Some issues associated with Pakistan's Karachi Nuclear Power Plant (KANUPP)

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Summary

Pakistan's Karachi Nuclear Power Plant (KANUPP) is a 137 MWe (gross) Canadian designed and built CANDU reactor that is now three years away from the end of its 30 year design lifetime. It has a very poor record of electricity generation, marked by low availability and frequent shutdowns, suggesting poor management of the plant by the Pakistan Atomic Energy Commission (PAEC). Over the last decade a range of systems at the plant have been showing signs of ageing and obsolescence but PAEC insists on continuing to operate it. Rather than permanently shut down and decommission the reactor, PAEC has asked for and received support from Canada with a major effort to try to keep the reactor running for another decade. Given its record and its location, barely 20 km from the 10 million people who live in the rapidly growing coastal city of Karachi, the continued operation of KANUPP raises troubling questions.

History

Pakistan's efforts to obtain a nuclear power plant from Canada began in February 1961, when, according to the history of Atomic Energy of Canada Limited (AECL):

> *"The Pakistan Atomic Energy Commission first came calling... The Pakistanis had followed Canadian aid to the Indians, and they were anxious not to fall behind. The Pakistani atomic chief, Dr. Usmani, had had it in mind to ask for an experimental reactor similar to the NRX clone already operating in India [under the name of CIRUS]."*[1]

The government of Pakistan approved the project in January 1964, and in the autumn of 1964 Canadian General Electric (CGE) submitted a firm proposal.[2] On May 24, 1965 the Pakistan Atomic Energy Commission signed a turnkey project contract with CGE where CGE agreed to design, supply, construct, and commission a 137 MWe CANDU type nuclear power plant close to the city of Karachi. This became known as the Karachi Nuclear Power Plant, or KANUPP.

On 24 December 1965, Pakistan signed an agreement with Canada dealing with this purchase, in which Canada agreed to finance the Canadian portion of the foreign exchange cost, and it was agreed that "the fissionable material produced in the Station will be used only for peaceful purposes." The International Atomic Energy Agency was eventually given a role in safeguarding the reactor through an agreement signed between Canada, Pakistan and the IAEA on 17 October 1969.[3]

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1 R. Bothwell: Nucleus: The History of Atomic Energy of Canada Limited, University of Toronto Press, 1988, p. 383

2 R.J. Graham and J.E.S. Stevens, Experience with CANDU Reactors Outside of Canada : Kanupp, Karachi, Pakistan, RAPP, Rajasthan, India, AECL, CNA-74-203, 1974

3 Agreement between the government of the Islamic Republic of Pakistan, the government of Canada, and the International Atomic Energy agency for the Application of Safeguards, Canada Treaty Series, 1969, no. 15.

KANUPP was to be CGE's first (and eventually only) nuclear power plant, and AECL agreed to assist CGE with research and development information applicable to the reactor, and operating experience on AECL research reactors and the Nuclear Power Demonstration (NPD) and Douglas Point nuclear power stations. AECL also agreed to provide information on health and safety matters related to the reactor. AECL also made an arrangement with PAEC, whereby AECL would provide the same support to PAEC as it had done to CGE, once the reactor was finished. This agreement was to last for the lifetime of the reactor.[4]

KANUPP is modelled on the Douglas Point and NPD reactors. It is a 137 MWe (gross), 125 MWe (net), CANDU type reactor. It uses about 30 tons of natural uranium as fuel and about 140 tons of heavy water both as a moderator (to slow the neutrons and allow them to induce fission) and as a coolant, which carries away the heat produced by fission in the fuel and eventually heats normal water to make steam to drive turbines that would produce electricity.

Pakistan had no input in designing or building KANUPP. According to CGE, "essentially all manufactured equipment was imported into Pakistan."[5] This reflected Pakistan's very limited nuclear capability in terms of scientists, engineers and relevant industrial manufacturing capacity. These constraints were eventually to determine how effectively Pakistan could manage KANUPP.

