

**Institute of Nuclear Energy Research** Atomic Energy Council, Executive Yuan



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### 2011 Annual Report Institute of Nuclear Research

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## Preface

#### Calmness Improves Endurance, Deep Plowing Enhances Strength.

*Guide Technical Research with Strategic Planning -Direction of Development for Application Research Organization at National Laboratory Level.* 

Climate variation and the issue of greenhouse gas emission bring the opportunity to the development of nuclear power globally. However, last year the 311 incident in Fukushima, Japan seriously damaged the confidence of the general public in nuclear power. This also urges our government to readjust the current energy policy. Nuclear power generation will be reduced steadily without causing power shortage and unreasonable billing structures.

To substitute nuclear energy, besides looking for renewable and low-carbon energy sources, we rely on the adjustment of industrial structures, management of demand and supply, energy saving technology development, and power generation efficiency improvement. Because of energy safety and carbon reduction, combination of diversified energy is the natural trend of development. New energy technologies should not be over expected before having major breakthrough in cost, stability and general acceptance. Our country is densely populated and there are limited resources. Only through practical and careful evaluation of the pros and cons of each energy supply and its contribution in carbon reduction, covering the shortcomings with advantages but not readily giving up any option, we may establish a diversified and reliable low-carbon energy supply system. This should be the only solution for Taiwan to cope with global warming and the soaring price of fossil fuel.

INER engaged in 15 research projects last year such as developing green energy technologies and carbon reduction, advancing the nuclear safety technologies to establish a safe and secure homeland, strengthening radiation safety and radiation quality of medical care to improve people's health, strengthening intellectual property management and application to assist the industrial and economic development.

In terms of the development of overall organization, INER is willing to accept external evaluation to establish the institutional culture for excellence. Last year, we had significant achievements such as getting the recognition from National Science Council (NSC), Ministry of Economic Affairs (MOEA), Ministry of the Interior (MOI) and Atomic Energy Council (AEC). In particular, INER is the only institute that has been awarded the Group Superior Award three consecutive times by NSC. We also obtained the "Group standardized Award" of MOEA, and the "Outstanding Award" of AEC with a project entitled "Strengthening Governance Efficiency with Business Management"

In the area of human resource management, INER is the only "Blue chip" employer for eight consecutive years by the Defense Industry Reserve Duty System of Ministry of National Defense (MND) and the Military Training of MOI. In terms of the management of R&D projects, INER obtained the Quality Management System Authentication Certificate from Bureau of Standards, Metrology and Inspection MOEA. The ranges



Preface

of the certificate include design, development, service and maintenance of the service and verification of nuclear knowledge, the value-added derived from nuclear technology, and industrial R & D and promotion of people's livelihood. In addition, INER also became the first laboratory having the GLP certification of radiation toxicology from the Department of Health.

Technology research and development wise, the INER helped a company to obtained the Technology Award of Clean Production Promotion by Ministry of Economic Affairs Industrial Development Bureau with its special high alumina bricks refractory re-use technology, which won various prizes when attending the 2011 Taipei World Expo of Invention and Technology and had attracted numerous proposals for contract signing.

INER's task is to find a strategy to address energy security and technology programs and to balance between environmental protection and the application of atomic energy for peace. Everything we do is to enhance the competitiveness of the country.

What Taiwan missing is the independent energy? What we must do are forward-looking, integrated, large-scale and platform-based plans. We shall primarily let strategic research guide technical research. We target at technologies not readily available in Taiwan or irreplaceable technologies as the core subjects in which we put our efforts. We work hard to increase energy safety, environmental protection, national health, and for a vision to become an institution that provides complete strategy and technology solutions for R & D.

To solve the problem of global warming, we need to integrate domestic R & D institutions. INER, a national energy institute is a leading entity in developing relevant strategies and technologies corresponding to the overall goals of the government policy. INER possesses rich human resources. The expertise of our personnel covers all areas in the mainstream of environmental protection industry. We have accumulated considerable experiences in developing energy technologies and in conducting analysis of energy strategy. We are on an excellent trajectory for even more remarkable achievements, and we look forward to the next opportunity for reporting them.

Director-General





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56 persons

156 persons

83 persons

66 persons

361 persons

Unit: Thousand NTD

(16%)

(43%)

(23%)

(18%)

(Time of data: December, 2011)



16%	Statistics of Job Ca Research Staffs
18% 43%	Researcher
	Associate Researcher
27%	Assistant Researcher
2370	Research Assistant
	Research Staffs

#### 2011 Annual Budget

Administration and Safety	1,361,565	55%
Management, Operation and Maintenance	99,621	4%
R&D Programs	904,288	36%
Technology Promotion and Service	127,970	5%
Total	2,493,444	100%

## **Events of the Year**



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#### **3-1** Fukushima Daiichi Accident Related Technical Support on Nuclear Safety and Radiation Safety

Chi-Jen Chen

#### (1) Activities

After the Fukushima Daiichi accident occurred in Japan, the Institute of Nuclear Energy Research (INER) provided the information and material about the accident as a service to the public. In addition, we gathered and examined all available information and performed evaluations and analysis to understand its implications based on the requests of AEC and TPC. INER has completed 16 major technical supporting works. As part of the efforts, information was provided to the AEC and it was applied to the interrogation in the Legislative Yuan and used in the press conference, public hearing and nuclear safety exercises. Technical works include the radiation dosage evaluation, the establishments of standard procedures, accident analysis, integrated safety assessment and emergency preparedness etc. Details are as follows:

- 1. Severe accident script of Chinshan, Maanshan and Kuosheng NPPs were completed and used in the nuclear safety exercises. The emergency response capabilities can therefore be enhanced.
- 2. SBO (Station Black Out) scenario analysis and case study of Chinshan, Maanshan and Kuosheng NPPs were completed as the technical basis for nuclear safety regulatory and "Comprehensive Safety Assessments to the NPP".
- 3. Complete the SBO analysis based on different ultimate response strategies. The results can be used as the reference of the ultimate response guidelines.
- 4. Support AEC, TPC and Radiation Monitoring Center with the analysis of Fukushima Daiichi accident and provide technical training on NPP accident assessments.
- 5. In response to the Fukushima Daiichi accident, a project: "risk assessments, alternative radioactive source term and thermal hydraulic safety analysis" will be performed.
- 6. Provisions to protect the plants against nature disaster were enhanced and the EPZ related planning was improved. The regulatory basis for emergency preparedness was also enhanced. Research and development related to the mitigation of the accident and the ultimate response guidelines were performed.

#### (2) A Study of Severe Accident Management Strategy on the Fukushima Accident

The Fukushima Daiichi accident was associated with extended SBO (station blackout) plus loss of ultimate heat sink. The three units progressed into core melt, hydrogen burn, and RPV failure severe accident. The RCIC system in unit 2 and RCIC/HPCI systems in unit 3 survived for 2-3 days. During this period, the core water level was maintained and the emergency fire engine and water source were ready for RPV (reactor pressure vessel) injection. However, the injection flow is too small to maintain the RPV water level above top of active fuel (TAF) after the trip of the RCIC/HPCI. This is because the RPV and containment stayed at a pressure relatively higher than that of the small fire engine, partly contributed by the delayed venting.

A depressurization strategy has been proposed: to depressurize the reactor slowly by opening the SRV while the RCIC is still available so that the goals of reactor depressurization and cool down can be achieved at the same time. (The purpose of slow depressurization is to avoid the RCIC/HPCI trip). In addition, the containment venting is used to reduce the back pressure. With this strategy, the reactor can be brought to and maintained at a relatively safe state (namely, a high water level and low pressure state). Under this state, the impact of the RCIC/HPCI trip will be minimized and the reactor water inventory can be supplemented by various low pressure injection methods. An analysis was performed to demonstrate the adequacy of this strategy. The assumptions of the analysis are listed below: We assume extended SBO plus loss of ultimate heat sink occurred in the Chinshan (Mark-I containment) nuclear plant just the same as that occurred in the Fukushima. The raw water tank in the mountain is used as a low pressure injection system. The RCIC is assumed to be available for 38 hours (similar to the availability of RCIC/HPCI in Fukushima Daiichi unit 3). The simulation results of MAAP5 (Modular Accident Analysis Program version 5) indicate that fuel is always covered by the coolant and core melt can be avoided with proper incorporation of containment venting and RPV depressurization strategies as mentioned above.





#### (3) Radiation Safety

In response to the concerns of the potential radiological accidents caused by the Fukushima Daiichi accident (311 event), the INER organized mission teams based on the program established beforehand to monitor the environmental dose, the foods imported from Japan and the passengers traveling from Japan at the Taoyuan Airport. In addition, samples were taken at sea and emergency missions (including Q&A concerning radiological screening in foods and calibration of instruments) were executed. For the "boundary control" at the Taoyuan Airport, related contamination detection procedures were set up after the 311 event and as many as 146,406 passengers were detected. Twenty-seven passengers were found contaminated and they came through the control point after being cleaned. Starting from March 15, 2011, we conducted dose assessment for the possible dispersion of radiation fallout using the meteorological data of the Central Weather Bureau and estimate the impact to Taiwan. We strictly monitored the evolutionary development of Japan's nuclear accident and issued new information on the "Fukushima disaster bulletin" of the Atomic Energy Council Website as a reference to the public. For the part of imported foods, radiological inspection and screening were done for the foods imported from Japan regulated by Food and Drug Administration, Council of Agriculture and Ministry of Finance, and radiological detection for the sea food captured along Taiwan's coasts and domestic vegetables and fruits were simultaneously performed. There were totally 17,135 cases of radiological analyses that aimed to assure the radiation safety of people's diet and life. To avoid the public panic over radiological accidents, chemical disasters emergency response drills corresponding to both 311 event and anti-terrorism were performed to demonstrate our capacity for the anti-terrorism measures and inter-ministry deployment systems. We took part in "No. 17 Nuclear Safety Drill", "2011 Jin-Hwa Drill" and "2011 Taoyuan Airport Crash and Radiation Materials Rescue and Relief Drill" to concretely strengthen the emergency capacity of domestic authorities to effectively reduce the society fears for the radiation threat and ensure their safety.



Sampling at Sea



▲ Dose Assessment for the Possible Dispersion Of Radiation Fallout Following the Meteorological Data of the Central Weather Bureau



 Dose Assessment For the Possible Dispersion of Radiation Fallout to Estimate the Impact to Taiwan

## **3-2** Institute of Nuclear Research Awarded 2011 National Standardization Award

#### Jong-Rong Wang, Fang-Chyi Lou

Since year 2000, Bureau of Standards, Metrology & Inspection, M.O.E.A. R.O.C has held the "National Standardization Award" to encourage and reward the government departments, groups, enterprises, and individuals who performed outstandingly on National Standards. In year 2005 our department joined and won the competition of "Corporate Standardization Award" with good quality of practice to promote standardizations among customers and suppliers. In year 2011, we were invited to join the competition of the 12<sup>th</sup> "Group Standardization" Award.

Since the founding of Institute of Nuclear Energy Research, we've been continuously following the ideals of professional safety, innovation, and high standard on our research. From year 2002, with our accumulated know-how on nuclear power research since early years, our department was appointed of new research projects such as new energy, renewable energy, and Plasma engineering. Currently we are dedicated in research areas of nuclear power control, environmental protection, and nuclear medications and we've got good research results on solar energy, fuel batteries, etc, which are applied in industrial purpose to strengthen our local technical know-how. In the future we will continue to plan energy strategies and develop energy technology, and we hope to provide the complete solution to energy safety and the decrease of greenhouse gas emission.

Our department has involved in authorities of technology development and radiation safety, and we apply our know-how in many areas such as medication, agriculture, manufacturing, and businesses. We not only provide standard reference for industry, government, and academy, but also assist nuclear advisory council (Atomic Energy council), Taiwan Power Company and relevant nuclear power industry in managing nuclear power safety. The nuclear power safety standards are verified by domestic and overseas professional nuclear power associations, and part of standards are accredited by domestic associations such as Atomic Energy Council (AEC), Taiwan Accreditation Foundation (TAF), and National Science Council and some are accredited





The photo of awarding ceremony



Awarded "Group Standardization Award"



by overseas associations such as the International Bureau of Weights and Measures (BIPM), International Laboratory Accreditation Cooperation (ILAC), and Asia-Pacific Metrology Programme (APMP), etc. In recent years our department has proactively devoted to developing patents as basis of international promotion and domestic technology transplant in industry, so as to exchange abundant domestic technical know-how with international professionals and to stay connected with them.

Being tested and refined by the corporate award, we made our technical know-how more solid and we promoted and used the know-how to national relevant industries based on those standards. It's not only an honour for our department to join this competition and won the award, but also a repeated approval of our achievement in practicing standardizations. It's our new responsibility for us after being awarded. We will more proactively promote standardizations and guide our local industry to upgrade. Together we can face the severe challenges of domestic and overseas energy and environmental issues and further lead us to a promising new future.

#### **3-3** The Involvement and Proposed System of Government – Using Enterprise Management Technology to Enforce Performance of the Administration Management

#### Hei-Kuang Lee

The government achieves policy objectives by way of the implication of performance management by objectives. These performance objectives and performance indexes are subject to the artificial process through a business information system to retrieve, compile and output data of the analysis of the investment of resources and results in the past. There is no total or complete solution of performance indicators among government organizations, explicitly it is a time-consuming work to finish, and apparently there are some gaps exist between performance management and public expectation of the execution time. In order to enhance the performance management of administration of INER, by way of careful assessment and systems analysis, INER makes full use of business intelligence technology, builds real-time key performance indicators system (referred to as KPI system). By the introduction of the spirit of enterprise management to the government, thus improve government performance and efficiency.

INER's solution of the government performance improvement implies the effectiveness of the management perspective. It can illustrate by way of the administrative triple system - planning, implementation and assessment:

(1) Planning - the integration of plan, budget and staffing management: the planning, including plan, budget and manpower information are integrated into information systems from the beginning of the administration planning. In accordance to various budget information reviews from the Executive Yuan and the Legislative Yuan, the budget information is instantly revised and produce the budget Beige Book finally. Thus it enhances the efficiency of data processing. By the way, the manpower and project information, along with its corresponding managerial responsibility and accountability at all levels, are automatically transferred to the budget management system, procurement system, electronic attendance management system. It dramatically enhances the management effectiveness and efficiency of the planning stage. For the operations of the outside commissioned project, once the service orders for any one premises (the premises

described in our 50 hectares, 109 buildings) start, all associated supporting units will get the message at the same time, the relevant units also start operation simultaneously, significantly increasing the performance of technical services and efficiency.

(2) Implementation - integration of unit information and real-time feedback: the information in the application of information systems for business processes, real-time analysis of the algorithmic performance information will automatically bring together, to produce the chart of the performance, the status of online business executives at all levels. It will be not necessary for support units (personnel, accountant, secretary, project planning) to provide an analysis of information. Instead, managers can get performance information by online access of the information system at any time. It enhances the timeliness of performance management. The performance management is improved compared real-time analysis to show now with once a month manually pooled analysis in the past.

(3) Assessment - the integration of performance management and information transparency: the indicators information are transparent through different levels of managers. Managers at all levels can see the current status of the performance of this unit as well as other units, thus enhance self-warned effect and promote the healthy competition for the year-end evaluation. It also provides a transparent and objective system.

INER's solution also highlights the effectiveness of the continuous improvement. By way of the development of the KPI system, it results the review and improvement of policy management system, process improvement, integration of hardware, software and information system, etc. It then derives to specific targets for improvement. INER's solution benefits the effectiveness of the organizational culture. By way of introduction of thinking and operation speed of enterprise, it drives the government departments to adhere to the thinking way and working model of enterprise. Therefore it leads to the concrete implementation of the spirit of entrepreneurial government to enhance the effectiveness and efficiency of government services.

INER's solution involves innovation, it includes the following: (1) unique: This solution should be the first government departments, which using business intelligence technology to successfully integrate various sources of information and build up a real-time KPI system for performance management. (2) integration of business operation perspective: This solution implies the integration of cross-business operation which includes project management, budget management and human resource management. (3) integration of timing perspective: This solution provides the process integration across three time intervals - the planning, implementation and assessment. (4) integration of organizational perspective: This solution included the organization of horizontal business units, auxiliary units and all vertical business colleagues at all levels of personnel and managers.

