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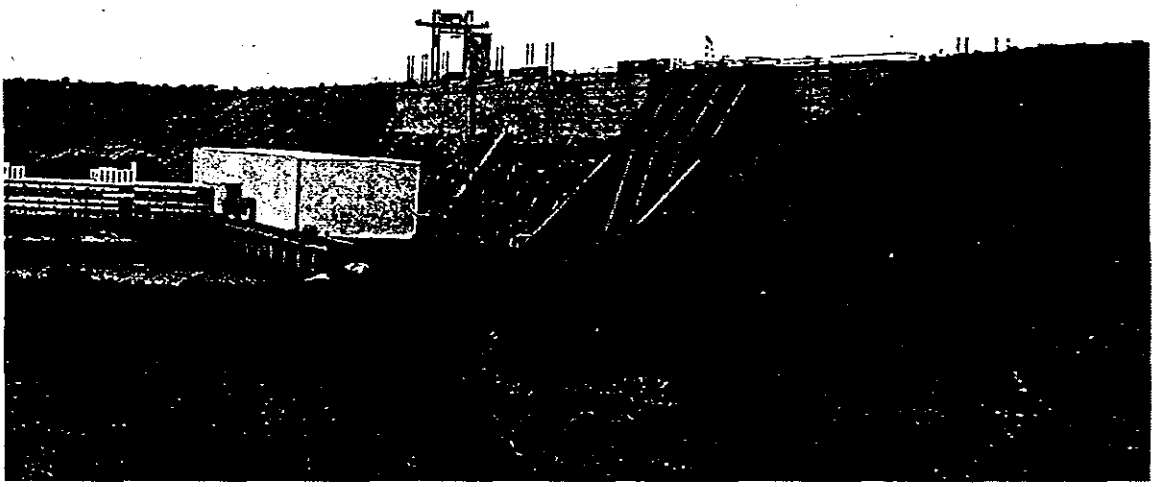
Kainji Dam and Power Station

Niger State, Nigeria

TECHNICAL ASSESSMENT REPORT



September 2001

TECHNICAL ASSESSMENT REPORT

Kainji Dam and Power Station

Niger State, Nigeria

Prepared by the

United States Army, Corps of Engineers
Kainji Dam Technical Assessment Team

Sponsorship provided by the

United States Aid for International Development

September 2001

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EXECUTIVE SUMMARY

Technical Assessment of Kainji Dam, Niger State, Nigeria

Through funding provided by the United States Aid for International Development (USAID), the United States Army, Corps of Engineers (USACE) performed a technical assessment of Kainji Dam at the request of the Nigerian Federal Government, on 10-15 July 2001. The USACE Technical Assessment Team (TAT) consisted of mechanical, electrical and civil engineers specializing in hydropower hydraulic analysis, design, operation and dam safety monitoring. The USACE was chosen to perform this assessment because it is a government agency in the hydropower business experienced in operation and maintenance of aging hydroelectric infrastructure and have no financial interest in the Kainji Station. The purpose of the assessment was three-fold; first, to provide Nigeria's National Electric Power Authority (NEPA) with short-term recommendations to attain their goal of 4000 MW of sustained peaking capability by December 2001. Secondly, to provide recommendations for long term reliable availability and optimization of water resources. And thirdly, to assess the structural integrity of the dam and review the Dam Safety program. The TAT met with Kainji project management and staff, conducted an inspection of the power station, and discussed histories of operation, maintenance and repairs of the station and equipment. An exit briefing was conducted on Sunday, July 15th, with the entire management staff. The TAT performed a limited inspection of the Jebba Hydropower Station on 16 July 2001 while enroute back to Abuja from Kainji. Jebba is immediately downsteam of Kainji. The TAT held an outbriefing with the technical and management staff after the inspection.

The general consensus of the TAT is that Kainji is a viable power station, and with a corporate focus on powerhouse cleanliness, maintenance, repairs and some upgrades, should provide another 25 years of reliable and dependable operation. The turbines are in excellent shape, major electrical equipment is operable or being updated, the dam structure is in very good condition with an excellent dam safety program at the project and corporate level. Kainji power station is at an age when, like many power stations of a similar age worldwide, outages have become common and repairs are needed. Asea Brown Boveri (ABB) is making current repairs and upgrades on Units 7, 8 and 11 that should return the units to available status by November 2001. These actions should remedy the short-term objectives of maximum possible availability from Kainji and contribute toward NEPA's goal of 4000 MW of sustained peaking capability by December 2001. The project has additional problems that need to be addressed very soon to meet long term reliability goals. Failure to address these problems will result in continued equipment failures that will create extended outages and have high repair or replacement costs. A coordinated business plan to address these problems need to be enacted.

The NEPA business plan should focus on the following areas: 1) increased maintenance and powerhouse cleanliness; 2) improved processes for acquiring replacement and spare parts; 3) repair and modernization of selected equipment; 4) changes to unit operations to fully utilize available water resources, and; 5) increase communications and networking with the international hydroelectric community; and 6) Dam Safety.