The deal for KANUPP was made possible by Canadian government assistance. The $63 million cost of the plant was financed by Canada, half as external aid at 0.75% interest over 40 years, with 10 years grace period, the other half at 6% over 15 years with 5 years grace period.[6] In effect, KANUPP was financed through a $23 million soft loan and a $24 million credit from Canada, and $3.6 million from Japan, which paid for the supply of turbines from a Japanese company.[7]

Why did Canada supply KANUPP? A study of the history of Canadian nuclear exports suggests that a number of factors were at work:

> *"The KANUPP transaction was motivated by several domestic and political concerns. First, Canada needed to sell its reactors to more than one country, and, therefore, the Pakistani sale was critical to the industry. Second, Ottawa hoped that the involvement of the privately owned Canadian General Electric would increase domestic competition in Canada by giving credibility to a second supplier. Third, Pakistan was a Commonwealth partner, and Canada felt an obligation to aid members of the Commonwealth. Fourth, Canada had already exported reactors to India, and it was important to the government that Canada play a balanced role in the region. Fifth, Pakistan was a firm member of the western alliance, and played a strategic role in the containment of communism in Asia."*[8]

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4 Agreement between the Government of Canada and the government of Pakistan relating to the construction of the Karachi Nuclear Power Station, Canada Treaty Series 1965, no. 26

5 R.J. Graham and J.E.S. Stevens, Experience with CANDU Reactors Outside of Canada, AECL, CNA-74-203, 1974

6 Ron Finch, Exporting Danger – A History of the Canadian Nuclear Energy Export Program, Black Rose books, Montreal, 1986, fn. 48, p.160

7 Zalmay Khalilzad, Pakistan: The making of a Nuclear Power, Asian Survey, v. 161, no. 6, June 1976

8 Duane Bratt, CANDU or CANDON'T: Competing Values Behind Canada's Nuclear Sales, The Nonproliferation Review, Spring-Summer 1998, pp. 1-16

Why did Pakistan want KANUPP? Pakistan had started a programme in nuclear science and technology in 1954 as a response to the US "Atoms for Peace Program," which had offered a vision of the dawning of a new nuclear age where nuclear science and technology would be the key to economic development. Pakistan's first step had been limited to trying to train nuclear scientists and engineers, mostly in the US, since there was nowhere and no one in Pakistan with either relevant facilities or skills. By the early 1960s these newly trained scientists and engineers sought a mission and facilities to develop the skills and careers they had embarked upon. A nuclear power plant was the obvious choice.

While many other countries were thinking about pursuing nuclear power, Pakistan paid particular attention to developments in India. India had launched a major nuclear power programme in the late 1940s, and by the mid-1950s had built its own experimental research reactor, and negotiated the purchase of a reactor from Canada (CIRUS) that went critical in July 1960. Six months later Pakistan asked Canada for a similar reactor.

Another factor about India's nuclear programme that had raised concern in Pakistan was a possible Indian nuclear weapons programme. The possibility of creating the infrastructure for its own nuclear weapons programme may also have formed part of Pakistan's decision making. Soon after signing the deal for KANUPP in 1965, there were demand in Pakistan for a reprocessing plant; which could only have served to separate plutonium from KANUPP spent fuel, and the only use for that plutonium would have been in nuclear weapons.

Running KANUPP

The Karachi Nuclear Power Plant (KANUPP) reactor attained criticality on 1 August 1971 and in October 1971 power was first fed to the electricity supply system. The plant was inaugurated on 28 December 1972.[9] It is worth recalling that it was during 1972 that Pakistan launched its nuclear weapons programme.

It was not Pakistan's nuclear weapons ambitions that created problems for KANUPP, it was India's. India's nuclear weapons test in May 1974 created a problem for the Pakistan-Canada nuclear relationship. The Indian test used plutonium produced in the Canadian supplied CIRUS reactor and led to demands for far greater safeguards on such nuclear reactors. A history of Canada's nuclear industry relates that:

> *"After the Canadian government announced its Dec. 1974 safeguards policy, an attempt was made to increase the contractual promises on the KANUPP reactor... the Canadian government worked to conclude a safeguards agreement with Pakistan similar to the ones being negotiated with Argentina, South Korea, and India. The major safeguards under discussion included a Pakistani commitment to not develop a nuclear explosive device, to conduct a PNE [peaceful nuclear explosion], Canadian government approval of the reprocessing and enrichment of Canadian supplied uranium or material produced in the KANUPP, and an increase in the number of IAEA safeguards applicable at KANUPP. The negotiations did not go well."*[10]

On 22 December 1976 Canada's Secretary of State announced a new nuclear policy where:

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9 PAEC: Karachi Nuclear Power Plant, PAEC, undated, but after 1980

10 Ron Finch, Exporting Danger – A History of the Canadian Nuclear Energy Export Program, Black Rose books, Montreal, 1986, p. 97

> *"shipments to non-nuclear weapons states under future contracts will be restricted to those which ratify the Non-Proliferation Treaty or otherwise accept international safeguards on their entire nuclear program. It follows from this policy that Canada will terminate nuclear shipments to any non-nuclear state which explodes a nuclear device."*[11]

Pakistan had not signed the Non-Proliferation Treaty and would not accept full-scope safeguards that would cover its entire nuclear program (including its secret nuclear weapons related facilities). Canada withdrew its support to Pakistan, which included suspension of all supplies of fuel, spare parts and technical assistance to KANUPP.