The characteristics of this solution are: (1) suit for a wide range of units: administration authorities and R&D institutions. (2) strengthen business integration: it contains the business units and support units. (3) shorten the lag time: it can use lag indicators to achieve feedback management, also can use the lead indicators for feed-forward management. (4) cover a wide range of information: it is now incorporated into more than 14 information systems, namely, plan and budget pipeline, budget management, procurement, plan and human hours, electronic attendance, human resources, library information, etc. (5) flexibility of phased implementation : it has completed major KPI items like: project control and evaluation indicators: journals, report, patents, technology license fee and technical service revenue reached indicators and their



details. Human resource indicators: project manpower, organizational learning, and manpower usage indicators and their details. Financial indicators: the implementation of the Capital Account, Current rate of implementation of the commissioning plan, implementation of the budget available balance indicators and their details. Operational resource indicators: the equipment assets, documents, procurement rate of implementation indicators and their details. Safety indicators: access control systems. We will continue to build a comprehensive organization and management indicators in the future.

The customer facet of this solution is as following. This system integrates the business process and its users, including managers at all levels and all business colleagues. By way of information integration, it improves the service level of internal customers. To aspects of external customer service, it will accelerate the speed of operations and returns of the performance management and evaluation for the services to government departments. For business services, it will accelerate the flow of external customer service operations.

In June 2011, INER's solution has won the Outstanding Award from the Atomic Energy Council, and now it is competed with other solutions from other government organization in the Executive Yuan, ROC.



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## **3-4** First GLP Radiotoxicology Laboratory at INER in Taiwan

#### Tsui-Jung Chang

Radiotoxicology Laboratory (RadioTox Lab) at Institute of Nuclear Energy Research (INER) has successfully passed the "Good laboratory practice (GLP) for nonclinical radiotoxicology studies" authentication by the Department of Health (DOH), the Executive Yuan in August 2011. RadioTox Lab is the unique qualified GLP Testing Facility in Taiwan focusing on radiotoxicology of radiopharmaceuticals. Radiopharmaceuticals should be firstly tested in acute toxicity in rodents to evaluate the safety margins in human. RadioTox Lab owns the abilities for evaluation of extended acute toxicology of radiopharmaceuticals in rodents. The new drug <sup>188</sup>Re-liposome developed by INER has been proved targeting tumoral tissue specifically by Enhanced Permeability and Retention effect (EPR effect). Our previous findings suggest that <sup>188</sup>Re-liposome is a promising candidate for cancer therapy in C26 murine colon carcinoma ascites and solid tumor model. Thus, we evaluated the extended 28-day acute toxicity of <sup>188</sup>Re-liposome administered via single intravenous injection in Sprague-Dawley rats in accordance with the guidelines of Good Laboratory Practice (GLP). Rats were administered via intravenous injection with 188Re-liposome (185 MBq, 55.5 MBq and 18.5 MBq), normal saline as blank control or non-radioactive liposome as vehicle control. Mortality, clinical signs, food consumption, body weights, urinary, biochemical and hematological analyses were examined. In addition, gross necropsy and histopathological examinations were also performed at the end of the follow-up period. None of the rats died and no clinical sign was observed during the 28-day study period. Only male rats receiving <sup>188</sup>Re-liposome at high dosage (185 MBg) displayed a slight weight loss compared with the control rats. In both male and female rats, the WBC counts of both high-dose and medium-dose (55.5 MBq) groups reduced significantly 7 days post injection, but recovered to normal range on Study Day 29. There was no significant difference in urinary analyses, biochemical parameters and histopathological assessments between the <sup>188</sup>Re-liposome-treated and control groups. The toxicology report will support the approval of Investigation of New Drugs (IND) of <sup>188</sup>Re-liposome by DOH.

The standard operation procedure (SOP) for automated computer management system is also one of key elements in the lab. After establishment of GLP RadioTox Lab, it offers regulatory-level toxicology studies conducted under GLP standards. Protocols can be designed according to sponsor's strategy for preclinical development. Moreover, RadioTox Lab prepares for collaboration with domestic/international universities, hospitals and pharmaceutical companies following Contract Research Organization (CRO) mechanisms to promote the development of radiopharmaceuticals.





## **3-5** External Communication and Information Disclosure

Yung-Fu Hsu

Information transparency is one of INER's core value. INER concerns about its neighbors and strives to clarify any doubts regarding safety issue and at the same time publicizing the development of nuclear technology and its contribution to our daily life. Related tasks are categorized as following:

#### 1. Communicating with its neighborhood

- (1)Listening to neighbors: Visiting the neighborhood in order to gain understanding about the concerns over safety issues.
- (2)Contributing to its neighborhood: To sponsor local activities and provide assistance to low-income families.
- (3) Sponsoring medical examinations.
- (4) Hosting technical tour for general public.
- (5) Inviting the neighbors to participate in the sampling operation of the surroundings, calculating the impact of radiation effectiveness to its neighborhood by radioactivity analysis and establishing accurate database based on the results of this operation.

#### 2. Press Conference

To improve the effectiveness of communication, INER has held press conference with four guidelines:

- (1) Reaching out to the people
- (2) Sharing manifestable knowledge
- (3) Publicizing vision
- (4) placating the anxiety

The following is the summary of the press conferences held in 2011

Date	Title
01/26/2011	The Progress of Increasing Power of Taiwan Nuclear Power Plants
07/01/2011	Create Epoch in Taiwan Medical Service in Higher Order Phantom Equipment-The Development of BreastPET Positron Emission Tomography Instrument
09/19/2011	Another Taiwan-Developed Medicine –Good News for Osteogenesis Patients

#### 3. The Visiting of Distinguished Guests

To strengthen the cooperation with the governmental ministries and to increase the management capacity, INER continued expanding the cooperation network.

The followings are visits by our distinguished guests in 2011:

Date	Title
01/05/2011	Jen-Chang Chou and Shih-Chun Wang, the preceding general directors of INER, visted INER.
03/12/2011	Hsiang Shi Yan, The Minister of Economic Affairs, and Sheng Chung Lin, the Government Affairs Vice Minister, visted INER.
04/22/2011	Ching-Chuan Kuo, The Conscription Director, and other distinguished guests visted INER.
05/25/2011	General Yu-Shu Chu, the Third Theater Commander, and his subordinates visted INER.
07/20/2011	Liang-Wen Tsai and Yu-Pu Hu, the Members of Examination Yuan, visited INER.
08/03/2011	Ming-Chien Kao, the Member of Examination Yuan and the Honorary Professor of National Taiwan University, held speech in INER.
09/16/2011	Yu-Pu Hu, the Dr. of Clinical Pharmacokinetics, held speech in INER.
09/16/2011	Yu-Dong Fu, the chief secretary of Taoyuan County Environmental Protection Bureau, and the members of Taoyuan County Council visted INER.
09/28/2011	Mr. Lai-Ho Huang, the Assistant Commissioner of Economic Affairs, and Mr. Han-Chang Hsieh visited INER.
10/11/2011	Li Shuan, the Dr. of The Psychiatric Department, held speech in INER.
12/07/2011	Dr. George Apostolakis, the Member of NRC, visited INER.

#### 4. Seminars & Exhibitions

INER held 9 large-scale seminars and meetings in 2011 in the fields of Nuclear Security, Nuclear medicine and Energy, etc. To promote international standards and to improve exchange of technology and knowledge sharing, INER also participated in 8 exhibitions in the fields of Nanotechnology, Energy and Environmental Protection.

The followings are the Seminar & Exhibition held in 2011:

#### a. Seminar & Meeting

- (1) The Eighth Conference on Capability of Human Dose Estimating Meter
- (2) Conference on the Inspection Standards for Spotlight Solar System
- (3) 2011 Conference on Management of Nuclear Waste
- (4) 2011 Conference on Imaging of Neural Molecule
- (5) 2011 Conference on the Inspection Technology of Nuclear Components
- (6) 2011 Conference on Advanced Technology of III-V Solar Cell
- (7) 2011 Conference on Power of Free Radiation Dosage
- (8) The Twenty-ninth Taiwanese-Japanese Conference on Engineering Technology
- (9) 2011 TECRO-AIT Joint Standing Committee on Civil Nuclear Cooperation Annual Meeting



**M** Events of the Year

#### b. Exhibition

- (1) Special Tour Exhibition of the Economic Development of the Past Century
- (2) 2011 Taipei International Invention Show and Technomart
- (3) 2011 Taiwan Nano Exhibition
- (4) PV Taiwan 2011
- (5) Centennial Celebration Hosted by Bureau of Military Services, Ministry of the Interior
- (6) The Carnival for the New Ideas of Safe consumption and Consumer Protection
- (7) Research and Development Forum for Green Energy Technology, Taoyuan County
- (8) Sunlight, Green Energy, Happy Ocean Exhibition on Life Powered by Green Energy: City of Kaohsiung

#### **5. Reception for General Public**

In 2011, there were 66 receptions for general public to promote government's technology policy and INER's achievements in R&D so that the general public has the opportunity to understand the application of atomic science and technology in life and the status of low-carbon energy development.









#### Improvement of Nuclear Safety Regulatory Technology Research

Lih-Yih Liao

This research program has been implemented for three years. The aim is to assist AEC in ensuring nuclear safety regulatory quality and enhancing public confidence in nuclear safety. The Program is composed of nuclear safety regulation research (to support the Department of Nuclear Regulation), emergency preparedness and radiation dosage evaluation (to support Department of Radiation Protection), and radioactive waste management technology development (to support the Fuel Cycle and Materials Administration). The main achievements in year 2011 are summarized as follows:

#### 1. Nuclear Safety Regulatory Technology Development:

For the study of risk-informed regulation, this project is focused on the fire events PRA model which is of highly importance when applications of risk-informed fire protection rule are implemented in Taiwan. This effort is one of the attempts to systematically introduce the PRA standards for different hazard groups for domestic applications. In the area of digital instrumentation and control (DI&C) study, we developed a guideline for reviewing digital instrumentation and control (DI&C) system tests was based on the present constructing condition of Lungmen Nuclear Power Plant (LMNPP) and Interim Staff Guidance (ISG) proposed by U.S. Nuclear Regulatory Commission (USNRC). In the area of modeling and verification of TRACE safety analysis code, Lungmen TRACE model was established and assessed. For the material degradation study, experimental results showed that the yield strength and ultimate tensile strength of the steels did not decrease significantly in the 0.5 wt% saline spray environment, but a remarkable decrease in elongation was observed in the 5 wt% saline spray. Furthermore, a notch could exacerbate the saline corrosion degradation and aggravate the hydrogen embrittlement of SS304.

#### 2. Development of Technical Tools in Support of Emergency Preparedness and Radiation Dosage Evaluation:

In aspect of radiation safety assessment and the radiation protection, a standard procedure for assessing dose of radioactive gaseous / liquid effluents from routine operation of nuclear facilities was established for Lungmen nuclear power plant based on the program "GASDOS II LQDOS II" developed by INER. Regulator Guide 1.109 is the major reference for these codes and it can provide a methodology for the usage and reference of the reviewers. In addition, in the area of dose evaluation and investigation for proton therapy facility, MCNP-X code was used to evaluate the neutron energy response functions of the multi-spheres neutron spectrometer within the neutron energy of 20 MeV. The results were compared with those of other publications with good agreement, which implied that the evaluation techniques were correctly established in this study. Furthermore, for the nuclear facility physical protection and vehicle barrier evaluation, three kinds of most popular vehicles in Taiwan are simulated to bump into the vertical concrete cask (for spent fuel dry storage). Finally, in aspect of atmospheric dispersion of radioactive pollutant released from nuclear power plants, the evaluation results of dispersion and the meteorological information are integrated and shown on Google Earth GIS that can be shared to decision makers and other stakeholders conveniently and quickly. Hence, the platform can enhance the quality of decision making for a nuclear power plant disaster.

#### 3. Development of Radioactive Waste Management Technology

A research and development was performed for the management of low-level waste (LLW) thermal insulation material. The results showed that the compression process was the most effective and economic technology for the treatment of these wastes. The efficiency of surface decontamination for Co-60 and Cs-137 reached 93.8% and 87.3%, respectively. But the radiation level of treated simulated radioactive perlite still couldn't meet the clearance criteria of 100 Bq/kg. For the performance assessment of LLW disposal, the international cases were evaluated and the model suitability, data reliability, assumption reasonability of safety assessment were studied. We conformed the necessary analysis tool and parameter, performance requirements, reliability and reasonable of examine points. For the LLW information database guideline, by way of the cloud computing concept and the Service-oriented Architecture (SOA), an overall radioactive waste package record management system, has been proposed. For the LLW package characterization and verification, a moveable gamma dosimeter detection system is established. The system can measure cement-consolidated waste packages effectively and efficiently. For the management of the spent nuclear fuel, status of worldwide spent nuclear fuel management and disposal technology is reviewed. The international experience including the international practices and trends of R&D can benefit the policy making of domestic SNF final disposal program.

#### Study of Risk-Informed Regulation on External Events

#### Jyh-Der Lin

The Fukushima Accident depicted the importance of external events risk study. While the operational performance of nuclear power plant can be significantly enhanced through various risk-informed applications, the success of a risk-informed application is dependent on the correct use of the associated probabilistic risk assessment model, also in its completeness. This project introduces in sequence the related standards for external events PRA. In this year, the focus is on the internal fire event. The development of PRA standard is one of the major regulatory approaches of the USNRC to ensure the technical adequacy of PRA models in various risk-informed applications. Based on the PRA standard, the associated peer review is performed to validate that the PRA is of necessary quality. The standard, comprising various requirements for the technical elements in a fire PRA model, characterizes the evaluation process of fire PRA application to verify whether the capabilities of PRA elements are sufficient to support the decision making. The capabilities of PRA elements are expressed in terms of capability categories which represent their levels of compliance with different quality requirements. This project is focused on the fire events PRA model which is of highly importance when applications of risk-informed fire protection rule are implemented in Taiwan. This effort is one of the attempts to systematically introduce the PRA standards for different hazard groups for domestic applications.

The project also develops a prototype of risk significance determination tool for the inspectors to use in their assessment of risk implication of inspection findings. The project has completed the prototype for internal events based on the Lungmen nuclear power plant model. It can be provided for regulatory use after the verification and validation process as appropriate and helps to extend the inspection scope for the inspector.



#### 1-2 A Study on Software/Hardware Design of Instrumentation and Control (I&C) Modernization Related Regulatory Issues

Cheng, Tsung-Chieh

This study developed a guideline for reviewing digital instrumentation and control (DI&C) system tests based on the present constructing condition of Lungmen Nuclear Power Plant (LMNPP) and Interim Staff Guidance (ISG) proposed by U.S. Nuclear Regulatory Commission (USNRC). Furthermore, this study investigated human performances while utilizing computerized procedure system and human system interfaces. Finally, the scope and definition for the critical digital asset (CDA) of DI&C systems in nuclear power plant is identified in this study based on regulatory guide proposed by USNRC, such as RG 1.152 and RG 5.71.

This study proposes a 3D tool of the field cabinets in the LMNPP so that the maintainability and human factors issues on field cabinets can be reviewed and discussed in the conference room. A large rearprojection stereoscopic display established by this project can be used to present virtual environments, such as a main control room and a fuel handling machine. The virtual reality (VR) technology can be implemented on observing and analyzing human behaviors while they are operating DI&C systems. The results of this study can contribute to the resolution of DI&C related regulatory issues.

By using human factors principles and VR technology, the study will continually evaluate operators' performance in the main control room and field and to enhance DI&C operating safety and training performance during the nuclear plant lifecycle. In the future, the study presents a subset of the research and development and practical solutions with academic and industry partners, such as: (1) Modeling operating team decision making with emergency procedures. (2) Implementation of ecological interface design for enhancing situation awareness of nuclear process control. (3) Critical features of emergency procedures: Empirical insights from nuclear power plant operation. (4) Using VR technology for operator performance and human reliability.



▲ A 3D Tool to Introducing Field Cabinets in the LMNPP



▲ A Large Rear-Project Stereoscopic Display



Applying VR technology in the LMNPP



▲ Recognition and Control Mechanism of CDA

#### 1-3 Study of Fuel Cladding Properties and Operating Strategy at High Burnup

#### Hsiao-Hung Hsu

Hydrogen embrittlement is one of the major degradation mechanisms for high burnup fuel cladding during reactor service and spent fuel dry storage, which is related to the hydrogen concentration, morphology and orientation of zirconium hydrides. Hydrogen in zirconium alloys has a low solubility and will precipitate in a form of brittle zirconium hydride when the solubility limit is exceeded. During reactor operation, zirconium hydrides could be reoriented from the circumferential direction into the radial one when the fuel cladding was subjected to thermal cycling under a hoop stress of sufficient magnitude. In this work, J-integral values for X-specimens with different hydride orientations are measured to evaluate the fracture toughness of Zircaloy-4 cladding.



Hydrogen concentration, hydride orientation and temperature are the factors affecting the fracture toughness of Zircaloy-4 cladding, governing the embrittlement behavior. In this work, hydride orientation effect on Zircaloy-4 cladding with 300 wppm hydrogen concentration was firstly studied.

