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IDENTIFICATION OF EFFORTS REQUIRED FOR CONTINUED SAFE OPERATION OF KANUPP

BY

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KARACHI NUCLEAR POWER PLANT
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A B S T R A C T

Kanupp, the first commercial CANDU PHWR, rated at 137 MWe, was built on turnkey basis by the Canadian General Electric Company for the Pakistan Atomic Energy Commission, and went operational in October, 1972 near Karachi. It has operated since then with a lifetime average availability factor of 51.5 % and capacity factor of 25 %.

In 1976, Kanupp suffered loss of technical support from its original vendors due to the Canadian embargo on export of nuclear technology. Simultaneously, the world experienced the most explosive development and advancement in electronic and computer technology, accelerating the obsolescence of such equipment and systems installed in Kanupp. Replacement upgrading of obsolete computers, control and instrumentation was thus the first major set of efforts realized as essential for continued safe operation.

On the other hand, Kanupp was able to cope with the normal maintenance of its process, mechanical and electrical equipment till the late 80's. But now many of these components are reaching the end of their useful life, and developing chronic problems due to ageing, which can only be solved by complete replacement. This is much more difficult for custom-made nuclear process equipment e.g. the reactor internals and the fuelling machine.

Public awareness and international concern about nuclear safety have increased significantly since the TMI and Chernobyl events. Corresponding realization of the critical role of human factors and the importance of operational experience feedback, has helped Kanupp by opening international channels of communication, including renewed cooperation on CANDU technology.

The safety standards and criteria for CANDU as well as other NPPs have matured and evolved gradually over the past two decades. First Kanupp has to ensure that its present ageing-induced equipment problems are resolved to satisfy the original safety requirements and public risk targets which are still internationally acceptable. But as a policy, we are committed to upgrade the safety as far as possible, towards current standards and criteria. We are already modernizing our operational safety practices. We also intend to update our safety analysis, to confirm the current standards and criteria which are applicable in the context of the original plant design, and implement corresponding equipment upgrades where feasible, or special procedures to compensate where possible.

This paper identifies the diverse upgrading efforts required in these three major areas, i.e. obsolescence, ageing and safety. A cost-benefit criterion is envisaged to prioritize their implementation with the available resources, to keep Kanupp operating safely, even beyond its originally intended lifespan.

1. INTRODUCTION

1.1. Performance

KANUPP, rated at 137 MWe, net 125 MWe was built on CANDU technology of the 1960's. First criticality was achieved on 1st August, 1971, the plant was synchronized with the Karachi grid in October, 1971 and went into commercial operation in Oct. 1972.

To operate and support a single NPP unit in a country with a negligible industrial infra-structure, a narrow engineering and technological base and limited resources has been a challenging task. Over the years Kanupp has lived upto this challenge and, inspite of heavy odds and numerous difficulties, the plant had been operated safely at varying loads depending upon the plant conditions and the load demand.

By the end of 1990 the plant had generated 5.6 billion units with an average lifetime availability factor of 51.5% and capacity factor of 25%. KANUPP achieved its highest availability factor of 82.4% in 1986. The safety record has been very satisfactory so far, as proven by regular testing and reliability analysis. Average personnel radiation exposures have been well within the ICRP limits. Releases of radioactive material through gaseous and liquid effluent have remained within 7% of ICRP limits.

Kanupp has proven to be an economic and technological asset to Pakistan. This performance has to be continued and bettered, and even prolonged beyond the expected life if possible.

1.2. History

Over the last eighteen years of plant history, Kanupp has seen many phases of international cooperation. The Canadian government imposed an embargo on export of nuclear technology and materials to Pakistan in 1976. A US embargo on export of high technology to Pakistan has existed throughout. The Pakistan Atomic Energy Commission responded to this situation by a policy of self-reliance, implemented through the following organizational changes.

- a fuel fabrication plant,
- a new Division in Kanupp for design and development of mechanical spares,
- a new Division in Kanupp for developing solutions to electronic, computer and C & I problems,
- a new unit in Kanupp for In-Service Inspection.

The unfortunate events in TMI and Chernobyl emphasized the role of the human being and the importance of exchange of operational experience towards improving human performance. The role of the

IAEA, which has always been very cooperative to Kanupp, was strengthened. INPO, WANO and COG were formed. This helped Kanupp by opening international channels of communication, eventually leading to the decision of the Canadian Government in 1990 to provide technical support to Kanupp through IAEA / COG, on safety related matters. Early this year, direct bilateral technical cooperation has also been allowed.

