2nd ASEAN Workshop on Nuclear Power Safety Research
7 – 8 March, Bangkok, Thailand

Research Activities on Nuclear Safety in Singapore

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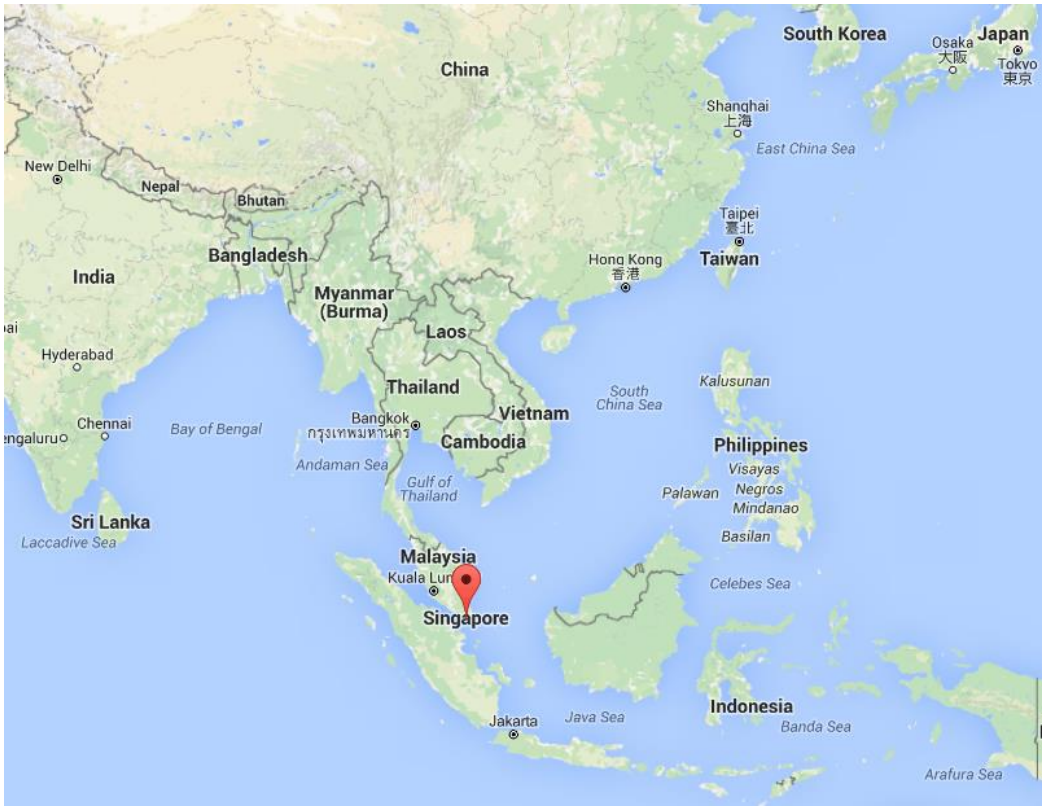
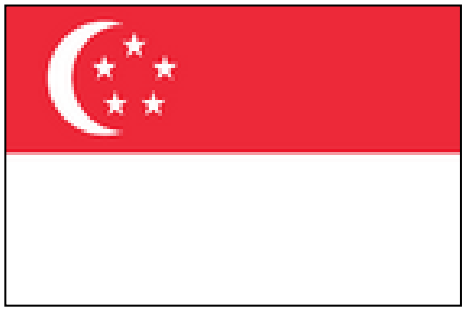
Outline

- Introduction
- Setting up of NSREP & SNRSI
- Research Activities in SNRSI
  - Nuclear Safety
  - Radiochemistry
  - Radiobiology
- Manpower Development
- R&D Infrastructure Build-up
- Collaboration with International Organizations
- ASTEC
- Activities of National Environment Agency (NEA) in Singapore

Brief Information on Singapore

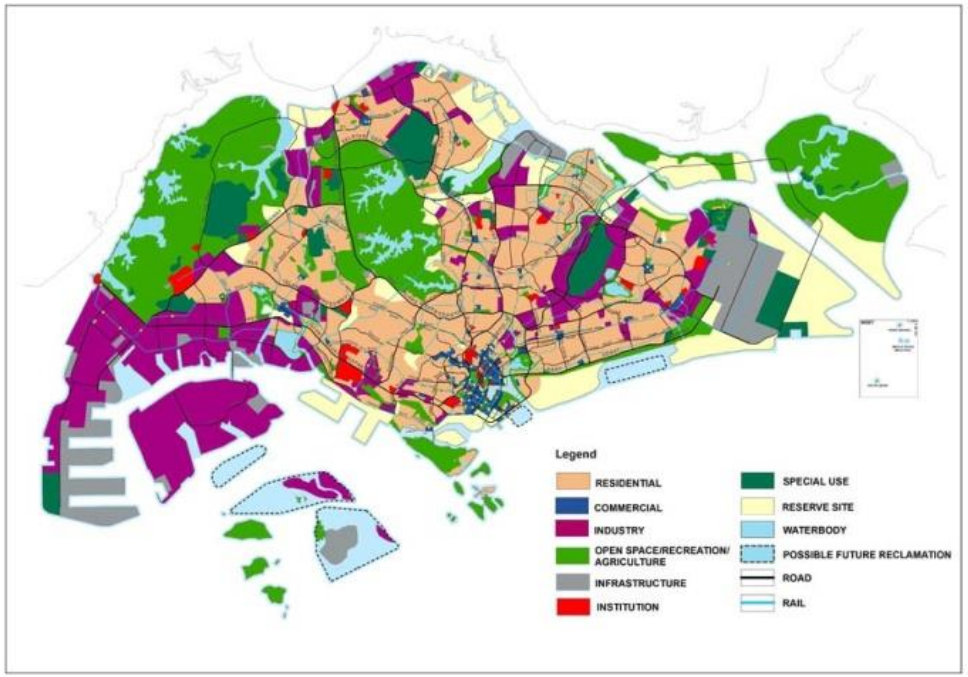
- Population: 5.535 million
- Population density: 7,697 per km^2
- Land area: 719.1 km^2
- Located on the southern tip of the Malay Peninsula in Southeast Asia, between the Indian Ocean and the South China Sea
- No natural resources





Nuclear Power in Singapore?

After a two-year pre-feasibility study, Singapore has announced in parliament in October 2012 that it will **NOT** pursue nuclear power with current Nuclear Power Plant (NPP) technology:



"… the risks to Singapore, given that we are small and dense, still outweigh the benefits at this point. As we are planning for the very long term and not for our immediate energy needs, we prefer to wait for technology and safety to improve further before reconsidering our options."