Increased Maintenance and Housekeeping

Dirt and dust render many of the equipment controls inoperable and puts much of the equipment at serious risk. The existing central ventilation system is not operable and needs to be repaired or replaced so that the station can be pressurized to keep out dirt and dust. The dirt and dust mixes with oils and solvents and creates an environment that is near impossible to keep equipment and controls operating correctly and also makes monitoring of future problems difficult. Older equipment requires increased maintenance and monitoring which is difficult to perform when equipment is dirty. Situations currently exist where controls of major equipment and auxiliaries are not functioning properly which could lead to failures and major damage. An additional set of draft tube bulkheads is also needed so that unit outages can be scheduled for repairs and routine maintenance.

Replacement and Spare Parts Acquisition

Aging equipment requires replacement parts that are often difficult to locate. The Kainji Dam technical staff, which is knowledgeable about the equipment and required parts, needs to have direct communications with manufacturers and vendors to find or have manufactured replacement and spare parts. NEPA's communication infrastructure needs improvement to facilitate technical discussions between project staff and suppliers. This will allow efficient problem solving and the location of acceptable products. In-house acquisition processes need to be revised to allow effective procurement.

Repair and Modernization of Equipment

Kainji power station has equipment that needs repair or modernizing. Items needing repair include the intake gate seals and gate controls, the ventilation system, leaking oil heads and miscellaneous inoperable controls. ***Unit 6 governor pumps and controls should be repaired immediately to prevent the loss of control and runaway of the unit.*** Modernization is needed for the rotating exciters and air-blast breakers, which should be replaced with static and SF6 type equipment, respectively. Generators 7 and 8 should be tested to determine their remaining life. Generators 9 and 10 appear to need rewinding soon and the transformer for Units 9 and 10 should be replaced. The mechanical portion of the governors should be rebuilt with available kits, and the control portion of the governors should be modernized with electronic equipment. Damaged dam monitoring instrumentation needs to be replaced and updated to maintain data and confidence in the existing dam and water impounding structures. Unit 6 throat ring leakage needs pressure grouting repairs similar to what was done to Unit 5 prior to the runaway. Generator and line protection relaying should be scheduled for replacement over the next 5 years. All the repairs and modernization should be prioritized and budgeted over the next 5 years.

Optimization of Available Water Resources

The current hydropower operation at Kainji is not economically utilizing the water resources

available in the project's drainage area. Because of reliability and capacity adequacy problems throughout the NEPA system, Kainji units are forced to produce too much base load generation during non-peak hours. This inefficient use of stored water prematurely draws down the reservoir, reducing the project's capability to generate during peak demand periods and further putting the electrical system at risk of an inadequate power supply for future periods. Unnecessary base load operation of the units increases wear and tear thereby accelerating unit deterioration. The lack of adequate capacity in the NEPA system is not allowing the Kainji units to operate at their economic optimum. During peak demand periods, these units should be displacing expensive thermal generation with high fuel cost to maximize the benefits from the capital investment made in the project. There are no major operational issues at the Jebba Hydropower Station. Hydrological and generation data management at both Kainji and Jebba needs to be modernized to improve operational planning and water management. The Hydrologic and Generation/Operation Sections at Kainji and Jebba projects are in critical need of updated computer equipment to efficiently retrieve, store, analyze and manage hydrologic and operational data. Another critical need at the Jebba project is modern elevation stage gages and streamflow meters to accurately record hydrologic data.

Expanding generation capability into one or more of the empty bays at Kainji would not be a prudent investment at this time. All available NEPA resources should be focused on improving operations and maintenance and increasing the availability of the presently installed units. Potentially, an additional unit could realize some benefits by operating as a synchronous condenser to provide voltage stability on the national grid. A rigorous hydrologic, economic and load growth analysis should be performed in order to determine the feasibility of expanded generation at Kainji.

Improve Networking and Communication with International Hydropower Community

Many worldwide utilities are experiencing the same problems as the Kainji Hydropower Station. Discussions with technical staff at these utilities, accessibility to databases of technical papers, and subscribing to industry periodicals and newsletters would provide an invaluable source of information and technical support to the hardworking and talented staff that exists at Kainji and Jebba Hydropower Stations. NEPA should get more involved in hydropower industry conferences and technical seminars to establish a valuable network with industry peers.

Dam Safety

The Kainji Hydropower Station was assessed from a dam safety perspective and the project was found to be well designed and has been maintained in a manner that assures that the project is safe for continued operation for the foreseeable future. The structures have an extensive array of instrumentation installed for the monitoring of seepage and deformation. A review of seepage and deformation readings revealed no unusual problems. Presently embankment dam piezometers can not be read due to malfunctioning readout meters. The Project Dam Safety personnel were found to be very knowledgeable and are performing in a superior manner. The Dam Safety program as it presently exists is satisfactory to ensure detection of significant deficiencies should they occur, but formalization of existing practices and implementation of others will ensure that processes and knowledge are carried forward to the next generation.

The TAT made a brief stop at the Jebba Hydropower Station on the return trip to Abuja. Jebba is a newer plant and is not yet seeing the failures and need for spare parts to the degree of Kainji. However, Jebba personnel also expressed a need for better procurement processes and communication with equipment suppliers.