Meanwhile, OSART Missions from the IAEA visited Kanupp in 1985 and 1989. An ASSET Mission also visited Kanupp in 1989 to analyze the retraction of two reactor fuel channels and recommend immediate and long-term actions.

Kanupp has experienced three occasions when the regulatory body imposed restrictions on plant operation. The plant was shutdown in 1988 until replacement of the cracked Fuelling Machine Snout Jaws. In 1989, plant power level was restricted after the ASSET Mission till confirmation of the integrity of the fuel channels after suspected damage due to CO2 Annulus Gas System malfunction. Early this year, plant operation was allowed only at 50% power for a limited period because only 4 out of the six boilers were available.

Kanupp has also utilized various longer shutdowns to instal the following major improvements so far.

- Process Water Heat Exchanger retubing with titanium.
- Improved software package on the plant control computers.
- Replacement of Process Salt Water Pumps casing and associated piping.
- New Turbine Machine Monitoring System.
- New Closed Circuit TV System for monitoring Reactor Building.

1.3. <u>Significant Phenomena</u>

The serious issues requiring significant efforts to resolve, which we have faced so far, can be generally classified into three major areas, i.e. Obsolescence, Ageing and Safety.

<u>Obsolescence</u> is generic to all technology. In order to remain competitive, manufacturers must divert their resources from supporting older products to development of better technology which is cheaper to produce and maintain, and thus eventually declare the older technology uneconomical.

But the way this has happened in electronics over the last three decades is unprecedented. Partly, this was because the newer technologies also offered an order of magnitude improvement in capabilities with each new generation.

The generic solution to obsolescence is redesign with newer technology, at a suitable level, e.g. component, module, subsystem or system level, and design of suitable interface to equipment not replaced. But such solutions have been complicated for Kanupp by the lack of technical support from original vendors.

Ageing is also generic to all plant equipment. The term implies a group of diverse phenomena, e.g. corrosion, erosion, fatigue, vibration, wear, crud deposition, oxidation and crack development, changes in material properties due to irradiation. The worst affected components are usually heat exchangers, steam generators, pumps, pipings, valves, seals, gaskets, and packings etc.

The generic solution is to identify the particular process or phenomenon causing the degradation, before catastrophic failure if possible, then either remove or combat the cause, or schedule replacement before catastrophic failure.

This can be applied easily to repairable or replaceable components, but replacement is difficult for custom designed components which cannot be reordered. Custom refabrication is difficult and expensive.

The evolution of nuclear power technology from prototypes to large scale commercial application, has been necessarily accompanied by the evolution of standards including safety.

The nuclear power industry has always strongly realized its special, drastic and long-term implications to personnel and public safety. But the incidents at Three Mile Island and Chernobyl have drawn the attention of the ordinary populace also towards the safety of nuclear power and its importance as a global phenomenon transcending political boundaries. The importance of the human being has also been emphasized, and efforts to improve it by means of operational experience feedback have increased.

It is a tribute to the original designers of Kanupp that the safety targets set by them and easily achieved so far, in terms of overall risk to the public, are still valid and internationally acceptable.

But many other evolving design criteria and practices are new to Kanupp. The generic solution to evolving standards is to determine their applicability and implementation of those improvements which are feasible.

1.4. Identification

The rest of this paper identifies all the significant improvements which are foreseen under these major areas to ensure the continued safe operation of Kanupp, even beyond the expected lifetime. An integrated plan of action is also outlined.

2. OBSOLESCENCE

Obsolescence has affected Kanupp equipment in the order of their complexity. Serious maintainability problems requiring costly solutions occurred on computers, then on elaborate electronic instrumentation e.g. nuclear and radiation, and finally on simpler electronic equipment such as controllers etc. Pneumatic instrumentation and control equipment is still made, but nuclear power plants with their large-scale information systems can no longer do without standardized electronic instrumentation. Fortunately, obsolescence has not significantly affected our electrical, mechanical or process equipment so far.

Normally, replacement of obsolete equipment, in collaboration with the original vendors, is a part of their normal after-sales support, and is an ongoing process in a large plant. But this process was hampered in case of Kanupp by the export embargoes.

As a result, we were unable to benefit from gradual replacements at an equipment level. Many piece-meal solutions in the form of locally designed module and subsystem replacements were implemented and have allowed us to survive the embargoes. But by the mid 80's we had reached a situation where replacement of entire systems and even groups of systems was necessary at a system functional level.

The following such activities are at various stages of execution, to combat significant obsolescence problems.