"We will, therefore, support research in relevant areas of nuclear science and engineering, and train a pool of scientists and experts through education programmes in local and overseas universities. We will also play an active role in global and regional cooperation on nuclear safety. …"

NSREP

- In October 2013, the National Research Foundation (NRF), Prime Minister's Office, Singapore approved a five-year budget of $62.9M to develop a Nuclear Safety Research and Education Programme (NSREP).
- In recognition of the fact that it would take more than 10 years to build credible capability in nuclear science and safety, and to demonstrate a long-term commitment to attract scientists and engineers to this discipline, NSREP has been given in-principle approval for a 15-year implementation period, subject to review before the end of each five-year funding period.

SNRSI

- Singapore Nuclear Research and Safety Initiative (SNRSI) is the technical arm of the NSREP to execute its R&D and educational programmes.
- Set up in 2014, SNRSI is hosted by the National University of Singapore as a university-level research institute.
- SNRSI serves to concentrate nuclear expertise and knowledge in a single institute, and sustain a critical mass of manpower.
- Other activities include:
  - Coordinating nuclear safety education programmes for the wider community of stakeholders in Singapore
  - Managing the NSREP postgraduate scholarship.

Initial Research Focus

- **Nuclear Safety Analysis**
  - Conduct simulation studies of the processes in NPP to understand the risk and consequences of possible emergencies, and the spread of radioactive contaminants in various incident scenarios.
- **Radiochemistry**
  - Develop capabilities for reliable detection and accurate measurement of radioactivity; support NEA and other government agencies in establishing baseline levels of radioactivity in our local environment and imported materials before the region goes nuclear.
- **Radiobiology**
  - Study the effects of low-dose radiation on human health, to enable us to determine the appropriate levels of protection and courses of action in response to radiological threats. Develop expertise in dosimetry and bio-dosimetry.

Nuclear Safety Analysis

- **Severe Accidents in Nuclear Power Plants**
  - Use simulations to understand the impact of a NPP severe accident
  - To build capability in modelling severe accident progression, radioactive emission and the mitigation measures for reduction
  - Accessing the safety of newer reactor design.
- **Integrating Numerical Weather Prediction (NWP) and Atmospheric Transport of Radioactivity**
  - To assess the feasibility of developing a prognostic hazard zoning demonstrator to be used in Singapore's environmental conditions, starting initially with RIMPUFF from ARGOS integrated with the NWP output.
- **Inverse techniques for source location and estimation based on radioactivity and meteorological sensor data**
  - To study the source estimation method and estimate the severity of radiological incident using the network of sensors which will be set up in Singapore and the region.

Radiochemistry Research

- **Development of Capabilities for Characterization and Survey of Environmental Radioactivity**
  - To establish environmental sampling and radioanalytical techniques for radioactivity monitoring in Singapore including rapid measurements of radioisotopes e.g. Sr-90, H-3 and uranium isotopes.
  - To develop competencies for categorization of radioactive materials in the field as part of readiness for emergency response in Singapore.
  - Have participated and done well in IAEA ALMERA proficiency tests.
- **Transport of Key Radionuclides in Local Urban Matrices**
  - To develop analytical techniques to analyse caesium and strontium in the urban matrices such as reinforced concrete and asphalt that are representative of those used in Singapore. This study is important in remediation work and also in understanding ecological impact of the radionuclides, especially in our water system.

Radiobiology Research

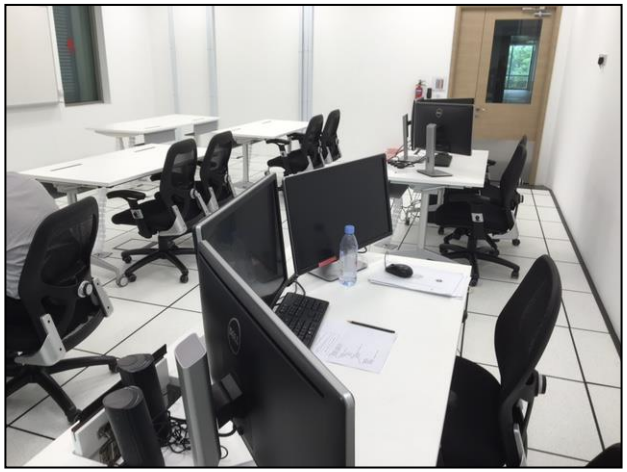
- **Bioindicators of Chronic Low-dose Exposure to Ionising Radiation**
  - Develop in-house chronic low-dose irradiation capability with variable dose and dose rate to identify changes in miRNA expression after CLD exposure, using lymphocyte cell lines and blood as a model.
- **Development of High Throughput Dicentric Assay Capability**
  - To reduce the dependence on trained personnel and increase the throughput of the generation of dose estimates to serve as a triage diagnostic in radiation-related exposures incidents.
- **Low Dose Radiation Exposure-Induced Changes Of Brain**
  - Functional studies to understand the effect of radiation exposure on postnatal mice on cognition impairment and aging, and their relationship with brain developmental changes.
- **Rapid Test Kit For Field Triage Of Acute Ionising Radiation Exposure**
  - To establish a panel of protein and nucleic acid biomarkers in a local population cohort selected to reflect the normal range of health conditions found in the total population using Principle Component Analysis.

Manpower Development

- **Objective:**
  - To attract and train manpower to support SNRSI's build-up of R&D capabilities
- **Target:**
  - About 30 researchers in each of the three research focus areas supported by a small team of technical and admin support by 2025.
- **Postgraduate Scholarships:**
  - Since 2015, 7 scholars have been sent to prestigious universities in UK, France and Japan to pursue their PhD or Masters studies in fields of Nuclear Engineering and Science including waste management and radiobiology.

R&D Infrastructure

- In 2014, $18.5 million was approved for a facility at the CREATE Tower on NUS Campus to kick start SNRSI's capability development efforts. Physical renovation started in early 2016.
- Offices and Computer Lab for Nuclear Safety Analysis (420 m^2) was completed in August 2016.

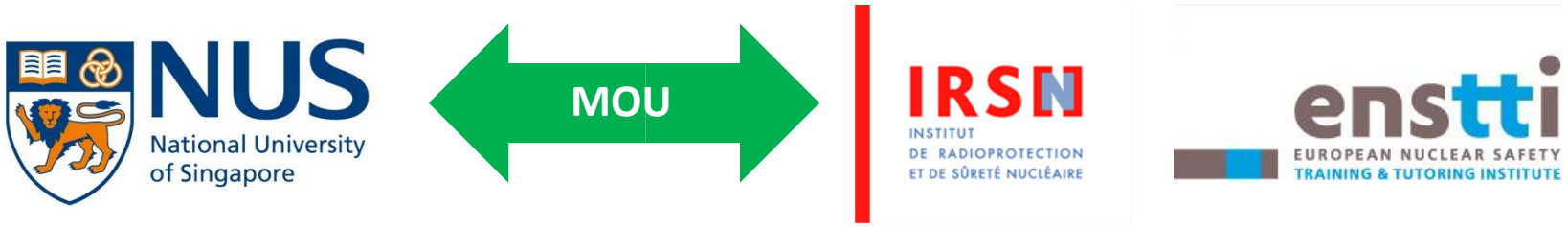


R&D Infrastructure

- Works on the Radiochemistry and Radiobiology Laboratories at basement of CREATE Building with a total area of 1,210 m^2 (excluding the engineering space) have just been completed.
- Plan for a dedicated building of about 8,000 m^2 to be ready by 2020 to cater for the new research areas, returning scholars and co-locating related facilities such as Secondary Standard Dosimetry Lab (SSDL).

