The ROK's Nuclear Energy Development and Spent Fuel Management Plans and Options

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Status of and Prospects for Nuclear Power in the Republic of Korea

One of the most rapidly growing developed countries in the world today, South Korea (the Republic of Korea, or ROK) has been increasingly relying on nuclear power since 1978, when it started its first commercial nuclear power plant. The ROK imported 96.5% of its primary energy resources (at a cost of 121.7 billion US dollars) from abroad in 2010, to compensate for its lack of domestic reserves.[1] This high level of imports is the energy supply security consideration driving the ROK's reliance on nuclear power. As of August 15, 2012, the ROK had 23 power reactors in operation, with a total capacity of 21.7 GWe. The ROK reactor fleet as of August 2012 consisted of 19 pressurized water reactors (PWRs) and four CANDU heavy water reactors (HWRs), the latter with a combined capacity of 2.8 GWe,[2] An additional 6.6 GWe of PWRs were under construction,[3] and additional PWRs capacity was planned that would bring South Korea's total nuclear generating capacity up to 42.7 GWe by 2030.[4]

Figure 1 shows the expected reference case trend in installed nuclear capacity through 2030. Table 1 shows the generating capacities and expected initial operating dates of South Korea's power reactors through 2024.[5] Although the 2011 Fukushima accident caused the ROK government to review its plans for reactor construction, the net result of that review is not expected to result in major changes to existing reactor construction plans—perhaps a year or two delay at most for some units. A larger factor affecting nuclear power plan could be what happens when a new administration takes office in the ROK in early 2013.

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[1] Korea Energy Economics Institute, *2011 Energy Info. Korea*, December 2011.

[2] Retrieved August 15, 2012 from website: http://www.khnp.co.kr/NOP/action?cmd=NOPA01

[3] Retrieved August 15, 2012 from website: http://www.khnp.co.kr/NOP/action?cmd=NOPB04; http://www.khnp.co.kr/NOP/action?cmd=NOPD03 http://www.khnp.co.kr/NOP/action?cmd=NOPE03.

[4] National Energy Committee, *The 1st National Energy Basic Plan (2008-2030),* August 2008 (Korean).

[5] Ministry of Knowledge Economy (MKE), *The 5th Basic Plan for Long-Term Electricity Supply and Demand (2010 ~ 2024),* December 2010.

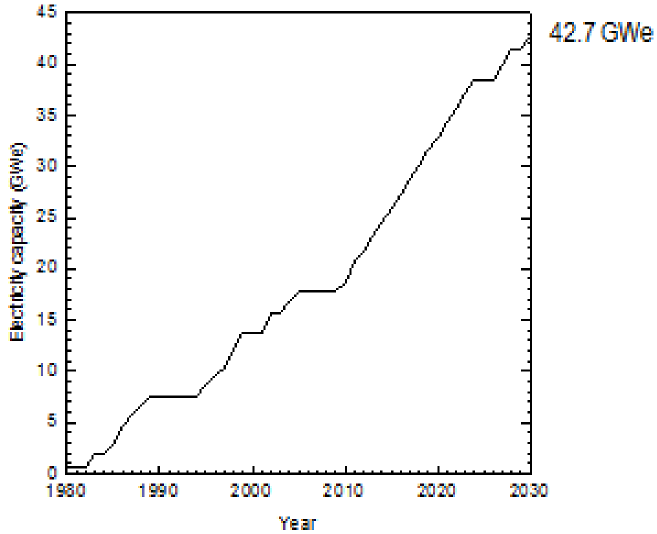

Figure 1. Installed nuclear generation capacity in South Korea (1980-2030)[6]

[6] National Energy Committee, *The 1st National Energy Basic Plan (2008-2030)*, August 2008 (Korean); Ministry of Knowledge Economy, *The 5th Basic Plan for Long-Term Electricity Supply and Demand (2010 ~ 2024)*, December 2010.

