References of Super LWR and Super FR studies of the University of Tokyo and Waseda University at Oka-laboratory February 27, 2019

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1. Yoshiaki Oka, Seiichi Koshizuka, Yuki Ishiwatari and Akifumi Yamaji, "Super Light Water Reactors and Super Fast Reactors, Springer 2010
It includes calculational methods of core and fuel design, plant dynamics and control, plant startup and stability, safety and fast reactor design

2. Yoshiaki Oka, Hideo Mori, editors, "Supercritical-pressure Light Water Cooled Reactors", Springer 2014
It includes experimental results of thermal hydraulics, materials, material coolant interactions as well as the single pass core design and the safety analysis of Super LWR and Super FR

3. Yoshiaki Oka, et. al., SCWR symposium papers from 2000-2013 held in Japan, Germany, Canada and China
It includes the progress and summary of the studies at that time.
3.1 Y.Oka et.al., "Research and development of super light water reactors and super fast reactors in Japan", Proceedings of The 5th Int. Sym. SCWR (ISSCWR-5) Vancouver, British Columbia, Canada, March 13-16, 2011, K002

3.2 Y.Oka et al., "Progress of Super Fast Reactor Phase 2 Project and Studies of Waseda University", Proceedings of The 6th International Symposium on Supercritical Water-Cooled Reactors ISSCWR-6 March 03-07, 2013, Shenzhen, Guangdong, China , ISSCWR6-13035

4.Presentation by power points
4-1. Yoshiaki Oka, "Special lecture, Super LWR and Super FR R&D", Joint ICTP-IAEA Course on Science and Technology of Supercritical Water-Cooled Rectors (SCWRs), International Center for Theoretical Physics, Trieste, Italy, 27 June to 1 July, 2011

4-2 Yoshiaki Oka, "SC19 Plant dynamics and control", Joint ICTP-IAEA Course on Science and Technology of Supercritical Water-Cooled Rectors (SCWRs), International Center for Theoretical Physics, Trieste, Italy, 27 June to 1 July, 2011

5 Jianhui Wu and Yoshiaki Oka, "Improved Single pass core design for high temperature Super LWR"、Nuclear Engineering and Design, 267(2014) 100-108

Latest core design of Super LWR, Safety analysis of the reactor is found in the section 2.1.2.4 of the second book (ref.2)

6.Quinjie Liu and Yoshiaki Oka, “Single pass core design for a Super Fast Reactor”, Annals of Nuclear Energy 80(2015) 451-459

7.Sutanto and Yoshiaki Oka, “Accident and transient analysis of a super fast reactor with single flow pass core”, Nuclear Engineering and Design 273(2014) 165-174

Comments

Super LWR (thermal neutron spectrum reactor with UO2 fuel)

Several tens of test reactors of various kinds were constructed in USA and other countries in 1950s and 1960s (see for example, Robert Loftness, “Nuclear power plants” van Nostrand 1964), but SCWR is a new reactor which was not constructed/tested before. There were large uncertainties when GIF started in the early 2000s. The uncertainties decreased through the conceptual design and fundamental experiments of thermal hydraulics and materials.

LWR was developed based on the subcritical-pressure coal fired power plant technologies in 1950s. The purpose of Super LWR study was to pursue capital cost reduction of light water cooled reactors by using supercritical coal fired power plant technologies. It is once-through direct cycle without recirculation of the coolant. Recirculation pumps and steam-separators and dryers of BWR and steam generators of PWR are not necessary. Turbines and outlet coolant piping are compact due to the high specific enthalpy of supercritical water. The capital cost reduction will be understood by comparing the sizes of major equipment such as RPV, piping, pumps and turbines between LWR and coal fired power plants.

The other advantage is high thermal efficiency, 44%. It is directly applicable to the power cost reduction through fuel cycle cost, operation and maintenance cost etc.

Whole coolant is purified after condensation as coal fired power plant. It is good for controlling material-coolant interaction. Coolant flow is monitored as primary safety signal. It is more reliable than monitoring water level. When depressurization occurs, core is cooled by the induced coolant flow in the once-through coolant cycle.

Safety system, containments and severe accident measures will be chosen from the experience of LWR, such as either active or passive, suppression pool or dry containments, core catcher or in vessel retention.

In the early design of Super LWR and Super FR, core internals were complex such as two pass core where the coolant flows part of the core with downward first and the rest of the core upward afterwards, not to decrease the average outlet coolant temperature with the once through direct cycle. The latest Super LWR and Super FR design adopted single flow pass core where the coolant flows upward. The design and analyses showed that average outlet coolant temperature is 500C.