International Collaborations

- In support of our education and training efforts, an MOU was signed between NUS and the French Institute of Radiological Protection and Safety agency (IRSN) in May 2015.



- This gives Singapore access to Training courses conducted by the European Nuclear Safety Training & Tutoring Institute (ENSTTI) and Simulation Codes (ASTEC, SOFIA* and CATHARE).

** The license for using SOFIA (Simulator for Observation of Functioning during Incident and Accident), an engineering simulator, is still being worked out.*

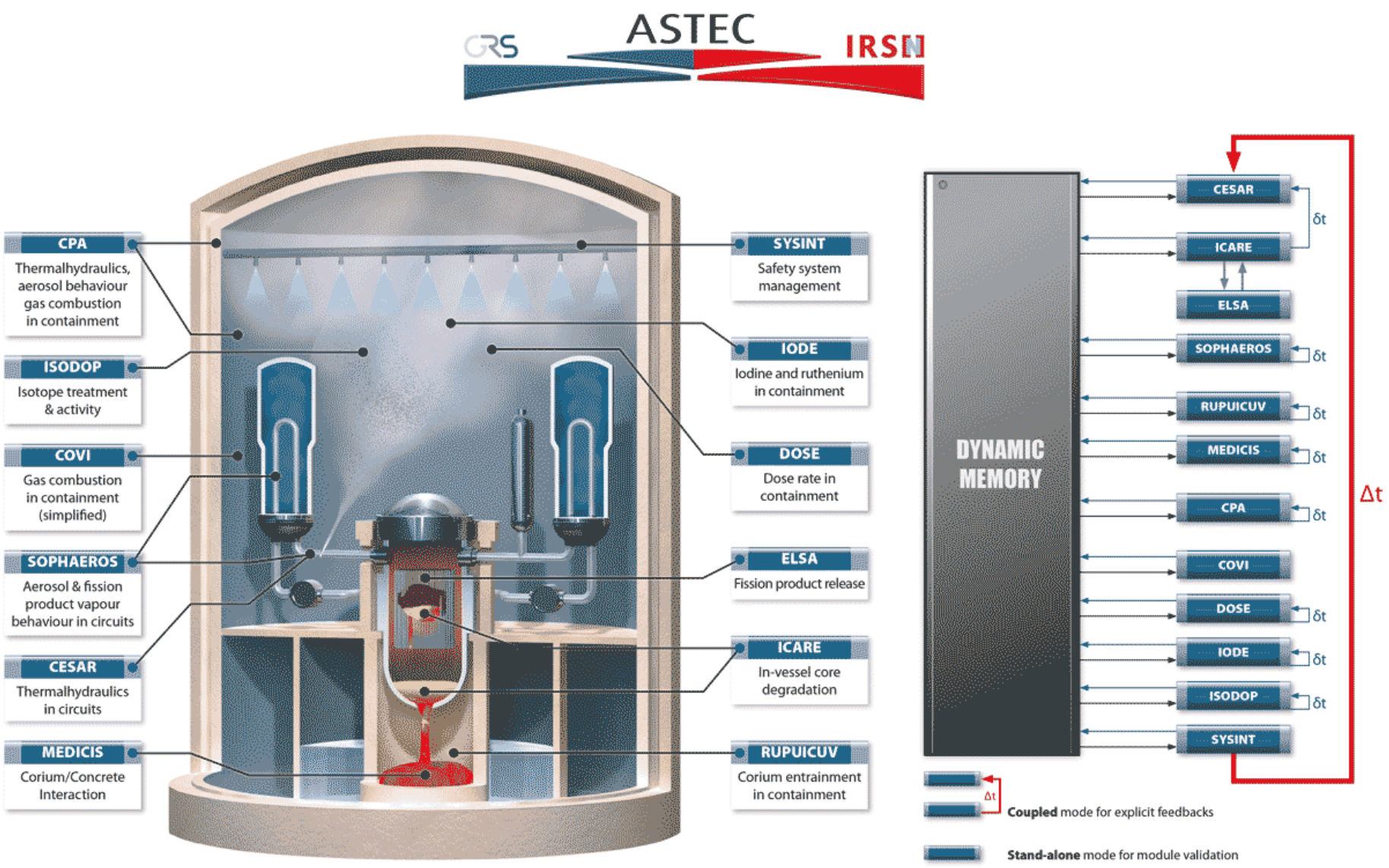
ENSTTI Courses

- Two rounds of three 1-week ENSTTI courses catering to local agencies such as National Environment Agency and Maritime & Port Authority were conducted in Singapore, covering:
  - Radiation protection
  - Safety of transport of radioactive materials
  - Surveillance of environmental radioactivity
- A regional training course on “Surveillance of Environmental Radioactivity” was conducted on 5 – 9 December 2016.
  - The course was attended by participants from Singapore, Indonesia, Thailand, Cambodia, Vietnam, Laos and Myanmar.
- The second regional training course on “Regulation Control of Radiation Protection in Medical Applications” will be conducted on 27 – 31 March 2017. Two more are in the pipeline.

ASTEC

- The MoU with IRSN also provides SNRSI access to ASTEC (Accident Source Term Evaluation Code), a software package to simulate the progression of severe accident in water-cooled reactor, from the initiating event to the release of radioactive products out of the containment.
- Jointly developed by IRSN (France) & GRS (Germany) since 1996, ASTEC has become the reference European SA integral code in SARNET.
- The codes have been validated with more than 160 tests at about 50 experimental facilities and the models are considered to close to the current State of the Art (notably for modelling release of Fission Products)
- Complete code documentation provided to users on physical models, users' manuals with sample input decks and user guides.
- The Software structure has very high modularity so that it can be used for separate, coupled or integral effect tests.