Table 1. Current and planned nuclear power capacity in South Korea through 2024

Site	Unit	Type	Capacity (MWe)	Initial Operation
Kori	Kori-1 Kori-2 Kori-3 Kori-4 Shin-Kori-1 Shin-Kori-2	PWR PWR PWR PWR PWR PWR	587 650 950 950 1000 1000	Apr. 1978 Jul. 1983 Sept. 1985 Apr. 1986 Dec. 2010 Dec. 2011
Shin-Kori	Shin-Kori-3 Shin-Kori-4 Shin-Kori-5 Shin-Kori-6 Shin-Kori-7 Shin-Kori-8	PWR PWR PWR PWR PWR PWR	1400 1400 1400 1400 1400 1400	Sept. 2013 Sept. 2014 Dec. 2018 Dec. 2019 Jun. 2022 Jun. 2023
Yonggwang	Yonggwang-1 Yonggwang-2 Yonggwang-3 Yonggwang-4 Yonggwang-5 Yonggwang-6	PWR PWR PWR PWR PWR PWR	950 950 1000 1000 1000 1000	Aug. 1986 Jun. 1987 Mar. 1995 Jan. 1996 Apr. 2002 Oct. 2002
Ulchin	Ulchin-1 Ulchin-2 Ulchin-3 Ulchin-4 Ulchin-5 Ulchin-6 Shin-Ulchin-1 Shin-Ulchin-2 Shin-Ulchin-3 Shin-Ulchin-4	PWR PWR PWR PWR PWR PWR PWR PWR PWR PWR	950 950 1000 1000 1000 1000 1400 1400 1400 1400	Sept. 1988 Sept. 1989 Aug. 1998 Dec. 1999 Jul. 2004 Jun. 2005 Dec. 2015 Dec. 2016 Jun. 2020 Jun. 2021
Wolsong	Wolsong-1 Wolsong-2 Wolsong-3 Wolsong-4	CANDU CANDU CANDU CANDU	679 700 700 700	Apr. 1983 Jul. 1997 Jul. 1998 Oct. 1999
Wolsong	Shin-Wolsong-1 Shin-Wolsong-2	PWR PWR	1000 1000	Mar. 2012 Jan. 2013

All of the nuclear power plants in South Korea are located along the coast of the peninsula, as shown in Figure 2.[7] On September 14, 2012, MKE announced that Yeongdeok and Samcheok both located on the East coast, have been identified as new sites for nuclear power plants.[8]

Satellite images of each of the four nuclear power plant (NPP) sites in the ROK are provided as Figure 3 through Figure 6.

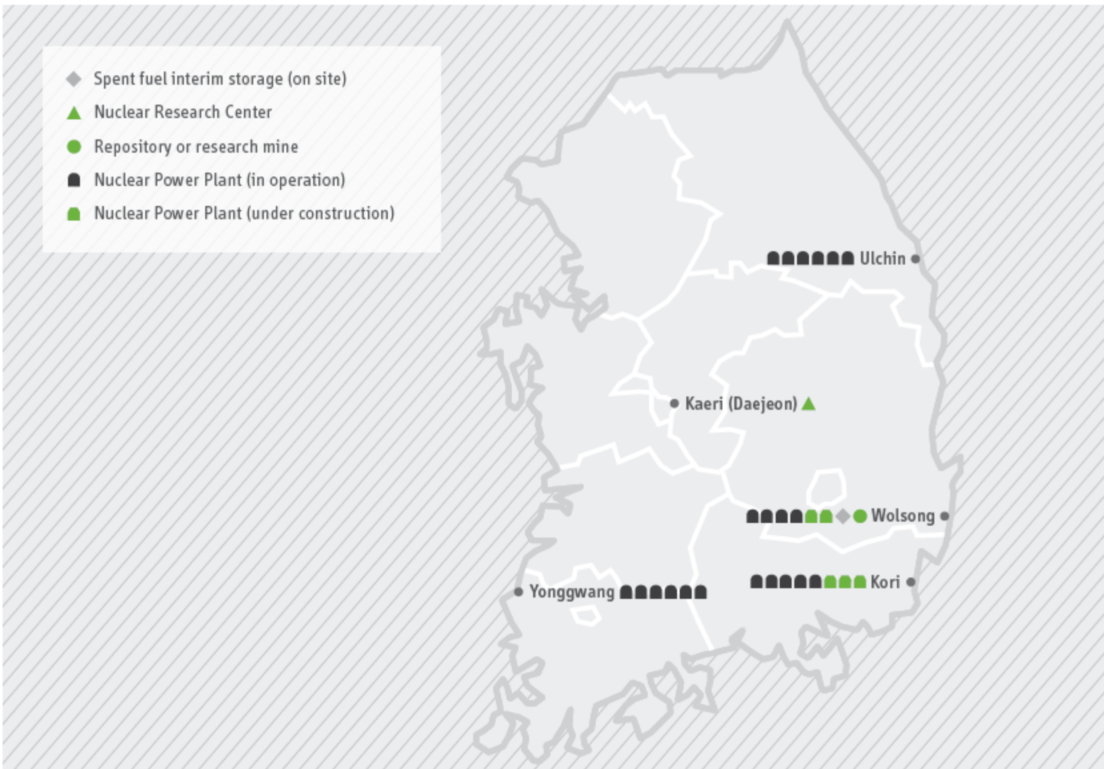

Figure 2. Locations of South Korea's nuclear power plants

[7] International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors: Experience and Lessons from Around the World*, September 2011, p.62.