2.1. Computers, Control & Instrumentation

The functional replacement of the following systems was considered first separately, then as an integrated project [3] including improvement of the control room by means of additional (not in the original design) computerized Operational Information Systems intended to assist the Operators in their routine work, normal plant operation and in recognizing and handling abnormal and emergency situations.

A Joint Engineering Study with potential vendors was completed in 1988 to establish bid specifications. Contract has yet to be signed.

a. Dual GEPAC 4020 Plant Control Computers used for direct digital control of Reactor Power, Steam Pressure and Turbine Load, monitoring of coolant channel outlet temperatures for trip function, monitoring of bearing temperatures and other important analog parameters, annunciation of internally generated and externally sensed binary alarm contacts through Group Windows and Sequence Printout, and routine / demand logging of important plant parameters.

These computers are intended to be replaced with distributed dedicated microcontrollers for each function. The logging and annunciation functions are intended to be expanded in a larger and comprehensive Process Information System based on general purpose computers.

b. Two PDP-8 Computers used for remote control of the operation of the two on-power Fuelling Machines. This system is intended to be implemented with industrial PC-AT systems. The software has been developed and is being tested.

c. All electronic and pneumatic Control & Instrumentation loops used for analog process parameters e.g. pressure, level, flow and temperature. A standardized signal level (4-20 mA) and mutually compatible electronic C & I equipment series is intended to be adopted, and interfaced to the new central computerized Process Information system.

This not only covers conventional systems, but also the Safety Instrumentation Loops used for measurement and monitoring of such analog process parameters to provide binary trip conditions to the logical circuits in the Reactor Protective System and Engineered Safeguards. Class 1E qualified equipment shall be used for these loops.

2.2. Fire Alarm System

This conventional relay-based system is intended to be replaced with a modern, intelligent system covering the new areas of the plant buildings, and providing better self-testing and alarm identification facilities.

2.3. Nuclear Instrumentation

The instrumentation for the nuclear and radiation parameters also needs to be replaced.

a. Five Channels are installed for measurement of Reactor Neutron Power by means of Ion Chambers, three for Reactor Protection and two for Reactor Power Control systems. All these have to be replaced.

Contract has already been awarded for replacement of the following loops.

b. Area Radiation Monitoring inside the Reactor Building. The function is to be enhanced to include Accident Range Gamma Monitoring (not in the original design).

c. Stack Iodine Monitoring

d. Tritium in Air Monitoring in the Reactor Building to detect Heavy Water leaks and provide personnel warning.

e. Tritium in Water Monitoring, to detect Heavy Water leakage into the Boiler Feedwater System and the Process Water System (used for cooling equipment).

2.4. On-line Chemical Instrumentation

Kanupp presently relies on manual sampling of the chemical parameters of various process systems. Modern on-line instrumentation is intended to enhance the quality and speed of monitoring.

2.5. Turbine Machine Monitoring System

The special instrumentation used for monitoring the performance of the Turbine-Generator installed by Hitachi, the original vendor, has been replaced with a modern electronic system offered by Philips.

2.6. Closed Circuit Television System

The original and obsolete system providing visual monitoring of the Reactor Building has been improved by a modern system providing better coverage of more areas.

2.7. Telecommunication

The obsolete cable and telephone exchange used for communication with the external world has been replaced with a modern microwave link and digital telephone exchange, providing more lines as well as digital data communications facilities.

2.8. Switchyard Extension

A contract has been awarded for expanding the existing 4160 V power distribution switchyard to cover the power requirements of the additional offices and facilities added since plant commissioning, using standard 11 kV equipment used normally in Pakistan.

3. AGEING

3.1. Solutions already implemented.

We have already faced and identified the following ageing induced problems, and implemented locally developed routine or permanent solutions.

3.1.1. Conventional Systems

Following steps have been taken to resolve problems due to proximity to sea (corrosion due to airborne sea-salts) and use of sea water for condensing steam and for cooling Process Water, causing corrosion, erosion, carry-over of silt, sea weeds, in-rush of sardines and barnacles growth on pump house equipment and associated systems.

- Travelling intake salt water screens replaced with corrosion resistant material such as stainless steel.

- Condenser tubes kept clean by reversing flow, and ferrous sulphate addition at frequent intervals to create protective layer on tubes.

- Process Water heat exchangers aluminum brass tubes replaced with titanium tubes.

- Process cooling water pump casing and main headers piping replaced.

- Radiator air cooling installed for Diesel generators, replacing the sea water cooling.

- Other equipment i.e. meteorological tower, station transformer radiators and high voltage transmission towers, which were badly affected by corrosion, were replaced.