Modules in ASTEC

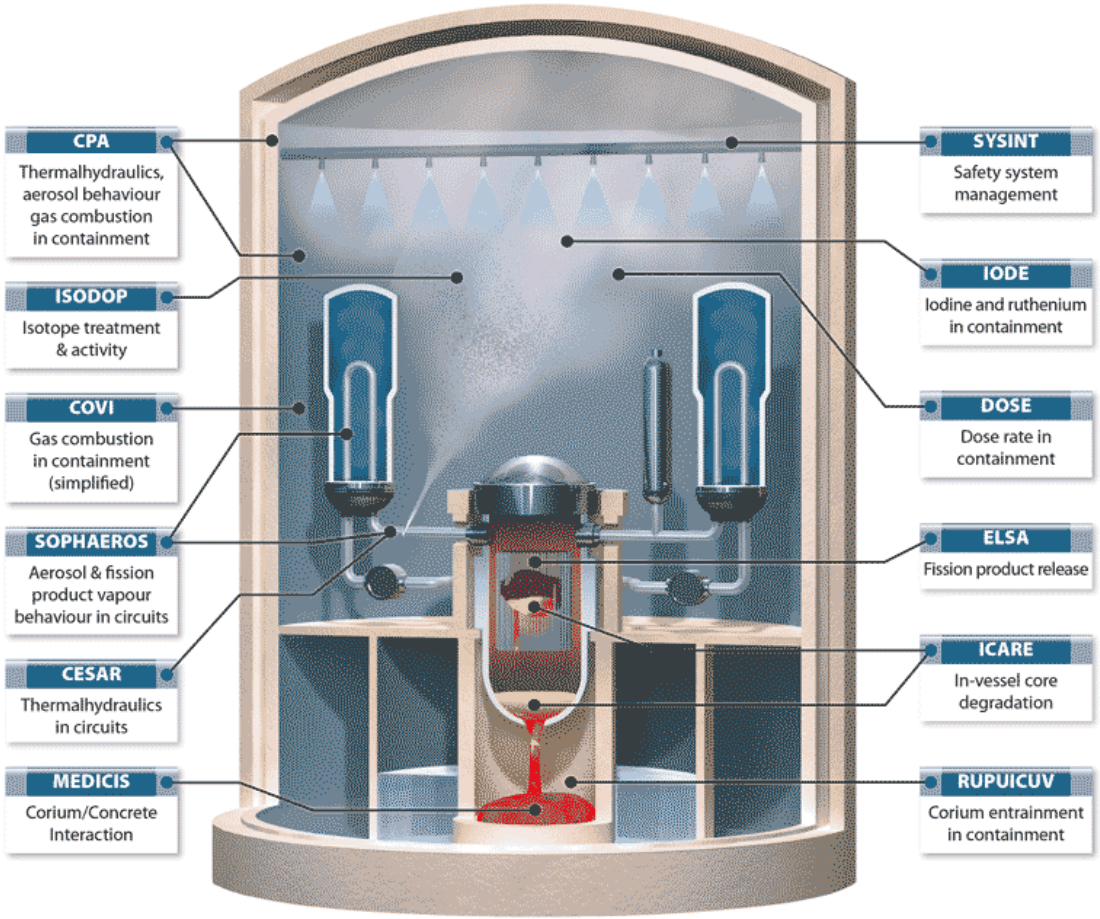


Modelling in ASTEC

- Phenomena that are modelled in ASTEC:

No	Severe accident modelling tools required	Current Generation Large PWR
1	Fission product estimation	ASTEC needs this
2	Thermal–hydraulic modelling of reactor circuit for transport of heat, gases and fission products	ASTEC - CESAR & SOPHAEROS
3	Modelling of reactor core melt and fission product release from fuel	ASTEC - ICARE
4	Modelling of fission product transport & thermal hydraulic modelling in containment	ASTEC - CPA & SOPHAEROS
5	Hydrogen production and combustion modelling	ASTEC - CPA
6	Engineering safety feature – Water sprays, filters, pool suppression	ASTEC - SYSINT
7	Molten core and concrete interaction	ASTEC – MEDICIS
8	Additional considerations	ASTEC cannot model steam explosion and structural failure of containment

A possible gap that can be filled by other software, e.g., WIMS and FISPIN



Full Plant Simulations with ASTEC

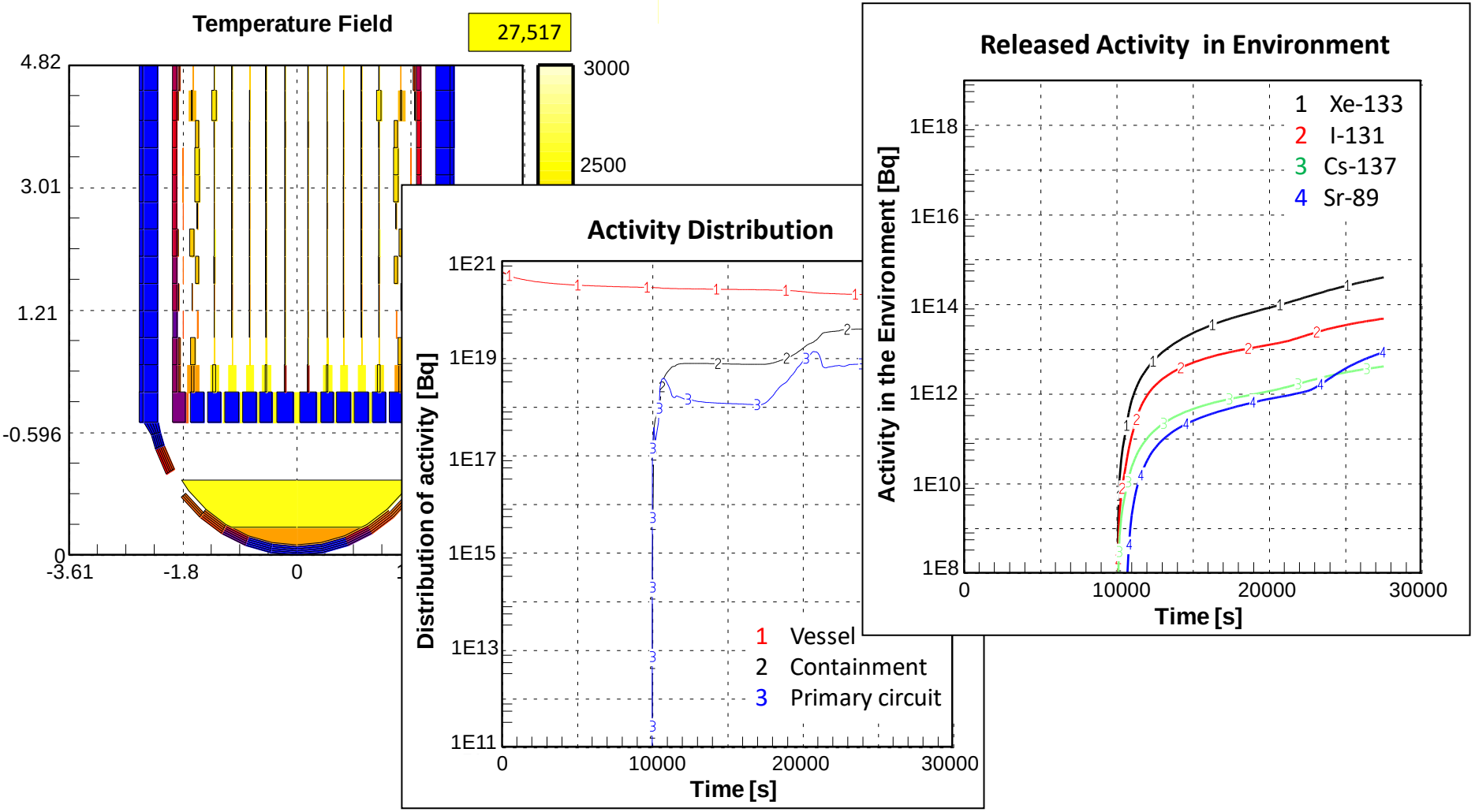
- ASTEC allows us to run full plant simulations (with given plant data) for different accident scenarios, e.g., TGTA-H2, under different conditions.