[8] http://www.ytn.co.kr/_ln/0102_201209140905445385

Figure 3. Satellite image of Kori NPP site (Google Earth, October 10, 2010)

Figure 4. Satellite image of Yonggwang NPP site (Google Earth, October 10, 2010)

Figure 5. Satellite image of Ulchin NPP site (Google Earth, October 10, 2010)

Figure 6. Satellite image of Wolsong NPP site (Google Earth, October 10, 2010)

Status of and Prospects for Spent Fuel Generation

As of the end of 2009, 4,867 tons of spent PWR fuel and 5,894 tHM (tons heavy metal) of spent HWR fuel were stored in the spent fuel storage facilities at South Korea's four NPP sites. Table 2 shows the spent fuel inventories at the four sites as of the end of 2009.[9]

Table 2. Inventory of spent fuel at NPP sites in South Korea as of the end of 2009

Site	Reactor type	# of reactors	Inventory of spent fuel (tHM)
Kori	PWR	4	1,762
Ulchin	PWR	6	1,401
Yonggwang	PWR	6	1,704
Wolsong	HWR	4	5,894

Projections of spent fuel generation depend on the capacity factors of the reactors (that is, what fraction of the time they operate and at what average fraction of their nominal capacities), and the burnup of spent fuel (that is, the number of megawatt-days of heat that can be generated from a kilogram of fuel before it is "spent"). The average discharged burnup level for spent PWR fuel is around 50,000 MWd/tHM in today's reactors. Heavy-water reactors are fueled with natural uranium, and the burnup rate is about 7,100 MWd/tHM. Assuming that all NPPs have thermal efficiencies of 33% and capacity factors of 90 percent, with 60-year lifetimes for the PWRs and 50-year lifetimes for the HWRs, the projections through the year 2050 of cumulative spent fuel generation in South Korea from reactors completed by 2030 are given in Figure 7. This study estimates approximately 51,000 tons of spent PWR fuel and approximately 20,000 tHM of spent HWR fuel will be generated from the 35 PWR and 4 HWR units that will be deployed by 2030 under a "reference" or "Business as Usual" nuclear capacity expansion scenario.[10]

South Korea started to research and designed a central interim spent-fuel storage facility and repository for low and intermediate level waste (LILW) in 1986. The implementing organizations for this effort were KAERI and the Ministry of Science and Technology. In July 1988, the Korean Atomic Energy Commission (AEC) announced that a centralized away from reactor (AFR) facility would be constructed by December 1997. In December 1988, the AEC announced the intention to construct a wet-type AFR with a capacity of 3,000 t of spent fuel. Due to strong opposition from local potential host communities that have developed in the wake of these announcements, all attempts to acquired AFR sites have failed since 1987. In 1996, the responsibility for radioactive waste management was transferred to then Ministry of Commerce, Industry and Energy and to KEPCO. In September 1998, the AEC announced that a LILW disposal facility would be built by 2008 and an interim spent-fuel storage facility would be built nearby by 2016. The AEC also announced the intent to acquire 2,000 t of spent fuel storage capacity at a dry facility AFR site by 2016. Due to continuing difficulties in securing sites since 1996, the AEC decided to pursue separate sites for the LILW repository and the central spent-

[9] Do-Hee Han, "The Korean Strategy for Nuclear Fuel Cycle," KAERI, June 2010.

[10] Author's calculations.

fuel storage facility. The AEC recently announced that it would adopt a public and stakeholder engagement process to help to reach agreement on a site for an AFR spent fuel storage facility.[11]

In the ROK, the Ministry of the Knowledge Economy is primarily responsible for making and approving plans regarding nuclear reactor deployment. Although there has been some limited public concern about reactor deployment and other nuclear energy plans in the ROK, the role that the public has in terms of input to nuclear energy-related decisions is extremely limited. As of this writing, it does not seem that the Fukushima accident has significantly affected thinking on the part of nuclear policymakers regarding reactor deployment in the ROK.