Kainji Hydropower Station equipment problems are similar to those experienced by other utilities worldwide. However, NEPA should meet the challenge, as other utilities are doing, of using their technical expertise and the experience of the industry and it's vendors, to evaluate and prioritize needed repairs, upgrades and replacements. Resources need to be made available so that maintenance work can be accomplished in a planned and cost effective manner before costly major equipment outages and failures occur.

Part I: GENERAL

1.1. Authority

The Interagency Agreement signed on 21 June 2001, between the United States Agency for International Development (USAID) and United States Army Corps of Engineers (USACE) transferred funds to USACE for activities in Nigeria. Under Section 632(a) of the Foreign Assistance Act of 1961, as amended, and the Foreign Operations, Exporting Financing and Related Programs Appropriations Act, 2000 (Public Law 106-113), the USAID hereby agrees to transfer to the U.S Army Corps of Engineers the funds appropriated for Economic Support Fund. The USACE will use the funds to assemble a Technical Assessment Team (TAT) to perform a site survey and evaluation of the Kainji Dam and Powerhouse in Niger State, Nigeria.

1.2 Project Description

The Kainji Hydropower Station is located on the Niger River, in Niger State, approximately 800 km upstream of the river delta near Port Harcourt. The first units of the powerhouse were placed into operation in 1968. The dam consists of a 2,315 meters (m) long right embankment section and a 1,340m long left embankment section separated by a 550m long concrete intake and spillway structure. A navigation lock is situated near the center of the left embankment section. There is also a 4,115m long embankment saddle dam located approximately 1.6 kilometers (km) east of the project. The maximum height of the saddle dam above the foundation is 80m at the right river channel.

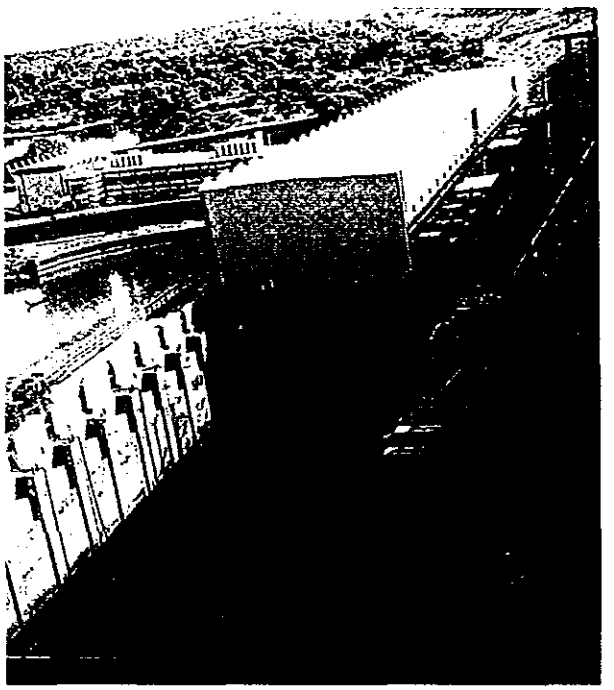

Figure 1. *Kainji Dam powerhouse looking down from the crest of the dam.*

At the time of the TAT visit, four of the eight powerhouse units were available for service, Units 6, 9 10 and 12. Units 7, 8 and 11 are being repaired and/or rehabilitated by Asea Brown Boveri Group (ABB) and are scheduled to be back in service by November 2001. Unit 5 is unavailable indefinitely because it was severely damaged in a runaway event in November 2000. Units 1 through 4 are not installed but are open bays with installed penstocks and other structural work completed.

The Kainji powerhouse is operated with all available units generating and the load distributed among them. Units are normally loaded at 50-60 percent. This allows for spinning reserve when additional power is needed. Requests for generation come from the National Control Center (NCC), which controls the distribution of electric power throughout Nigeria. The plant operators manually distribute the generation demand from NCC equally between the available units. As the head changes, mechanics in the governors change to the appropriate cam to get the best efficiency possible.

1.3. Objectives of the Technical Assessment Team

The objectives of the USACE Technical Assessment Team's (TAT) assessment of the Kainji Hydropower Station and dam were three-fold. First, to provide NEPA with short-term recommendations to attain their goal of 4000 MW of sustained peaking capability by December 2001. Secondly, to provide recommendations for the power station's long term reliability and optimization of water resources. And thirdly, to assess the dam structure and dam safety program. The USACE was chosen to perform this assessment because like the National Electric Power Authority (NEPA), it is a federal government agency in the hydropower business experienced in operation and maintenance of aging hydroelectric infrastructure and has no financial interest in the Kainji Hydropower Station.

