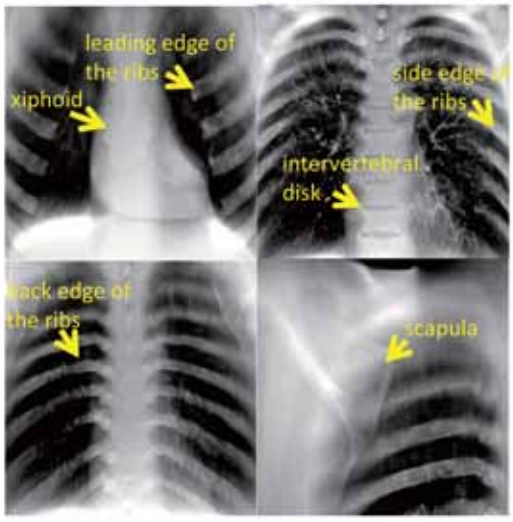


Fig. 7: The observation of organs at different depth of slices

The TomoDR limited-angle 3D imaging technique produces images with high image uniformity, few artifacts and high computational efficiency. The low-dose imaging performance is recognized by domestic and foreign medical experts. This technique is forward-looking and in line with our goal of improving people’s well-being.

3-3-6 Software Acceleration Technology for Radiography

Radiological images are generated after the process of radiograph and the computation of special algorithms. Accurate algorithms are used in order to obtain high quality radiological images, which is accompanied by complex and time-consuming calculations. However, rapid and accurate reconstruction results are indispensable for both the hospital and patients. Not only does it speed up the procedure and shorten the waiting time after radiograph, but also provides a more reliable reference for diagnosis. Therefore, our limited-angle 3D imaging system uses precise system model in reconstructing calculation, and we are devoted to the study of high-performance computing hardware and software technology, which provides an important solution for fast and high quality nuclear medicine imaging.

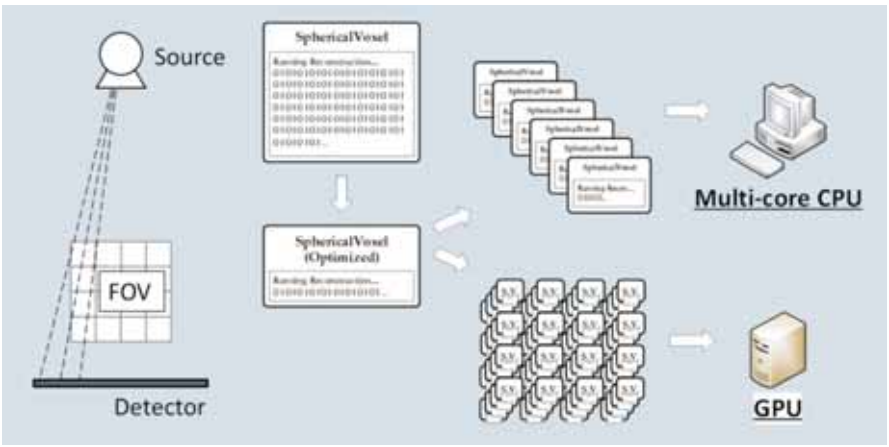


Fig. 1: The illustration of parallel computing

Medical image processing is a kind of application suitable for parallel computing because of a great amount of calculation resulted from the large dimensional system matrix. Based on the experience of software acceleration developed for symmetric-oblique-detector PET system, we analyze the X-ray limited-angle 3D imaging reconstruction algorithm thoroughly in the same manner. Through decomposing the dependent part of algorithms and solving the problem of memory capacity owing to parallel computing, our reconstruction algorithms are well-adapted to massively parallel computing. By the combination of massively parallel computing with GPUs, the X-ray limited-angle 3D imaging reconstruction algorithm not only achieves low-cost high-performance computing power, but also upgrades the commercial competitiveness of our system.