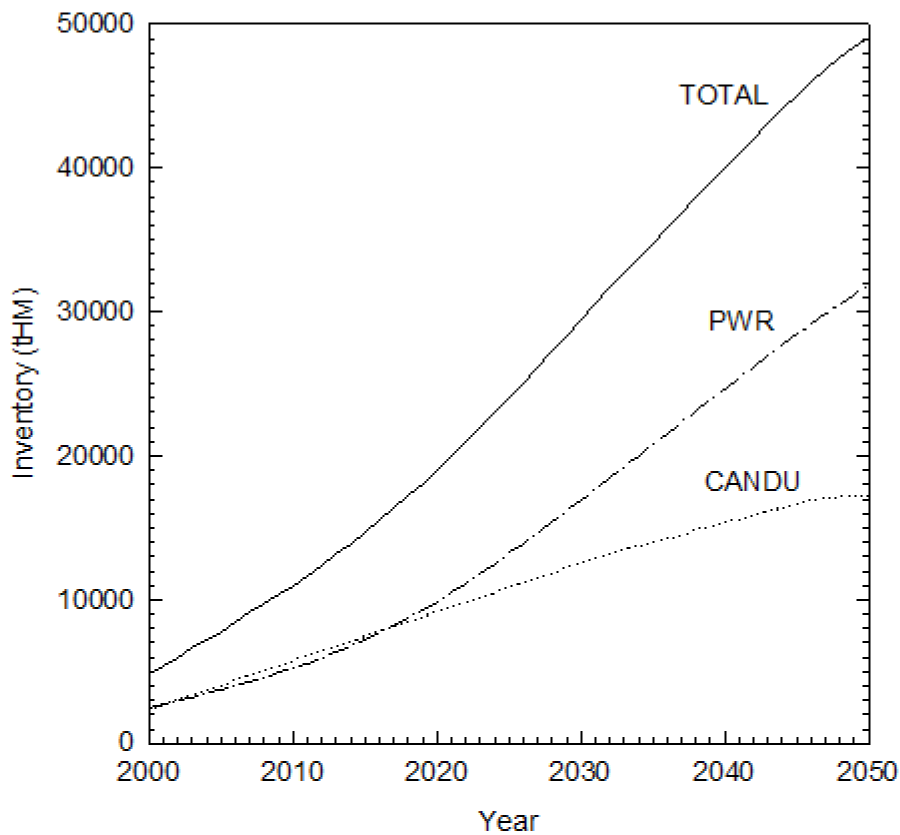

Figure 7. Cumulative inventory of spent fuel generation in South Korea (2000-2050)

Shortage of Sites' Storage Capacities for Spent Fuel

[11] South Korea chapter of *Managing Spent Fuel from Nuclear Power Reactors,: Experience and Lessons from Around the World*, International Panel on Fissile Materials, September 2011; Seong-Won Park, "Pyroprocessing Technology for Sustainable Nuclear Energy," Presentation given at a workshop on Status of Reprocessing Worldwide and Pyroprocessing in South Korea, Seoul, South Korea, October 26, 2012.

The ROK maintains its inventory of spent reactor fuel in wet storage spent fuel pools at each of the four reactor sites, and at a dry storage facility at Wolsong. Table 3 shows current, planned and potential pool spent fuel storage capacity in South Korea through 2021.[12]
Dry storage facilities are only used for CANDU spent fuel at the Wolsong site, partly because of the much lower burnup of CANDU spent fuel than that of PWR spent fuel (and thus the higher volume and lower radioactivity of CANDU spent fuel. CANDU spent fuel is transported to the dry storage facilities via a road on the reactor site; the dry storage site is adjacent to the reactor site.

Multi-reactor nuclear plant sites in South Korea do not use centralized spent-fuel pools accepting fuel from multiple reactors. Rather, for each reactor, the spent fuel pool is located in the fuel building next to the domed reactor containment building at ground level. The spent fuel pools at ROK reactors are typically 40 or more feet (12 meters) deep. Although the sizes of the spent fuel pools in use varies among ROK reactors, by way of example, the spent fuel pools serving the Yonggwang 5 and 6 units is 902 cm long, 743 cm wide and 1204 cm deep.[13]

[12] International Panel on Fissile Materials, *Managing Spent Fuel from Nuclear Power Reactors: Experience and Lessons from Around the World*, September 2011, p.69.

[13] Jungmin Kang, "Alternatives for Additional Spent Fuel Storage in South Korea," *Science & Global Security*, Vol. 10, No. 3, 2002.