1.4. Technical Assessment Team Members

1.4.1 USACE/USAID

David C. Wong	Mechanical Engineer Project Manager	USACE Transatlantic Programs Center, Winchester, Virginia
Stephen (Duke) Loney	Mechanical Engineer Hydroelectric Design Center	USACE Portland District Portland, Oregon
Richard Hannan	Civil Engineer/Geologist Dam Monitoring & Safety	USACE Portland District Portland, Oregon
Kamau Sadiki	Civil Engineer Hydropower Analysis Center	USACE Northwest Division Portland, Oregon
Lawrence E. Harris	Electrical Engineer Hydro Operations	USACE Mobile District Mobile, Alabama
John Brodman	Sr. Energy Policy Advisor	USAID, Abuja Mission

1.4.2 NEPA

O.K. Ozoemena	General Manager (Generation)	Kainji Region, Kainji Niger State, Nigeria
A.T. Onabanjo	Asst.General Mgr (Generation)	Kainji Power Station
G.O. Oguntolu	Proj. Monitoring, Rehabilitation	NEPA HQ, Abuja
Umeh Godson	Dam Inspector and Rehab	NEPA, Lagos
Andy Akingbotolu	Electrical Engineer	Kainji Power Station
Sam Oguntunde	Mechanical Supervisor	Kainji Power Station
F. I. Adeyelure	Principle Mgr. (Generation)	Kainji Power Station
Rasaki Alabi	Zonal Safety	Kainji Power Station
Kenneth Okeke	Technical Services	Kainji Power Station
Mike Ofomata	Protection/Control/Metering	Kainji Power Station

I.B. Akambi	Hydrologist	Kainji Power Station
D.O. Adekila	Mechanical Manager	Kainji Power Station
O.G. Ogundiran	Mgr., Dam Instrumentation	Kainji Power Station

1.5. Chronology of Events

Monday, July 9	Technical Assessment Team arrives in Abuja
Tuesday, July 10	Entrance meeting at NEPA headquarters with Mssrs. Makoju, Ozoemena, and Oguntolu
Wednesday, July11	Travel to Kainji and TAT introduction and initial briefing with Kainji management.
Thursday, July 12	TAT tour of Kainji power station. Break-up into groups by technical discipline for discussions.
Friday, July 13	Continued TAT inspection and discussions by technical disciplines.
Saturday, July 14	Continued TAT inspection and discussions by technical disciplines.
Sunday, July15	TAT and NEPA group tour of Kainji National Wildlife Park. TAT exit briefing on findings and recommendations to Kainji management staff.
Monday, July 16	Travel to Jebba Hydropower Station. Brief meeting with Jebba management staff and group walkthrough tour of project features. TAT return to Abuja.
Tuesday, July 17	TAT briefing on findings and recommendations to NEPA Director Makoju, then to U.S. Ambassador to Nigeria Mr. Howard F. Jeter, and later in the evening to Nigerian Presidential Advisor on energy policy Mr. Adobe Obe.
Wednesday, July 18	TAT briefing to USAID Regional Deputy Ms. Sherri Suggs. TAT evening departure back to USA.

Part II: TECHNICAL ASSESSMENT TEAM FINDINGS

2.1 MECHANICAL EQUIPMENT

2.1.1 Turbine Descriptions

Turbines 5 and 6 are 120 MW Francis runners manufactured by Voest-Alpine with a rated head of 38m, rotating at 107 rpm, and a rated flow of 378 cubic meters per second (cms). These turbines have not been Gibson performance tested since their original commissioning. They were commissioned in 1978 as part of a contract with Units 11 and 12 Kaplan runners.

Turbines 7 through 10 are 80 MW Kaplan runners manufactured by English Electric. Units 7 and 9 were commissioned in 1968 and Units 8 and 10 were commissioned in 1969. These units have not been index performance tested since their original commissioning.

Turbine 11 and 12 are 100 MW Kaplan runners manufactured by Voest-Alpine. Units 11 and 12 were commissioned in 1975 and 1976, respectively.

2.1.2 Turbine Condition

In general, the turbines have operated well and are in good condition. Except for the items discussed below, they have not required excessive maintenance or repairs. There is little shaft run-out, no significant bearing problems and very little cavitation. We would expect the major turbine components to perform reliably for years to come.

Unit 5 – Francis Runner: The damage to the Unit 5 turbine is unknown but assumed not repairable and requires total replacement after a runaway incident in November 2000. Governor pressure was lost and the unit accelerated beyond maximum design speed. A generator over-frequency relay tripped the unit off line. Automatic closure of the intake gates did not occur and the unit continued to runaway. During runaway, the rotating parts of the unit moved up and down approximately 300mm, the rotor scraped the stator bars, the wicket gates link arms and operating ring disassembled and control of the unit was lost. Water pulsations from the uncontrolled flow blew out the draft tube door and liner and the whole powerhouse flooded and equalized at tailwater level, which was at Elevation 103.3m mean sea level (msl) at the time.