- Frequency of painting of all the plant equipment which is exposed to corrosive atmosphere / environment increased.

3.1.2. Standby Heat Exchangers

The tubes of one of the two heavy water standby heat exchangers failed due to fretting caused by process water flow induced vibration only after three years of plant operation. All tubes of heat exchangers were checked by ECT and the tubes showing thinning in excess of acceptable limit were plugged. The tube bundles were also strengthened by installing more fasteners. Later inspections showed no or slight ageing effect. However, the tube bundles of the standby and charging heavy water heat exchangers are being fabricated locally and shall be replaced in about two years time.

3.1.3. Moderator System Valve Gasket

As against the current practice of providing double gasket arrangement, valves in the Moderator System at Kanupp are provided with conventional single gasket arrangement using neoprene gasket at the bonnet. This neoprene gasket in one of the moderator pump discharge valves failed (age-ng degradation due to embrittlement) and caused a large D2O spill.

The frequency of inspection / replacement of the gasket of all such valves has been increased. Study for improvement to the existing poor jointing system is continuing.

3.1.4. Differential Pressure Transmitter casing bolts.

A differential pressure transmitter between south outlet and north inlet-header failed due to breaking of two out of four chrome plated steel bolts used for joining the two metal casings enclosing the bellows assembly, resulting in D2O leakage.

The bolts on all such transmitters have been replaced.

3.1.5. Plant Control Computers Magnetic Drum Memory

The life of the Magnetic Drum Memories used in the plant control computers is limited by damages to the magnetic surface caused by dust or head mechanism failure, and by the life of the sealed motor bearings. Luckily there are several spare head positions, and we have been able to limit the magnetic surface damages by proper dust filtering precautions. But regular bearing replacement cannot be avoided.

The manufacturer recommends this as a factory job. But due to difficulty in access, we carried out the replacement in house. The life of these devices has thus been prolonged considerably.

3.1.6. Fuel Handling Computer PDP-8 Magnetic Tape Memory

The two DEC PDP-8 fuel handling computers use magnetic tape for bulk memory. With use, the read-write head has deteriorated. As the heads are obsolete, heads of a different model were altered mechanically and fitted in place of the old heads. Replacement of the entire computer system is also planned (2.1. above).

3.2. <u>Existing Problems</u>

The following ageing induced problems are still outstanding, and require significant efforts to solve them.

3.2.1. Steam Generators

Kanupp has six steam generators with Monel 400 tubes. Tube failure with ageing is a well known and expected phenomenon. In fact the performance of Kanupp has been better than expected in this area. ISI was therefore attempted in 1989 but the ECT probes could not saturate the tube material which has undergone eighteen years of temperature cycling.

Steam Generator # 3 developed a small leak in 1989, which developed upto 4 kg/hr over two weeks at the end of 1990. The plant had to be shutdown for more than a month to isolate the leaky boiler since Kanupp did not have the technique to detect and plug leaky tubes at that time.

The plant had to be operated with 4 out of the normal six boilers. The regulatory body gave short-term permission to operate in this condition at 50% power.

The leak was detected and plugged in March 1991. But we still have to develop the ISI capability to prevent such occurrences in future, and also the complete and qualified techniques for leak detection and plugging in future. Technical cooperation from the original Canadian vendor is expected.

3.2.2. Dump Valves

Six dump valves, connected in series parallel arrangement, are provided in the helium balance line to trip the reactor. The valves are 10 inch butterfly valves with diaphragms and elastomer seals connected to the upstream pressure to minimise leakage when the valves are closed.

The dump valves, provided by the vendor, were modified and special elastomer seals were installed by Canadian General Electric. No spare seals, their drawings and other parts are available. Only once a dump valve was opened for inspection. Due to daily trip tests and relatively frequent plant trips experienced, the dump valves have been subjected to rather severe duty. It is planned to inspect and, if required, replace the valves with the new version but installation of seal, in absence of drawing and proper seal maybe difficult.

3.2.3. Fuelling Machines

Fuelling Machines and end fitting components are a critical part of the primary pressure boundary when in use. They are highly complex, custom built, and subject to very high radiation levels. We have experienced the following ageing-induced problems so far. Some have been solved for now, but the basic issue of fabricating replacements for custom-built parts remains and becomes more serious with time.

- A D2O hose ruptured leading to a major heavy water spill.

- D2O head circulating pump canned motor developed micro-crack due to excessive rubbing. D2O seeped into stator winding deforming the stator can.