The end of support for Pakistan's nuclear programme also included the termination of a $3.5 million deal for a fuel fabrication plant.[12] PAEC was left to manage KANUPP as best it could. Its first task, completed in 1977, was to built its own fuel production plant. In 1978 PAEC had produced its first test fuel bundle and begun to fuel KANUPP with locally fabricated fuel in 1980.[13]

The development of an indigenous nuclear fuelling capability led to another crisis over safeguards at KANUPP. In late 1981 the IAEA Director General informed the Board of Governors of the IAEA that given Pakistan's capacity to produce and use its own fuel, the agency could no longer certify that diversions of spent fuel containing plutonium from KANUPP had not taken place.[14] The IAEA asked for a major upgrade in the safeguards at KANUPP to overcome this problem, including the relocation of video cameras and installation of new electronic surveillance equipment (fuel bundle counters), to some of which Pakistan agreed.[15] In early 1983, after further negotiations with Pakistan and the introduction of additional safeguards, the IAEA was again able to certify that there was no diversion at KANUPP.[16]

KANUPP Performance

As a power reactor, a measure of how well KANUPP has been managed is its energy availability factor. If the plant is operating for some period of time at a capacity smaller than its maximum capacity, then the energy availability factor is the ratio of the energy that could have been produced during this period by a capacity equal to the unavailable capacity and the energy that could have been produced during the same period by the maximum capacity.

From Table 1, it can be seen that KANUPP has a lifetime energy availability factor (as of the end of 1997) of about 28.6%. This is among the lowest in the world for any nuclear power plant and compares badly with that of other CANDU type reactors. Only the Rajasthan Atomic Power Plant, RAPPS-1, a CANDU in India, has a poorer performance, with an availability factor of 23.1%.

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11 Ron Finch, Exporting Danger – A History of the Canadian Nuclear Energy Export Program, Black Rose books, Montreal, 1986, p. 97
12 Duane Bratt, CANDU or CANDON'T: Competing Values Behind Canada's Nuclear Sales, The Nonproliferation Review, Spring-Summer 1998, pp. 1-16
13 KANUPP: 25 Years of Operation,
14 IAEA is facing major problems in safeguarding Pakistan's Kanupp, Nucleonics Week, 8 October 1981
15 Pakistan has agreed to some upgraded safeguards measures, Nucleonics Week, 7 January, 1982
16 IAEA completes its desired upgrading of safeguards at Kanupp, Nucleonics Week, 3 March, 1983

Table 1: Lifetime energy availability factors for KANUPP and comparable reactors

country	reactor	supplier	Criticality	design net capacity, MWe	lifetime energy availability factor
Argentina	Embalse	AECL	13 -3- 1983	600	85.9%
Canada	Bruce -1	AECL	17-12-76	733	64.9
	Bruce -3	AECL	28-11-77	733	71.0
	Bruce - 4	AECL	10-12-78	733	98.9
	Bruce -5	AECL	15-11-84	750	82.7
	Bruce - 6	AECL	29-5-84	750	78.8
	Bruce -7	AECL	7-1-86	750	81.5
	Bruce -8	AECL	15-2-87	750	82.5
	Darlington -1	AECL	29-10-90	881	77.8
	Darlington -2	AECL	5-11-89	881	61.1
	Darlington -3	AECL	9-11-92	881	81.6
	Darlington -4	AECL	13-3-93	881	81.1
	Gentilly - 2	AECL	11-9-82	645	82.7
	Pickering -1	AECL	25-2-71	508	63.2
	Pickering -2	AECL	15-9-71	508	60.6
	Pickering - 3	AECL	3-5-72	508	70
	Pickering - 4	AECL	16-5-73	508	66.1
	Pickering - 5	AECL	23-10-82	516	75.8
	Pickering - 6	AECL	8-11-83	516	80.5
	Pickering - 7	AECL	22-10-84	516	82.5
	Pickering - 8	AECL	17-12-85	516	74.9
	Point Lepreau	AECL	25-7-82	630	85.5
India	Kakrapar -1	NPCIL	3-9-92	220 (195)	51.8
India	Kakrapar -2	NPCIL	8-1-95	220 (195)	70.6
India	Kalpakkam -1	PPED	2-7-83	220 (150)	55.2
India	Kalpakkam -2	PPED	12-8-85	220 (150)	57.4
India	Narora -1	NPCIL	12-3-89	220 (200)	46.5
India	Narora -2	NPCIL	24-10-91	220 (200)	54.7
India	Rajasthan -1	AECL	11-8-72	207 (84)	23.1
India	Rajasthan -2	AECL	8-10-80	207 (184)	46.2
S. Korea	Wolsong -1	AECL	21-11-82	629	84.6
Pakistan	Kanupp	CGE	1-8-71	125	28.6
Romania	Cernavoda -1	AECL	16-4-96	660	86.7

