SMR: a good idea for Underground Nuclear Power Plants ?

Presented by Didier De Bruyn
on behalf of Prof. Shunsuke Sakurai,
President of the UNPP Commission form the International Society for Rock Mechanics & Rock Engineering (ISRM)

Prof. Sakurai is a past president of ISRM and a Prof. Emeritus of the Kobe University & Hiroshima Institute of Technology

Didier De Bruyn is deputy chairman of the Board of Directors of the Belgian Tunneling Association and member of the UNPP Commission

A short history for the ISRM Commission on UNPPs

Pierre Duffaut & Shunsuke Sakurai (former ISRM President) met in Beijing (2011). Sakurai met other people concerned with the use of underground space in Associated Research Centers for the Urban Underground Space (ACUUS) held in Singapore, and Sakurai had a strong confidence to establish ISRM Commission on UNPP. Consequently, we apply to ISRM for establishing the Commission on UNPPs (2012). The ISRM Board accepted the Commission (2013).

Purpose of the Commission

Feasibility of nuclear power plants siting underground is investigated.

On the basis of the results of the feasibility study, two Commission reports (2015) and (2017) have already been made up, and Commission report (2019) is now in preparation.

As the final outcome of the Commission on UNPP, we are aiming at preparing "Guideline for the Design and Construction Methodologies of Underground Nuclear Power Plants", and we are hoping that it will be published as one of the IAEA publications.

Members of the ISRM Commission on UNPPs (in 2019)

- Nick Barton, Norway, Nick Barton & Associates
- Didier De Bruyn, Belgium, Belgian Nuclear Research Centre (SCK-CEN)
- Pierre Duffaut, France, French Committee on Rock Mechanics
- Charles Fairhurst, USA, University of Minnesota
- Xia-Ting Feng, China, Northeastern University
- Sergei Gusak, Russia, Kola Mining Institute
- Il Soon Hwang, Korea, Chair professor of Ulsan National Institute of Science and Technology (UNIST)
- Anatoliy Kozyrev, Russia, Prof. of the Kola Mining Institute
- Jay Kunze, USA, Idaho State University
- C. F. Lee, Hong Kong
- James Mahar, USA, Idaho State University
- Derek Martin, Canada, University of Alberta
- Nicolai Melnikov, Russia, Prof. Academician of the Russian Academy of Sciences (2013-2018)
- Carl Wes Myers, USA,
- Matthew Pierce, USA,
- Shunsuke Sakurai, Japan, Kobe University
- Norikazu Shimizu, Japan, Yamaguchi University
- Jae-Joon Song, Korea, Seoul National University
- Raymond Sterling, USA, Louisiana Tech University
- Varun, USA, ITASCA
- Philippe Vaskou, France, GEOSTOCK
- Joseph Wang, USA, Lawrence Berkeley National Laboratory
- Zhiguo Zhang, China, Changiiang Institute of Survey, Planning, Design and Research
- Jian Zhao, Australia, Monash University
- Yingxin Zhou, Singapore, Building and Infrastructure, Defence Science & Technology Agency
- Resat Ulusay (ex officio), Turkey, ISRM President
- ISRM VP Asia (ex officio)

Number of members: 27 - Number of countries: 13

Background : the Fukushima-Daiichi accident

The Fukushima Daiichi nuclear power plant was seriously damaged by the Great East Japan Earthquake (moment magnitude M = 9.0) which occurred on March 11, 2011. The earthquake generated a giant tsunami with a run-up height of more than 20 m that struck the nuclear power plant (NPP), followed by the functional loss of the emergency power supply system due to flooding brought by the tsunami.

This accident caused the loss of reactor cooling water resulting in a hydrogen explosion of the plant and a core meltdown. As a result, radioactive materials were scattered and a vast area of the region was contaminated by radioactivity.

Even now, many people suffering from the Fukushima-Daiichi disaster cannot go back to their own town because of radioactive contamination.

Lesson learned from the Fukushima-Daiichi accident

Once a serious NPP accident occurs, like the Fukushima-Daiichi disaster, tens of thousands of people are forced to evacuate. Moreover, a vast area of land around the NPPs is contaminated with radioactive materials, resulting that a huge amount of money are required not only for decommissioning of the nuclear reactor, but also for decontaminating the radioactive environmental destruction around the NPPs.

