DEVELOPMENT OF NUCLEAR POWER IN SWEDEN

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Despite a total lack of domestic fossil fuels, national independence in the supply of electricity has been traditional due to abundant hydropower. Nuclear energy offered an opportunity to uphold this tradition because of large domestic uranium resources.

Consequently the early nuclear energy programme was focused on the heavy water - natural uranium system, which did not rely on foreign supplies of enriched fuel. The programme peaked in the construction of a 140 MWe boiling heavy water reactor of advanced design - Marviken. It incorporated, among other things, internal superheating of the steam.

Even before the reactor became operational the superheat concept ran into difficulties, which required a change in core configuration. Calculations showed, however, that the modifications would result in a positive void coefficient under certain conditions. This dealt the death blow to the project, since the instability was unacceptable for safety reasons - the project was abandoned one month before the reactor was to have started up in 1968. I am dwelling on this historic event at some length, since the same kind of instability that was rejected at Marviken, caused the accident at Chernobyl 16 years later.

Even before the end of Marviken the private utilities had pleaded for a shift to light-water technology, where international experience was accumulating. Enriched uranium had by then become a commodity on the international market. The heavy water project experience helped the Swedish supplier, ASEA-Atom (now ABB-Atom) to make the transition. In 1965 they received an order for a 440 MWe boiling light-water reactor, which became known as Oskarshamn-1. ASEA-Atom was the first company to supply light-water reactors without an American licence.

In order not to put all its eggs into one basket the Swedish State Power Board eventually ordered three pressurized water reactors from Westinghouse in addition to ASEA BWRs. Today there are twelve reactors in operation:

Plant (Utility)	Unit	Rating (MWe)	Commissioning year
Forsmark	F1 BWR	970	1981
(State Power Board)	F2 BWR	970	1981
	F3 BWR	1150	1985
Oskarshamn	O1 BWR	440	1972
(OKG)	O2 BWR	600	1974
	O3 BWR	1150	1985
Barsebäck	B1 BWR	600	1975
(Sydkraft)	B2 BWR	600	1977
Ringhals	R1 BWR	820	1975
(State Power Board)	R2 PWR	860	1976
	R3 PWR	915	1981
	R4 PWR	915	1983

The existence of a supplier within the country has been important to the success of the Swedish nuclear programme. Another factor of importance has been the way work and responsibility have been divided between the suppliers, the plant owners and the safety authorities.

After Oskarshamn-1, which was a turn-key project, procurement and project management rested with the utilities which thereby developed their own competence.

As to the division of responsibility between the safety authorities - the Nuclear Power Inspectorate and the Radiological Protection Board - on the one hand, and the utilities on the other, it is unambiguously stated that the ultimate responsibility for safety rests with the owner-operator. The authorities set their conditions, but it is the business of the plant operator to present the means of complying with them. The authorities then may accept or reject the proposals. This mode of interaction differs from that in e.g. the USA, where the regulations imposed on the operator are much more detailed. In our view the Swedish system stimulates independent thinking and the development of a safety culture at each plant.

Between 1976 and 1980 the utilities, on their own initiative, undertook comprehensive safety studies based largely on the PSA technique demonstrated in the American Rasmussen study of 1975. This resulted in modifications of the existing plants and improvements in the newer designs. The principles of redundancy, diversity and spatial separation of safety systems were extended. Among the safety features of the later BWRs are internal circulation pumps, which reduce the risk of great loss-of-coolant accidents. An early feature of the Swedish plants was the "30-minute rule", meaning that in case of an incident the operators need not interfere during the first half hour.

The Nuclear Power Inspectorate estimated that the improvements made since the early seventies had reduced the core-melt probability by a factor 10, to better than one in a hundred thousand reactor-years. Because of the extensive back-fitting of the older plants, the Inspectorate judged it impossible to make a safety ranking between the plants.

The TMI accident in 1979 prompted the Government to appoint an independent Safety Commission to review the conditions of the Swedish plants. The Commission report largely confirmed the foresight of the utilities but resulted in several further improvements, the most concrete one being the introduction of filtered containment venting: If, as a result of a core-melt accident, pressure builds up in the containment and threatens its integrity, the pressure is relieved through a filter, designed to hold back 99% of the radioactivity (except for the noble gases). With this system in place, an accident leading to acute off-site casualties or massive evacuations is judged to have a probability no greater than one in ten million reactor-years.

In the last decade the operating record has been very good which is reflected in the three performance indicators "energy availability", "scrams per unit and year", and "collective radiation exposure" of personnel.

Radioactive emissions have been a factor 50-100 below the permitted limits, giving maximum exposures to those living near the plants of some thousandths of the natural background.

If the nuclear power of some 70 TWh generated in one year by the twelve Swedish plants had instead been produced in coal-fired units of the standard normal for example in Denmark, this would have resulted in

65 million tons of CO_2
240 000 tons of SO_2
140 000 tons of NO_x

This last year continual record of excellence has been broken by several events. One was a steam valve failure at Barsebäck, trivial per se, which revealed a generic weakness in all five first and second generation BWRs. The steam jet tore off insulation material which ended up in the water pool below the reactor, blocking the emergency core cooling systems. In the (unlikely) event of a large pipe break emergency coolant might not have been available. All five reactors were ordered shut down for modification.

Another problem of concern is the recent detection of unexpected cracks in piping near the reactor pressure vessel in the oldest Oskarshamn-1 reactor. It is too early to say whether this problem is generic.

An important part of the nuclear power story in Sweden is the handling of the waste problem. The solution to the problem is nowhere so near implementation. Credit for this is due to the political opposition to nuclear power which brought about a strict legislation on waste disposal as a condition for plant operation.

The ultimate disposal method for high-level waste - in the form of spent fuel - is multibarrier encapsulation and deposition in carefully chosen bed-rock at a depth of 500 m. Many years of experimentation and analysis have been spent on this concept. Awaiting the opening of a final disposal site, a central intermediate storage facility, CLAB, at Oskarshamn, was completed in 1985. A special ship has been built to transport spent fuel from the plants. A final underground repository for intermediate waste is in operation at Forsmark.