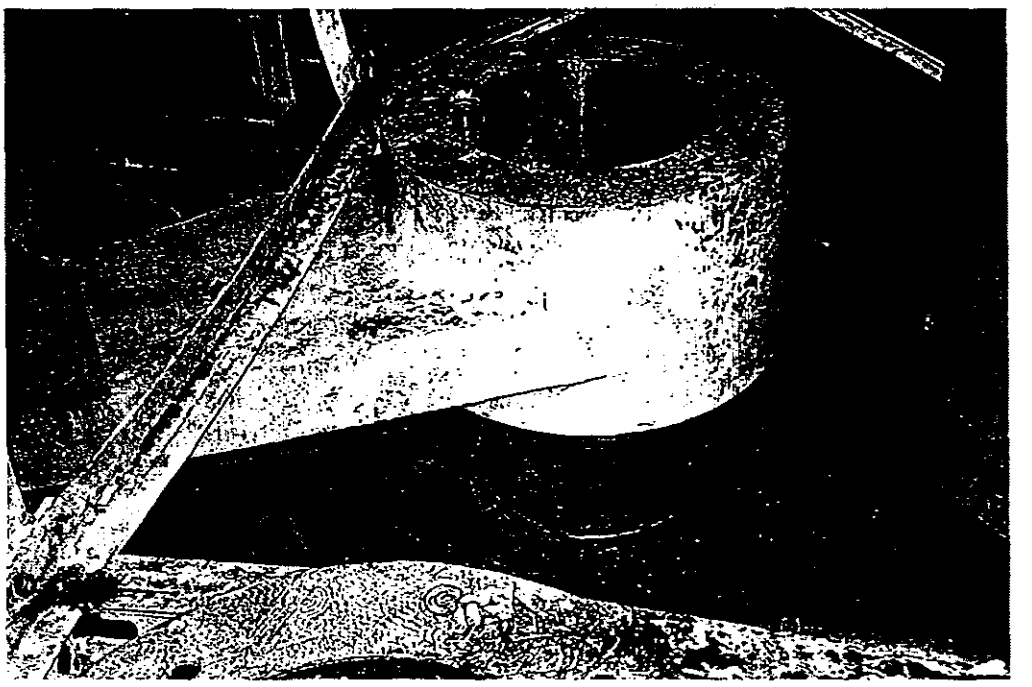

Figure 2. *Unit 5 wicket gate linkage showing vertical displacement caused by run-away event.*

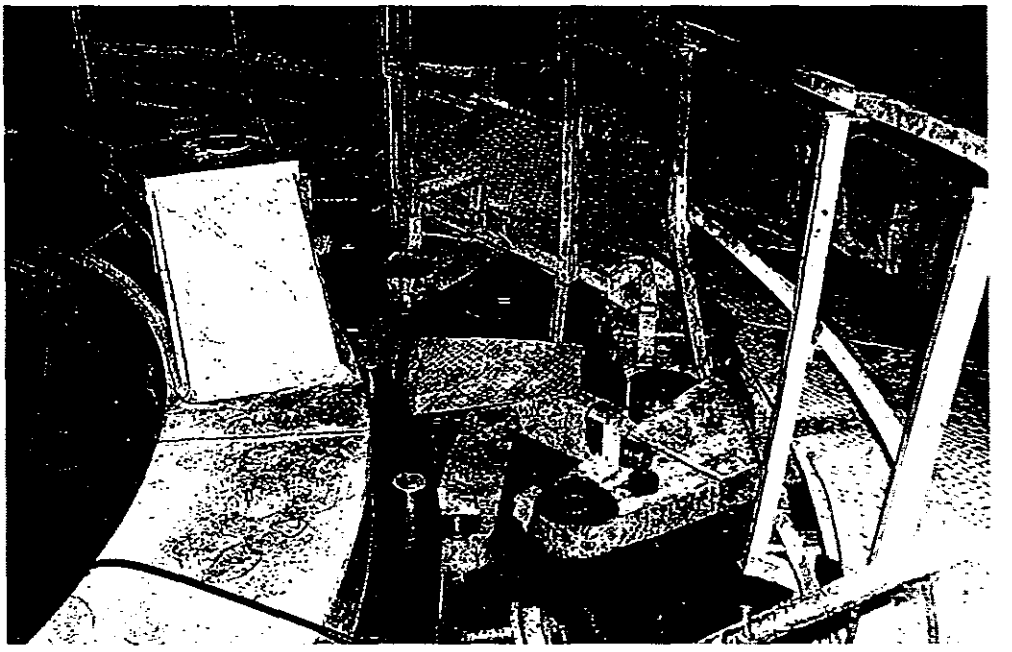

Figure 3. *Damage in Unit 5 turbine pit caused by run-away event.*

Unit 5 now sits where it stopped after the runaway event. The cover plates are askew, the turbine pit is in shambles with parts disconnected (See Figures 2 & 3). There are damaged windings in the generator housing, and the unit is sitting about 150mm above its design height. Damage to the generator and turbine is extensive. It took a month to dewater the power plant, which was

flooded to tailwater elevation at the time. The failure of the draft tube access door and a large section of the draft tube liner caused the flooding. The unit was completely sealed with the replacement of the draft tube liner section, making the turbine inaccessible. There is still a light coating of oil on the station structure and equipment, floating oil left behind as the plant was dewatered. Further inspection and evaluation may deem the turbine repairable, but unlikely. Some minor parts might be salvageable. The earliest that Unit 5 could be returned to service would be 18 months after award of repair/replacement contracts.

Unit 6 – Francis Runner: Inspection of the Unit 6 turbine revealed negligible cavitation and no blade cracking. The turbine runs smoothly at loads over 90 percent and rougher at lower loads. Due to the lack of cavitation and blade cracking, the turbine is in good condition. There is significant leakage from the draft tube liner that drains out through exposed areas around the draft tube access door.