1. At 25°C, J-integral values for 300-wppm hydrogen Zircaloy-4 cladding with radial hydrides are smaller than those with only circumferential hydrides. It can be induced that radial hydrides facilitate crack propagation and degrade the fracture toughness of Zircaloy-4 cladding.

2. At 300°C, J-integral values for hydrided Zircaloy-4 cladding at the 300-wppm hydrogen level with radial hydrides are close to those with circumferential hydrides. Although the morphology of the fracture surface is different, the better ductility of zirconium matrix at 300oC can diminish the extent of embrittlement of Zircaloy-4 cladding induced by zirconium hydrides.

The effort has been reported a paper entitled "Effect of hydride orientation on fracture toughness of Zircaloy-4 cladding" and published in Journal of Nuclear Materials 408 (2011) 64-72.

Hydride reorientation in Zircaloy fuel cladding is an important issue during the interim and long term of dry storage. In this work, the degradation of fracture toughness for Zircaloy cladding with hydride reorientation effect has been studied and offers a criterion to keep the integrity of fuel cladding during operation and dry storage periods.



<sup>▲</sup> Optical Micrographs Showing 300-Wppm Hydrogen Zircaloy-4 Cladding With (A) Circumferential and (B) 52.2% Radial Hydrides.



▲ Jmax Against Radial Hydride Percentage for Zircaloy-4 Cladding at 25oc And 300°c.



▲ SEM Fractographs of 300-Wppm Hydrogen Zircaloy-4 Cladding With 46.6% Radial Hydrides Tested at 25°c.



▲ SEM Fractographs of 300-Wppm Hydrogen Zircaloy-4 Cladding With 46.6% Radial Hydrides Tested at 300°c.

#### -4 Mechanical Degradation of Cold-worked 304 Stainless Steel in Salt Spray Environments

#### Ming-Fong Chiang

As a common practice, nuclear power plants have tentatively stored spent fuel in a spent fuel pool. For the last couple of decades, the fuel interim dry storage method has become a major option because of easy administrating and convenient transportation outside plants. The dry storage canisters, which are made of SS304, are used to keep the spent fuel integrity and prevent the fission products from leaking out. Although there have been no radiation release affecting the public, no radioactive contamination, and no known or suspected attempts to sabotage the storage canister over the last 20 years, corrosion will be a concern for metal components exposed to humid environments. Saline corrosion is one of the major degradation mechanisms for stainless steel 304 (SS304) spent fuel canisters during the dry storage period. High chloride content not only increases the pitting sensitivity, but also assists the crack propagation of austenitic stainless steel. In order to understand the reliability of the storage canisters in the saline atmosphere, the corrosion resistance and mechanical properties of cold-worked SS304 should be evaluated.

Slow strain rate tensile tests (SSRT) were conducted to determine the tensile strength and notched tensile strength (NTS) of cold-rolled SS304 in 0.5 and 5 wt% saline spray environments at 85°C in this study. Experimental results showed that the yield strength (YS) and ultimate tensile strength (UTS) of the steels did not decrease significantly in the 0.5 wt% saline spray environment, but a remarkable decrease in elongation was observed in the 5 wt% saline spray. A significant decrease in elongation measurements for smooth SSRT SS304 specimens tested in a saline spray of higher NaCl concentration, and the different fracture features for 0.5 and 5 wt% saline environments. Furthermore, a notch could exacerbate the saline corrosion degradation and aggravate the hydrogen embrittlement of SS304. The SCC susceptibility could be exacerbated by a notch. All notched tensile specimens tested in 0.5 and 5 wt% saline spray environments showed transgranular fracture features. That means hydrogen embrittlement could play a role in the fracture process of notched specimens. The SSRT results indicated that the highly cold-rolled specimens could slightly increase SCC resistance under the lower chloride containing spray, but that the cold work degree was not a dominant factor in the saline spray environment. However, the NaCl concentration is a crucial factor affecting the SCC susceptibility of SS304.





▲ Fractographs of 10% cold-rolled smooth SSRT specimens tested in 5% saline spray atmosphere. The boxed-area at a higher magnification is shown to the right of the left fractograph. The seriously inter-granular fracture mode on the periphery was observed.(IZ: inner zone, OZ: outer zone)





▲ Fractographs Of Notched SSRT Specimens Tested in 5% Spray Atmosphere (10% Cold-Rolled) the Boxed-Area at a Higher Magnification is Shown to the Right of the Left Fractograph. The Remarkable Intra-Granular Fracture Mode on the Periphery is Derived From Hydrogen Embrittlement.

#### **1-5** The Establishment of Standard Analysis Procedure for Assessing Dose of Releases of Radioactive Gaseous / Liquid Effluents from Routine Operation of Nuclear Facilities

#### Yung-Muh Yang

The impact of the releases of radioactive gaseous /liquid on the site boundary environmental dose from routine operation of nuclear facilities is one of the important radiation safety assessment items at nuclear facility site selection. "Ionizing Radiation Protection Act" was promulgated on January 30, 2002. Part of the spirit of this legislation was referred to ICRP-60 Report. For the routine operation of nuclear facilities, the evaluation method of population dose from waste gaseous discharge on the people surrounding the facility must be in accordance with the "Safety Standards for Protection against Ionizing Radiation " that was implemented at 2008. Based on the program "GASDOS II LQDOS II" developed by INER, this study establishes a standard analytical procedure for Lungmen nuclear power plant. The information of Lungmen nuclear power plant site investigation and the information of gaseous discharge radioactive sources from the Chapter 12 of the preliminary safety analysis report of ABWR Units were used as a case of the dosimetric assessment. A domestic standard assessment and review procedure in this regard can be developed and to be followed.

The influence of the releases of radioactive gaseous /liquid can be assessed by GASDOS II and LQDOS II codes. Regulator Guide 1.109 is the major reference for these codes and it can provide a methodology for the usage and reference of the reviewers.







#### **1-6** Development of Dose Assessment System for Nuclear Medicine Patient Release - to Protect Radiation Safety of the Public

Kuo-Wei Lee

Radiopharmaceuticals that enable direct detection of cellular activities and effective treatment toward cancer cells have become an important medical alternative for patients in the recent years. However, the implication behind the great amount of usage of nuclear medicine treatment is the increasing risks of radiation exposure of the public from nuclear medicine patients, since radioactivity retaining in the bodies would take a few hours or days to decay.

Therefore, the Institute of Nuclear Energy Research (INER) has proposed a "Self-Management of Radiation Safety at Home" system, based on the recommendation of the international radiation protection system, to set up the dose assessment manner for released nuclear medicine patients.

In this year, the dose assessment system depended on the time impact table was established to guide people who administrated the radioisotopes from working partner and family members. On the other hand, the speed up methodology for Monte Carlo method was developed to the simulating processes. Furthermore, we proposed a control system and a flow chart in a pattern to manage the Self-Management system. All we have to do is to instruct well everyone how to manage him- or her-self at home and at societal activities.

It is expected that this system would potentially benefit the patients of 500 thousand treatment/year of nuclear medicine and the public members of about 2 million/year. Taking precautions against a possible calamity could be an effective way for reducing background radiations that might induce cancers from medical behaviors as much as 50%. Thus, it would truly uplift the living environment of citizens for their health and maintain the quality of patient's household life.



▲ Relationships Between Dose Rates and Six Time Points of the Arbitrary Patients

#### **1–7** Radiation Protection Quality Assurance and Detectors Verification Technology Establishment

#### Jeng-Hung Lee, Shi-Hwa Su, Chien-Yung Yeh and Chin-Hsien Yeh

o fulfill the competent authority's needs for medical exposures quality assurance, radiation protection and control, INER developed related radiation dose calibration systems and evaluation technologies. INER also established the radiation detectors testing techniques and the verification platform which meet the international standards. The tasks concretely accomplished in 2011 are:

- (1) Made 3mL and 5mL syringe standard samples that are frequently used in hospitals with the INER-made high activity  $^{67}$ Ga radiopharmaceuticals; used the  $4 \varpi \gamma$  high pressure standard ionization chamber system to accomplish the radioactivity calibration for the radiopharmaceutical syringe samples. The existing method to calibrate dose calibrator using syringe standard samples is replaced by using vial samples and that improves the measurement accuracy of the radiopharmaceutical radioactivity.
- (2) Fabricated on-site calibration equipments of environmental dose monitoring instrument for nuclear facilities; established on-site calibration techniques for environmental dose monitoring instrument with the advantage of quitting the old method which has to take off the instrument from the lab and then put it back. With the new method, the environmental dose monitoring instrument can be calibrated timely and the connection function of the instrument is secured.
- (3) Took the chance that INER changed its extremity ring dosimetry system in 2011, we referred to the 2008 American National Standard of Performance Testing of Extremity Dosimeters (ANSI N13.32) and designed the calibration phantom needed for the extremity ring dosimeters; conducted measurement of correction factors and assessment of dose equivalent conversion factor; accomplished the establishment and testing of  $\gamma$  and X-ray dose calibration system for extremity ring dosimeter.



 Radioactivity Calibration for Radiopharmaceutical Syringe Samples



 On-Site Calibration for Environmental Dose Monitoring Instrument



## **1-8** Dose Evaluation and Investigation for Proton Therapy Facility

#### Ming-ChenYuan

Proton therapy is one of the most effective tools treating cancers. Comparing with the traditional high energy X-ray therapy, the proton therapy can give higher dose to tumors and reduce the side effect of radiation for the normal tissue. Therefore, it is expected that proton therapy facilities will be introduced into some domestic hospitals in the near future. Proton therapy facility produces a lot of high energy neutrons resulting from the collision of protons with accelerator components and the high energy neutrons could cause extra radiation dose on the hospital staff members and patients. How to measure and evaluate neutron dose is one of the main tasks of radiation protection.

The neutron energy induced by the high energy protons is higher than that induced by the nuclear fission. To measure the high energy neutron, an advanced multi-spheres neutron spectrometer was introduced, which was composed of 12 PE spheres from 3" to 18" in O.D., four spherical metal shells and a spherical He-3 proportional counter. The measurement data, neutron energy response functions of the neutron spectrometer will be inputted in an unfolding code to obtain the neutron spectrum and to evaluate the neutron dose of the measurement position.

In this year, MCNP-X code was used to evaluate the neutron energy response functions of the multispheres neutron spectrometer within the neutron energy of 20 MeV. The results were compared with those of other publications with good agreement, which implied that the evaluation techniques were correctly established in this study. On the other hand, a calibrated Cf-252 neutron field was measured by the multispheres neutron spectrometer. The measurement data and the neutron energy response functions were input into the UMG 3.3 unfolding code to evaluate the neutron spectrum of the Cf-252 neutron field. Compared with the Cf-252 neutron spectrum of ISO 8529, our result showed a little bit higher than that of the ISO 8529 in low energy region and the total area of the spectrum was also about 20% higher than that of the ISO 8529. That might be caused by the room scatter effect and the lack of precise physical parameters of the He-3 counter input in the MCNP-X. In the future, we will reduce the neutron room scatter effect and adjust the physical parameters of the He-3 counter input in the MCNP-X to improve the accuracy of the multi-spheres neutron spectrometer.



 Neutron Energy Response Functions of the Multi-Spheres Neutron Spectrometer



▲ Cf-252 Fission Neutron Energy Spectrum (Red: ISO 8529, Green: This Study)

#### **1-9** Nuclear Facility Physical Protection and Vehicle Barrier Evaluation Methods

#### Wu-Yueh Cheng, Tung-Liang Chu

For the new security requirements survey of the physical protection system this year, we study the IAEA INFCIR/225 enhancement path from rev. 4 to rev. 5, and compare them with the NRC 10 CFR 73.54. For the cyber security, NRC RG 5.71 is compared with FERC/NERC CIP-002~ 009, on these topics we have written 2 INER reports.

For the outsider intrusion vulnerability analysis, SAVI developed by the US Sandia National Laboratory is investigated. The man-machine interfaces and security equipments deployment are studied to find major constituent program modules, file formats. One INER report is published to report the SAV limitations and possible modifications for local applications.

The vehicle barrier evaluation consists of (1) Impact fracture analysis, (2) Dynamic energy & potential energy analysis, (3) Lateral force balance stability analysis. This year 3 kinds of most popular vehicles in Taiwan are simulated to bump into the Vertical Concrete Cask for Used Fuel Dry Storage. While maintaining the cask integrity, the maximum achievable velocities are calculated, these velocities are compared with those used in the isolation zone vehicle barrier at the Lungman NPP, one INER report is published.

For the SCI journal publication," Stiffened plate subjected to shock loading using the nonlinear finite element method," in which the non-linear finite element software LS-DYNA is used to study the reinforced concrete behavior under different explosive shock loads as shown in the following diagrams, is submitted. So that for this year, we have written 4 INER reports, and 1 SCI journal submittal. Last year the submitted paper "Dynamic response of a reinforced concrete slab subjected to air blast load" was accepted by "Theoretical and Applied Fracture Mechanics", and after some proof reading would be published.



FIRP Reinforced Concrete Plate

 Plate Displacement-Time History Under Different Shock Loadings



#### **1-10** A Modeling Validation Platform on the Estimation of Atmospheric Dispersion and Radiation Dose of Nuclear Power Plants

#### Hsin-Fa Fang

This project designed a Geophysical Information System (GIS) based platform to display the atmospheric dispersion of radioactive pollutant released from nuclear power plants and to verify the evaluation result. This project set up a standard procedure to get the dispersion modeling output and monitoring data. Therefore, the platform can calculate the difference of evaluation result and monitoring data to validate the model under official regulation standards of Taiwan Environmental Protection Administration. Be worth mentioning, the platform also can validate modeling by using the standard regulation of United States Environmental Protection Agency which has adopt ASTM D6589-00, Standard Guide for Statistical Evaluation of Atmospheric Dispersion Models.

Moreover, the evaluation results of dispersion and the meteorological information are integrated and shown on Google Earth GIS that can share to decision maker and other stakeholder conveniently and quickly. Hence, the platform can enhance the quality of making decision for the disaster of nuclear power plant to achieve the goal of radiation protection



▲ Calculation Result of Wind Field Displayed on Google Earth



▲ Display of Aerosol Dispersion Simulation Results

## **1–11** The feasibility study on Treatment Technology of NPP Wasted Thermal Insulation Materials

#### Yu Chao, Kin-Seng Sun, Hsien-Ming Hsiao, Yen-Hua Chang

The wasted thermal insulation materials generated from nuclear power plants (NPP) were mainly perlite and rockwool. Several techniques, including plasma melting, thermal melting, combining thermal and compression processes, surface decontamination and reuse as cement blend, have been carried out on the treatment of perlite and rockwool, respectively. This study tried to find out a more suitable, effective and economic technology for the treatment of these wastes.

Melting process had a volume reduction ratio of 4, but it needed to keep over 1000oC to get this good volume- reduction effect due to the excellent heat resistant properties of perlite and rockwool. So, in

the opinions of time and energy consumptions, melting process was not a suitable technology. Besides, the compositions of perlite are plant specific. Therefore, different results were obtained with the same treatment process. It was not recommended to deal with those thermal insulation materials by melting process.

For the combining thermal and compression processes, the benefit of volume- reduction for high temperature in lower pressure was distinct. When the pressure increased, the benefit of heat decreased. Combining process was not recommended unless some other special purposes were considered simultaneously. In room temperature, the volume reduction ratio could reach four and ten when a pressure of 600 kgf/cm<sup>2</sup> and 200 kgf/cm<sup>2</sup> were applied to perlite and rockwool, respectively. It was the most effective and economic technology for the treatment of these wastes.

With dropping liquid radioactive source on the surface of perlite, the simulated radioactive perlite was then immersed in several kinds of acidic or basic solution, followed by ultrasonic vibration to remove surface contamination. Experiment results showed that oxalic acid solution had the best decontamination effect. The decontamination efficiency for Co-60 and Cs-137 reached 93.8% and 87.3%, respectively. But the radiation of treated simulated radioactive perlite still couldn't meet the clearance criteria of 100 Bq/kg.

Cylindrical concrete specimens were produced by mixing perlite powder with cement under various aggregate to water ratios and the compressive strength of the solidified specimens has been examined. In the formula of W/B (water-binder ratio) = 0.5 and 10% of cement was replace by perlite powder, the specimens had similar performance to pure concrete. The 90-day compressive strength reached 230 kgf/  $\rm cm^2$ , which met the requirement of ordinary building. It is feasible that blending some releasable perlite powder with cement for civil engineering in nuclear power plants.