Source: Operating Experience With Nuclear Power Stations in Member States in 1997, IAEA, Vienna, 1998

The performance of KANUPP and RAPPS-1 compares badly not just with CANDUs, but any other reactors. Only Brown's Ferry-1 in the US has a comparable energy availability factor, 25.1%, and that is due to an accident in 1975. The next lowest is Brazil's Angra-1, which has had a life time energy availability factor of 40%.[17] These reactors stand out sharply from others in the world. There were only three reactors in the world with factors below 30%, one reactor with an energy availability factor between 35-40%, two between 45-50%, and the rest all larger than 50%. For comparison, 48 reactors had energy availability factors greater than 90%.[18]

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17 Operating Experience With Nuclear Power Stations in Member States in 1997, IAEA, Vienna, 1998
18 Operating Experience With Nuclear Power Stations in Member States in 1997, IAEA, Vienna, 1998

The annual energy availability factors for KANUPP in Table 2 show clearly the dip created by the problems associated with Canadian withdrawal of support in late 1976. But, they also show that subsequently PAEC was not able to operate the reactor particularly efficiently. The annual energy availability factor never exceeded 47.8%, which puts KANUPP among the six worst performing reactors in the world.

Table 2: Annual Energy Availability for KANUPP 1972-1997

Year	Annual energy availability factor %	Year	Annual Energy Availability factor %
1972	--	1985	21.8
1973	35.7	1986	43.5
1974	52.8	1987	25.1
1975	44.8	1988	15.6
1976	40.5	1989	5.6
1977	30.7	1990	34.3
1978	20.9	1991	33.8
1979	2.7	1992	45.5
1980	6.2	1993	33.8
1981	17.5	1994	47.8
1982	6.5	1995	42.1
1983	17.7	1996	28.3
1984	24.9	1997	35.3

Source: Operating Experience with Nuclear Power Stations in Member States in 1997, IAEA, Vienna, 1998, and Operating Experience with Nuclear Power Stations in Member States in 1992, IAEA, Vienna, 1993

KANUPP has not typically operated at or near full power (125 MWe). In 1997 for instance the average load was only 60 MWe.[19] At such low loads, KANUPP makes a very small contribution to the electricity supply system. However, even if KANUPP were operating efficiently, its design capacity of 125 MWe (net) would still constitute just above 0.7% of the total installed electricity generating capacity in Pakistan, currently about 16,752 MW. This fraction will fall below 0.7% as the installed capacity grows to 18,207 MW in 1999-2000.

Following a policy shift in the early 1990s of encouraging private sector participation in power generation, Pakistan now has several thousand megawatts of installed capacity that is above the peak demand. For 1997, it was reported that there was 4425 MW of such excess capacity, although because of inadequate investment in transmission and distribution only 45% of households have access to electricity.[20]

The contribution made by KANUPP even under ideal circumstances could be compensated for easily by small increases in the efficiency of the transmission and distribution of the electricity supply system as a whole. In Pakistan, losses due to transmission and distribution in the electricity supply system are in excess of 20% of the total generation of electricity - in 1997 they were 24.3%.[21] They have been at this level for a number of years and are equivalent to over 1500 MWe of installed capacity.[22] For developed countries, these transmission and distribution losses are typically less than 10%. A reduction of 3% in

19 Operating Experience With Nuclear Power Stations in Member States in 1997, IAEA, Vienna, 1998
20 4425 MW power in excess of peak demand, Dawn, 27 February, 1998
21 I.H. Raashed, WAPDA role to be limited to hydel power development, Dawn, 16 March, 1998
22 Pakistan Energy Yearbook 1996, Government of Pakistan, Islamabad, 1997

these losses (to say 20%) for Pakistan's electricity supply system would be sufficient to make up for the loss of KANUPP's electricity generation.