Table 3. Current, planned and potential spent-fuel storage capacity in South Korea through 2021

Site	Unit	Type	Pool storage capacity [a] (tHM) Existing	Increase: Planned	Increase: Potential additional
Kori	Kori-1	PWR	158.8		
PWRs	Kori-2	PWR	327.6		
	Kori-3	PWR	270.9	696.4	
	Kori-4	PWR	270.9	697.4	
	Shin-Kori-1	PWR	428.7		1024.5
	Shin-Kori -2	PWR	428.7		1024.5
	Shin-Kori -3 [c]	PWR	625.7		1480.1
	Shin-Kori -4 [c]	PWR	625.7		1480.1
	Shin-Kori -5 [c]	PWR	625.7		1480.1
	Shin-Kori -6 [c]	PWR	625.7		1480.1
Yonggwang	Yonggwang-1	PWR	270.9	697.4	
PWRs	Yonggwang-2	PWR	270.9	186.8	509.7
	Yonggwang-3	PWR	215.4	268.3	323.4
	Yonggwang-4	PWR	215.4	268.3	323.4
	Yonggwang-5	PWR	224.9	203.8 [b]	407.1
	Yonggwang-6	PWR	224.9	203.8 [b]	407.1
Ulchin	Ulchin-1	PWR	144.9	297.7	
PWRs	Ulchin-2	PWR	144.9	273.7	
	Ulchin-3	PWR	215.4	352.6	239.1
	Ulchin-4	PWR	215.4	352.6	239.1
	Ulchin-5	PWR	224.9		610.9
	Ulchin-6	PWR	224.9		610.9
	Shin-Ulchin-1	PWR	625.7		1480.1
	Shin-Ulchin-2	PWR	625.7		1480.1
	Shin-Ulchin-3	PWR	625.7		1480.1
	Shin-Ulchin-4	PWR	625.7		1480.1
Wolsong	Wolsong-1	HWR	842.7	(6,929, dry storage as of February 2010)	
CANDUs	Wolsong-2	HWR	736.8		
	Wolsong-3	HWR	736.8		
	Wolsong-4	HWR	736.8		
Wolsong	Shin-Wolsong-1	PWR	504.8		1024.5
PWRs	Shin-Wolsong-2	PWR	504.8		1024.5

[a] Pool storage capacity measured in metric tons of original uranium in the fuel (tons heavy metal or tHM). These values do not include the pool capacity for a full reactor core that is held open in case all the fuel in the current reactor core has to be unloaded quickly.

[b] Planned for installation in 2012.

[c] Shin-Kori 3,4,5 and 6, although contiguous with Kori 1,2,3 and 4 and Shin-Kori 1 and 2 are in a different local jurisdiction. Moving spent fuel from pools in one jurisdiction to pools in the other therefore would require permission from the second jurisdiction.

According to an analysis by the operator, Korea Hydro & Nuclear Power Co., Ltd, the saturation dates for the current spent fuel storage at the Kori, Yonggwang and Ulchin sites for spent PWR fuel, and at the Wolsong site for spent HWR fuel, will be 2016, 2021, 2018 and 2017 respectively.[14] KHNP did not fully consider the potential for dense racking arrangement of spent fuel assemblies in pools in its assessment—"re-racking" was assumed in the spent fuel pools of some reactors but not in others.

However, when KHNP has stated that the spent fuel pools at Kori will be full in 2016, it had considered only intra-site transshipment of spent fuel among pools of old 4 reactors, that is, for example, from the Kori unit 1 to unit 4 on the same site. The old spent fuel in the pools of the older (pre-2010) 4 reactors at the Kori site can be shifted to the pools built for the newer 2 reactors, that is, the Shin-kori units 1 and 2 that went into operation in 2010 and 2011, respectively, on the same site. If this intra-site transshipment of spent fuel is implemented, it extends the saturation year for spent fuel pools from 2016 to 2023.

At the Ulchin site, similarly, KHNP considered only intra-site transshipment of spent fuel among the pools of the old 6 reactors, that is, Ulchin units 1 to 6 on the site. The old spent fuel in the pools of the older 6 reactors can be shifted to the pools of the newer 4 reactors, that is, to Shin-ulchin units 1 to unit 4, which are to be put in operation on the same site from 2015 through 2021. If implemented, this extends the saturation year for spent fuel pools at the Ulchin site from 2018 to 2028.

With regard to the reactors on the Yonggwang site, KHNP's argument might be true, considering that there are no plans for new deployment of NPPs at the site until 2022 at the earliest.