Specimens No.	14 day compressive strength (kgf/cm <sup>2</sup> )			28 day compressive strength (kgf/cm <sup>2</sup> )				90 day compressive strength (kgf/cm <sup>2</sup> )				
	No.1	No.2	No.3	Ave.	No.1	No.2	No.3	Ave.	No.1	No.2	No.3	Ave.
50P00	290	191	218	233	233	202	210	215	NA	107	154	131
50P10	225	183	211	206	242	229	210	227	248	254	189	230
50P20	129	125	164	139	171	194	-	182	187	190	189	189
50P30	83	77	72	77	94	80	75	83	95	103	113	104

Table 1. Compressive Strength of Reused Perlite Concrete



▲ Compress Curves of (a) Wool and (b) Perlite in Room Temperature





#### 1-12 12 Development of Low-Level Radioactive Waste Measurement Technology

#### Ping-Ji Huang

Over the past three decades, The nuclear power plants in Taiwan have produced a great amount of low-level solid radioactive wastes (radwastes) through routine operations and maintenance. Most of the wastes are of non-contaminated or very low-level contaminated radioactive waste generated from dismantling process. If those wastes are all treated as low-level radioactive waste, a lot additional costs would be consumed for decommissioning. Based on local regulations, the composition and radioactivity of the nuclides of the wastes should be identified and accurately measured before being released or put into long-term storage.

Both gamma-ray spectrometry and gross gamma assay can be used as clearance techniques by measuring drums of radwastes. Counting systems such as plastic scintillation detectors have been operated to measure low activity waste in 208-Litre drums at INER for about 5 years. However, this equipment is shielded with heavy lead shield and can not be easily transported to measurement locations. A movable, non-destructive assay system (ISOCART) will be an ideal solution for in-situ gamma-ray measurements. In this project, we have evaluated the possibilities of measuring the activity of <sup>137</sup>Cs in thirty-five radwaste drums by using a single HPGe detector in a fixed position. This movable gamma-ray spectrometry system was compared to the capabilities of counting systems using two HPGe detectors or the plastic scintillation-based detector with  $4\omega$  counting geometry. From the measurements results of the thirty-five low-level radwaste drums, it was found that there was no significant difference among these three counting systems. This means that the movable gamma-ray counting system is comparable to the well-known multi-detector or plastic scintillation-based counting systems and suitable for the measurements of low-level <sup>137</sup>Cs radwaste produced from nuclear power facilities decommissioning.



▲ The Movable Gamma-Ray Counting System (ISOACRT)



▲ The Linearity of the Single- and Multi-HPGe Gamma-Ray Counting System.

#### **1–13** Information Management System and Database Upgrade for the Radioactive Waste Inventory Records of Nuclear Power Plants

#### I-Hsin Chou

To implement the future safety assessment for "Final Disposal Plan of Low-Level Radioactive Waste (LLRW)", it is necessary to recalculate and re-estimate the low-level-radioactive-waste-related records, which include the amount, radionuclide and classification of radioactive waste drums, etc. Although computerbased information management systems were developed by individual Nuclear Power Plant (NPP) and interim radioactive waste storage facilities, there is no consistency between the systems. As a result, there tends to be difficult in tracing and analyzing radioactive waste. Therefore, the main results of this project are: (1) to develop an integrated radioactive waste record database based on the IAEA recommendation, Fuel Cycle and Materials Administration requirement, and Waste Acceptance Criteria for the future final disposal (2) using software program and data analysis tool to improve technical capability as well as to ensure the correctness and integrity of the LLRW record. The prototype of information management system design is also useful for the upgrade project of LLRW information management systems for LLRW facilities, which are inside Chinshan, Kuosheng, and Maanshan NPP.



▲ Low-Level Radioactive Waste (LLRW) Lifecycle Records

E procession	<ul> <li>Multi-layer structure</li> </ul>	歷史資料查詢	服業物桶管理
And a second sec	<ul> <li>Integrated design</li> </ul>	IBM系統資料查詢	廢棄物桶資料維護
	<ul> <li>Integrated detabase</li> </ul>	繁硕检整资料查询	廢棄物桶資料查詢 批次產生難測核種比活度
	Scopo widor	比例因數管理	統計圖報表
		分析樣品管理	年產量賽採累計圖報表
	<ul> <li>Easy operation</li> </ul>	比例因數計算	廢棄物源產量圖
		比例因數室證	廢棄物源月產量衰減圖
	<ul> <li>Process control</li> </ul>	D to C比值管理	廢棄物源衰減圖
	<ul> <li>Object-oriented</li> </ul>	各年度比例因數	校種変滅累計圖
Harrison Trees	Customized design	影默於定管理	
	• Customized design	国化/非固化方式設定	板號管理
And a state of the second	<ul> <li>Analysis of nuclides</li> </ul>	衰變常數設定	操作事件查询
"	Carling fratering and	電廠設定	資料庫匯出
TITITI NESSAR	<ul> <li>Scaling factor report</li> </ul>	機組設定	
÷IIIII Qube	<ul> <li>Web-based interface</li> </ul>	廢棄物源設定	

▲ The Prototype of LLRW Information Management System Design


# **1–14** Study on the Management Plan of the Spent Nuclear Fuel

Li-Min Chi

In 2011, INER had proposed a new project "Study on the Management Plan of the Spent Nuclear Fuel". The mission of the project is to provide technology solutions and strategic management plan to help safe, efficient handling, and disposition of spent nuclear fuel in Taiwan.

Two main tasks had been finished in 2011:

#### (1) Review on the status of worldwide spent nuclear fuel management

The status, 34 nuclear power countries worldwide, of spent nuclear fuel disposal is reviewed. It includes the information of management organization, nuclear power policy, nuclear power plant units and capacity, status and future development of storage, reprocessing, and final disposal. The practices and trends of spent nuclear fuel management focus on several issues, such as nuclear power plant operation period extension, new reprocessing process development, national disposal plan and agency setup, disposal technology development, and public acceptance. Most of the country has deferred the decision on direct disposal or reprocessing.

### (2) Case review on the international status of research and development for spent nuclear fuel disposal

Worldwide status of spent nuclear fuel disposal is reviewed. This study focuses on the international status of research and development of disposal technology. Some cases of disposal program of technology advance countries, such as Belgium, Finland, France, Japan, Sweden, Switzerland, and United States of America, are discussed. It includes the information of site characterization, disposal facility design, and long-term safety assessment.

The international practices and trends of R&D for SNF disposal focused on several issues, such as underground research laboratory, supercontainer, monitoring and retrievability, full-scale demonstration, safety case assessment, and public acceptance.

The experience of foreign countries can benefit the SNF final disposal program of Taiwan.



▲ Spent Nuclear Fuel Disposal Concepts in Taiwan

### Nuclear Facility Decommissioning and Radioactive Wastes Management

#### Wen-Shou Chuang

Nuclear power, under the condition of secured nuclear safety and proper radwaste management, is a sound option that can fulfill both stable energy supply and greenhouse gas emission reduction. The use of nuclear power will also improve Taiwan's power generation structure by lowering the carbon-emission electricity. To make less impact on the environment as well as the public, the radwaste generated from nuclear power facility operation and maintenance must be 'safe' and 'volume-reduced'. In order to safely apply nuclear energy, both the nuclear facility decommissioning and radioactive wastes management are the major concerns.

This project is aimed to develop radwaste management related technologies required for nuclear power system lifecycle. The strategy is to first perform studies on the current facilities of INER for establishing the core technologies. Next, the dismantling of unused nuclear facilities and the treatment of problematic radwaste that have been stored long ago in INER will be gradually carried out. The established technologies will provide support to the operation domestic nuclear power plants as well as the management of decommissioning radwaste in the future. In 2011, the achievements of INER are summarized as follows. For the volume reduction of decommissioning waste, remote-controlled lifting technology for large-scale nuclear components, stabilizing and canning technology for sludge retrieved from TRR spent fuel pool, clearance technology for large radioactive waste, and activity measurement technology for metal wastes have been established. For the treatment of special radioactive liquid waste, solar evaporation system for tritium-containing wastewater, organic wastewater treatment processes and inorganic adsorbents for radionuclide removal have been evaluated. For the final disposal of radwaste, technology for determining lodine-129 in environmental samples, the hydrogeological conceptual model of nuclear power plant, and concrete disposal containers with high structural integrity have been developed.



### 2-1 The Remote-Controlled Lifting Technology Research for High Activity Large-Scale Nuclear Components

#### Pei-Hsiang Huang

The implementation of the remote control lifting technology research this year is in accordance with the future decommissioning. Therefore, the purpose of this project is to develop a nonlinear control crane model with characteristics such as simple operation, precise positioning, and limited vibration. In order to construct a secure remote-controlled lifting technique for the nuclear facility decommissioning work in the future, we introduce the intelligent control technology which imports the space vector information and crane location into the calculation of the controller.

The crane itself is a highly complex nonlinear system; it is difficult to obtain its dynamic model. In this research, we propose a neural sliding mode control, and use two neural networks for the design. The first neural network estimates the equivalent control through the weight adjustment, the system state remains in the sliding surface and converges toward the equilibrium point along the sliding surface. The second neural network is used to adjust the weighting parameter matrix, which contains the slide moving slope parameter matrix G and the impact of impending rate parameter matrix K. Using of estimation to improve the control of principles can quickly return to sliding surface from unstable condition; such that the final overall system can eliminate errors, improve cut jump phenomenon, and has a shorter looming and smooth sliding time in order to achieve the best control effect.

The research refers various domestic and foreign remote-lifting methods and path planning principles; meanwhile, we compare the advantages and disadvantages of the various controllers to develop neural sliding control technology, in order to control technology with the TRR reactor components dismantling of lifting planning in the lifting operation. In the case, it can ensure to inhibit the swing and accurate positioning, and also achieve security and the exact requirements of the decommissioning operations.





Simulation Equipment

 Experimental Result as Crane Tracking, Swing Angle and the Length of Cycloid.

### **2-2** Water Purification Trial for TRR Spent Fuel Pool

#### Chun-Ping Huang

Since March 2010, the transuranic contaminated high activity spent resins, which temporarily stored in the TRR spent fuel pool (SFP), has begun cleanup. Approximately 926 m3 of SFP water was further contaminated by fission products and actinides; by the observation of 137Cs and <sup>90</sup>Sr during 2008 to 2011, it reveals that the activity concentrations of the radionuclides increased dramatically since cleanup. Furthermore, the clarity of water was interfered with by uncertain suspended solids, so the under water tasks were seriously disturbed.

In order to improve the quality of TRR SFP water, a purification system (capacity 1.0 LPM) which cascade with three pore sizes ceramic filters (5, 0.9, and 0.22  $\mu$ m) in series was employed. The main advantages of using the ceramic filter in the treatment of liquid radioactive wastes are radiolysis resistance and backwashable, which increase the lifetime and reduce the secondary wastes. The turbidity of the original water was 4.37 NTU, which was then improved to 2.3, 1.9 and 0.8 NTU for pore sizes of ceramic filters. Most of suspended solids were removed by 0.22  $\mu$ m ceramic filter.

The diatomite-based ceramic filter is capable to remove suspended solids and to adsorb ionic radionuclides (especially for 137Cs). More than 99% of gross  $\beta$  and gross  $\alpha$  were removed by the

purification system. The radioactivities of filtrate have met the acceptance criteria of liquid radioactive wastes treatment facilities in INER.

The diatomite-based ceramic filter has been proved that it is sufficient for the purification of water in TRR SFP, and the system will gradually scale up to improve the turbidity and to reduce the activity concentrations of radionuclides.



Activity Concentrations Monitoring of <sup>137</sup>Cs ► and <sup>90</sup>Sr in TRR SFP (2008~2011)





The Removal of α -Emitters in Water After Treated by Each Filter.

<sup>▲</sup> The Activity Concentration of  $\beta$  -Emitters, <sup>137</sup>Cs and <sup>90</sup>Sr in Water After Treated by Each Filter.



# $2\text{--}3 \begin{array}{c} \text{Stabilizing and Canning the Sludge Retrieved From} \\ \text{TRR Spent Fuel Pool} \end{array}$

Yaw-hwa Shiu

In the project of decommission of Taiwan Research Reactor(TRR), removing the sludge from spent fuel pool and stabilizing the retrieved irradiated uranium-containing sludge for long term dry storage is a vital step in the cleanup of TRR spent fuel pool.

During long time wet storage in the spent fuel pool, aluminum cladding and canisters of TRR spent fuels are corrosively breached and deteriorated as the uranium metal fuel oxidized and expanded. This has allowed some dissolution of uranium, transuranics and fission products into the spent fuel pool water. The sludge in the pool is of highly variable composition, which is formed from the dissolution materials as well as the corrosion of cans, equipments inside the pool water and also spalled concrete from the pool walls.

For the purpose of safe long term dry storage, the retrieved spent fuel pool sludge is designed to be stabilized by being oxidized in air at elevated temperature in the hot cell. After that, the stabilized sludge need to be canned and sealed by welding. And the plutonium and uranium content of the sludge would be determined by Neutron Coincidence Counter (NCC) system for accounting balance of nuclear material to meet the safeguard requirements.



## 2-4 Establishment of Clearance Technique for Large Radioactive Waste

#### Huang-Sheng Chiu

According to "Regulations on Clearance Level for Radioactive Waste Management" issued by the Atomic Energy Council, Executive Yuan on 2004, the radioactive waste is feasible to be released if its activity of specific activity is lower than the regulatory value. To fulfill the policy on waste reduction and to meet the need for clearance technique, the INER has set up the Clearance Measurement Laboratory (CML) and established the techniques on instrument calibration, quality control, and whole-drum measurement, etc.

The CML introduced the movable gamma ray detection system, ISOCART, specifically for measuring large radioactive waste. First, the performance of the movable gamma ray detection system was evaluated by measuring the low level radioactive cemented barrels, and the results were compared with the ultra-low level gamma ray detection system (AQ2) and the plastic scintillator detector (SWAM2). The results showed that the deviations were within 20 % in the tests of 35 low-level radio waste barrels, where the deviations were within 10 % among the 30 tested barrels. It was demonstrated that the movable gamma ray detection system can run stably and accurately. Besides, the cemented barrels were arranged in square (with four barrels), in cube (with four and eight barrels) and in rectangular (with six and eight barrels) to simulate the geometry of large radioactive waste. The results of the measurements showed that the deviations were consistently within 20 %.



▲ Movable Gamma Ray Detection System (ISOCART) Treated by Each Filter.



 Plastic Scintillator Detector (SWAM2)



▲ Simulation of Large Radioactive Waste



### 2-5 Energy Spectrum Analysis for Nai (TI) Detector and Fns99 Assembly on the Application of Metal Waste Measurement

#### Kuo-Jen Lin

Nal (TI) detector is the most popular scintillation material for gamma-ray spectroscopy. FNS99, an electronic assembly which is developed by INER, can change Nal (TI) detector's output pulses into spectrum and also counts the number of the incoming pulses. The radioactivity of nuclides can be measured according to the counting number. However, the resolution of Nal (TI) detector is not good enough such that an overlapped spectrum appears if there are many nuclides exist inside the measured object. This spectrum-overlap phenomenon causes some difficulties to distinguish nuclides and to calculate the corresponding radioactivity.

Mono-energetic calibration source spectrum consists two parts, one is an energy peak whose distribution is similar to Normal Distribution in mathematics, the other is a scattered low-energetic spectrum due to Compton Effect. These two spectrum have particular correlation. Extracting characteristics of these two spectrum can be done by means of doing some mathematical operations. According the extracted correlations, each nuclide's spectrum can be obtained by doing several mathematical operations. Then the radioactivity intensity of each nuclide can be determined.



▲ HMI : System Configuration Setting

<sup>137C</sup>s, 54Mn, <sup>60</sup>Co and <sup>40</sup>K are four major nuclides in metal waste, other radioactive nuclides can be very low in percentage and thus can be overlooked. After applying the proposed algorithm on 5 NaI (TI) detectors and FNS99 assemblies system and using calibration sources of these four nuclides to calibrate the system, the measurement results show that the estimated radioactivity error can be less than 10%. It illustrates it is feasible to implement a system which is capable of qualitative nuclide identification by using the proposed algorithm. And the system can be applied in metal waste clearance management.



▲ HMI : Measured Spectrum



HMI : Measured Result of Activities

## 2-6 A Study of Thermal Efficiency of an Experimental Solar Evaporator

#### Chung-Yung Lin

The solar-driven desalination is a promising green technology. For instance, the solar evaporator is applied to wastewater treatment, desalination, and chemical processes. The main equipments of the experimental solar evaporator, which have been successfully installed, are the U type vacuum-tube collector with an area of 62 m2, steam separator, and the falling film evaporator with an area of 0.8 m2. The test results show as follows. The maximum temperature of the steam separator is up to above 120, and the low pressure steam is steadily supplied by the solar evaporator. The output rate of the distillate is approximately 20 L/h, and the overall thermal efficiency of the experimental solar evaporator is 24%. Hence, the feasibility of the solar evaporator for the desalination process is confirmed.