Thus a lesson learned from the Fukushima-Daiichi disaster is how to prevent the immediate scattering of radioactive materials right after a hydrogen explosion.

As far as the security of NPPs is concerned, one of the urgent issues is to prevent the disasters due to earthquake, tsunami, and even human errors which must be taken into account. Moreover, unpredictable cause including threat of terrorism currently becomes a crucial issue.

In order to avoid any environment destructions due to various types of serious accidents of NPPs, siting NPPs underground must be one of potential options.

Current issue of Fukushima-Daiichi NPP

In the Fukushima-Daiichi a hydrogen explosion has occurred due to core melt-down which requires that the melted nuclear fuel (debris) must be continuously cooling by water. However, a problem is that used cooling water is contaminated with radioactive substances, so that it cannot be directly discharged to flow into the sea, unless the radioactive substances are removed.

Thus, in the Fukushima-Daiichi, filtering radioactive substances of the used cooling water has been performed. However, the filtering is not easy, hence the treated cooling water still contains radioactive substances, particularly the removal of tritium is extremely difficult resulting that the contaminated water must be stored in storage tanks, which are built on the ground surface of the power plant yard. As a result, the number of the tanks increases year by year, hence the manufacturing cost of the tanks becomes tremendous amount, and nobody knows when it will come to an end. Moreover, there may be no more space to build the tanks in about three years.

To solve these problems, UNPPs are one of the solutions. In other words, there is no other choice to select UNPPs as far as nuclear energy is used for generating electricity.

UNPP is not a new idea !

It is noted that the idea of UNPPs is not new, but started to be studied in the 1950s. The first underground nuclear reactors were built in Russia and Sweden in the 1960s, followed by others in Norway, France and Switzerland.

The UNPP in Lucens, Switzerland, started operation in 1968, but was shut down in 1969 after a partial core meltdown; no damage for surrounding environment was reported.

The Chooz A 350 MW PWR in France, started operation in 1968. It was the 1st UNPP with a significant power output, 350 MW, while the Russian ones were kept secret at that time. It was closed in 1992.

History of UNPPs built in various countries in the past

1954 Zhelenznogorsk, Siberia (+2) URSS
1954 R1 Research Reaktor, Stockholm, Sweden
1960 Halden, 1st underground civil reactor, vapor for a paper mill, Norway
1964 Agesta, town heating, Sweden
1965 Chooz A, national electric network, France
1968 Lucens, pilot plant, Switzerland, closed in 1969 after a partial core melt, without any harm.
1968 Chooz A, France, 1st significant power PWR output 350 MW, closed in 1992.
1976 Swedish Underground Nuclear Power Plant.

But the first conference on UNPP happens only in ….

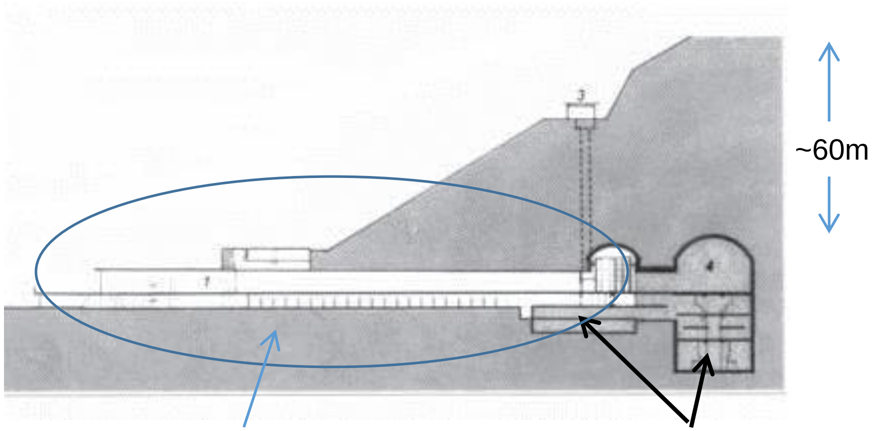
1981 Hanover Conference

The Lucens reactor accident

The Lucens reactor accident mentioned in the previous slide is extremely important as proof the ability of a cavern to contain radionuclides released during a reactor accident and prevent them from being released to the environment, and no damage for surrounding environment was reported.