The situation of storage of spent fuel at Wolsong is somewhat complex, compared with at the other PWR sites. According to a law entitled "Special Act on Support for Areas Hosting Low and Intermediate Level Radioactive Waste (LILW) Disposal Facility", dated 2005, spent fuel-related facilities cannot be built in the local area that hosts the LILW site, which includes the Wolsong site. Some South Korean nuclear experts argue that the law means that no more dry storage facilities are to be built after 2017 when current dry storage will be full. However, the Korea Radioactive Waste Management Corporation (KRMC) argues that those dry storage facilities at Wolsong are "tentative" ones, not the types of "interim" storage that are banned by the 2005 Special Act of LILW. "Tentative" storage means storage of spent fuel on site under the control of KHNP, whereas "interim" storage means storage of spent fuel on site or at an AFR site under the control of KRMC, though this is an administrative difference only, as there is no physical difference between "tentative storage" and "interim storage".

KHNP has expanded the capacities of dry storage at Wolsong by 680 tHM in 1990, 907 tHM in 1998, 680 tHM in 2002, 1134 tHM in 2006 and 3528 tHM in February 2010 for a total of 6,929 tHM dry storage capacity and 3,053 tHM pool capacity as of August, 2012. Whether or not dry storage facilities at Wolsong violate the special Act of LILW is still controversial and needs to be clarified by the ROK government.

[14] Ki-Chul Park, "Status and Prospect of Spent Fuel Management in South Korea," *Nuclear Industry*, August 2008 (in Korean)

Figures 8, 9 and 10 show the dry spent fuel storage facilities at the Wolsong site. 300 concrete silos (3,120 tHM) have been installed at Wolsong since 1990 while 7 MACSTOR/KN-400 modules (3,227 tHM) have been installed since 1990.

Figure 8. Concrete silo and MACSTOR/KN-400 at Wolsong (Google Earth, October 10, 2010)

Figure 9. Concrete silo at Wolsong[15]

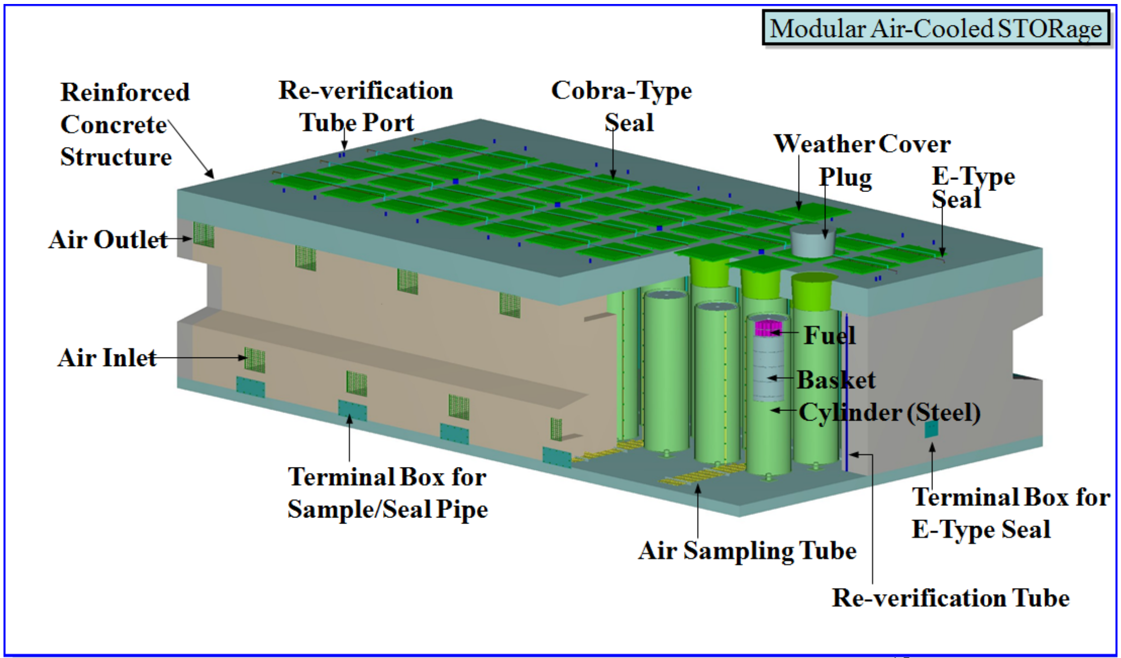

Figure 10. MACSTOR/KN-400 modules at Wolsong[16]

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[15] "Status and Prospect of Spent Fuel Management," KRMC, October 2011 (Korean)

[16] Ibid.