Experimental Solar Evaporator



▲ U Type Vacuum-Tube Collector



▲ Temperature Distribution of Solar Evaporator

▲ Variation of Radiation Intensity



# **2-7** Feasibility Study on Treatment for Organic Radioactive Liquid Waste

#### Chin-Chang Shen

INER has been receiving low-level radioactive liquid waste generated from domestic hospitals, research institutions. They are temporary stored in tanks without treatment. In order to properly manage such waste and to avoid possible harm to the environment, experiments and tests were perform in this study to determine the appropriate treatment methods for handling the radioactive waste. Due to the precipitation by gravity over time, the radioactive organic liquid waste was separated into the top organic layer, middle aqueous layer, and the bottom jelly layer. The analysis results indicate that organic layer accounted 23% of the total waste and no chlorine was detected. The middle layer accounted 75% of the total waste and contained 0.7% sodium chloride, while the bottom jelly layer accounted about 2% of the total waste and contained 0.94% chlorine ions.

The combustible top and bottom layers can be can be treated by incineration method while the

aqueous layer can be treated first by Fenton's method or gelation procedure then followed by high-temperature incineration. In this study, the highly absorbing material (PLM) was used to absorb the liquid waste which then was transformed into solid combustible furnace. Each kilogram of PLM could absorb 45 kg of aqueous solution. This method can be performed using the existing equipment without adding extra capital cost for equipment. We hope this method will serve as a reference for future studies on organic liquid waste treatment.



 PLM Solidified Product and the Ash of High Temperature Oxidation



Current Major R&D Activities

## **2-8** Development of Inorganic Adsorbent for the Removal of Cs-137 Radionuclide

#### Kou-Ming Lin

Cesium-137 is a man-made radionuclide produced from nuclear fission reaction. It has a halfdecay life of approximately 30.17 years and has been applied to civilian applications such as calibration of radiation detector, radiotherapy (for killing cancer cells), measurement of liquid flow, measurement of object thickness, and disinfection of medical equipment as well as food. In general, cesium-137 containing liquid waste is generated from schools, research institutes, hospitals, nuclear facility decontamination, and nuclear power plant operation. Since Cs-137 has a long half-life and can emit  $\beta$  and  $\gamma$  radiations, its presence in the environment will pose serious threat to human health and, therefore, must be carefully managed.

Cesium-137 is very soluble in water; as a result, it will spontaneously exist in liquid waste. The commercial products for Cs removal are quite expansive. For example, the price of DT-30a is around NT\$72,000/ft3 and that of Cs-Treat is around 343,000/kg. Due to the recent severe accident at the Fukushima Dai-ichi Nuclear Power Plant in Japan, the demand for Cs-removing adsorbent has skyrocketed. The inorganic Cs adsorbent developed by INER called "AC-5BZ" has high selectivity, excellent radiation



AC-5BZ

resistance, and good hydraulic/mechanical properties. Its particle size can be controlled in between 0.5~2 mm. It has high adsorbing capacity and low cost (approximately NT\$1000/kg). Since AC-5BZ is inorganic, the secondary waste generated after treatment is very stable and can be easily disposed of. AC-5BZ is produced entirely by domestic technology. The production process has been tested and verified to produce products with good quality. Currently, the adsorbent has been produced and will be used by INER's liquid waste treatment plant. Patent application for the adsorbent is undergoing. The results of this technology have been published in the 2011 Cross-Strait Radwaste Treatment Symposium. In the future, the technology will be further promoted to domestic nuclear power plants as well as other foreign countries.







# **2-9** The Determination of Iodine-129 in the Environmental Samples using ICP-QMS

#### Wei-Hsi Chen

This study is concerned with an analytical method based on inductively coupled plasma quadrupole mass spectrometry (ICP-QMS) to determine the long-lived radionuclide, I-129, in the environmental samples. The seaweed samples were decomposed by microwave digestion system then iodine in the digested solution was separated by extraction and back-extraction from matrices for ICP-QMS measurement. Calibration standards and samples solutions were prepared in 1% TMAH aqueous matrix in order to prevent memory effect from iodine during ICP-MS measurement. The background interference of mass at 129 from Xe-129 and H2I-127 were eliminated by means of purging O2 (0.8 mL/min) and He (3.0 mL/min) into collision cell before quadrupole mass analyzer of ICP-QMS. The concentration ranges of calibration for the iodine isotope 127 and 129 were 0.5~30 ppb and 5~1040 ppt, respectively. This technology can be applied to directly determine I-129 in the underground water and the detection lime can conform to the standard drawn by USEPA for maximum content level (MCL) 5.7 ppt in the drinking water.The method detection limit (MDL) of I-127 and I-129 in solid samples were 0.63 mg/kg and 0.6 µg/kg, respectively, and MDL of I-129 could be lowered 30 times than that of traditional radioactivity counting. In this study, I-129 content in both of seaweed (Ulva) and NIST SRM4359 were lower than 0.6 µg/kg.



▲ Quadrupole ICP MS Instrument



Flow Chart of Sample Pretreatment

## 2-10 Hydrogeological Conceptual Model of Nuclear Power Plant

#### Ching-Fang Shih

This research develops site specific hydrogeological conceptual model for Nuclear power plant according to the EPRI-1016099 "Groundwater Protection Guidelines for Nuclear Power Plants" report. The hydrogeological conceptual model is regarded as a framework of radionuclides transport in groundwater if leakage occurred, and the characteristics of contaminated groundwater will be performed. In order to establish the model such as the site layout, geological exploration data and groundwater monitoring information are referred to define the hydrological and geological structure units and groundwater system first, and then combines with geological information system to complete the preliminary digitalized static conceptual model. This basic model has definite boundary condition and property of groundwater system in site domain.





### 2-11 The Research and Development of Concrete Disposal Containers with High Structural Integrity to Endure for 100 Years

#### Ching-Tu Chang

This project is proposed for the research and development of concrete disposal containers with high structural integrity to endure for 100 years. Currently, domestic low-level radwastes are contained in steel drums and temporarily stored at nuclear power plants or in Lanyu repository. Long-term storage may have caused changes of chemical and physical properties for these waste forms, which eventually leads damage of the containers. The repacking of these damaged containers will produce more waste and add extra costs. INER has successfully developed a so-called "high performance concrete". The high performance concrete has high compressive strength of greater than 55MPa with extremely good workability. In addition, the HIC (High-Integrity Container) made from high performance concrete also possesses the good mechanical strength.

In this project, verification experiments and application report for HIC will be conducted and completed according to the Standards and Application Guide of HIC for Low-Level Radwaste announced by FCMA. The work items in this project include: (1) Concrete formulation and material quality verification. The optimal conditions to formulate high performance concrete will be developed. (2) According to the standards of

HIC, quality and reliability tests for high performance concrete will be conducted. (3) Moreover, material characterization technologies will be developed to help the design and fabrication of HIC. (4) To fulfill the requirements set in the application guide for making good quality HIC, improvements on the concrete mixer will be carried out. (5) Besides the fabrication of HIC, various tests on the structural integrity of HIC as well as the test reports will be completed in this project. (6) 100 high-integrity containers will be provided to Kuosheng Nuclear Power Plant for evaluation.



▲ HIC Fabrication Equipment



Current Major R&D Activities

### 3

### Isotope Researches and Applications in the Medical Field

#### Yu-Chin Tseng

Improving healthcare based on isotope researches is one of INER major goals. Radiation Application Technology Center (RATC) at INER employs its strengths in radionuclide production, synthetic chemistry, unique radiopharmaceutical chemistry, and a plant complying with the current good manufacturing practices (cGMP) to underpin the discovery, development and evaluation of novel radiopharmaceutical processes. In addition to radiopharmaceutical production, INER has established a Cobalt-60 facility, accredited with ISO13485: 2003+AC2007, ISO9001, to provide irradiation services to domestic companies.

Given that cancer is a leading cause of death worldwide, the projects to develop radiopharmaceuticals for the diagnosis as well as management of various cancers are high priority in INER. <sup>188</sup>Re-liposome, a radiopharmaceutical designed to targeting tumoral tissue specifically by enhanced permeability and retention effect (EPR effect), has been proven as a promising candidate for cancer therapy in C26 murine colon carcinoma ascites and solid tumor model. In the fiscal 2011, the 28-day extended acute toxicity of <sup>188</sup>Re-liposome has been investigated in Sprague-Dawley rats with in-house established Radiotoxicology Laboratory. The information obtained from this study will serve as a safety reference in early-phase clinical trials. Furthermore, an exploratory investigational new drug application (eIND) of <sup>188</sup>Re-liposome was submitted to Taiwan Food and Drug Administration (TFDA) in August 2011. The trial will soon be conducted to evaluate its efficacy and benefits for patients. INER researchers have been involved in the development of a promising radiopharmaceutical InerTA, a radioiodinated thymidine analog, for imaging lung cancer in a LL/2 lung carcinoma-bearing mouse model. The radiopharmaceutical was confirmed highly accumulated in the tumors. Since the current diagnostic approach of gastric cancer still relies on invasive procedures, it is highly desired to develop a non-invasive approach such as molecular imaging for the diagnosis of gastric cancer. We devote to the study for seeking out new biomarkers to characterize gastric cancer by using twodimensional differential gel electrophoresis (2D-DIGE). Three biomarkers were discovered and verified. The over-expressed GRP78 protein holds promise to diagnose more accurately and treatment gastric cancer in research and clinical practice. Adjuvant Chinese herbal medicine has been suggested as an alternative treatment among cancer patients on the prevention and treatment of radiotherapy side effects. INER's research team has found that Antrodia cinnamomea (AC) can ease the radiation-induced cytotoxicity. Moreover, AC could also enhance the radiation-induced inflammatory effects and cytotoxicity in tumor cells dose-dependently. INER has undertaken the fabrication of the prototype of breast PET, an imaging modality for breast cancer screening with high sensitivity. Before conducting a clinical trial, the verification of electrical safety and electromagnetic compatibility for this modality has been performed in fiscal year of 2011.

INER has established the Radiotoxicology Laboratory (RadioTox Lab), which is the first testing facility in Taiwan focusing on radiotoxicology of radiopharmaceuticals. The RadioTox Lab has passed the "Good laboratory practice (GLP) for nonclinical radiotoxicology studies" authentication by the Department of Health (DOH), the Executive Yuan in August 2011.

The development of radiopharmaceuticals targeting to central nerves system is also a major aim at INER. In the early August 2011, INER has entered into a Distribution Service Agreement with Biomolecular



Technology Comercio (BMT) to market INER TRODAT-1 kit, the first technetium-99 labeled dopamine transporter imaging agent in the world, in Brazil. In order to reduce the radiation exposure to operators in production of radiopharmaceuticals as low as reasonably achievable (ALARA), the auto-synthesizer for manufacturing <sup>123</sup>I-ADAM, a serotonin transporter agent, has been developed at INER. This invention was awarded the Bronze Medal at "2011 Taipei International Invention Show and Technomart. Because the increasing need of biomedical implants for orthopedic diseases, the orthopedic biomaterials become the focused items in biotechnology industry. We have prepared the nanocomposite material with high strength, good biocompability, and low cell toxicity. IINER is undertaking the development of an in vitro diagnostic kit for the diagnosis of nasopharyngeal carcinoma based on  $\gamma$ -irradiated carbon nanotubes.

In the future, INER will continue to develop and market leading edge technologies, radiopharmaceuticals and tailor-made solutions for healthcare, which will improve the quality of life to human beings.

## **3-1** An GLP Extended Acute Toxicity Study of <sup>188</sup>Re-liposome in Rats

#### Chia-Che Tsai

The new drug <sup>188</sup>Re-liposome developed by INER has been proved targeting tumoral tissue specifically by Enhanced Permeability and Retention effect (EPR effect). Radiopharmaceuticals should be firstly tested in acute toxicity in rodents to evaluate the safety margins in human. RadioTox Lab owns the abilities for evaluation of extended acute toxicology of radiopharmaceuticals in rodents.

We evaluated the extended 28-day acute toxicity of <sup>188</sup>Re-liposome administered via single intravenous injection in Sprague-Dawley rats in accordance with the guidelines of Good Laboratory Practice (GLP). Our previous findings suggest that <sup>188</sup>Rhenium-labeled pegylated liposome (<sup>188</sup>Re-liposome) is a promising candidate for cancer therapy in C26 murine colon carcinoma ascites and solid tumor model. The purpose of this study is to collect enough information for determination of the safety and effectiveness of 188Reliposome. Rats were administered via intravenous injection with <sup>188</sup>Re-liposome (185 MBg, 55.5 MBg and 18.5 MBq), normal saline as blank control or non-radioactive liposome as vehicle control. Mortality, clinical signs, food consumption, body weights, urinary, biochemical and hematological analyses were examined. In addition, gross necropsy and histopathological examinations were also performed at the end of the follow-up period. None of the rats died and no clinical sign was observed during the 28-day study period. Only male rats receiving <sup>188</sup>Re-liposome at high dosage (185 MBq) displayed a slight weight loss compared with the control rats. In both male and female rats, the WBC counts of both high-dose and medium-dose (55.5 MBq) groups reduced significantly 7 days post injection, but recovered to normal range on Study Day 29. There was no significant difference in urinary analyses, biochemical parameters and histopathological assessments between the 188Re-liposome-treated and control groups. The information generated from this study on extended acute toxicity of <sup>188</sup>Re-liposome will serve as a safety reference for radiopharmaceuticals in early-phase clinical trials.

### **3-2** Evaluation of Radioiodinated Inerta as a Proliferation Imaging Probe in a Mouse Lung Tumor Model

#### Hung-Wen Yu

Lung cancer is the leading cause of cancer deaths in women and men throughout the world. The highresolution of computed tomography (CT) and magnetic resonance imaging (MRI) are anatomic imaging techniques, but are hard to detect the small lesion in the early stage, due to the limitation in detection sensitivity. This drawback has been overcome through the use of positron emission tomography (PET) and single photon emission computed tomography (SPECT), which are frequently used in oncology as a functional and molecular imaging routine, both provide the information about the biological behavior of tumor cells such as metabolism, proliferation, receptor density. One of important characteristic of malignancies is the uncontrolled rate of cell division. Accurate information of proliferation rate would be valuable for reflecting the response of chemotherapy or guiding optimal clinical management. Molecular imaging with a radiotracer that is proliferation specific would be valuable for tumor detection and, especially, in reflecting the tumor response to treatment. Radiolabeled thymidine analogs can be used to image cell proliferation in-vivo.

This study aims to evaluate a novel radioiodinated thymidine analog \*InerTA) as a probe for imaging tumor in a LL/2 lung carcinoma-bearing mouse model. \*InerTA was labeled with <sup>123</sup>I/<sup>131</sup>I and was prepared in high radiochemical yield (>85%) and radiochemical purity (>95%). Biological characterization studies of \*InerTA including serum stability, cellular uptake and scintigraphic planar imaging were performed. The results indicated that the percentage of intact \*InerTA in mouse serum after 24 h incubation was greater than 90%. The result demonstrated good in vitro stability of \*InerTA. The accumulations of \*InerTA in LL/2

cells increased with time. The cell-to-medium ratio (C/M) of \*InerTA reached 97.24  $\pm$  5.34 after 8 h incubation. Gamma planar imaging of \*InerTA in LL/2 lung carcinoma-bearing mouse clearly delineated the tumor lesion with increasing tumor-to-muscle ratio from 6.98  $\pm$  1.02 at 4 h post injection to 14.49  $\pm$  1.89 at 24 h post injection. In this study, the radioiodinated \*InerTA was successfully prepared with high yield and radiochemical purity. \*InerTA was highly accumulated in the tumors and is demonstrated as a potential radio-probe for clinical tumor imaging.



 Cellular Uptake of Inerta in LL/2 Lung Cancer Cells.



▲ The Planar Gamma Images of Mice Bearing LL/2 Lung Carcinoma (Arrow Head) After Injection of Inerta.