C1. Design goal of 500C average outlet coolant temperature was set for using the conventional supercritical steam turbines without major modification. For the single pass core, thermally insulated water rods and small fuel sub-assemblies in the periphery of the core are adopted not to decrease the average outlet coolant temperature. Inner surface of RPV is cooled by the inlet coolant of 280C as PWR. Thermal sleeve is equipped with the outlet coolant nozzles for mitigating the thermal stress.

C2. Maximum cladding surface temperature criterion of 650C for the core design looks adequate from the data which were obtained by out of pile corrosion experiment of the cladding material (improved austenitic SS cladding). In-pile loop testing of a fuel rod and fuel rod bundles will be the next step for the development, as was proposed in HPLWR program. Average outlet coolant temperature of 500C and the maximum cladding surface temperature of 650C are consistent each other from fuel rod integrity at abnormal transients, corrosion during steady state operation and also from thermal stress limit of the outlet coolant nozzles.

Use of zirconium hydrides as the moderator will be an option for the simplification of the fuel assembly structures, although neutron absorption with zirconium is higher than that of water (hydrogen). The experience of zirconium hydrides of KNK reactor in Germany will be useful for the study.

C3. Material coolant interaction is important subject for operation, but it needs to be studied with test reactors as was LWR.

C4. Enrichment of Super LWR will be reduced, when ceramic material is used for the channel box and the water rods. Solubility of ceramic material in the supercritical water needs to be assessed. Use of ceramic material for the fuel cladding will be not straight forward, because it requires innovative method for the seals/welding of the ceramic fuel cladding. The experience of the accident tolerant fuels will be useful.

Super fast reactor

The purpose of Super FR study was to pursue the reactor concept of lower power cost than light water cooled and moderated reactors (thermal neutron spectrum reactors). Power cost is primarily important for commercialization of fast reactors for the competition with other power sources.

Fast reactor does not need moderator. The power density is higher than thermal neutron spectrum reactors. It is advantage in economy. But fast reactors need plutonium for the fuel. It is disadvantage for commercialization in the world-wide. Priority of the developments is lower than Super LWR which uses uranium fuel.

Most R&D are common among Super LWR and Super FR. The experiments of thermal hydraulics, materials and material coolant interaction were carried out with the funding of Super FR, but the results are directly applicable to Super LWR. MEXT was in charge of fast reactor R&D in Japan, It is the reason why project of Super FR was funded and the experiments were carried out under the name of Super FR at the university of Tokyo and Waseda University.

The single flow pass core of Super FR adopts blanket fuel assemblies with MOX fuel pellets in the lower part of the fuel rod, not to decrease the average outlet coolant temperature. The power swing of the blanket fuel assemblies with burn up is mitigated by the heat from the MOX fuel. Breeding was not the purpose, because there are plenty of spent LWR fuels which contain plutonium. The power density of Super FR is higher than Super LWR, But I am not sure power cost of Super FR is lower than that of Super LWR.

Breeder is the dream of the fast reactor research. Breeder version of Super FR was also studied.

CF1. High breeding ratio will be not possible by using fuel assemblies by light water cooled reactors as was known from high conversion LWR study. Tube in shell type fuel assemblies increases fuel volume fraction and good for breeding, but it is exotic concept. Fracture of the welding of the coolant tubes to the shell by thermal cycling need to be prevented. Uranium resource will be not exhausted, because it increases with exploration and mining technology developments as other natural resources.

CF2. Energy group structure of neutron cross section library in the resonance energy region should be subdivided for accurately calculating breeding ratio of Super FR where zirconium

hydrides layer is used for negative coolant void reactivity.
Yuki Honda, Sadao Uchikawa and Yoshiaki Oka, " Reconstruction of cell homogenized macroscopic, cross sections for analyzing fast and thermal coupled, cores using the SRAC system", Journal of Nuclear Science and Technology, 2014 Vol. 51, No. 5, 645-655

CF3. Flattening the core of Super FR will be the other way for negative coolant void reactivity at LOCA. The diameter and thickness of RPV (reactor pressure vessel) will increase. For smaller power rating, it will be OK.

Other comments

For university research, conceptual study of Super LWR and Super FR is good subjects for students and researchers to be familiar with the LWR design and analysis methods. Collaboration between reactor physics and thermal hydraulics researchers are necessary for computational method developments. For industry, it is a seed for the innovation and ventures for commercialization. For R&D institutes, it is a subject to conduct experiments with their facilities.

I did not study Super LWR and Super FR, since I left Waseda University in March 2014. I serve as the chairman of Japan Atomic Energy Commission from April 2014. I am not in the position of promoting particular reactor types as the chairman of JAEC. Restart of LWR is primarily important in Japan. I need to improve nuclear energy utilization and R&D in Japan. It is not technical one.