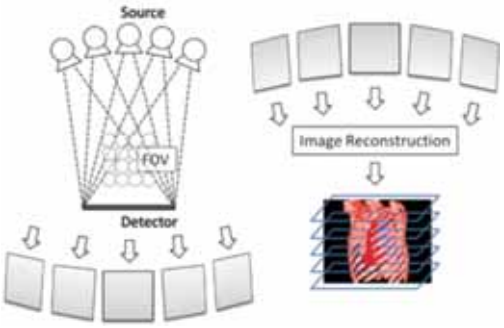


Fig. 2: The illustration of limited-angle 3D imaging and reconstruction technology

Fig.3: GPU parallel computing server

A large amount of computational load of the X-ray limited-angled imaging system is accelerated by parallel computing, which is realized by a multi-core CPU mode and a large number of parallel GPU modes, wherein the latter is subjected to several optimization adjustments. The experimental results show that the time of 10 iterations can be reduced to 6 minutes in the case of reconstructing the image of chest phantom. Compared with the existing commercial model-based algorithms, the computing time is reduced significantly, which falls into the acceptable range of clinical applications. Moreover, through the operation of GPUs to achieve massively parallel computing, our system can effectively reduce the cost of computing hardware and maintain a high degree of computing power simultaneously.

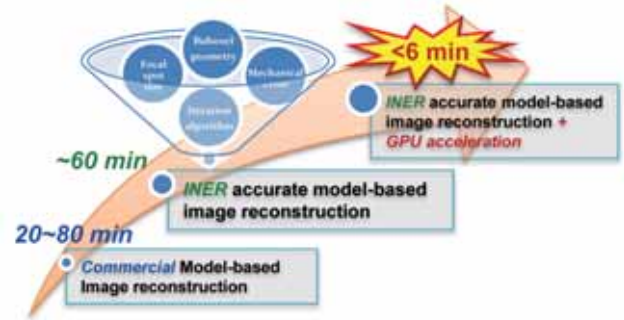


Fig. 5: high accuracy and fast reconstruction results achieved by proprietary algorithmic parallelism technology

The goal of this acceleration technology is that the computation time of image reconstruction can be shorten to at least equal to current business systems under the premise of using the accurate system model. Nevertheless, medical image processing usually needs not only strong computing capability but also a large number of memories to store the raw data and the temporary data. Therefore, not merely do we make algorithms parallelize but likewise we consider the effect of finite memory space with respect to implementation and computational efficiency. In addition, the optimization of performance tuning against the hardware is an important issue after the implementation of parallel computing.

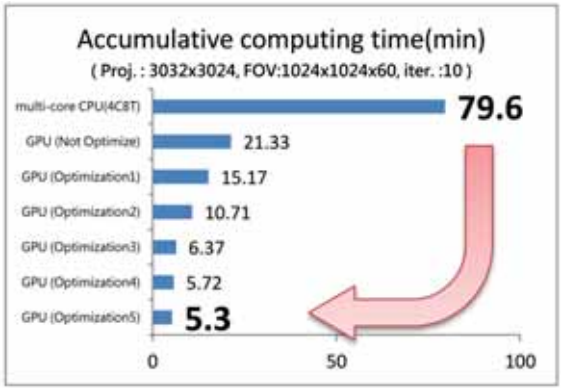
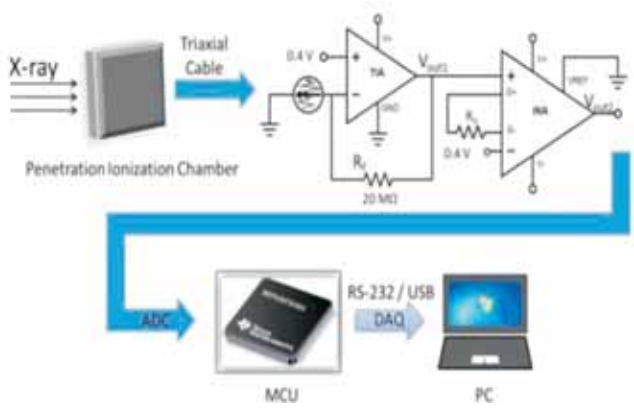


Fig. 4: reduction of computing time achieved by proprietary algorithmic parallelism technology