### **3-3** Glucose Regulated Protein 78 as a Target of Gastric Cancer Improves the Diagnostic and Therapeutic Efficacy of Micelles-Mediated System

#### Chun-Chia Cheng, Mei-Hsiu Liao

Gastric cancer (GC) is one of the malignant tumors with high morbidity and mortality. The current diagnostic approach of GC still relies on the invasive biopsy procedure by gastroscopy and following pathological examination. A reliable non-invasive diagnostic technology for GC in clinical practice is not available yet, and it therefore becomes an important issue to develop an efficient non-invasive diagnostic tool with high specificity and high sensitivity, such as nuclear imaging. Therefore, we screen the potential tissue biomarkers of GC by two-dimensional differential gel electrophoresis (2D-DIGE) and evaluate their further application in the diagnosis and treatment of GC. The clinical GC tissues were collected from the local medical centers, such as Cheng-Hsin General Hospital and Taipei Medical University Hospital, and used as the samples for proteomic analysis. The differential proteins of interest were validated by the western blotting and immunohistochemistry method. We found three significant biomarkers of GC after the verification, including up-regulated glucose regulated protein (GRP) 78, glutathione s-transferase pi (GSTpi), and down-regulated alpha-1 antitrypsin (A1AT). The overexpressed GRP78 in tumor membranes could be a specific target of GC. Therefore, a synthetic GRP78 binding peptide, WIFPWIQL, was used to bind with polymeric micelles. The specific peptide could help the micelles to target and accumulate in the tumor tissues while the micelles stabilize the peptide in vivo. In our study, the polymeric micelles-encapsulated drugs, including fluorescent DiR and doxorubicin, were used in the fluorescent imaging and chemotherapeutic evaluation with a mouse xenograft model of GC. The peptide-binding micelles was also tried to label with the radioisotope Indium 111 (In-111). The results showed that the peptide-binding micelles can bind to GC MKN45 cells in vitro, and improve the delivery efficiency of polymeric micelles in vivo. The peptide-micelles labeled with In-111 could be used for nuclear imaging and has a diagnostic and therapeutic potential for GC. In conclusion, our study successfully screened GRP78 as a reliable tissue biomarker of GC in a proteomics basis, and GRP78-binding peptide improved the targeting efficiency of polymeric micelles in a mouse xenograft model of GC. The GRP78-targeting strategy may possess the potential for the diagnosis and treatment of GC in clinical practice in the future.



▲ mGRP78BP was applied in accumulating DiR/micelles to MKN45 cells in vivo. In vivo imaging indicated that mGRP78BP-DiR/micelles accumulated in the xenograft tumor more than DiR/micelles. At 24 hours after injection, mGRP78BP-DiR/micelles had higher signal accumulation in tumor than DiR/micelles group, \*p<0.05 (Right).



▲ At 24 hours after injection, mGRP78BP-DiR/ micelles had higher signal accumulation in tumor than DiR/ micelles group, \*p<0.05.

## **3-4** The Development of Evaluating Platform for Using Health Foods to Reduce Radiotherapy Side-Effects

#### Ping-Fang Chiang, Po-Ching Cheng

Radiotherapy is the principal treatment modalities available for cancer. However, the course of treatment usually induces various toxicities and side effects, which causing suffering for the patients and often resulting in interruption of treatment. Adjuvant Chinese herbal medicine has been a popular alternative treatment among cancer patients on the prevention and treatment of radiotherapy side effects, then improving their quality of life.

Antrodia cinnamomea (AC) is a fungus commonly reported to possess anti-inflammatory, antihepatitis B virus and anticancer activities in Chinese folk medicine. In this study, we evaluated the efficiency of the extracts of AC to ease the radiation side effects by analysis of viability in normal immune cells and two cancer cells with different radiosensitivity. We further detected the alterations of cytokine and inflammation gene expressions on all of cells. The inductions of apoptosis were also analyzed for estimating inhibition of the radiation toxicity. Our results revealed the effective dose range of AC was 100-150µg/ml to ease radiation-induced cytotoxicity in a time-dependent manner. The cell injury by radiation was inhibited about 37-56%. On the other hand, the amplifications of radiation damage after AC pretreatment appeared only in radiosensitive BT-474 cells but not in radioresistant HT-29 cells.

Our data revealed AC inhibit Th2 responses to substitute Th1 response to avoid over-activated cytotoxic and inflammatory responses that caused tissue damage. AC can also improve the radiation-induced inflammatory genes of the immune cells, and the anti-inflammatory effect was more obvious as longer duration treated. In addition, AC enhanced the radiation-induced inflammatory effects and cytotoxicity in both tumor cells dose-dependently. The level of anti-radiation was higher than 20-fold of the HT-29 cells. Here we also showed AC effectively inhibit radiation-induced apoptotic responses of immune cells, whereas enhance the role of apoptosis on tumor cells with radiation, especially in BT-474 cells.

Follow-up animal experiments will be need to complete series of research results and further provide reliable data on established a unique, effective model for the assessment of anti-radiation efficiency of

health food. Once established, this model system can be further tested against a whole range of other potential health food including other active substances from other mushrooms and fungi.



▲ Experimental Design Process





 Comparison of Radiation-Induced Mitochondrial Membrane Potential Changes After AC Pretreatment in Spleen Immune Cells, HT-29 And BT-474 Cells By FACS Analysis. All Cells Were Pretreated With Different Doses of AC Before Radiation as Indicated.

# **3-5** INER Receives Certificates of Electrical Safety and EMC Tests for INER Breast PET

#### Sheng-Pin Tseng, Meei-Ling Jan

With 40 years of radiation-related R&D experience and the support of Ministry of Economic Affair and Atomic Energy Council, INER developed a dedicated imaging system for breast cancer– INER BreastPET. Its features include the detection capabilities of dense breast and axillary lymph node sites, low cost, large detection area, short imaging time and high sensitivity. It offers acquisition modes not only for imaging breast local region but also for imaging axillary lymph node metastases.

After completion of the development of INER BreastPET prototype, INER started the pre-clinical preparation. In order to protect the safety of the subjects, the safety and effectiveness testing of medical equipments is indispensable. Therefore, pre-clinical test data, electrical safety (IEC60601-1) test reports, are essential for the application of clinical trials.

To overcome the disadvantages that it is not easy to prepare spare parts of high-end and large-scale medical equipment for electrical safety and EMC testing, functions of INER BreastPET were independently modularized into several subsystems during the development phases, and were integrated into whole BreastPET according to the modules testing results. The concept of modular system designs not only saves the developing and testing time, simplifies the system update processes, but also reduces the development cost. INER BreastPET has passed 52 tests of electrical safety and EMC in accordance with IEC60601-1-1 and IEC60601-1-2 specifications, including normal heating, leakage current, radiated emission and susceptibility, etc. and successfully obtained the certificates issued by the Electronics Testing Center (ETC), Taiwan. It is the first domestic case of high-end and large-scale medical equipments certificated. Now, INER Breast PET is ready for next milestone, clinical trials.



▲ The Process of a Medical Equipment Form R&D Phase to Entering the Market



**3-6** The Auto-Synthesizer of Iodine-123-ADAM for Serontine Transporter Radiopharmaceuticals (2011 Taipei International Invention Show and Technomart Award the Bronze Medal Presented)

Kang-Wei Chang

Neuroimaging is a noninvasive and quantitative imaging methodology to characterize neuropsychiatric disorders like Parkinson's disease, schizophrenia, depression and Alzheimer's syndrome. This methodology not only can be used in routine clinical examination, but also can be applied in monitoring therapeutic effects. In the past, using anatomic images (like CT and MRI) have some difficulties in detecting subtle changes in the brain, which is hard to apply to clinical level. Nuclear medicine imaging (like PET and SPECT) can improve the process in evaluating brain lesions whatever in the patient or animal model. Now some radiopharmaceuticals including <sup>123</sup>I-ADAM, <sup>123</sup>I-IBZM, and 123I-IMPY has been confirmed the clinical utilities in the assessment of brain lesions and have the potential for marketing applications.



The Award Presented in 2011 Taipei International Invention Show and Technomart



To reduce the radiation dose to operator as low as reasonably achievable (ALARA) is an important issue in production of radiopharmaceuticals. Therefore, the development of an auto-synthesizer for manufacturing these radiopharmaceuticals will be highly desirable.

The purpose of this study is to develop a fully automated controlled system with a compact synthesizer module for the synthesis of <sup>123</sup>I-ADAM. The reaction processes include: (1) Injected with <sup>123</sup>I-NH4I, precursor and other solution; (2) Oxidation reaction; (3) Quench and neutralization with NaHCO3; (4) Purification, separations and collection.

This synthesizer module have some superiorities: (1) All programs is operated in an closed system, and device with charcoal trapper used to absorb the release gas of radioactive <sup>123</sup>I that can reduce the environmental radiation; (2) The system will be refinement with this small volume; (3) All system will base on automatic control for production for shortened the reaction time; (4) The radiochemical purity will be greater than 95%, which meets the requirements of radiopharmaceutical for clinical application; (5) The control software was designed step by step precisely for automatic <sup>123</sup>I-ADAM labeling process; (6) During the process performance, the analogue signal, pressure and variation or radiation dose can be monitored and recorded simultaneously to reflect the reaction situation at that time.



▲ The Software Interface System of Autosynthesizer for <sup>123</sup>I-ADAM Syntheis



 The Closed System to Avoid Non-Essential Radio Dose

 $\blacktriangle$  The Prototype of Autosynthesizer

## **3-7** Study on the Properties and Cytotoxicity of Medical Bone in Nanocomposites

Te-Hsing Wu

Because the increasing need of biomedical implants for orthopedic diseases, the orthopedic biomaterials become the focused items in biotechnology industry. The purpose of this program is to carry out the related experiments to evaluate the biological responses and the standard animal test models of the testing orthopedic biomaterials. We are going to perform the biocompability tests with conventional technique and  $\gamma$  -ray irradiation for a composite bone material made from N-isopropyl acrylamine, N,N'methylene bisacrylamide and acryl acid. It is attempted to apply this hydrogel that has high strength and low friction characteristics for bone material re-construction. To analyze the effect of cytotoxicity tests with different types composite bone graft material on L929 cell for comparison, MTT and LDH assay of composite bone material extracts were used treat on L929 cells and observation. From the analysis results, the nanocomposite bone prepared by this project had good biocompability. We also have completed the experiments of mechanical property and biocompability in vitro. The results indicate that its compressive strength can come to 40Mpa. And the average value is about 20 Mpa. So they are fitted to act as bone materials for bone defects. In cell attachment experiments, we use MTT and LDH assay to carry out the cell growth on bone materials. The results indicated good cell viability which up to 85% of control by MTT assay. The nanocomposite bone materials also show low cell toxicity according to the results of LDH assay. And from the results, they showed that composite bone of different types have good biocompability and low cell toxicity. Then we will apply the ISO-14791 base on risk assessment procedures...etc. This study will develop an appropriate testing procedure for new orthopedic bone materials. It is expected to occupy partial markets of internal markets and served for numerous patients.







### **3-8** Development a Detection Anti-EBV IgA Kit by Co-60 Irradiated Nano Material

Chen Kuan-Yin

Nasopharyngeal carcinoma (NPC) is an important and common cancer in Taiwan, Singapore, Hong Kong, southern China (Guangdong, Guangxi, Hunan, Jiangxi, Fujian), Malaysia and southern Asia, where large population of ethnic Chinese are gathered. Most patients are generally males between 30~50 years old.

Epstein-Barr virus (EBV) is one of the herpesvirus family and closely linked to several diseases and tumors, including Burkitt's lymphoma, Hodgkin's disease, peripheral T-cell lymphoma, some gastric cancers and NPC. Several researchers pointed out that patients with nasopharyngeal carcinoma within the EBV antigen will produce a corresponding antibody IgG and IgA. Patients are infected EBV via saliva. Previous literatures indicated that NPC patients with this tumor have high levels of a broad spectrum of EBV antibodies than healthy individuals. Early symptoms of NPC are innocuous, especially at early stages of the disease, and serologic diagnosis using EBV-specific antibody-based assays had become an integral part in diagnostic work-ups of NPC in most centers. Study of these antigens and antibodies, for the relationship between EBV and nasopharyngeal carcinoma and early diagnosis are important.

We use carbon nano tubes (CNTs) irradiated by Co-60 to investigate the utilization of highly sensitive kit to diagnosis EBV in early stage. The Institution Review Board (IRB) of Mackay Memorial Hospital has approved the ex-vivo trail (11MMHIS089) for the diagnosis methods. And we hope the kit will mature soon and help all the people.

### **4** Renewable and New Energy Technologies

Ying-Sheng Lee

The institute of Nuclear Energy Research (INER) has been engaged in the development of renewable and new energy technology for more than ten years. The research topics in 2011

Include: high concentration photovoltaic (HCPV) systems, polymer solar Cells, thin film epitaxial silicon/ upgraded metallurgical-grade silicon solar cells, small/medium wind turbine systems, micro grid technology, scale-up technology for cellulosic ethanol production, solid oxide fuel cells (SOFC), hydrogen storage materials, clean carbon technology and energy models.

The energy conversion efficiency of the InGaP/GaAs/Ge triple-junction solar cell has reached 39.07% under 128 suns for MOCVD epitaxial growth. The highest outdoor conversion efficiencies of the CPV modules are 31.66% (476X) and 28.47% (1000X), respectively. Photovoltaic module qualification Laboratory of INER has passed the certification of TAF and UL lab, which can provide services of qualification testing conforming to standards of IEC 62108 and UL 8703 for domestic vendors. The performance of polymer solar cells fabricated in our laboratory is comparable to that of international level; large area manufacturing processes towards low cost, low energy-consuming and time-saving are being developed. For thin film epitaxial silicon solar cells, a maximum conversion efficiency of about 13.2% is achieved with an upgraded metallurgical grade silicon (UMG-Si) substrate of 4×4cm2. In response to the foreseeing demand of the design evaluation specific for vertical axis wind turbines (VAWT), a simplified model for the VAWT was developed in 2011 to assist the domestic VAWT manufacturers for preparing the design documents in compliance with IEC 61400-2. A "Microgrid Test Field" with total capacity of hundred-kW scale including wind power and HCPV generations has been constructed in Taiwan by INER. The characteristics of this autonomous microgrid technology consist of reactive power control, low voltage ride through (LVRT), frequency droop control, protection coordination, and energy management for microgrid. The cellulosic ethanol conversion process has been improved from conventional separate hydrolysis and fermentation (SHF) process to simultaneous saccharification and fermentation (SSF) process. Another major achievement is the successful development of recombinant glucose/xylose co-fermentation yeast for the future simultaneous saccharification and co-fermentation (SSCF) process. The first national prototype of a thermally self-sustained SOFC power system has also been successfully demonstrated with an electric power output of 760 W. In the development of clean carbon technology, computational fluid dynamics (CFD) model inside the gasifier and process design for poly-generation applications with electricity and chemical products are evaluated. A kilogram-scale CO<sub>2</sub> sorbent production system has also been constructed, from which the sorbent has been characterized for high-temperature carbon capture by INER. A number of modifications have been made in INER MARKAL energy model in 2011 such as revision for assumptions of BAU, adjustment of settings of emissions reduction scenario, update of parameters settings for residential and commercial sectors, etc. Furthermore, a MARKAL elastic demand (MED) model was also introduced.



### **4–1** Development of High Concentration Photovoltaic System Technologies

#### Hwa-Yuh Shin, I-Tao Lung

Featuring with high energy conversion efficiency, low temperature coefficient, and the greatest potential for cutting the cost of solar power generation, technologies of High Concentration Photovoltaic (HCPV) gradually draw the attention of the solar market. According to a presentation of Soitec in May 2011, quoted information from CPV Consortium, it says that CPV market will experience a compound annual growth rate (CAGR) of 145% in the next five years, and forecast that the installed CPV will reach 1.8 GW by 2015. INER has developed HCPV system technologies since 2003, including epitaxial and manufacturing process of III-V solar cell, manufacturing process of concentration solar module, solar tracker manufacturing, establishment of system monitoring and integration, grid techniques, and solar module qualification, etc. The accomplishments are: 54 patents acquired, 11 items of technology transferred, and 29 items of technical services provided till the end of 2011. INER has effectively integrated the upstream, middle-stream, and down-stream of domestic industry to reduce the system cost, and promote the industrialization of HCPV. The R&D achievements of INER HCPV technologies are listed as follows:

- (1)Via the application of MOCVD epitaxial growth method, the epitaxial structures of monolithic InGaP/ GaAs/Ge triple-junction solar cells and the concentration solar cell process were conducted. The best energy conversion efficiency of the completed triple-junction solar cell reaches 39.07% under 128 suns;
- (2)Fresnel lens was designed and manufactured by injection molding, adopting PMMA certified by UL as its material, the highest outdoor conversion efficiencies of the CPV modules, under the geometric concentration ratio of 476 and 1,000 are 31.66% and 28.47%, respectively;
- (3)A four-quadrant sun position sensor with corresponding mechanism and a tracking controller were developed to solve insufficient accuracy of the sun position sensor under low solar illumination. It uses pin-hole principle and special jig against worse environment. After the outdoor integration test, the result proves that the tracking accuracy reaches ±0.1 degrees under the condition of greater than 250 w/m2 of direct normal irradiance (DNI);
- (4)With the cooperation of domestic vendor, INER has applied the embedded system to HCPV central control and monitoring system and accomplished the software and hardware structure of wireless communication;
- (5)Photovoltaic module qualification Laboratory of INER has passed the certification of TAF and UL lab, which can provide services of qualification testing conforming to standards of IEC 62108 and UL 8703 on the concentration photovoltaic modules manufactured by domestic vendors.