	IRSN (post-VD3 update)	
Scenario type	Core melt frequency (per year/reactor)	% of total core melt frequency
Loss-of-coolant accidents (LOCA)	1.2×10^{-06}	16%
Loss-of-coolant accidents occurring with containment bypass (V-LOCA)	2.2×10^{-07}	2.9%
Steam line break accidents (FWLB, SLB)	5×10^{-08}	0.7%
Steam generator tube rupture accidents (SGTR)	1.1×10^{-08}	0.1%
Total loss of heat sink or associated systems (H1)	1.3×10^{-06}	17%
Total loss of the steam generator feedwater supply (TGTA-H2)	1×10^{-06}	14%
Station blackout (H3)	2.9×10^{-06}	38%
Loss of onsite power (PDS)	5.1×10^{-07}	6.8%
Transients involving automatic shutdown failure (ATWS)	3.3×10^{-08}	0.4%
RCS transients[3]	3×10^{-07}	4%
Total core melt frequency	7.5×10^{-06}	100%

Distribution, by scenario type, of core melt frequency according to the findings of IRSN's post-VD3 level 1 PSA for CPY 900 MWe series. (Ref: Jacquemain et. al. (2015))

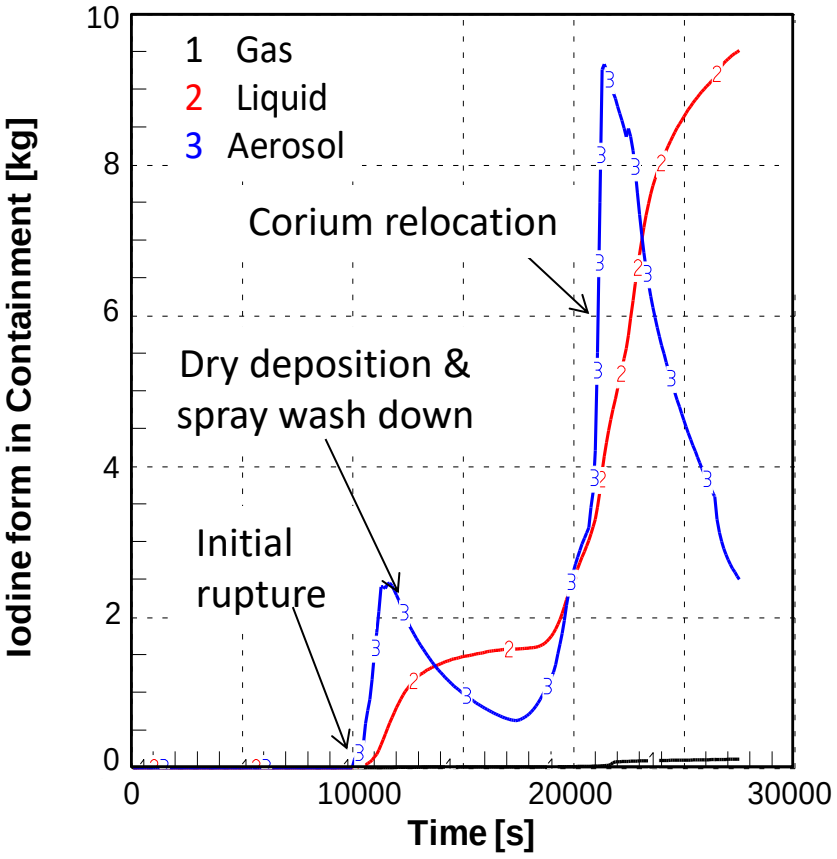
Results from ASTEC Runs

- ASTEC provides useful outputs for the important parameters for studies of different scenarios, e.g.,

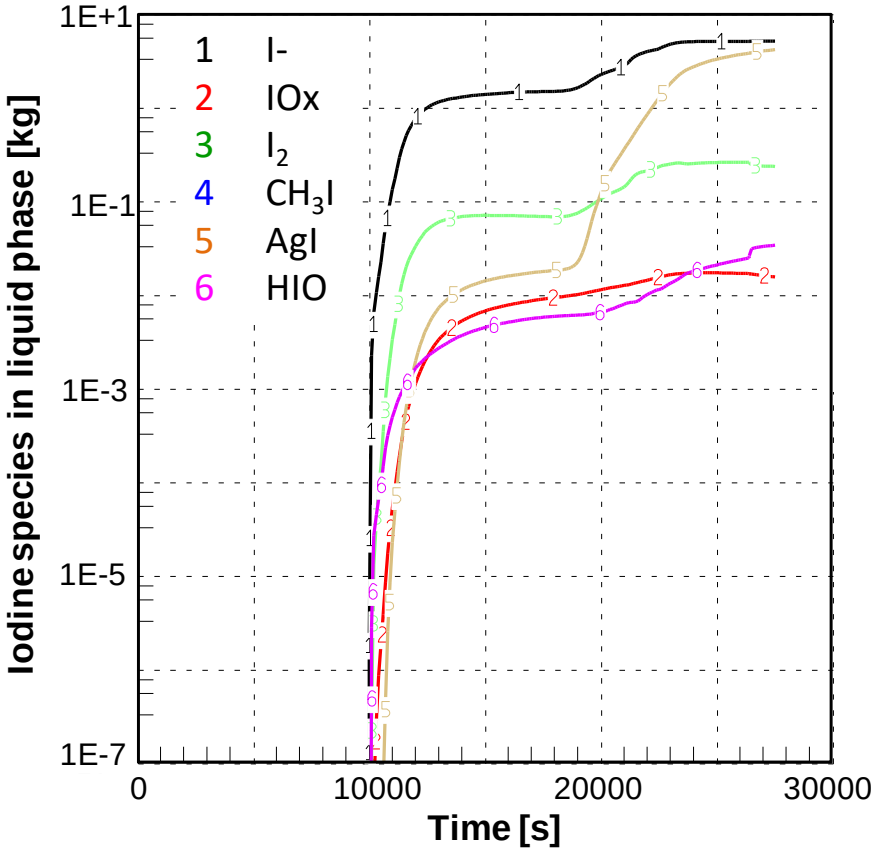


Results from ASTEC Runs

- ASTEC also provides Iodine distribution in containment – accounts for iodine chemistry, radiolysis and deposition.