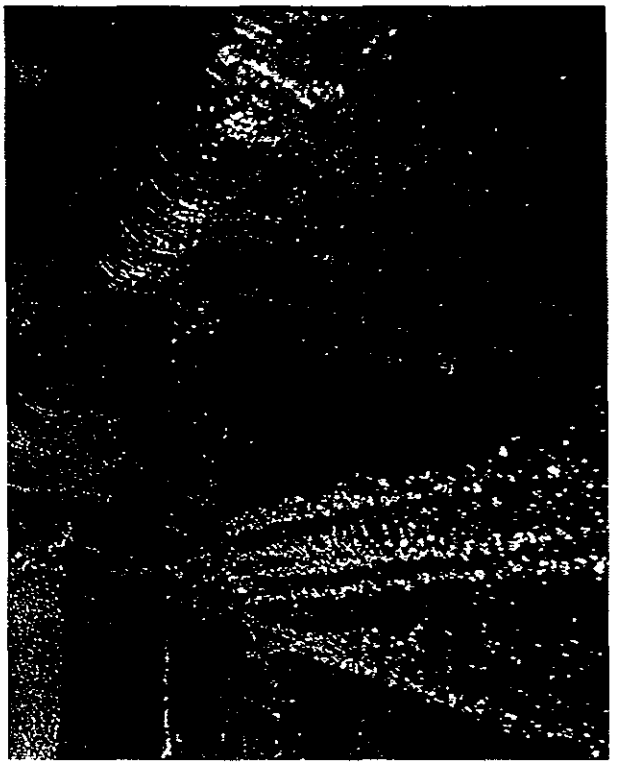

Figure 4. *Unit 6 draft tube throat ring cracks and leakage.*

Unit 5 had similar leakage, which was successfully grouted and minimized prior to the runaway incident. The same grouting should be done for Unit 6. Leakage also occurs at the throat ring through cracking and condenser piping penetrations. Cracks appear to be from fatigue rather than corrosion, probably from induced stresses from fabrication welding, installation and operating vibrations. Quality weld repair and monitoring should continue.

Units 7 through 10 - Kaplan runners: A visual inspection of the Unit 8 runner, which, according to the maintenance staff, is representative of Units 7 through 10, revealed the runner to be in excellent condition.

Figure 5. *Unit 8 turbine blade and hub.*

There is no evidence of cavitation on the blades, hub, cone or throat ring. None of 7-10 turbines have been index tested since initial performance testing. The stainless steel runner and throat ring had minimal surface roughness and it's assumed that runner efficiency should be like-new condition (assuming the governor maintains proper blade-gate relationships and operators utilize proper cam selections). None of the Units 7-10 runners have been disassembled. Maintenance staff indicates the blades operate smoothly without stick-slip. There is minor leakage from the hub and oil head, which drips into the rotating exciter and creates maintenance problems. The condition of these runners is good and should give years of reliable service with routine maintenance.

Units 11 and 12 - Kaplan runners: Through TAT discussions with the Kainji maintenance staff, it was learned that the wetted surfaces of Units 11 and 12 have little cavitation and that the turbines run smoothly. Unit 12 has had two wicket gate lower bushings replaced and in 1989 had water leakage into the oil head. During the ABB rewind, Unit 11 runner was disassembled and rebuilt by project staff to correct the problem that was experienced in Unit 12. Condition of the runners is good and should give years of reliable service with routine maintenance.

Figure 6. *Unit 11 Kaplan runner on a pedestal.*

2.1.3 Turbine Recommendations

The Kainji turbines are in good condition, and with routine maintenance, should provide years of reliable service. Replacement of minor auxiliary equipment such as bearing coolers, head cover pumps and packing boxes should be expected. The TAT recommends the following actions be taken as soon as practical to restore the turbine to near optimal operating condition:

1) Unit 6 throat ring should be grouted similar to Unit 5 repairs to reduce leakage and corrosion.
2) Cracks and leakage around the throat ring should be monitored closely and repairs made as needed.
3) Annual inspections should continue with special attention to wicket gate bushings and seals, bearing babbiting, oil leakage and blade cracking.
4) Turbine pits should be kept clean so that any new problems can be easily spotted and maintenance access is easier.
5) Unit 5 turbine needs to disassembled and thoroughly inspected. The need for replacement is likely but some components may be reusable.

3.1 GOVERNORS

3.1.1 Governor Description

Units 5, 6, 11 and 12 governors are Italian Sadelmi Cogepi mechanical governors. Units 7-10 have English Electric electrical governors. All governors are of standard design for their age with, fly-ball governor, mechanical pilot valve, restoring cables and distributor valve. Each unit has a 24.6 kg/cm^2 hydraulic system with two gate servomotors.