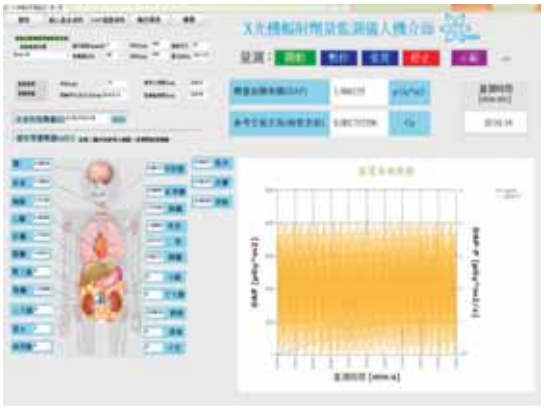
Accelerated by proprietary algorithmic parallelism, the reconstructed time can be greatly reduced. The reconstructed image not only can meet the requirements of low cost and high accuracy, but also can be completed in a reasonable time. The computing time for reconstruction is no longer a major consideration in clinical practice. Not only does it reduce the waiting time between imaging and imaging, but also it makes researchers focus more on other new technology applications. In the research, we can refine or accelerate other reconstruction correction models such as attenuation and penetration correction so that the image quality can be further improved within a reasonable computing time.

3-3-7 Establishment of dose area product meter prototype for medical diagnostic X-ray

Taiwan has a strong base in the information and communications technology (ICT) industry; there are a number of manufacturers involving with research and development of X-ray imaging industries, such as the X-ray tube assemblies, image sensors and medical image archiving and communication systems. However, in the early days of the transformation of fraditional industries, manufacturers are still insufficient-experienced of radiation measurement and dose assessment. The Dose-Area-Product (DAP) meter developed by the INER is a key component of the X-ray imaging system that allows immediate assessment of radiation doses for X-ray diagnostics. It can fulfill the lack of relevant technology and foster technology autonomy of the product.

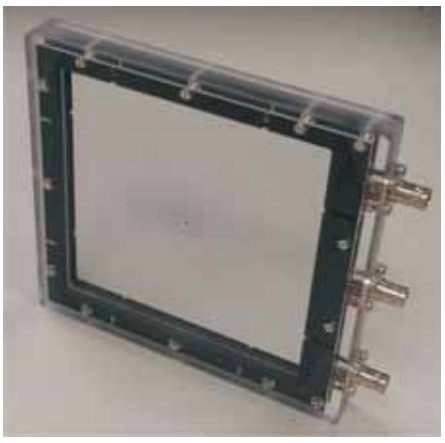


The electronic circuit design of the meter

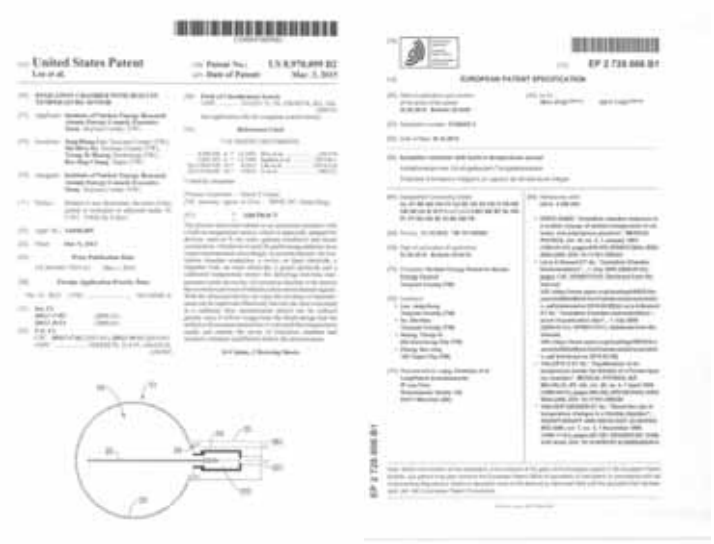


Human–machine interface

This DAP meter includes three parts: transmission ion chamber, meter and human-machine interface. The transmission ion chamber is designed to be transparent so that both X-ray and visible light can penetrate easily to avoid the presence of chamber structures on X-ray images. In addition, a dual-channel ion chamber design was developed to allow DAP and entrance dose to be measured at the same time. The meter is designed to measure the picoampere current produced by the ion chamber, which converts the electronic signal to a radiation dose and displays it instantly. The human-machine interface is designed to allow the user to control the meter on the remote computer and also includes the function of the dose evaluation. The built-in conversion factor database can convert DAP into equivalent dose and effective dose for use by physicians or radiologists.