- Snout jaws developed cracks over a period of time within and along the groove, being the maximum stressed areas. The snout jaws cracks propagated in 1988 as revealed by ISI. Plant operation was not allowed by the regulatory body till replacement with locally manufactured and extensively tested snout jaws. Inspections still continue.

- Cracks in the head ram spline shaft due to continued and extended service. Shall be replaced with new one.

- Failure of mechanical seal 'o' ring installed in charge tube axial drive due to ageing.

- Closure plug locking problem. The shield plug was found damaged and the charge tube latch finger had broken inside the end fitting.

- Shield plugs sticking on rotation. Investigation revealed that tail end was causing restriction both in axial and rotary motion due to bulging / deformation. Machined to original size before replacement.

- Two fuel bundles entangled due to damaged end plate of one, entered Fuelling Machine magazine together and prevented rotation. Dislodged by special procedures. The incident is attributed to hammering received by the bundle against the channel sealing surface.

3.2.4. Heavy Water Systems

Ageing effect on heavy water systtemsespecially the primary heat transport system is also beginning to show up although the chemistry of fluids in the primary as well as the secondary side is being strictly maintained within the specified limits.

3.2.5. Reactor Fuel Channels

In 1989, fuelling problems led to detection of two reactor fuel channels (G-12 & F-15) retracted by 0.4 inches and 0.375 inches respectively in cold shutdown condition. Subsequent inspection revealed reactor fuel channel G-12 to be sagged by 49 mm and F-15 by 12 mm. In-depth investigation indicated that abnormal operation of the CO2 (annulus cover gas) system created corrosive environment in the gap between the end fitting made of SS403 and carbon steel calandria extension tube. This hypothesis will be confirmed after removal and metallurgical examination of these damaged pressure tubes and ISI of some others.

The reactor is permitted to operate only at reduced power until the fuel channel integrity is thus confirmed.

Short term improvements of the CO2 System have been implemented to prevent further corrosion. Other channels are being monitored for retraction. No further evidence has been observed.

3.2.6. Cables.

The ageing effects of irradiation on cables are a known phenomenon. The extent of damage in Kanupp has yet to be determined.

3.3. Common Actions.

3.3.1. Most of the outstanding problems are concerned with custom built equipment on the nuclear island. The technical cooperation of original vendors is essential for long-term solutions.

3.3.2. Problems on the nuclear island are mostly also significant to safety, as demonstrated by regulatory constraints on plant operation.

3.3.3. Many of the problems faced so far and even those which have been solved, were detected through catastrohic failure. This is highly undesirable. Although preventive testing and maintenance schedules are already in place, a systematic Surveillance program is necessary to minimize this mode of problem identification.

3.3.4. Efficient feedback of operational experience from other plants and equipment vendors is also very useful in replacing potential breakdowns with preventive maintenance.

4. SAFETY UPGRADES AND IMPROVEMENTS

4.1. Existing Safety Criteria and Targets

Through regular testing and reliability analysis of its safety relevant systems and procedures, Kanupp has been constantly maintained a good performance against the safety criteria and targets established by its original designers, and still acceptable to our regulatory body. The overall public risk target is still internationally acceptable.

The regulatory body has also been very much watchful and has imposed necessary restrictions whenever there have been potential threats to the existing criteria and targets.

The significant problems presently falling under this critical category are all ageing-induced. Naturally Kanupp is very much interested in solving these problems as soon as possible, so that it can regain full capacity with confidence.

4.1.1. Confirmation of the integrity of the Reactor Fuel Channels probably damaged by the deficient CO_2 Annulus Gas System (3.2.5. above), which have to be removed and metallurgically examined, along with ISI of some other channels, followed by necessary long-term improvements to the CO_2 System.

4.1.2. The ISI of the Steam Generators (3.2.1. above) to prevent future leakages.

4.2. Improvement towards current safety criteria and standards.

Although Kanupp has been generally aware of the gradual evolution of safety philosophy beyond its original design and mandatory targets, as more and more modern NPPs were built all over the world, specific comparisons and potential improvements have been spelled out only since 1985 when the first IAEA OSART Mission visited Kanupp and recommended some improvements in our Operational Safety practices.

In 1987, as a part of the Joint Engineering Study for the replacement of the obsolete Safety Instrumentation Loops mentioned earlier, we compared our Protective System philosophy with the much higher level of redundancy, the concept of local coincidence, and greater automation in Safety Systems prevalent in modern NPPs. We found that the low level of redundancy and the global coincidence in Kanupp are safe enough but cause higher probabilities of plant outages. We also faced, for the first time, the practical difficulties in applying modern safety standards and criteria to old plants. Some of these were reflected in a paper on this issue presented in the last similar IAEA Technical Meeting [1].