KANUPP and the Effects of Ageing

In 1984, the CANDU Owners Group (COG) was established by the Canadian nuclear power companies that operate CANDUs and AECL, and subsequently grew to include the companies or state-sector organisations operating these reactors in other countries. In 1988, the Annual Report of COG noted that "discussions were opened with the Canadian government on the possible participation of India and Pakistan in the COG Information Exchange Program."[23] In the following year's Annual Report, it was noted that "India and Pakistan joined this program [the Information Exchange Program] mid-year..."[24]

The motivation for Pakistan to join was problems with KANUPP. It was recognised within PAEC that after nearly twenty years of operation Kanupp had problems that PAEC could no longer deal with alone. In its report "25 Years of KANUPP", PAEC admitted:

> *"After two decades of operation, signs of normal ageing and obsolescence are becoming apparent. Many critical components are reaching the end of their designed life and need to be replaced."*[25]

In specialist nuclear industry journals the description of the effects of ageing at KANUPP were more detailed and more troubling:

> *"Pakistan's* KANUPP *CANDU reactor became obsolete almost immediately after it was built, according to plant director J. A. Hashmi... The plant is now reaching the limits of maintainability… The most serious problems of obsolescence have been in KANUPP's computer, instrumentation and other electronic equipment, with the most complex of them being the worst affected…. Despite preventive maintenance and testing, many of KANUPP's ageing problems have been detected through catastrophic failure."*[26]

A Canadian team visited KANUPP in 1989 and identified a host of problems. These included: bellows leaks, condenser tube leaks, heat exchanger tube leaks, sticking and rupture in the refuelling machine, problems with the shield plug, flow blockage in one channel, and problems with computer software and hardware.[27]

Following these visits, in May 1991, COG signed a deal with PAEC whereby COG was to become the agent and manger for a "Safe Operation of KANUPP" project. The project scope was described as:

> *"a number of physical inspections of the plant, as well as safety analysis of the original design using current techniques and standards. Contracts with New Brunswick Power for a radiological protection audit at KANUPP, and for erosion-corrosion examination of*

23 CANDU Owners Group 1988 Annual Report, Chairman's Message
24 CANDU Owners Group 1989 Annual Report, p. 18
25 KANUPP: 25 Years of Operation, PAEC, Islamabad, 1996
26 J. Wood: Life Extension for Pakistan's Kanupp; Nuclear engineering International, Dec. 1991, pp. 54
27 KANUPP seeking safety upgrades from Canadian vendors, utilities", Nucleonics Week, April 30, 1992, pp. 2-3

> *the plant's main steam and feedwater piping were successfully carried out in 1991. Contract negotiations with AECL for fuel channel assessment are nearing completion..."*[28]

Against this background, between May 1992 and March 1993, the Canadian Atomic Energy Control Board (the independent nuclear regulatory agency in Canada) considered safety issues at KANUPP. Its March 1993 Significant Development Report (issued to members of the Board prior to a meeting) noted that:

> *"In May 1992, the International Atomic Energy Commission Agency sent the Government of Canada a report on the Canadian-built nuclear power reactor KANUPP, near Karachi in Pakistan. The report identified improvements needed to bring the reactor to an acceptable standard of safety."*

On the basis of the information in this report, and some additional information, AECB staff questioned how continued operation of the reactor could be justified, given the apparently serious safety problems. In November, 1992, the President of the AECB advised External Affairs and International Trade Canada (EAITC) that on the basis of the limited information available to us, our opinion is that continued operation is imprudent, and recommended that the Director General of the IAEA be informed accordingly. The Permanent Representative and Ambassador of Canada to the IAEA recently informed Dr. Blix, the Director General, of this view.

The IAEA responded quickly to this letter and a meeting was held between AECB staff and staff of the IAEA on 8 March 1993, at which the various safety problems of the KANUPP reactor were discussed."[29]

Meanwhile, Pakistan insisted on keeping KANUPP running. In 1992, the Pakistan Atomic Energy Commission (PAEC) requested US $40 million from the government to keep KANUPP operating.[30] By 1993, based on the promise of Canadian aid, PAEC announced that the Pakistan government had approved a US $32 million package for the "Safe Operation of KANUPP" (SOK) project. This is about half the $63 million initial cost of the power plant.