Dual-channel transmission ion chamber



Ionization chamber with built-in temperature sensor
US Patent left and EU Patent Certificate (right)

INER has a number of patents on the DAP meter design, such as: "penetration ionization chamber", "Penetration ionization chamber with covering protection electrode structure," for the ion chamber structure improved, have been patented by the Republic of China. The Unique design of the "Ionization chamber with built-in temperature sensor" can immediately detect the actual temperature within the cavity to carry out radiation dose measurement signal correction, effectively improve the ion chamber measurement accuracy, and has received invention patents from the Republic of China. the United States and the EU. In addition, the design of the meter, entitled "Using voltage ride through frequency histogram for a low current measurement device", has been patented by the Republic of China and is in the process of US patents applications.

The design of the DAP meter developed by INER is based on the International Electrotechnical Commission (IEC) standards, including IEC 60580 Dose area product meters, IEC 60601-1 medical electrical equipment safety, IEC 60601-1-2 electromagnetic compatibility, IEC 62304 software validation and so on. Most countries' regulations for medical equipment are based on IEC standards, so manufacturers will be able to quickly meet the requirements of governments and apply for listing.

Compared with other manufacturers, INER started late but has a number of innovative designs, such as covering protection electrode, built-in temperature sensor, etc., to effectively improve the measurement performance. In addition, the Chinese human-machine interface allows domestic people to easily operate and is conducive to seize the huge market in China.

Product family that can be developed by INER

In the future, INER will optimize the prototype to match the manufacturer's requirements to achieve better functionality, safety, convenience and operational intuition, and make its appearance appealing. In the dose assessment function of human-machine interface, INER will develop a variety of dose conversion factor database to respond to national conditions, enhance business competitiveness. In addition, INER will continue to develop family of products, such as X-ray machine automatic exposure control detectors and various types of ion chamber for radiation therapy or radiological diagnosis.

MEMO

Date . .

4 2016 highlighted events and memorabilia

Events of the Year

4-1 2016 highlighted events and memorabilia

1.INER had transferred Controlnet Co. its Technology of Power Generation Forecast and Intelligent Energy Management System for Renewable Energies, which was applied to the preventative microgrid construction of Taiwan Power Company (TPC). As well, INER also assisted Controlnet Co. in building a preventative microgrid system at Fushan elementary school in Wulai, New Taipei City. The launching ceremony was held on January 18, 2017. It is the first disaster-prevention microgrid system in Taiwan and is capable of fully supplying electricity to the local disaster-prevention center, household uses, and emergent firefighting for up to 14 days. It will effectively improve the situation of blackout caused by typhoons.

2.On March 1, 2016, the production technology of metal-supported solid oxide fuel cell developed by INER was transferred to Han Tai Technology Co., Ltd., following the technology of ceramic-supported solid oxide fuel cell transferred to LEATEC Fine Ceramics Co., Ltd. It makes significant progress in promoting the solid oxide fuel cell to domestic industries.

3.On March 11, 2016, the 5th International Symposium on Taiwan Nuclear Cardiology was held at Taipei co-sponsored by INER, the Society of Nuclear Medicine Taiwan(R.O.C.), Taipei Veterans General Hospital and Show Chwan Memorial Hospital. The symposium was focused on perfusion and innervation in nuclear cardiology, especially the clinical applications of I-123 MIBG.

4.INER held the "Workshop on Wind Turbine Reliability and Applications" during March 14-15, 2016, with the invited speaker Prof. Sorensen from Aalborg University, Denmark. There were approximately 40 attendees from Taiwan Power Company, China Steel Corporation, and TECO. The event strenthens international communication on offshore wind turbine technology and promotes the domestic technological capability.

5.The collaborative items of "Durability test and evaluation of degradation mechanism for SOFC, and material development and characteristic study for SOEC" and "Design evaluation technique for the offshore wind turbine" were proposed by INER to be discussed in the 12th Taiwan-Japan joint energy seminar held in Taipei during April 21-22, 2016.

6.INER and Bureau of Standard, Metrology & Inspection (BSMI) co-hosted the IEA Task 27 2016 meeting at Taipei during April 25-27, 2016. Presentations were given by domestic and international experts coming from Spain, the U.S.A., Denmark, Italy, etc. The topics included the development of industry and policy for small wind turbine, design and evaluation, verification of the Chigu small wind turbine test site. Technical capability and test environment of small wind turbine in Taiwan were presented. International communication and corporation were also achieved.