In 1989, an ASSET Mission was invited to Kanupp to analyze the retraction of two reactor fuel channels. They pinpointed the probable direct cause, several indirect causes and contributing factors, and recommended corresponding short and long-term corrective actions, including a thorough comparison of the Kanupp Safety features against modern CANDU safety standards and practices.

The potential safety upgrades towards modern standards, identified by Kanupp itself, the ASSET Mission and the followup Expert Review of Kanupp safety features, can be divided into three classes.

4.2.1. Operational Safety.

TMI and Chernobyl have emphasized the human being as the weakest link in the chain. On the other hand, some well handled incidents in modern CANDU NPPs [4] and in Kanupp [6] have shown us the strong benefits of intelligent, well trained and knowledgable personnel. It is obvious that beyond the basic equipment required, safety and handling of incidents depends on, and can be improved much more, at a lower cost, by concentrating on the quality of the human beings. The increasing international emphasis on good Operational Safety practices and exchange of operational experience feedback reflects the same considerations.

Kanupp has accordingly already initiated action on many of these items.

4.2.1.1. Inculcation and improvement of 'Safety Culture' among the operations and management personnel, could improve analysis of safety significant events and prevention of incidents. In this direction, two training courses have been established on 'Basic Safety Principles' and 'Systematic Root Cause Analysis'.

4.2.1.2. A comprehensive Surveillance program is being established, as mentioned under Ageing (3.3.3. above) also.

4.2.1.3. A comprehensive Operational Quality Assurance program is being established.

4.2.1.4. The routine ISI Program is being expanded to include the reactor fuel channels, steam generators and BOP piping, in line with modern CANDU practice.

4.2.1.5. The Operating Policies and Principles (O P & P) document is to be modernized to include better guidance on permissibility of various situations, and Allowed Outage Times for critical equipment.

4.2.1.6. The Emergency Operating Procedures can be improved by

- flowchart presentation format,
- symptom orientation,
- human factors review of the Control Room.

4.2.1.7. The possibility of performing containment test at higher pressure is to be investigated.

4.2.1.8. Current CANDU Maintenance techniques and programs are to be reviewed for possible adoption at Kanupp. Local capability for steam generator repair is to be developed.

4.2.1.9. The manpower development programs can be improved by using a Training Simulator and updating the curricula.

4.2.1.10. Feedback and exchange of operational experience (ref. 3.3.4. above also) from other NPPs can be improved by on-line connection with international nuclear information networks e.g. CANNET, IRS, INPO, WANO etc.

4.2.2. Equipment improvements

The following potential improvements towards new design principles and criteria have been quickly identified without deep analysis.

New design principles are often stated in context of certain already developed concepts. Sometimes the terminology of the new requirement is also newly developed. Therefore the applicability of new design principles and concepts to older plants has to be judged and justified very carefully in the context of the complete original plant design philosophy.

4.2.2.1. Some valves in the Emergency Injection System do not meet the single failure criterion and modern reliability targets. Modern CANDU NPPs have high pressure Emergency Coolant Injection. This implies potentially very major modifications to the Moderator System.

4.2.2.2. The single shutdown system in Kanupp does not meet the reliability targets achieved by modern NPPs with diverse shutdown systems. This also implies very major modifications.

4.2.2.3. The following aspects of the post-LOCA conditions may not be provided for adequately. Proper study is required to identify corrective measures.

- Flow of water to the Sump Pumps maybe blocked by debris blown off during the incident.

- The process equipment e.g. Moderator Pumps and other motorized valves, as well as the I & C equipment necessary to maintain cooling flow, may not be able to operate in the post-LOCA environment including flooding.

4.2.2.4. Although the Kanupp buildings were designed to withstand the maximum ground acceleration expected, none of the equipment is tested or qualified according to modern practice for seismic events.

4.2.2.5. The possibility of loss of Booster cooling due to prolonged station blackout, has been considered but may not be provided for adequately. Proper study is required to identify corrective measures.

4.2.2.6. The possibility of loss of secondary heat sink (feedwater to the boilers) due to pipe rupture or prolonged station blackout, has been considered but may not be provided for adequately. Proper study is required to identify corrective measures.

4.2.3. Safety Analysis Updating

According to a recent statement on the policy for upgrading of older nuclear power plants [5], they must ensure that:

- original safety criteria and targets are met, and
- risk to the public is no greater than originally perceived.