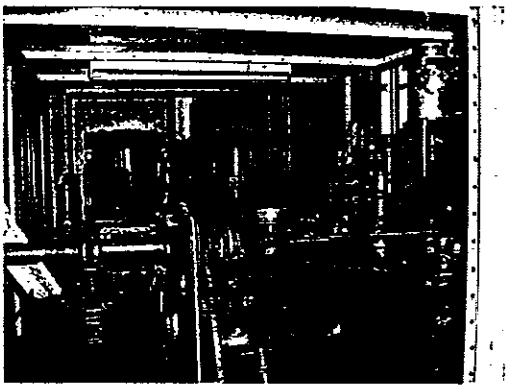

Figure 7. *Mechanical governor for Unit 6.*

3.1.2 Governor Condition

Like other governors over 25 years old, Kainji governors need repair and upgrading. The pilot and distributor valves leak and need to be replaced or rebuilt. Governor pumps have failed and need to be replaced. Unit 5 governor parts have been used to supply parts for Unit 6. Governor equipment on the turbine floor for Unit 6 was damaged by fire in the area of the accumulator tank, oil pumps and controls. Currently, Unit 6 governor pump runs continuously due to fire damaged controls. It is also making a raspy noise, possibly from the bearings, but does seem to load and unload successfully. However, this condition is not desirable and could possibly lead to a loss of governor oil pressure, similar to the failure that started the runaway event experienced on Unit 5. The mechanical fly-ball controls and restoring cables should be replaced with a modern electronic type, which keeps the turbine operating at maximum efficiency. Repairs need to be made to the oil heads on Units 7-12 that leak oil down into the rotating exciter.

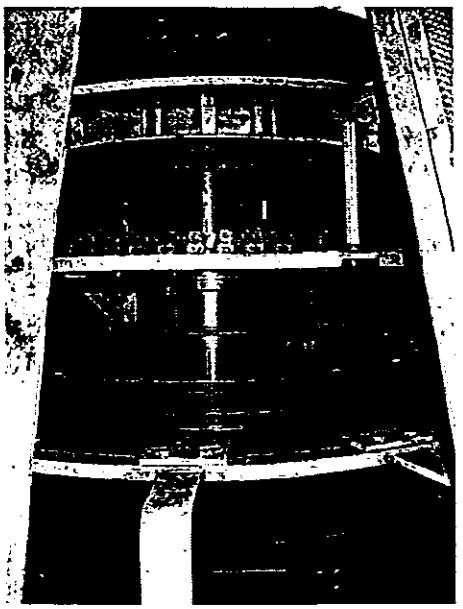

Figure 8. *Unit 7 Exciter.*

3.1.3 Governor Recommendations

Kainji governors need repair and modernizing. Companies such as General Electric/Woodward can provide turnkey services to inspect, design, manufacture and install needed components. The following actions are recommended by the TAT to ensure reliable operation of the turbines:

1) Rebuild or replace governor oil pumps and controls.
2) Modernize governor cabinets with electronic controls and rebuilt or replaced pilot and distributor valves
3) Repair oil head leaks

4.1 VENTILATION SYSTEM

4.1.1 Ventilation System Description

The existing ventilation system design has three large supply fans with a louvered and filtered intake to provide clean air and pressurize the power station. The air is distributed through wall openings and ductwork to the power station. High bay ventilation fans exhaust the air and provide flow-through ventilation.

4.1.2 Ventilation System Condition

The power station ventilation is inoperable and contributes significantly to the lack of cleanliness and reliable operation of equipment and controls. Currently, only one of the three ventilation fans is operable. With the fans inoperable, the plant is not continuously pressurized which creates major dust problems in the plant due to windows and doors left open. The outside dust and dirt particles mixes with powerhouse oils and humidity to create an unacceptable environment for operating equipment. The dust and dirt gets onto and into electrical contacts, controls and relays and renders them inoperable, a very dangerous condition contributing to faulty operation and damage to equipment. Dirt and dust mixes with oils and lubricants to form destructive grime which inhibits proper lubrication that causes damaging hot spots and makes it difficult to perform maintenance and corrective diagnostics. The lost of control of Unit 5 could be linked to poor ventilation of the powerhouse. Dust and grim on electrical connections, inhibiting their ability to function properly, may have caused delayed annunciation of loss governor oil pressure and faulty controls for the intake gate closure.

Figure 9. *Ventilation system air supply fan.*

4.1.3 Ventilation System Recommendations

The ventilation system must be repaired as a high priority item. The fans appear repairable with replacement pillow-block bearings and electrical repairs. Intake filter media should be provided to filter out dust and insects. Without these repairs, continued failures of components due to uncleanliness will result in additional outages and costly damage to major equipment. Filter systems are now available that are made with disposable material that automatically advances a new filter when the old filter becomes clogged. This is usually sensed by a photoelectric cell that detects a lower level of light passing the filter. We have found that this system is both inexpensive and low maintenance. Fixing the powerhouse ventilation system will allow closing the doors and other openings to filter out dirt, dust, bugs, etc. that are entering the powerhouse and damaging equipment. Lack of a clean air supply and poor circulation may be the cause of higher temperatures when the TAT was on the generator and turbine floors, and even at lower elevations, also. This is cause for concern, since some of the new equipment being installed is solid state electronics. These electronic components are more sensitive to heat and dust than the older equipment. This may require additional cooling in the form of forced air or possibly air conditioning for the equipment to operate optimally.