The detailed information of the Lucens accident is given in the next slide.

Lucens Reactor Accident



Reuse

Grouted Chambers
(Reactor core and fuel pond)

Today: Lucens Cultural Centre
--Museum of Archaeology and History
--Storage for Cultural and Natural Artifacts

Reactor
CO$_2$ cooled, Heavy water moderated, 30MW$_{th}$, 7MW$_{el}$, 1962 construction begins, 1966 went critical.

Accident (January 21, 1969)
Moisture in coolant → corrosion + fuel channel blockage→ cladding melted + pressure tubes ruptured→ explosion→2/3s core inventory released → Reactor vessel "damaged severely" + 5 tons contaminated HW flooded fuel handling room (4.44TBq primarily Cs137 and Sr90).

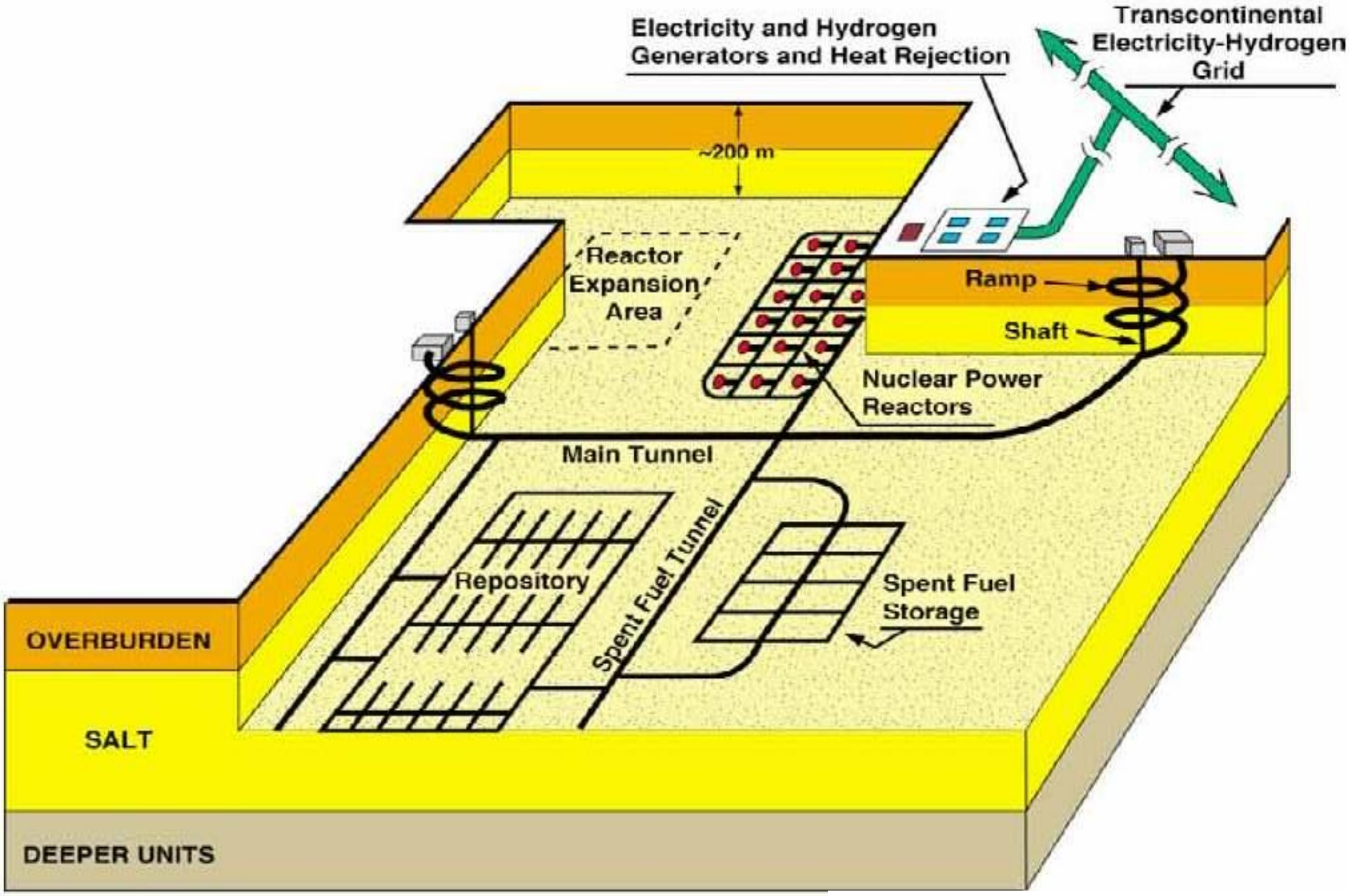
D&D …included grouting of reactor chamber and fuel storage chamber. Delicensed 2003.