Both of these are confirmed by the actions already mentioned above, using the existing safety analysis. But we intend to go one step further, to confirm the second principle even by the latest analysis techniques and methodology.

Modern Safety Analysis is based on consideration of some additional postulated initiating events (PIEs), and better analysis of existing accident sequences with modern software tools and methodologies. Analysis of Kanupp by these modern tools and considerations may confirm the potential improvements already identified above without proper analysis, in the context of the complete plant design, and indicate some other potential improvements.

4.2.3.1. The Kanupp Final Safety Analysis Report (KFSAR) is to be updated including additional postulated initiating events (PIEs), using improved analysis tools (software codes). This has to start with acquisition and assimilation of these new tools and methodology.

4.2.3.2. Probabilistic Safety Assessment (PSA) is a modern tool to create dynamic models of plant safety. Presently only Level 1 (modelling of core melt frequencies for various PIEs) is considered sufficient to identify significant areas of improvement.

5. AN INTEGRATED PLAN OF ACTION

5.1. Chronological relation of activities.

The various improvements identified so far to ensure continued safe operation of Kanupp, have been described in detail above and classified into three major areas of improvement. A short list of all these items is given in Appendix 1.

The general chronological relationship in the progress on the major areas of improvement, as best visualized at this juncture, is shown graphically in Fig 1.

5.2. Resources Required.

At this stage, it appears that most of the problems and possible improvements have already been identified, although analysis may indicate a few more ageing phenomena and possible improvements in safety beyond the mandatory targets upto modern standards. The total resources required for these diverse upgrading activities in the areas of obsolescence, ageing and safety, are overwhelming.

5.2.1. Thanks to the previously imposed policy of self-reliance, Kanupp does have more extra technical manpower (besides that required for routine plant operation and maintenance), than most other NPPs. But even this may not be sufficient.

5.2.2. We are fortunate that the international community (IAEA) has always, and the Candu community (COG) has recently understood and responded so rapidly to our needs for technical cooperation, specially on evolving CANDU technology. We look forward to continued and increased cooperation in future.

5.2.3. But the financial implications of all these activities are most important. We have to improve plant availability and minimize deratings to maximize availability of funds, while investing judiciously in terms of payments for equipment and services, and cost of shutdowns for implementation of the improvements. On the other hand, the resulting improvements in plant availability and safety could extend the plant life beyond the originally projected 30 years (2002 AD).

5.3. Integrated Planning.

It is obvious that smart planning and coordination of all these resources is very critical. An Integrated Master Plan was recommended in the safety features review done as ASSET Followup, and also by the Advisory Committee on Power And Engineering setup by the Pakistan Atomic Energy Commission, as well as required by the IAEA for management of their technical cooperation activities. Fig 1. is a very brief outline of the first draft of the Master Plan prepared early this year. Obviously it maybe revised considerably as we go along, due to results of analyses undertaken, and unforeseen ageing effects.

5.4. Priorities.

The success or efficiency of any plan depends on the optimum utilization of the available resources at all times. It is therefore essential that all the resources required by each set of acitivities should be realized, and the exact benefits expected should be quantified, for comparison with other activities competing for the resources. In this light, our order of priorities between the various areas of improvement can be described as follows.

5.4.1. Threats to plant availability must be given top priority. This also automatically implies any outages or derating imposed by policy under the existing mandatory safety criteria & targets.

5.4.1.1. Obsolescence (Section 2. above) posed the first direct threats. In our isolated environment, Kanupp would have been shutdown long ago without some of the locally developed piece-meal solutions in the form of modular and subsystem replacements. But due to this early start, these system level replacement and upgrading activities are now closest to implementation.

5.4.1.2. Safety significant ageing-induced equipment problems (4.1. above), have been identified only in the last two years. These items thus also receive top priority, although action on these is just starting.

5.4.1.3. However, unless all the ageing phenomena (section 3. above) are analyzed, identified beforehand through adequate surveillance (4.2.1.2. above), and combatted in a planned fashion, more such forced outages and deratings can be expected.

5.4.2. Our regulatory body has not imposed any mandatory revisions or additional conditions to the original Safety Analysis. Our overall targets of public risk are still internationally acceptable. Improvements beyond these are therefore not mandatory. But as a policy, the Pakistan Atomic Energy Commission is still committed to improving safety as much as possible.

The current safety criteria, standards, practices and analysis methodology adopted recently in more modern plants are still very useful, for comparative guidance, to establish potential directions of improvement, to quantize the potential safety benefits which could be derived in terms of the overall criterion i.e. public risk, and thus optimize the expenditure on improvement of safety beyond the original mandatory limits or targets.