The Measured I-V Characteristic of Monolithic Stacked-type InGaP/GaAs/Ge Triple-junction Solar Cell Under Concentratedlight Illumination



▲ UL 8703 Program Certificate for Solar Module Qualification Lab Granted by UL

### **4–2** Development of Polymer Solar Cells

#### Chih-Min Chuang

Polymer solar cells have become the most promising third generation solar cells due to their advantages of low weight, mechanically flexible, and environmentally friendly process. All solution process can be used to fabricate polymer solar cells with roll-to-roll technique. The rapid manufacturing process makes polymer solar cells exhibit attractive advantages of large area and low manufacturing cost. Furthermore, polymer solar cells can be combined with portable consuming electronics products; it expands the practicality of polymer solar cells and broadens the breadth of market applications. Polymer solar cells will become a chief portable energy technology of low cost and off-grid as a combination of improved performance of solar cells and large area manufacturing process.

Our study was focused on (1) a large area process and (2) high performance of polymer solar cells. We developed spray coating process to fabricate polymer solar cells with large area. Spray coating process atomizes an active layer solution (P3HT/PCBM) and the droplets are deposited uniformly on the substrate. A power conversion efficiency of 3.3% is achieved by spray coating process; it has kept pace with the highest efficiency in literature. Moreover, an area of 100 cm<sup>2</sup> is achieved by spray coating process. In addition, we developed inkjet printing process to fabricate the hole transport layer and electrode of polymer solar cells. At present, the efficiency of large area polymer solar cells is 2.7% by combining inject-printing electrode with spray-coating active layer.

The high performance of polymer solar cells was fabricated by using spin coating process. By optimizing the hole transport layer and annealing condition, the optimal efficiency of 5.2% was achieved in P3HT/  $PC_{70}BM$  system. The highest efficiency of ~ 5% of P3HT/PC<sub>70</sub>BM was reported in literature. In addition, we developed a quantum dot/polymer hybrid solar cell to improve the efficiency of present polymer solar cell. This kind of hybrid solar cell is able to originate a comprehensiveness patent. The efficiency of  $Cu_2S/P3HT/PCBM$  can reach 4.2% at present.

In our study, whether large area or high performance of polymer solar cells, their efficiencies were reach an international first-class level. In future we will continue to develop large area process of solar cells towards low manufacturing cost, low energy consuming and time-saving; it will have a lot of opportunities to set up its unique patents.





# **4-3** R&D of the Thin Film Epitaxial Silicon/Upgraded Metallurgical-Grade Silicon Solar Cell

#### Tsun-Neng Yang

Thin film epitaxial silicon solar cells are considered potentially viable alternatives to low-cost, low efficiency amorphous silicon solar cells as well as high-cost, high-efficiency bulk crystalline silicon solar cells. The material selected for the substrate is inexpensive < 5N purity Upgraded Metallurgical Grade Silicon (UMG-Si), which is considered too "dirty" to be suitable for solar cell production directly. A home-made 2-inch vacuum-free Atmospheric Pressure Chemical Vapor Deposition (APCVD) system is used. Insitu HCl gas gettering of a 4×4cm<sup>2</sup> UMG-Si substrate is first performed with subsequent deposition of a ~20µm thick high quality epitaxial layer on top of the gettered UMG-Si substrate at 1,150°C. The resultant product, referred to as Epitaxial Wafer Equivalent (EpiWE), is further processed utilizing the traditional bulk silicon solar cell process and forms the so-called thin film epitaxial silicon solar cell. The maximum conversion efficiency of about 13.2% is achieved at present.

UMG-Si material has several advantages, including the lower investment cost, the lower power consumption and low carbon footprint, etc. In addition, the generic thin-film epitaxial silicon solar cell process is very similar to the traditional bulk silicon solar cell process except for the addition of the in-situ

HCl gas gettering and epitaxial deposition processes. The similarity to traditional bulk silicon technology is a big competitive advantage, as it can be expected that the implement of this thin film epitaxial technology in existing production lines is easier than that of other thin-film technologies. The future benefits will be capable of sustaining our country's competitiveness and market share in the global silicon solar cell industry.



### **4-4** MicroGrid Technology Development

#### Yung-Ruei Chang

The well developing renewable energy systems in modern world, ether in individual house or in small communities, belong to small-scale dispersed generation system. However, due to the intermittent and uncertain characteristics, the high penetration of renewable power generation will brings power fluctuation phenomenon and cause dramatic impact to the operation of regional power system. Dispersed Generation (DG) and MicroGrid (MG) technology provide possible solutions, especially for national energy security and national carbon emission reduction.

INER is currently developing the low voltage microgrid technology. A "Microgrid Test Field" with total capacity of hundred-kW scale including wind power and high concentration photo voltaic (HCPV) generations has been firstly constructed in Taiwan by INER. The Microgrid Test Field can provide an integrated platform that is not only for academic research purpose, but also for industry testing and implementation. Based on these facilities, INER is moving forward to developing an autonomous microgrid technology including reactive power control, low voltage ride through (LVRT), frequency droop control, protection coordination, and energy management for microgrid. We believe that the microgrid technology will contribute to energy saving, carbon emission reduction, and industry demonstration as well as national energy policy in the future.





# **4-5** Development of Design Assessment Technique in Compliance with IEC 61400-2 Standard

Chung-Chi Tung, Wei-Nian Su.

The small-and-medium-sized enterprises have been actively involved in the development of small-andmedium-sized wind turbine systems these years. The European countries and America also noticed the uniqueness of this market and started their own regulation for small wind turbine system. Inevitably, the type certification of small-and-medium-sized wind turbine will become mandatory in the near future.

IEC 61400-2 is the design requirement for small wind turbines among various IEC standards. The methodologies and models developed in IEC 61400-2 are primary for the horizontal axis wind turbines (HAWT). In other words, the equations and models cannot directly apply to the vertical axis wind turbines (VAWT). However, there have been many commercialized VAWT systems in the market up to date in

Taiwan. Therefore, in response to the foreseeing demand of the design evaluation specific for VAWT, the development of models and standards specific for the VAWT system is necessary. In 2011, INER developed the simplified model for the VAWT and assisted the domestic VAWT manufacturers for preparing the design documents in compliance with IEC 61400-2. Furthermore, INER is also actively participating in the technical committee for modification of the standard to fit the characteristics of VAWT and it is expected to finalize the modification task in June 2013.

The derivation of the simplified VAWT model involves basic theory, engineering judgment, research papers, and test data. An ongoing benchmark process has been initiated since December 2011. It is anticipated that the accuracy and completeness of the model will be greatly improved in 2012. INER will continuously works on the development of analysis technique for both of HAWT and VAWT systems. In cooperation with wind turbine test sites, the technical aspect of the type certification for the small-and-medium-sized wind turbine systems will be established in the near future.



## **4-6** The Development and Research of Scale-up Technology for Cellulosic Ethanol Production

#### Chiung-Fang Huang

The Cellulosic Ethanol Program of the Institute of Nuclear Energy Research has dedicated to the research and development of production technology of bio-ethanol from rice straw since 2006, and completed the construction of a first-of-its-kind demonstration-scale facility in Taiwan in 2009. Through years of efforts in research and technology development, INER has accumulated substantial experience and advanced technologies as well in cellulosic ethanol production.

Based on data acquired from operation of the demo-scale facility, it would provide reliable indigenous information to domestic industry interested in cellulosic ethanol for evaluation on production cost, carbon credit and energy efficiency. In 2011, the project has kept continuing on the test-run operations in the



one ton/day cellulosic ethanol pilot plant and seeking improvement in facilities. Eleven test-runs of whole plant operation have been carried out; each test-run was operated in 5 consecutive days feeding based on a basis of feedstock input capacity of one ton rice straw per day and totally took ten to eleven days each test-run. Cellulosic ethanol conversion process has also been improved from conventional separate hydrolysis and fermentation (SHF) process to simultaneous saccharification and fermentation (SSF) process. The need for the enzyme has also reduced to 10-15 FPU/g cellulose in the SSF process, 50% of reduction compared to the previous enzyme usage in SHF process. Meanwhile, fed-batch fermentation and two-stage temperature controlled SSF processes have been developed, the final ratio of solid to liquid content of 20% is reached with the maximum ethanol concentration of 3.2%, equivalent to 55-60% of ethanol conversion. It is estimated that 160 liters of ethanol can be produced from one ton dry mass of rice straw with the established cellulosic ethanol process. In the development of on-site production of cellulose, a 1,000Lscale of on site cellulase production facility has been established. Taking rice straw as inducible substrate, the enzyme activity of crude extract can be enhanced to 20 FPU/mL with combination of concentration technology. It is expected to flexibly prepare the designed cellulase activity packages according to the requirement of test-run operations in pilot plant. Another major achievement to focus is the successful development of recombinant glucose/xylose co-fermentation yeast. This co-fermentation yeast developed in INER has been applied to lab-scale simultaneous saccharification and co-fermentation (SSCF) process and the ethanol concentration of 40g/L can be reached within 96 h fermentation; the maximum conversion efficiency of total sugars to ethanol is up to 0.47 g/g (91%). This result demonstrates that the application of the INER developed recombinant glucose/xylose co-fermentation yeast in the SSCF process would be in great help to enhance the competitively of cellulosic ethanol production technology. Future investigation will focus on the engineering scale-up study of the co-fermentation yeast SSCF process.



▲ Fermentative Application of INER's Co-Fermenting Yeast Strain on SSCF Process



1,000L-Scale of on Site Cellulase Production Facility



 Simultaneous Saccharification and Fermentation (SSF) Process for Cellulosic Ethanol

## **4-7** MARKAL-ED Energy Model - The Verification Analysis for BAU and the Emissions Reduction Scenario

#### Jong-Shun Chen, Hui-Chih Chai

The MARKAL research group of Institute of Nuclear Energy Research (INER) has accomplished and published a series studies on energy-relevant analysis by applying MARKAL model since 2006, including (1) The establishment of the energy model (INER MARKAL) and the BAU (Business As Usual) analysis. (2) The BAU analysis and the verification of electricity sector modeling. (3) The BAU analysis and the verification of industry sector modeling. (4) The BAU analysis and the verification of transport sector modeling. (5) The database construction for sector-specific energy technology parameters. In order to improve the rationality of the model and the correctness of simulation results, basic assumptions are updated according to both international situations and domestic policies.

During 2011, the focuses of verification analysis are described as follows: (1) Assumptions of BAU are revised to be aligned with the Nationally Appropriate Mitigation Actions (NAMAs). (2) Settings of emissions reduction scenario are also adjusted according to the carbon emissions reduction goal and the nuclear phase-out policy of Taiwan. (3) Technology parameters settings of residential and commercial sectors are updated.

Furthermore, we introduce the MARKAL Elastic Demand (MED) model and ahead than other domestic MARKL research groups. The MED model is an extension of standard MARKAL with more complex treatment of demand elasticity, which can be used to evaluate the effects of energy prices on demand for each sector. Considering the demand response to energy price variation is not only crucial for optimizing sector's carbon emission but also important for analyzing the cost-benefit of a policy. For the purpose of comparing the results with other countries, the default elasticity is employed in the present study stage. However, localizing the elasticity is the next target in our research.

Simulation results of our research shows that the  $CO_2$  emission in 2020 and 2025 under BAU are close to the CO2 emissions estimated independently from each sector. This result provides the evidence that

assumptions are correct. Supposing that the CCS will be commercialized after 2020 and comparing the BAU and emission reduction scenario, we knew that (1) the total capacity will increase 7.4% and the total electricity production will decrease 18.2%. (2) The existed power generation will placed by the coal plant with CCS and NGCC with CCS. (3) There will be almost 30% electricity generated by renewable energy. We will continue to devote our attention to develop the INER MARKAL model and update the relevant database. Our vision is to build up a platform for policy comparisons based on common assumptions and database.



▲ CO<sub>2</sub> Emissions Under the BAU





#### Electricity Production Under the BAU and the Emission Reduction Scenario

### **4-8** Development of Clean Carbon Technologies

#### Yau-Pin Chyou, Po-Chuang Chen, Yi-Shun Chen

National Science Council (NSC) approved the national energy program (NEP) on June 9, 2009, for which 30.3 Billions NTD will be allocated for a timeframe of 5 years, to be devoted to R&D on energy policy, energy technologies, energy saving and carbon abatement, personnel training and expertise development, etc. The action represents one of the options to implement the guidelines for sustainable energy policy inaugurated since June 5, 2008, which aims to develop "low-carbon economy," to fulfill the requirements for economic development, environmental protection and social justice. This program proposes the R&D strategy of clean carbon-based technologies (2009.12 ~ 2013.12), complied with the NEP Framework.

This work focuses on the viewpoints of both practical development and advanced research, which covers clean coal, carbon capture and reutilization, advanced gas separation/hydrogen production, etc. The aim is to develop carbon capture-ready processes for the need of sequestration, and advanced hydrogen generation technologies for the era of hydrogen economy in the future. At present, the program consists of two projects: (1) Commissioning of an integrated test facility for clean carbon system, which includes gasification, system design and optimization, warm/hot gas separation and clean-up; and (2) Carbon capture technology development, which focuses on pre-combustion capture with solid sorbent.

The overall R&D achievements in year 2011 are shown in the following descriptions. Computational fluid dynamics (CFD) model inside the gasifier and process design for poly-generation applications with electricity and chemical products are evaluated in this work. Commissioning the hot model of three-dimensional granular bed filter (GBF) with the sub-systems of the Particle-Counter-Sizer-Velocimeter Probe (PCSV-P), heater of filter granules, heat exchanger, etc. is finished to supply the high-temperature environment for experimental study under 3000C. Warm/hot gas desulfurization sorbents are synthesized

and the analyses of physical properties, such as XRD, BET, ICP etc., are performed. The results exhibit that the sorbent of 20 wt%Fe<sub>2</sub>O<sub>3</sub>/Al<sub>2</sub>O<sub>3</sub> provides better performance, maintaining H<sub>2</sub>S concentration below 500 ppm for about 36 minutes, and its calculated sulfur capacity reaches 6.3g-S/100g sorbent. A hot-flow testing system consisted of two interconnected fluidized-bed reactors is built to investigate the solid flow and chemical reaction phenomena. A kilogram-scale CO<sub>2</sub> sorbent production system has been constructed, from which the sorbent has been characterized for high-temperature carbon capture by INER.

To comply with the domestic technology R&D policy, a feasibility study project on sustainable clean coal technologies has been undertaken at INER since 2005. This work represents the follow-up efforts for mitigating greenhouse gas emissions from sustainable development viewpoints. It is expected that this strategic planning will establish the essential foundation for technologies needed to fulfill the policy of energy saving and carbon abatement.



▲ The Hot Model of Moving Granular Bed Filter



 Breakthrough Curves of Alumina-Type Desulfurization Sorbent

1	Stirring reactor with a heating system	5	Filter bucket
2	Vacuum filter	6	Controller
3	Ladder	7	Squeezing die
4	Dryer	8	Pulverizer

 A CO<sub>2</sub> Sorbent Production System With the Scale of Kilograms





### **4-9** Development of Solid Oxide Fuel Cell Technology

Ruey-yi Lee

INER'S SOFC project was initiated in 2003. In compliance with the government's energy policy, this project focuses on setting up of power systems and production of component materials to continue improving self-developed technologies. The objective of this project is to build up efficient, reliable and cost-effective SOFC systems. Main achievements in 2011 are briefly outlined as follows:

- Development of planar anode supported cells (ASC): the anode, electrolyte and cathode layers of the cell were produced by the tape casting, spin coating, and screen printing, respectively. The maximum power density of the cell reached to 652 mW/cm<sup>2</sup> at 800°C. A degradation rate less than 1%/khr was obtained for a long-term testing over 1400 hours.
- Development of planar metal supported cells (MSC): the cells were manufactured via the atmospheric plasma spraying process. The MSC cell exhibited a maximum power density of 650 mW/cm<sup>2</sup> at 750°C. A degradation rate less than 1 %/khr was achieved at test conditions of 400 mA/cm<sup>2</sup> and 700°C for a long-term testing of about 2000 hours.
- 3. Development of nano-structured reforming catalysts for natural gas: innovative nano-structured catalysts with reduced Pt and CeO<sub>2</sub> particles dispersed onto the  $Al_2O_3$  carriers were produced to effectively prevent the migration and coalescence of the metal crystallites. After thermal cycles, the catalysts remained thermal stable with a conversion ratio higher than 95%.
- 4. Completion of a self-sustained SOFC power system: configuration and layouts for a SOFC power system was designated and established. Operating modes, data acquisition, power conditioning, instrumentations, and control logics were identified and settled. A series of system validation tests were carried out to check functions and interfaces of components. The first national prototype of a thermally self-sustained power system has been successfully demonstrated with an electric power output of 760 W.