According to a recent study performed by an expert group composed of members of South Korea's nuclear establishment, the storage pools at the ROK's four reactor sites, Kori, Ulchin Yonggwang, and Wolsong are projected to be full by 2028, 2028, 2024 and 2025, even considering re-racking and intra-site transshipment between NPPs at individual PWRs sites, as well as the installation of two additional MACSTOR/KN-400 modules at Wolsong.[17]

National Policy on Spent Fuel Management

At its 253rd meeting in 2004, the AEC announced that national policy for spent fuel management would be decided later in consideration of progress of domestic and international technology development, and that spent fuel would be stored at a reactor sites through 2016 under KHNP's responsibility.[18] Since South Korea has not decided whether to directly dispose of or recycle spent fuel, it currently has no national plan on geologic disposal of spent fuel.

Legal and Institutional Issues in the Radioactive Waste Management

Key ROK National laws related to spent fuel and radioactive waste management are the Atomic Energy Act (AEA) and the Radioactive Waste Management Act (RWMA). The AEA provides for matters concerning safety regulations, including permission for construction and operation of radioactive waste disposal facilities. The RWMA, which determines all aspects of managing radioactive waste, was enacted on March 31, 2008. Based on the RWMA, the Korea Radioactive Waste Management Corporation (KRMC) and the Radioactive Waste Management Fund were established in January 2009. According to the RWMA, KHNP, the utility company, should annually deposit to the Fund the cost of decommissioning of nuclear power plants, disposal of low and intermediate level waste (LILW), and spent fuel management.[19] Funds for these activities are collected from electricity consumers via tariffs; data how these funds are collected and disbursed for nuclear sector activities in the ROK are not yet public information.

With regard to the governmental organizations concerned with radioactive waste, the main administrative authorities in the ROK are the Ministry of Knowledge Economy (MKE), which supervises the nuclear power program, and a newly founded Nuclear Safety and Security Commission (NSSC) under the jurisdiction of the President,[20] which is responsible for nuclear safety regulations including the licensing of nuclear facilities as well as nuclear security. The Atomic Energy Committee (AEC) under the jurisdiction of the Prime Minister is the supreme organization for decision-making on national nuclear policies. The NSSC is responsible for matters concerning the safety of nuclear facilities and radioactive waste management. NSSC is

[17] Korean Nuclear Society, Korean Radioactive Waste Society and Green Korea 21, "Alternatives and Roadmap of Spent Fuel Management in South Korea," Aug. 19, 2011 (Korean)

[18] 253rd meeting of Korea AEC in 2004. See, for example, Ministry of Education, Science & Technology, *Korean Third National Report under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*, dated October, 2008, and available as www.kins.re.kr/pdf/Korean%20Third%20National%20Report%202008.pdf

[19] Ibid.

[20] Retrieved August 16, 2012 from website: http://www.nssc.go.kr/nssc/english/introduction/purpose.html.

also responsible for developing licensing criteria for the construction and operation of radioactive waste disposal facilities, for developing technical standards for operational safety measures, and for assuring safe management of radioactive waste at every stage of the life cycle of waste disposal facilities, including the site selection, design, construction, operation, closure and post-closure phases. MKE also develops and implements management policies regarding radioactive waste treatment, storage and disposal. These policies are prepared by MKE and deliberated by the AEC before implementation.

KAERI's Plan on Pyroprocessing and Fast Reactors

As of this writing (August, 2012), South Korea's debate regarding spent fuel management is focused on "pyroprocessing," driven by the Korean Atomic Energy Research Institute (KAERI). KAERI has been developing pyroprocessing in which plutonium and other transuranics are electrochemically separated from uranium and fission products in spent fuel after the dissolution of spent fuel in molten salt. Pyroprocessing is different from typical aqueous reprocessing, which separates pure plutonium from other spent fuel components. KAERI argues that with pyroprocessing, less spent fuel waste would need to be disposed of, so that the transuranics, after being separated and fabricated into reactor fuel, can eventually be fissioned in fast neutron reactors.[21] The push for pyroprocessing in the ROK is happening partially because Japan has established its own spent fuel reprocessing capacity, and because, although a reprocessing plant could not be put into operation by the time that the PWR spent fuel pools begin to fill up in the 2020s, the expectation is that reprocessing spent fuel could provide a justification for establishing an additional central storage site for spent fuel waiting to be reprocessed that would be located near the site where the reprocessing plant would be built. KAERI insists that pyroprocessing and recycling of spent fuel is the best alternative for reducing the future burden of geologic disposal of spent fuel, a view supported by the Ministry of Education, Science and Technology (MEST). Figure 11 shows KAERI's plan for deployment of pyroprocessing and fast reactors in South Korea. A 10-year US-ROK joint study on pyroprocessing has been underway since 2011. No plans as to the location of potential pyroprocessing or fast reactor facilities in the ROK have been announced to date.