5.4.2.1. The modernization of operational safety practices (4.1. above) offers obvious improvements, requiring relatively small additional resources. This should not have to wait for any safety analyses. These are therefore already being undertaken.

5.4.2.2. Improvement of safety systems towards modern standards must then begin with modernization of our safety analyses (4.2.3. above) to determine those modern safety criteria and standards which are applicable in the context of the older plant design, and quantize the benefits of each possible equipment improvement.

5.4.2.3. The feasible equipment improvements can then be undertaken in the optimum order to maximize the safety benefits obtained against each investment in resources.

5.4.2.4. Some equipment improvements which are not practically feasible could be compensated somewhat by special procedures.

6. CONCLUSION

If the principles and priorities established in the Integrated Plan of Action above are followed judiciously, there is a good chance that Kanupp can overcome the previous setbacks due to obsolescence and isolation from original vendors, fight ageing and improve plant safety and availability to the extent that it may continue to operate even beyond its expected lifetime.

APPENDIX I

AREAS OF IMPROVEMENT TO ENSURE CONTINUED SAFE OPERATION OF KANUPP

OBSOLESCENCE
1. Computers, Control & Instrumentation
2. Fire Alarm System
3. Nuclear Instrumentation
4. On-line Chemical Instrumentation
5. Turbine Machine Monitoring System
6. Closed Circuit TV System
7. Telecommunication
8. Switchyard Extension

AGEING SIGNIFICANT TO SAFETY
1. Reactor Fuel Channels (RFC) Integrity Assessment
2. CO2 System Improvement
3. Steam Generators Inspection & Repair
4. Fuelling Machine Problems
5. Cables

IMPROVEMENT OF OPERATIONAL SAFETY PRACTICES
1. Maintenance
2. ISI Periodic Inspection Program
3. Operations
3.1. Prevention & Analysis of Significant Events
3.2. Modernize O P & P
3.3. Improve E O P s
4. Establish Surveillance Program
5. Establish QA Program
6. Improve Manpower Development
7. International Computer Networking

IMPROVEMENT OF SAFETY SYSTEMS TOWARDS MODERN STANDARDS
1. KFSAR Update
2. PSA Level 1
3. LOCA Handling
3.1. Emergency Cooling Reliability
3.2. AD Sump Pump blockage by debris
3.3. Environmental Qualification
3.3.1. Process Equipment
3.3.2. I&C Equipment
4. BS Cooling Reliability
5. Secondary Heat Sink Reliability

Mar 20, 1991

	1985	86	87	88	89	90	91	92	93	94
1. OBSOLESCENCE										
Technological Upgradation at System Level		A	AB	BC	CC		DD	DD	DD	
2. AGEING										
Conventional Systems	– –	ABCD		– – –		>	on-going			
Reactor Fuel Channels					AB	C	DD	D		
Steam Generators					A		D			
3. SAFETY IMPROVEMENT										
Operational Safety Practices	B				BB	C	DD	DD		
Modernize Safety Analysis					A	B	CD	DD	D	
Improve Safety Systems						A	BB	BB	BC	DD

Phases

A - Identification
B - Analysis and Recommendation
C - Assessment & Planning
D - Implementation

FIG 1. PROGRESS ON MAJOR AREAS OF IMPROVEMENT TO ENSURE CONTINUED SAFE OPERATION OF KANUPP

REFERENCES

1. 'Issues relating to Safety Evaluation and Improvement of Safety Standards of Older Nuclear Power Plants' by Azfar Beg, Jamshed A. Hashmi. IAEA Technical Committee Meeting on Progress in HWR Design and Technology, Montreal, Canada, Dec 6-9, 1988.

2. 'Kanupp Operating Experience' by S. Badshah Hussain. 1st Meeting of IAEA Technical Committee on Operational Experience Feedback on PHWRs. Vienna 1989.

3. 'Kanupp Control Computers - Obsolescence, Perseverance and Evolution' J. A. Hashmi, J. Iqleem, Zia Siddiqui, Tariq bin Tahir, Tariq Habib. COG CANDU Control Computer Conference, NOv 11-13, 1990, Toronto, Canada.

4. 'Safety of Ontario's Nuclear Power Reactors' The Hare Report, 1988.

5. 'The Canadian Approach to Nuclear Power Plant Backfitting - the AECB View' IAEA Special Scientific Meeting on Nuclear Power Plant Upgrading and Life Extension, 18-19 Sept 1990.

6. Kanupp UOR-85-1 'F/M Hose Rupture' by Javed Iqbal.