Iodine in Containment



Iodine species in liquid phase

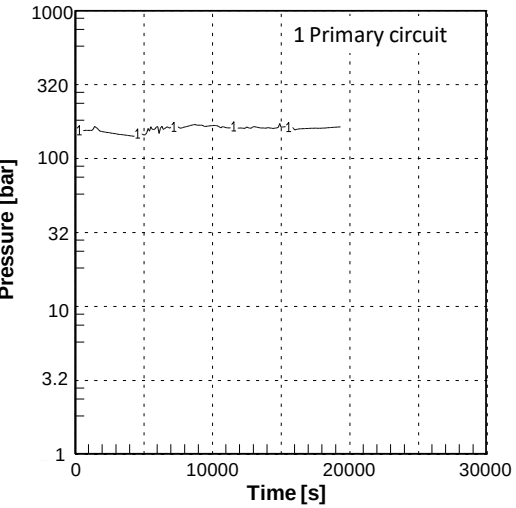
Results from ASTEC Runs

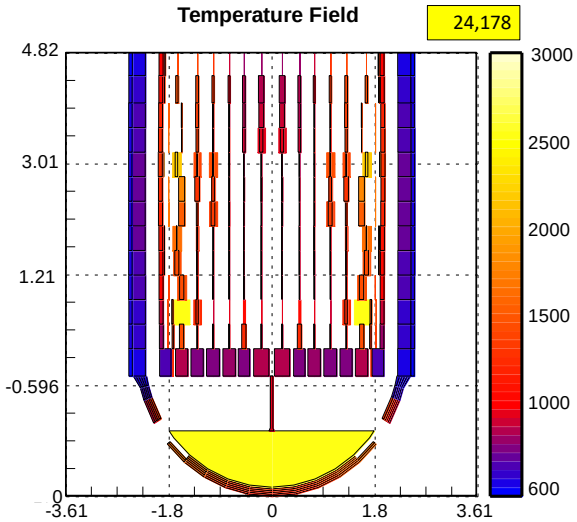
- Can also compare what happens if the operator did not perform certain operations, e.g., open the safety relief valve in the scenario of total loss of steam generator feedwater supply.

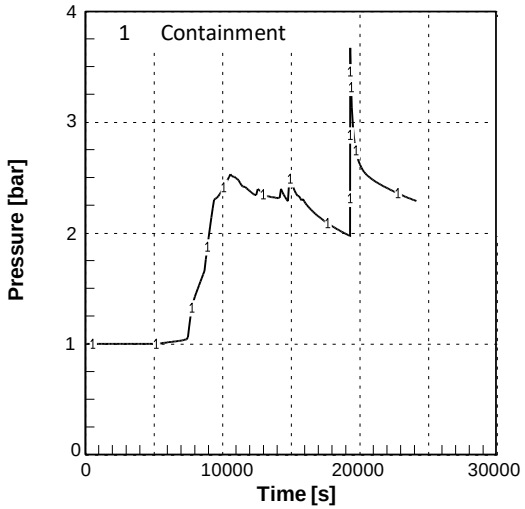
Event	Operator successfully open the valve	If operator did not open the valve
Accumulator discharge	2.78 h	Not activated due to high pressure
First release of fission product	2.78 h	3.19 h
Melt pool formation in core	6.01 h	3.35 h
Vessel rupture	7.33 h	5.36 h
Pressure load due direct containment heating	0.59 bar	1.63 bar