7."2016 Seminar on Seismic Qualification of Commercial Grade Items for Nuclear Power Plants" was held at INER on May 25, 2016. There were approximately 130 participants, among which 82 of them were from Taiwan Power Company and other industries and research related organizations. Major topics focused on MCC seismic testing, IEEE-344 standard, response spectrum theory, regulation as well as seismic betterment for tank foundation.

8.On June 15-17,2016, INER invited experts from the US Department of Energy's Civil Radioactive Waste Management (OCRWM), the National Agricultural Laboratory (ANL), and the Southwest Research Institute (SWRI) to conduct SNFD2017 report technology seminars, with about 50 participants from related industries, academia and INER.

9.A signing ceremony was held at Taoyuan City on July 20, 2016 for a licensing contract between INER and LEATEC Corporation to transfer the SOFC stack assembling technology to the company. The licensing signified an important link in the complete industrial supply chain, which is still under construction.

10.On August 11, 2016, the Joint Annual Conference of American Nuclear Society Taiwan Section and Women in Nuclear Taiwan took place in INER, with around 120 members attended the event.

11.This year INER celebrated the 48th anniversary, and held "the 48th Anniversary of INER and Family Activities Day" in August 19th. In addition to the celebration ceremony, there were open-offices, demonstration of INER's research and development results, family-fun activities, fairs, and film appreciations, etc. Not only the staffs and their family, but also the retirees were invited to participate in the celebration. The event was so well-responded and was recorded the most participants in past years.

12. In the announcement of Ministry of the Interior of September 2016, Mr. Zhang Weichen of INER Nuclear Fuels and Materials Division and Mr. Huang Derong of INER Physics Division, respectively, won the first and the eighth place of 104 annual merit awards in non-civil industry group (a total of about 12,000 in alternative services), while the INER also won the second place awards of non-civil industry group employers (a total of about 900 units).

13. On September 8, 2016, the Ministry of Finance informed INER that INER was awarded the first prize within the official budget organs. For which, INER participated in the 104 annual performance evaluation of the annual use of the public property of the Nation Property Adminstration.

14. 2016 Taipei Int'l Invention Show & Technomart was held on September 29 to October 1, 2016. In the event, INER won 20 awards, including one platinum award, seven gold medals, four silver medals and eight bronze medals.

15. The technologies of "Solid Oxide Fuel Cell and Manufacture Method Thereof" and "Thin Film Battery Structure and Manufacturing Method Thereof" patented by INER received, respectively, the Gold Medals of iENA Nuremberg 2016, a famous international invention show held at Nuremberg city of Germany, on October 29, 2016.

16. A joint press conference and signing ceremony was held in Taipei on Nov. 17, 2016 for the technology transfer of INER's biorefinery technology to Hiway Broadband company. Dr. Jing-Tang Yang, CEO of National Energy Program II, participated in the event to address a speech and, also, witnessed the technology transfer process.

17. INER held the "Workshop on Engineering Technology for Offshore Wind Turbine and Support Structures" on November 22, 2016. There were approximately 50 attendanees including experts from Stuttgart Wind Energy (SWE) of Stuttgart University, Germany, China Steel Corporation, and National Cheng Kung University, etc.

18. The team for plasma technology development on energy-saving film of INER won the group award of Distinguished Achievement Award for Civil Servants 2016 honored and presented by the Examination Yuan. The awards ceremony was held on December 14 at the conference hall in the Examination Yuan. At that time, President Tsai presented awards to the winners in person.

19. "The technology with diverse applications for depolymerizing and saccharifying lignocellulosic biomass" and "Manufacturing Techniques of Plasma-sprayed Metal-supported Solid Oxide Fuel Cells" were awarded the 13th National Innovation Award, respectively, by the Institute for Biotechnology and Medicine Industry on Dec. 22, 2016. It demonstrates the innovative contribution and strong economic competitiveness of INER's biorefinery technology.

20. On Dec. 23, 2016, Atomic Energy Council presented Awards of the 2016 Secure Operation and Excellent R&D of Nuclear Materials and Radioactive Waste. Two INER groups (the Team for Clean-up the Sludge Containing Spent Fuel Debris in TRR Spent Fuel Pool and the irradiated materials research team of hot laboratory) and an individual were awarded.

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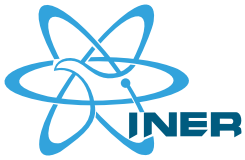

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