Pakistan expects that the SOK project with Canada will allow a ten year extension of the 30 year life expectancy of the KANUPP plant. This would imply that KANUPP will reach the end of its extended lifetime in 2012 and will then need to be decommissioned.

There are several reasons why PAEC insisted on continuing to operate KANUPP. One reason for keeping the plant running is that it was cheaper than decommissioning, which was estimated to cost twice as much as the SOK project. Another is that "KANUPP is one major window for acquiring from the West the technology required to build nuclear power plants in the country."[31] The only nuclear plant being built in Pakistan at the time the decision was being taken was a dedicated plutonium production reactor at Khushab, in northern Pakistan.[32] Since the Khushab reactor also reportedly relies on natural uranium and

28 CANDU Owners Group Annual report, 1991, cited on http://ccnr.org/india_pak_coop.html
29 Atomic Energy Control Board, Significant Development Report 1993 3, March 16, 1993, p. 6
30 "PAEC asks government for funds to extend life of KANUPP HWR", Nucleonics Week, March 12, 1996, pp. 6-7
31 A. Alam, Regime not to scrap Karachi nuclear plant, The Muslim, 15 January 1993
32 D. Albright, F. Berkhout, W. Walker, Plutonium and highly enriched uranium 1996, Oxford University Press, 1997, p. 279

heavy water, it is possible technology imported supposedly for KANUPP could have been diverted or copied for this new reactor.

A final reason for keeping KANUPP running may simply be that KANUPP is the only nuclear power reactor in Pakistan, at least until China completes building the 300 MWe nuclear power plant at Chashma. PAEC may have feared that during a period in which KANUPP was closed and Chashma not completed there could have been significant reductions in PAEC's budget, and perhaps questions raised about the necessity of the new plant at Chashma.

The Canadian justification for participating in the SOK project is that it is only about safety. Although it was noted that that "you cannot clearly delineate between operational efficiency and safety with a nuclear reactor".[33] A clearer expression of Canadian concerns may be that faced with Pakistan's refusal to shut an obsolete KANUPP, as suggested by the AECB, the Canadian government and the Canadian nuclear industry could not risk a potential accident at KANUPP that would then reflect badly on CANDU reactors in Canada and elsewhere, and damage a multi-billion dollar industry.

Under the Safe Operation of KANUPP project, it would appear as if Canada through the COG has resumed supervision of KANUPP. This is suggested by the description of events in December 1993, when a stuck fuel channel (G-12) was reportedly removed during a scheduled shut-down. PAEC reports that "The work was successfully completed by KANUPP station staff under the supervision of an AECL CANDU site team." PAEC further reported that:

> *"During the same outage, AECL Research Chalk River Laboratories staff completed a series of inspections on eight fuel channels that had been recommended by an International Atomic Energy Agency (IAEA) Assessment of Safety Significant Events Team (ASSET)."*[34]

The SOK project and the justification for Canadian support to KANUPP on the grounds of safety does not make clear whether the safety of KANUPP will be judged in comparisons to the requirements laid down in the late 1960s at the time it was being designed and built or whether the standards that will be used are those that apply now. PAEC reports suggest only that operational safety analyses "found the plant operation to be in conformity with laid down limits and prescribed original safety limits."[35] This would suggest that the requirements are those laid down in the laid 1960s and may not match what are considered now to be appropriate safety requirements.

Safety

There is little public information on the safety record at KANUPP. The annual PAEC reports offer little useful data. The outages experienced by KANUPP, given in Table 3, offer some insight. Although they may not all be directly safety related, outages may offer an indication into the extent of unplanned

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33 Canada to aid some KANUPP upgrades but only to ensure plant safety", Nucleonics Week, February 25, 1996, pp. 17-18

34 W.M. Butt, M.M. Cobanoglu, Fuel Channel Removal experience at KANUPP, 15th Annual Conference Canadian Nuclear Association, vol. 2., p. 6, Canadian Nuclear Society Toronto, 1994

35 KANUPP: 25 Years of Operation, PAEC, Islamabad, 1996

situations that arise and the corresponding inability of the operators to anticipate events. These can be crucial factors in the chain of events leading to accidents.