[21] Jungmin Kang, "South Korea in focus: The Politics of Spent Fuel Storage and Disposal," *Bulletin of the Atomic Scientists*, May/June 2011.

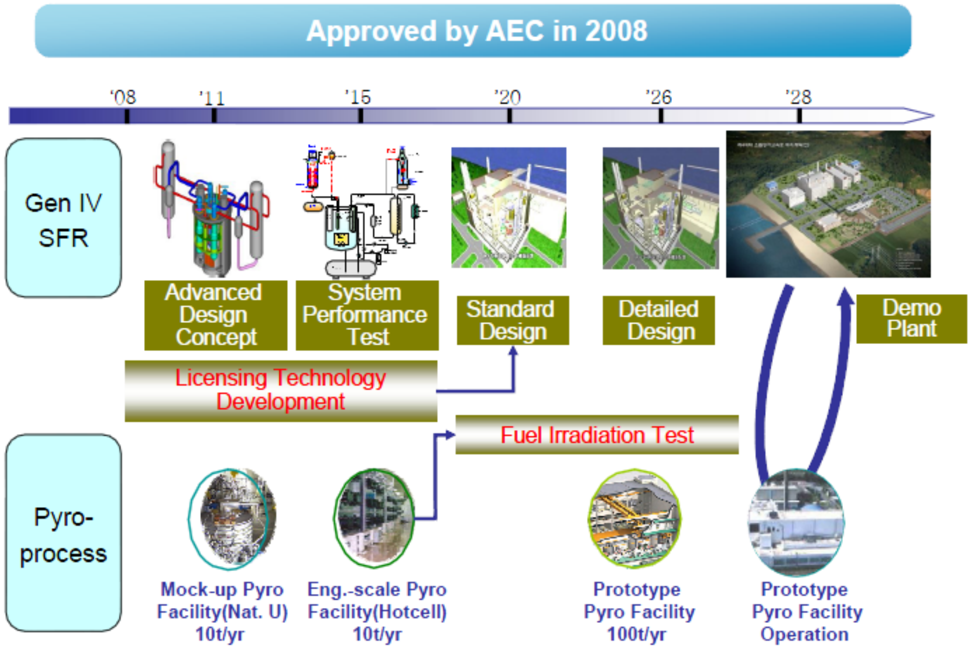

Figure 11. KAERI's plan on pyroprocessing and fast reactors [22]

Conclusion

The ROK's current nuclear capacity of 21.7 GWe will, under current plans, be approximately doubled by 2030. Given the current lack of pool storage capacity for PWR spent fuel problem of PWR spent fuel storage in the ROK will become worse in the near future. Decisions regarding the interim storage of spent fuel will play key roles in shaping nuclear fuel cycle activities and development in South Korea in the coming years because interim storage would provide flexibility in nuclear sector decision making whether or not the ROK moves toward pyroprocessing by delaying, possibly for decades, the day when final decisions regarding spent fuel management must be made.

A 10-year US-ROK joint study on pyroprocessing, begun in 2011, will likely also affect future nuclear fuel cycle activities and development in South Korea. If the joint study reaches a positive conclusion regarding pyroprocessing, it could affect the ROK government's consideration of deployment of pyroprocessing to resolve the ROK's spent fuel storage problems.
In terms of the potential impact of the Fukushima accident on ROK policy, the ROK public might, after seeing the Fukushima accident play out, be more accepting in the future of dry storage facilities if the public is more fully educated about the relative safety aspects of different spent fuel storage options. Te deployment of dry storage facilities for spent fuel will likely be a key factor affecting nuclear fuel cycle activities and development in the ROK in the coming years.

[22] Hansoo Lee, "Pyroprocessing Technology Development at KAERI," IPRC 2010, Nov. 29 - Dec. 30, 2010.

Finally, the public consensus on spent fuel management is very likely to be fully considered next year (2013) when a new administration comes to power in the ROK.[23] If the public is allowed a greater role in nuclear sector decision making, it would more directly affect nuclear fuel cycle issues in the ROK from a policy perspective, which could result in changes to existing plans in the nuclear sector.

[23] Jeonghwa Kim, "Status of Spent Fuel Management in South Korea," Panel session at a workshop on Status of Reprocessing Worldwide and Pyroprocessing in South Korea, Seoul, South Korea, October 26, 2012.