Consequences :
"no releases to the public"
(IAEA Tech Report 439. p. 123)

Even further the "Underground nuclear park" idea

- Wes Myers, a member of the ISRM Commission on UNPP, and a colleague have proposed to collocate at a single underground location many reactors and generators, facilities for used fuel storage and treatment, and the repository for the end waste disposal. The concept is called "Underground Nuclear Park" (Myers, C. W. & Elkins, N. Z. 2004), as seen in the next slide.
- Thus, radionuclides in the reactors as well as in the used fuel and nuclear waste would be protected against menaces from outside.
- For sure, the construction cost for UNPPs with one only reactor may be more than for surface NPPs, but conversely this extra cost is expected to decrease with the number of reactors in multi-reactor UNPPs. In any case, the extra cost is insignificant compared to the payment for damages and remediation works following an accident like Chernobyl and Fukushima.

Underground nuclear park



From Myers & Elkins (2004)

Small modular reactors (SMR)

- As far as the excavation cost of reactor caverns is concerned, it entirely depends on the size of the caverns for storing NPPs. It is obvious that the excavation cost increases with the size of the caverns. A large reactor requires a large underground cavern resulting in the excavation cost increasing, while the UNPPs with small modular reactors have an advantage in terms of excavation cost for small reactor caverns.
- It should be emphasized that the SMR-Based UNPPs have a great potential for rock engineers who have a lot of experiences on underground hydropower plants (see the next slide).

SMR-Based UNPPs Based on Underground Hydropower Plants

Globally, approximately 600 to 700 of the more than 45,000 hydroelectric plants in operation have their powerhouses sited underground.

Bridge Crane

Unlined Cavern Walls

Turbine-Generator

Manapouri Underground Hydropower Plant

Similarities between Underground Hydropower Plants and SMR-UNPPs:

- Generation of Electrical Power
- Proximity to Electrical Grid
- Cavern Type and Dimensions
- Large equipment size and weight
- Overall Operations
- Workforce Skills---in part

EXAMPLES

Name	Generation Capacity	Number of Turbines	Rock Type	Cavern Depth (meters) Dimensions	Add References
Churchill Falls, Canada	5428MW	11	Granite	~300m 25mW, 47mH, 296mL	
Manapouri, New Zealand	**850MW**	**7**	**Granite**	**200m** **18mW, 34mH, 111mL**	
Poatina, Australia	313MW	6	Mudstone	150m 14mW, 26mH, 91mL	
Snoqualmie Falls, USA	13.7MW	5	Basalt	82m 12mW, 9.1mH, 61mL	

Other advantages of UNPP

- Earthquakes & volcanic eruptions:
  - UNPPs are safer (for earthquakes, surface vibration can decrease by a factor 10);
- Leakage of water contaminated by radioactive substances:
  - By design: water pressure outside (⇨ depth) larger than pressure inside;
  - In addition: surrounding mass of very low permeability ⇨grace time for intervention.

To conclude :

- When an accident occurs, not only the NPP is out of service, not only people are forced to evacuate, but also decontamination is necessary !
- More and more, we need to take into account unpredictable causes (terrorism, earthquakes & tsunamis large than in the existing design “What if ?”).
- UNPPs offer such additional safety margins.

Thank you for your kind attention