Table 3: Outages at KANUPP

Outage cause	Average hours lost per year (1972-1997)	
	planned	unplanned
equipment related	--	1243
human factor	--	83
planned maintenance	1865	--
miscellaneous causes	5	142
Totals	1870 hours (78 days)	1468 hours (61 days)

Source: Operating Experience with Nuclear Power Stations in Member States in1997, IAEA, Vienna, 1998

The data would seem to suggest that equipment failure dominates KANUPP outages, leading to it being shut nearly two months of each year. It has to be closed for even longer for planned maintenance. It seems reasonable to expect that as the reactor ages equipment failure will increase, as will the time required for maintenance. KANUPP may have to be nursed through the coming decade.

Apart from the information on outages, there are only a few safety related general statistics. The operation of a nuclear power plant necessarily involves some exposure of workers and the surrounding environment and population to radioactivity. A typical standard used for occupational doses to nuclear industry workers is 50 mSv (millisieverts) per year. The average doses per worker year reported for KANUPP are substantially lower.

Table 4: Radiation dose reported for KANUPP workers

Year	Average dose per worker-year (mSv)	Year	Average dose per worker-year (mSv)
1971	1.00	1981	2.66
1972	2.09	1982	3.62
1973	5.09	1983	3.22
1974	4.53	1984	4.84
1975	7.84	1985	7.77
1976	5.46	1986	3.05
1977	2.88	1987	3.25
1978	3.20	1988	2.37
1979	7.04	1989	7.13
1980	4.23	1990	3.51

Source: PAEC data cited in Datafile: Pakistan, Nuclear Engineering International, May 1991, p. 53

This data may suggest that worker safety at KANUPP is well managed. However, these general statistics can conceal considerable variation in individual exposures. For instance, in 1992, PAEC reported that while the average dose was 2.4 mSv, the maximum dose to any person was 41% of the maximum permitted limit.[36] In 1993, PAEC admitted that the average radiation dose received by "radiation workers" was 8% of the maximum permissible annual radiation dose limit (i.e., about 4 mSv) but that the highest dose received by any person was 68% of the permitted dose (i.e., 34 mSv).[37]

36 PAEC Annual Report, 1992-1993
37 PAEC Annual Report, 1993-1994

One of the major sources of radiation exposure to workers have been the repeated leaks of radioactive heavy water. During irradiation in the reactor, the heavy water that is used as a moderator and coolant in CANDU reactors accumulates tritium, a radioactive isotope of hydrogen with a half-life of 12.3 years. A certain portion of the tritium produced in CANDU heavy water is lost in the leaks and spills. PAEC claims to require about 3-4 tons of heavy water each year to replace the loss, equivalent to about 3% of its total inventory of some 140 tons -- in comparison, CANDUs in Western countries typically lose only about 1% of their heavy water each year.[38]

The released tritium, chemically identical to normal hydrogen, contaminates the air in the form of either tritium gas or tritiated water vapour, which can be breathed in, ingested or assimilated through the skin, and can subsequently replace hydrogen atoms in organic molecules, including DNA, within the body. These tritiated biological molecules can be retained for long periods within the body and as the tritium decays can increase cancer risk.[39]

Heavy water spills and the attendant exposure to tritium have been associated with significant radiation exposures to workers at KANUPP. During the first five years of the reactors operation, PAEC admitted "the maximum permissible body burden of tritium was exceeded on quite a few occasions, particularly during heavy water recovery operations," with a total of 64 workers receiving twice or more of the maximum.[40]

Some of the spills of heavy water at KANUPP have been large. In early 1989, KANUPP lost 40 tons of heavy water (i.e., almost one-third of the total in the reactor) in a spill, and had to be shut down for several months.[41] It was claimed at that time there had been several earlier large spills that were covered up.[42]

Incidentally, the 1989 spill led to concerns at the IAEA about possible diversion of heavy water. Tritium can be recovered from irradiated heavy water, and only small amounts of it are required to be used as a boost gas for increasing several fold the yield of some kinds of nuclear weapons. In 1990, new safeguards directed at the heavy water were introduced at KANUPP.[43]

An additional concern about this spill of heavy water, and others that may not have been disclosed, is that it may have been associated with a reported six-fold increase in the radioactivity emitted to the environment from the plant that year.[44] Tritium is released to the atmosphere (and usually vented through a chimney stack) in the process of cleaning up spilled heavy water prior to reusing it, and the heavy water PAEC could not clean up and reuse may also have been vented to the atmosphere.