The main features of SOFC technology include: high fuel flexibility, module design, silent power generation, little pollutant emission, high energy-conversion efficiency, etc. The SOFC will be a viable technology for achieving the nation's goal on energy-saving and reduction of CO<sub>2</sub> emission. Nowadays, Japan, the US and European countries, stationary SOFC power systems are intensively undergoing in-field testing for early market penetration. It is highly projected that a prosperous expansion of the SOFC market will become reality in a few years. Currently, after years of elaborate efforts, INER has possessed the critical core technologies from powder to power for the SOFC. Afterwards, on the basis of current foundation, continuous improvement will be made. Moreover, to take advantage of Taiwan's strength on the "system integration" and "cost down" capabilities, this institute is willing to foster and/or to cooperate with domestic industry partners to launch a new potential energy industry on the SOFC technology.





- ▲ INER ASC Performance Testing Curves (Results From Cell Held At 800°c, 400 Ma/Cm2 For Various Periods)
- ▲ INER MSC Long-Term Performance Testing Curves



- ▲ Nano-Structured Catalysts for Natural Gas Reformer (Pt/Ceo<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub>)
- ▲ Flowchart for a SOFC Power System




## **4–10** Performance of Hydrogen Cartridge Containing Pt-impregnated Active Carbons

## Ming Sheng Yu

In this study, 100 grams of Pt-impregnated active carbons had successfully been synthesized per batch, and the hydrogen uptake capacity at room temperature and 6.9 MPa, was measured by TGA with around 130 mg specimen, could reach up to at least 9 wt%. In addition to that, we had the same results of hydrogen uptake while randomly screening 4 specimens from the same batch of synthesized specimens. It means that reproducibility of hydrogen storage capacity can be maintained. In the mean time, hydrogen can release at least 70% of its previously adsorbed amount as pressure decrease to atmosphere pressure at room temperature. It corresponds to release at least 6 wt% of hydrogen that is a target value of DOE.

In order to demonstrate the performance of hydrogen storage cartridge with Pt/ACs, a cartridge filled with about 15 grams of the sample mentioned above was tested by means of customer-build hydrogen adsorption/desorption systems. The total hydrogen desorption amount, is calculated by the constant released rate multiplying the released time, is only 1.2 wt%, that is much lesser than that expected from the TAG measurement's result with small amount of sample. The difference might be caused by the ignorance of heat management, since the reaction is exothermic during hydrogen adsorption process. Unless process heat is removed, adsorption of hydrogen will automatically stop especially with lots of samples. Currently, a heat exchanger covered around cartridge has been fabricated to manage heat involved in adsorption/desorption process for the following test.

Finally, a larger hydrogen storage cartridge, with volume about 700 cc and filling with about 150 grams of Pt/ACs, was connected to PEM fuel cell stacks to drive a slider with power rated 150W. This operation continues for 28 minutes when carrying a passenger weighted 50 Kg.

As these materials can satisfy DOE's target value for an efficient, safe, and cost-effective hydrogen storage system, it will become a viable energy carrier for vehicular hydrogen storage system or residential generator in the era of hydrogen economy.





▲ Hydrogen Storage Cartridge Provide a Slider With Power Rated 150W Running for 28 Minutes When Carrying a Passenger Weighted 50 Kg

▲ Hydrogen Release at Least 70% of Its Adsorption as Pressure Decrease to Atmosphere Pressure at Room Temperature

## **Environmental Plasma Technologies**

#### Chi-Fong Ai

The program of environmental plasma technology based on the plasma core technology has been conducted in the concert with the goal of the green environment. Whereas some related application technologies have been developing. For the thermal plasma environment-protection and energy research, firstly the plasma-assisted biomass gasification power generation prototype facility has succeeded in raising the pressure of the pressurized feeding system. After cleaning, the syngas produced is fed directly to microturbines and continuous power generation is completed. Secondly, following the unique one-step DME production process from syngas last year, DME has also been converted successfully to high quality gasoline-like fuel, creating opportunity of indigenous energy resource. Contracted work on the resource reclamation from aluminum dross into refractory has finished an industrial scale process plant of 5000 ton dross capacity.

For the research of non-thermal plasma clean deposition, firstly the roll-to-roll plasma deposition platform has demonstrated its continuous PECVD processing. A long and flexible sample of the intrinsic silicon film coated on S.S. substrate has been displayed in 2011 Taipei INST. Next, both of 1,200mm×300mm flexible and colorful thin film solar cell module for the building integrated PV application and 130mm×150mm flexible and colorful thin film solar cell module for the PIPV application are fabricated, whereas a potential application is obvious. In addition, the HIPIMS system developed in a manner of industrial scale, being equipped with the three column targets of 1,500mm in length, has completed. It is the biggest in the world up to now.

Looking to the future, the research in the area of environmental plasma will emphasize more on topics of new energy and energy saving, on innovating new technology and at the same time keeping on applying the accomplished results to the benefit of industry.

# **5–1** Recent Progress in the Plasma-Assisted Biomass Gasification for Power Generation

#### How-Ming Lee

Bioenergy from biomass is one of the energy resources useful for power and heat conversion. The International Energy Agency (IEA) pointed out that the energy abundance are in the order of coal, oil, nature gas, and then biomass. The fourth abundant biomass accounts for 11% of the primary energy source, and is the most widely used renewable energy sources (80%). IEA estimates that, by 2050, bioenergy will supply 38% of fuel and 17% of electricity to the world demand.

To better use of bioenergy, INER has been developing novel plasma gasification technology. With the unique characteristic of plasma, the performance of traditional gasifier can be improved and the drawback can be eased. For instance, the highly-elevated temperature of plasmas can enhance the syngas quality, the external controlled input of plasma energy leads to flexibility in the  $H_2$ /CO ratio, and the



chemically active species (i.e., radicals, metastables, ions etc.) generated by plasmas can easily decompose tars which are often serious troubles for traditional gasifiers.

INER now owns a pilot-scale plasma-assisted biomass gasification system for power generation. The design parameters are: the feeding rate:100 kg/h, the max gasifier temperature:1,600oC, the max gas pressure:10 kg/cm<sup>2</sup>, and the power generation capacity: 120 kVA. During the past year, progress has been made in the pressurized feeding system. The operating pressure is raised from 1 kg/cm<sup>2</sup> to 5 kg/cm<sup>2</sup>. The syngas produced, after cleaning, fueled a set of microturbines, which successfully and continuously generated electric power. Safety and feasibility of the pilot system are proven experimentally. In the future, the system scaled up with the help of the test data and experience of this project, could serve as the baseload for the distributed energy system in the countryside or rural area of Taiwan. It will also be beneficial to the achievement of the national goals of carbon reduction, alternative energy supply and developing new industries.



▲ Biomass Plasma Gasification R&D: (a) Homemade Steam Plasma Torch, and (b) The Plasma Gasification Could Achieve a Better Syngas Quality Than a Traditional One.

## **5-2** Biofuels R & D Extending From Dimethyl Ether Toward Gasoline Production

#### How-Ming Lee

IEA predicts that biofuels are going to account for 38% of fuel supply worldwide by 2050. INER has been developing biofuel technology. A series of dimethyl ether (DME) catalysts with high selectivity have been developed. With these catalysts, one-step conversion of syngas into DME can be achieved. DME is regarded as a substitute for LPG or diesel. Air pollutants in the exhaust of burning DME are significantly lower than those of diesel. Therefore DME is also regarded as one of potential clean fuels in the future. So far DME has been produced by two-step method, which syngas first converts into methanol and then dehydrates into DME. The INER's approach integrates the methanol synthesis process and the methanol synthesis step, speed up the reaction and enhance the single-pass conversion rate. In addition, by using only one reactor in DME synthesis, the economical benefit in the capital cost reduction for DME production is obvious.

With the success of DME production technology, a new topic of R & D this year is the gasoline production. INER has also successfully prepared a variety of highly efficient catalysts convert DME directly into gasoline-like oils. Analysis reports revealed that the octane numbers of the oils produced are higher

than that of the commercial 98 unleaded gasoline. The resultant oils are free of nitrogen, sulfur, and lead. And hence there are no air pollutants against the environment and the health from its combustion. Therefore, the oils produced by INER technique are of high grade. Annual profit of over 100 million NTD could be achieved optimistically, on the basis of a gasoline factory derived from INER technique with a production capacity of 10 thousands metric ton and with industrial wooden waste as raw materials. To concentrate its effort, INER has established a biofuel research center, equipped with R & D instruments and test platforms therein. INER will keep on developing new technologies related to DME, gasoline, and other high value-added biofuels, for the high value-added application in petrochemical industry, as well as for the pursuit of the national goals of energy independence, air quality, citizen health, and carbon reduction.



▲ Bio-Gasoline R&D: (a) Homemade High-Performance Catalysts, and (b) The Produced Biogasolines.

## **5-3** Refractory Made From Aluminum Dross Using Plasma Melting and Reclamation Technique – Developing an Industrial Production Process

#### Sheng-Fu Yang

The Institute of Nuclear Energy Research (INER) has been contracted by a local company to make refractory from aluminum dross using plasma melting and reclamation technique at 2010. The contract is continued this year of 2011 to develop its industrial scale process. The pretreatment system for aluminum dross comprises of grinding, sieving and baghouse units. The processes of producing refractory include compression molding machine, blender, sintering furnace and air pollution control devices. The production pilot run is completed and the product dimension is 230mm×114mm×65mm. The main operational parameters such as the press loading of compression molding, added amount of carboxyl methyl cellulose solution, calcination temperature are 200 ton, 8% (V/W) and 1200oC, respectively. The respective capacities of treating aluminum dross and generating refractory are 5,000 ton/month and 800 ton/month.

Test results of refractory showed that the bulk density, open pore, compressive strength and flexural strength are at 1.81±0.06 g/cm3, 14.2±0.05%, 391.2±13.5 kgf/cm2 and 68±5 kgf/cm2, respectively. Al2O3 is the main chemical composition at a proportion of 76.6%. The permanent linear change and pyrometric cone equivalent of refractory product are -0.1±0.15% and 36. The softening temperature (T2) of refractoriness under load test is at 1,566oC. Refractory meets the Characteristic Leaching Procedure (TCLP) tests and is environmentally benign. Accordingly, the Chinese National Standards (CNS), classifies it as high



alumina refractory brick (CNS 2352). Refractory generation from aluminum dross can reduce the landfill need and minimize the environmental impact. It is estimated that per kilogram reclaimed aluminum dross can decrease 0.93 ton carbon dioxide emission. The business of high alumina refractory bricks helps with the income and competitiveness for company.

In 2012, we will move onto the fiber cement composites made from man-made vitreous fiber (MMVF) and devote to reducing the energy consumption rate of melting incineration ashes to below 1.5 kWh/kg. We will remain the cooperation cooperates with local industries to solve their waste disposal problems.



Processes for Producing Refractory



## **5-4** Roll-to-Roll Plasma Coating Platform Successfully Demonstrates Continuous PECD Manufacturing Process

#### Cheng-Chang Hsieh

Roll to roll (R2R) plasma coating apparatus can provide a continuous and high-production efficient R2R deposition operation on the light-weight, thin and flexible substrates. The technique difficulty of R2R processes is rather high because it is not easy to interrupt the interference between adjacent chambers during coating process, which causes a series problem for good quality access to coated films, compared with the traditional in-line sheet to sheet coating processes isolated with on-off gate valve completely between adjacent chambers. Currently a set of R2R plasma coating system for PECVD process has been under construction at INER, including control system, vacuum chambers, gas gates, tension controller and showerhead-type plasma sources. The gas gate being key component is an aim to challenge. Developed processes of R2R PECVD using showerhead plasma sources under RF 40 MHz adjust to integration of three-layer a-si solar film on stainless steel (S.S.) substrates in the n-i-p configuration. The intrinsic layer i at the a-si solar cell with photosensitivity greater than 105 can be grown on S.S. flexible substrate. This characteristic meets the commercial requirement. A typical sample of two-meter long and flexible S.S. substrate coated with intrinsic a-si film by R2R continuous process has been displayed in the 2011 Taipei International Invention Show & Technomart (Taipei INST). However, the process gas mixtures in each chamber section being intensively isolated from adjacent section for continuous n-i-p layer coating process is still in effort.

We will keep on improving this R2R PECVD machine and its processes for the continuous deposition of n-i-p layers on flexible substrate, bringing about substantial cost reduction in flexible thin-film solar cell manufacturing. We expect that this complete self-supported techniques can assist local industries to upgrade their competitiveness in thin-film flexible solar cells in the future.



▲ Roll to Roll PECVD Machine



 A Flexible A-Si Film Solar Cell of Two Meter Long Displayed at 2011 Taipei INST





## **5-5** Market-Anticipated Energy-Saving Technology – Flexible Thin-Film Solar Cell Module Technology

### Min-Chuan Wang and Der-Jun Jan

One of the most promising energy-saving devices is photovoltaics. Photovoltaics (PV) are truly elegant means of producing electricity on site, directly from the sun, without concern for energy supply or environmental harm. These solid-state devices simply generate electricity out of sunlight, silently with no extra maintenance, no pollution, and no depletion of materials. Ideal one among these distributed applications is the building integrated photovoltaic (BIPV) system, incorporating photovoltaic properties into building materials, such as roofing, siding, and window glass, and thus offering advantages in cost and appearance as they are substituted for conventional materials in new construction. On the other hand, solar cells may also be incorporated into consumer electronics for energy-saving, such as notebooks, e-papers, etc. Photovoltaics incorporated into products, or product-integrated photovoltaics (PIPV), either for artistry or for capability can be another extended application, such as venetian blind.

The merit of the flexible energy-saving device is the use of the low-cost roll-to-roll (R2R) production technology. For the emphasis of energy-saving, INER has developed its own R2R plasma coating system. By its use, we have successfully accomplished the flexible and colorful thin film solar cell modules with the size of 1,200mm×300mm for the BIPV application. Furthermore, the flexible thin film solar cell module for consumer electronics with the size of 130mm×150mm has been also successfully made and integrated with the e-paper by joint research with a domestic electro-optical company. Because flexible thin film solar cells have offered advantages in light weight, flexibility, color, low cost and appearance, they have provided more opportunities for novel energy-saving products. These characters also form the key to open the niche market of energy-saving applications.



 1,200mm×300mm Flexible and Colorful Thin Film Solar Cell Module for the BIPV Application



 130mm×150mm Flexible And Colorful Thin Film Solar Cell Module for the PIPV Application

## **5-6** Business Promotion of the Unique High Power Pulsed Sputtering System

Jin-Yu Wu

A novel high-power pulsed dc magnetron system (HIPIMS) has been developed previously. The pulse target power loading in HIPIMS with a peak value up to several kWcm-2 is considerably higher than traditional target power loading (usually less than 20 Wcm<sup>-2</sup>) in conventional dc magnetron sputtering. The high target power density leads to the generation of very dense discharge plasmas in the vicinity of the sputtered target. Due to dense plasma density more than thousand times compared to conventional magnetron sputtering and high ionization rate about 70% to 100%, HIPIMS film qualities and performance are much better than conventional method. HIPIMS can easily deposit compound layers like TiN and CrN without target poisoning. In addition, there is no need to change any equipment of system except magnetron power driver. Therefore, HIPIMS has powerful potential for thin film coating in industry production.

A set of HIPIMS for industry production had developed in INER recently. This system consists of three magnetron sources with column-shape rotary Ti targets and each source is driven by 40KW average power modulated pulse power. The system chamber has a cylinder form with 1,800mm in diameter and 2,000mm in height, which is so far the largest coating system using HIPIM mode in the world. It can deposit various functional films on any workpiece, especially on huge moulds where the life is able to be extended. Complete commercial trials of more than one year were finished under practical mass production and long-term operation using an automatic control, and the result strongly showed that it can work for normal production. Besides, we have developed a new procedure for AZO films deposited on glasses. Their lowest resistivity is  $8.4 \times 10^{-4} \Omega$ -cm and while the sheet resistance is 20  $\Omega$ /, the transmittance keeps about 82%, which meets the commercial requirements.

To highlight the unique superiority of HIPIMS, the future development of its application will focus on the high value-added products being not capable by traditional magnetron sputtering.



▲ High Power Pulsed Magnetron Sputtering Coating System for Commerce Production





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