Results from ASTEC Runs

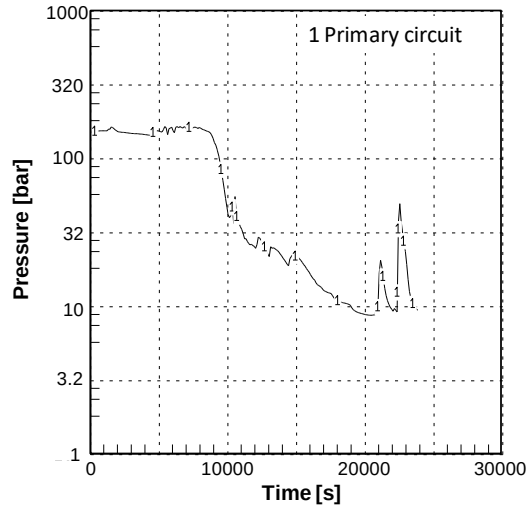
- Valve was not opened

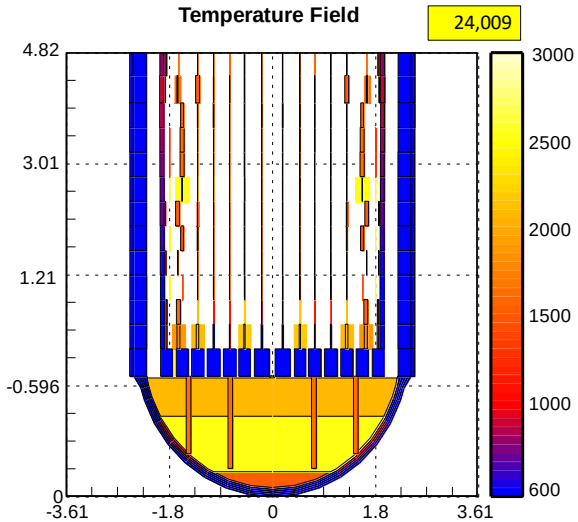


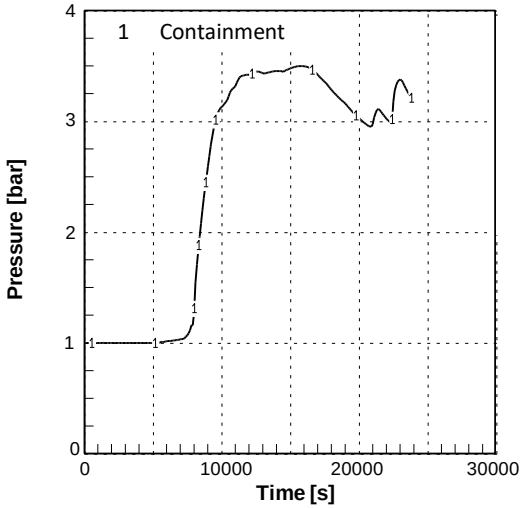




- Valve opened



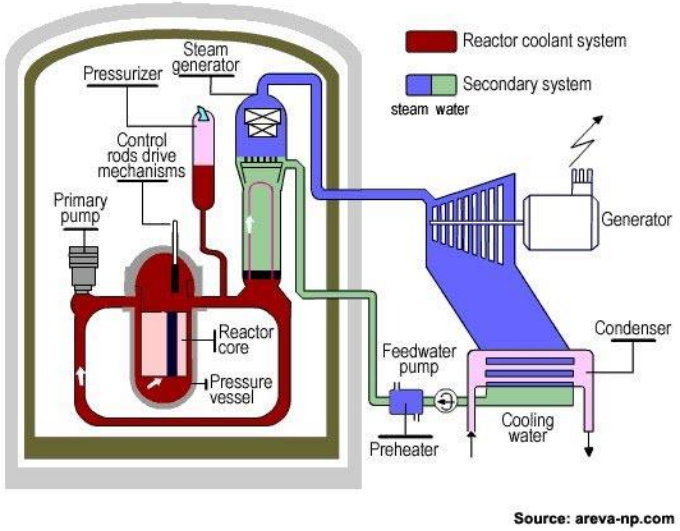




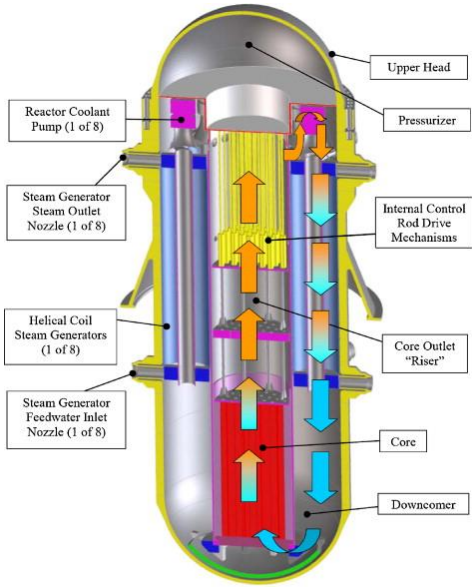
Possible Future Directions & Challenges

- Adapting ASTEC to SMR and HTGR – research into specific phenomenon

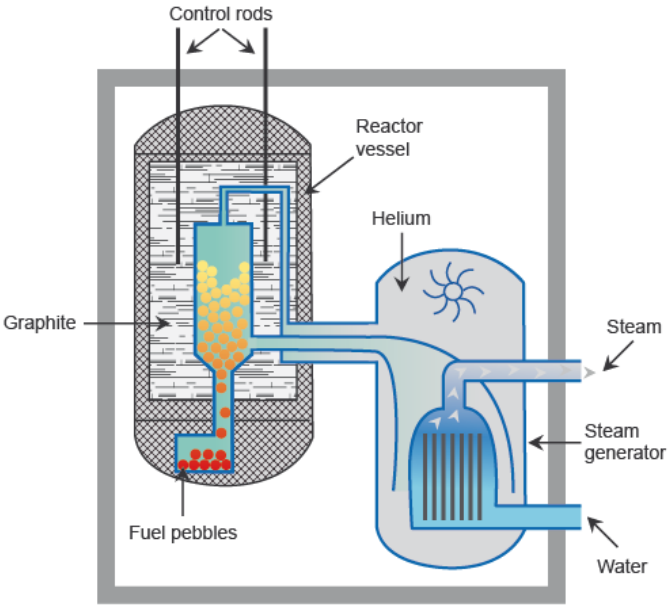
Large PWR: 1000 – 1300 MWe
UO2 pellet, LWR
Primary & Secondary circuits are separate



Integral PWR: 50 - 300 MWe
UO2 pellet, LWR
combine primary & secondary circuit into a pressure vessel



HTGR: ~ 160 MWe
Helium cooled and graphite moderated, TRISO fuel dispersed in graphite sphere



Note: Illustration are not drawn to scale

e.g. Westinghouse IRIS

- Challenges in obtaining representative plant and experimental data for validation

Singapore

2nd ASEAN Workshop on Nuclear Power Safety Research
7 - 8 Mar 2017, Thailand

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Radiation Protection & Nuclear Science Department
National Environment Agency
Singapore

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Scope

1. Background – Brief Information on Singapore

2. Capability Build-up & Activities
   i. Radiation Monitoring Network
   ii. Radiochemistry Lab
   iii. IAEA-ASEANTOM Regional Project RAS/9/077

Background – Brief Information on Singapore

- Singapore does not have any nuclear power plant or research reactor

- Applications of radiation and nuclear science are in the following areas:
  - **Medical**: Diagnostic radiography, nuclear medicine
  - **Industrial**: Non-destructive testing (NDT) in aerospace, petrochemical, construction, and ship building industries

- In Singapore, the Radiation Protection & Nuclear Science Department (RPNSD) under the National Environment Agency (NEA) is responsible for:
  - Safe use of ionising and non-ionising radiation in Singapore
  - Environmental monitoring of radioactivity
  - Implementation of various international conventions relating to radiological and nuclear matters that Singapore is a Party to

Capability Build-up & Activities

- To build capability and capacity in environmental radiation monitoring, plume dispersion modelling and laboratory analysis

- To work closely with regional partners to co-operate on issues relating to nuclear safety, security and safeguards and Emergency Preparedness and Response (EPR) to radiological/nuclear incidents

- To establish a regional radiation monitoring network to share information in a timely manner

Capability Build-up & Activities

NEA secured funding in 2013 to set up an environmental surveillance system and radiochemistry laboratory.