38 M. Hibbs, Incident in Pakistan raises questions about source of heavy water supply, Nucleonics Week, 29 May 1989
39 T. Straume, Health risks from exposure to Tritium, Lawrence Livermore National Laboratory, DE91-011008, 1991
40 S.D. Huseini, KANUPP operating experience and maintenance and inspection programmes, the Nucleus, 16, no. 3-4, July-December 1979, p. 19-27
41 PAEC Annual report, 1988-1989
42 S. Rehman, Pakistani press criticises KANUPP safeguards after plant restarts, Nucleonics Week, 2 November, 1989
43 Safeguards at Pakistan's Kanupp to be modified says IAEA's Blix, Nucleonics Week, 8 January 1990
44 PAEC Annual Report, 1988-1989

There are questions over how accurately KANUPP has been able to monitor its radiation hazards and in particular from tritium. According to PAEC, in 1992:

> *"KANUPP's radiation monitoring systems such as stack monitors, area gamma monitors and tritium monitors (tritium leakage in air or into light water systems) date back to mid sixties design and hardware. While the tritium in water monitors never operated satisfactorily, the others had started showing signs of ageing and effects of obsolescence."*[45]

There is reason to expect that in future there may be further problems with the heavy water system at KANUPP. It has been reported that "ageing of the heavy water system is noticeable... Ageing of the circuit components has also made heavy water leaks more frequent."[46] Presumably, the leaks may also become larger.

The Site

KANUPP is located on Pakistan's coast on the Arabian Sea. It takes water from the sea and uses it to carry away heat from the reactor. There have been problems of corrosion caused by this proximity to the sea. It was noted very early on that at KANUPP "all exposed metal was subject to a humid salt laden atmosphere, with the occasional addition of fine sand in this atmosphere, which rapidly destroyed protective coatings" including equipment inside the plant.[47]

More recently, in April 1998, it was reported that due to "sand depositing in the condenser" the Karachi Nuclear Power Plant was generating only 16% of its installed capacity "and may cease generating electricity in the near future."[48] However, PAEC has been seeking contractors to "repair and modify the plant's intake and outfall channels and pumphouse" as well as "dredging, channel reinforcement, and treatments to inhibit corrosion on structures exposed to sea water and tides."[49] This seems to be part of a larger set of concerns, including the effects of coastal erosion. There have been reports that "erosion caused by south-west monsoons along the Pakistani coast near Karachi is causing concern to KANUPP nuclear power plant management".[50]

The ageing of the reactor, its equipment failures, its leaks of heavy water, corrosion and erosion, and PAEC's determination to keep it running combine to raise troubling questions about the safety of the plant. Even a small risk is made significant by the location of the reactor. According to senior managers of KANUPP, the reactor is 20km from the centre of the city of Karachi.[51] However, this simple statement of distance conceals that there has been and continues to be enormous unplanned growth of the city. It had a population of 3.5 million in 1972 when the plant was finished.[52] In 1998 this population had grown

45 PAEC Annual Report, 1992-1993
46 J. Wood, Life Extension for Pakistan's KANUPP, Nuclear Engineering International, December 19991, p. 54-55
47 R.J. Graham and J.E.S. Stevens, Experience with CANDU Reactors Outside of Canada : Kanupp, Karachi, Pakistan, RAPP, Rajasthan, India, AECL, CNA-74-203, 1974
48 Kanupp may cease power generation in near future, The News, 5 April 1998
49 KANUPP intake repairs planned, Nucleonics Week, 3 December 1998
50 KANUPP threatened by erosion, Nuclear Engineering International December 1991, p. 13
51 I. Ahmad, W. M. Butt, Z. Siddiqui, J. Iqleem, Plant Life Extension at KANUPP: An update, Nuclear Engineering International, June 1997, p. 18-20
52 50 Years of Pakistan in Statistics, Federal Bureau of Statistics, Government of Pakistan, 1997

to about 10 million.[53] It is hard to believe that any nuclear plant proposed to be located within 20 km of such a large city would now be licensed in any country.

The urban growth experienced by Karachi has created problems for KANUPP. The demands made on the city's power and water supply have increased as has the pressure for new land on which to build. Senior KANUPP officials have complained publicly to the government about the need to ensure a regular supply of water to the plant and have expressed concern about encroachments (unplanned squatter settlements and business development) in the areas close to the plant.[54] Given that Pakistan's rate of growth of population officially is given as 2.6%, and the rate of growth of urban population may be significantly higher, these problems are likely to increase in the coming decade.

53 Provisional Results of Fifth Population and Housing Census Held in March 1998, Population Census Organisation, Statistics Division, Government of Pakistan, July 1998

54 Regular water supply to KANUPP directed, The News, 24 June 1998