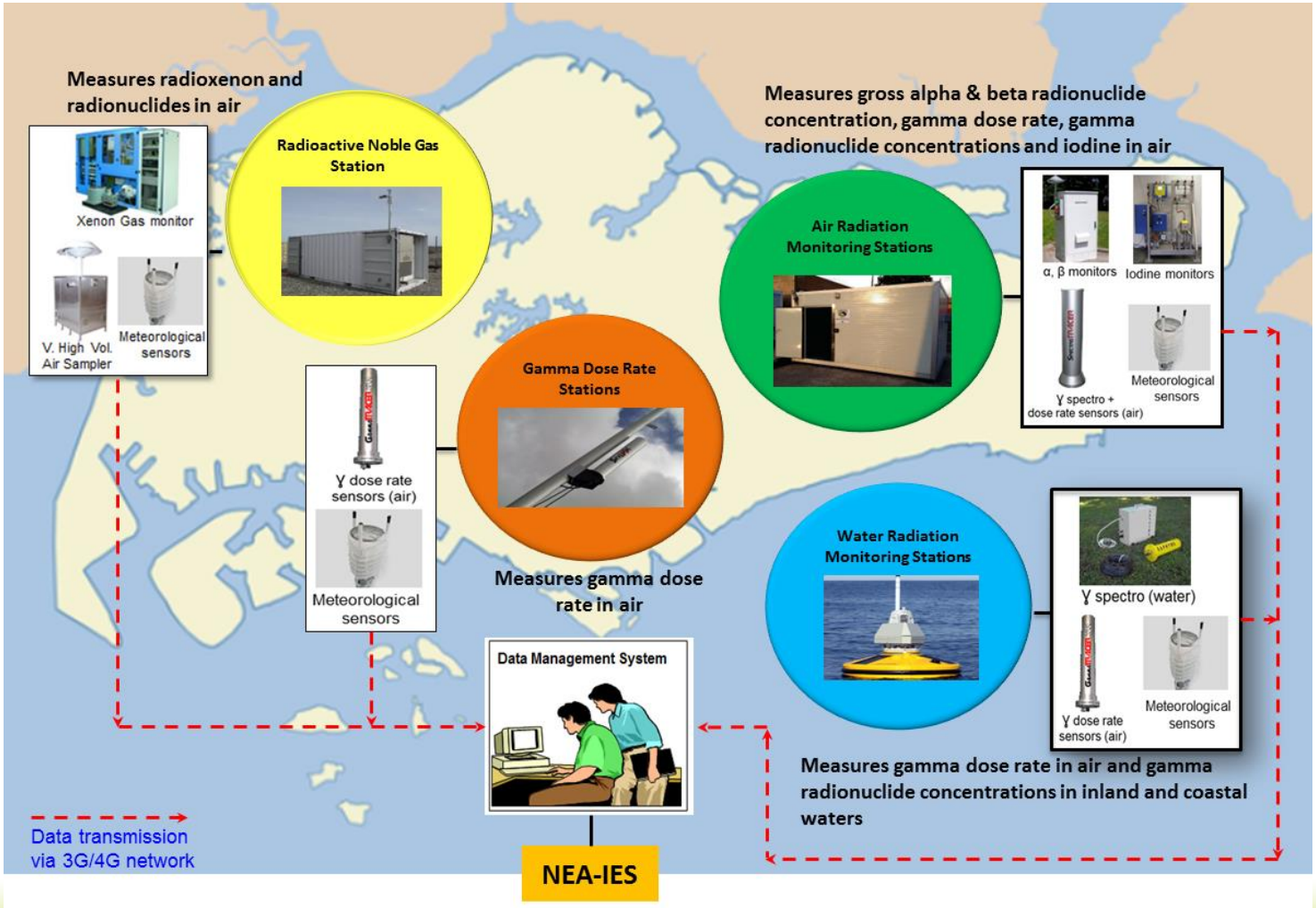
Objectives

a. Establish baseline background concentration levels of radionuclides in the environment, food and water while the region is “NPP-free”

b. Carry out continuous monitoring to enable us to detect any release of radioactive substances into the environment early

Ambient Radiation Monitoring Network (ARMNet)

To be fully commissioned by 2019



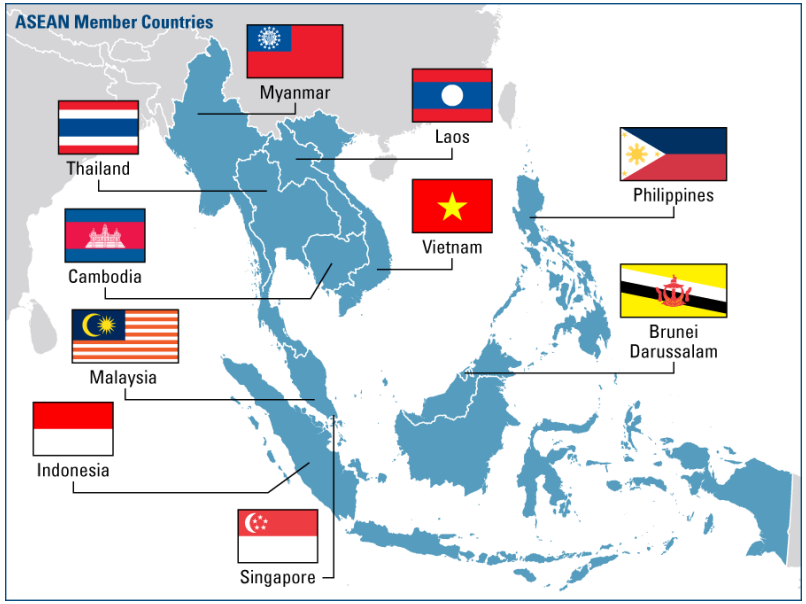
National Radiochemistry Laboratory

- Establish baseline radiation levels in ambient environment and food
- Operational by 2H 2017
- Trainings at established laboratories overseas

Formation of ASEANTOM

- Formed in Sep 2013, the ASEAN Network of Regulatory Bodies on Atomic Energy (ASEANTOM) is represented by respective regulatory bodies of all 10 ASEAN members.

- Objective
  - ✓ To enhance regulatory activities and further strengthen nuclear safety, security and safeguards within the ASEAN Community, by enhancing cooperation and complementing the work of existing mechanisms at the national, bilateral, regional and international levels.



ASEANTOM

Formation of ASEANTOM

- In Dec 2015, ASEANTOM was officially designated as an Annex I sectoral body under the ASEAN Political-Security Community

- Focal point for collaboration with the International Atomic Energy Agency (IAEA)
  - ✓ IAEA-ASEANTOM regional project RAS/9/077: Supporting Regional Nuclear Emergency Preparedness and Response in the Member States of ASEAN Region

IAEA
International Atomic Energy Agency

IAEA-ASEANTOM Regional Project RAS/9/077

- Jointly developed by Thailand and Singapore, in consultation with the other 8 ASEAN members

- Objective
  - ✓ To develop and implement emergency preparedness and response arrangements at the national and regional levels in the event of a severe nuclear and/or radiological incident.

- First phase of a multi-phase project that will lead to the establishment of the following:
  i. A regional radiation monitoring network
  ii. A regional environmental radioactivity database (maintained by a regional data centre)

IAEA-ASEANTOM Regional Project RAS/9/077

- Project will be implemented from 2016-2019
  - 1st activity - Regional Workshop on Project Coordination and Hazard Assessment, Bangkok, Thailand, 23 – 27 May 2016
  - 2nd activity - Regional Workshop on Radiation Monitoring and Information Sharing in an Emergency, Manila, Philippines, 12 – 16 Dec 2016
  - Upcoming activities include scientific visits, regional training courses

Our Environment

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