5.1 INTAKE GATES AND CONTROLS

5.1.1 Intake Gates Description

Each generating unit has two hydraulically operated, roller mounted intake gates. The hydraulic system is needed to raise the gates, and the gates are lowered by gravity via valve porting. The Vickers hydraulic systems are standard design with automatic, remote or local operation.

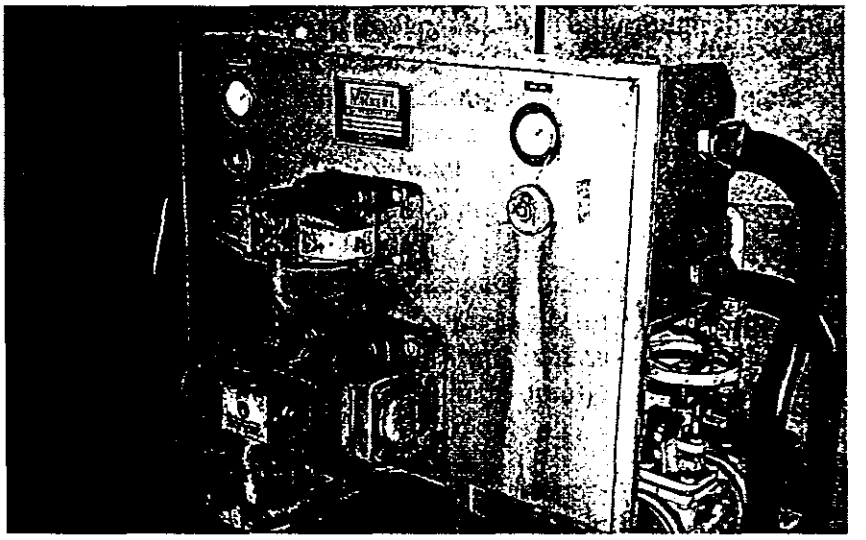

Figure 10. *Vickers intake gate controls.*

Normal gate operation would be via automatic control. The gates each have local stations in which to raise, lower, and stop the travel of the gates. There is also a set of three pushbutton controls and an indicator on the Unit Control Board for each unit to raise, lower, and stop the gates. The gates are used for both maintenance access and emergency closure of the water passageway.

5.1.2 Intake Gates Condition

The intake gates are currently inoperable while in the automatic or remote modes and pose a major threat to plant safety and reliability. ***Electrical equipment controls that operate the intake gates need to be fixed immediately.***

Figure 11. *Electrical panel box for intake gate controls showing dust contamination and poor maintenance.*

The steel gates are in good condition for their age, although a thorough inspection could not be done since the gates are suspended under water above the intake openings. The lower gate seals are reportedly bad and need replacing. Also, the cathodic protection and paint on the gates is original material and should be replaced and updated. Some leakage could be heard from the crest at the intake gate slots on Unit 5. The only set of stop logs available is installed in the Unit 5 slots. In case of an emergency, no stop logs are available for use on the other units.

The local control pushbutton stations for the intake gates inspected by the TAT appear to be generally inoperable. Many of the pushbutton station enclosures were open with temporary wiring and jumpers around wires and devices that were extremely deteriorated. Some work was ongoing in the Unit 11 slots where it appears that the hydraulic valves and controls were being replaced with new equipment.

Figure 12. *Unit 5 intake gate controls.*

5.1.3 Intake Gate Recommendations

The intake gate controls and hydraulic system need to be repaired and made operable as the highest priority. As the project has experienced with Unit 5, failure of the intake gate control system jeopardizes the reliability and viability of the entire plant. The TAT recommends the following actions be taken immediately:

1) Repair automatic and remote controls of operating equipment. The local control stations need to be replaced with new ones of a different design, as well as the remote control features from the control room, if the hardware is obsolete and not functioning properly. Since the remote controls for the Unit 5 intake gate did not work when needed from the control room, all other units should be exercised and checked by lowering and raising from the control room when the monthly unit checks are accomplished.
2) Procure replacement parts for the Vickers hydraulic equipment.
3) Replace lower gate seals.

6.1 MECHANICAL AUXILIARY EQUIPMENT

6.1.1 Mechanical Auxiliary Equipment Description

The Kainji Hydropower Station has the standard mechanical support system typical in all hydroelectric stations. Raw water is taken from the reservoir, strained and used for station service and generator, bearings, and transformer cooling. Compressors are provided for service air, generator brakes, governor air and circuit breakers. Carbon dioxide (CO2) is provided for fire protection. A lubricating and insulating oil storage, distribution and filtering system exist. Building and equipment drainage and unwatering systems are installed. Distribution piping and valves for all the systems run throughout the plant.

6.1.2 Equipment Condition

Most of the mechanical auxiliary systems are functioning but in need of maintenance, repairs or replacement. The service compressors seem to operating almost continuously indicating system leaks or need for compressor overhaul.

Figure 13. *Raw water control values showing leakage and poor maintenance.*

Numerous valves in the raw water system were leaking badly around the valve stems. The fire pumps, showing severe wear from frequent use, were operating continuously and are apparently being used for other purposes. The CO2 system looked good but there is no indication of how much CO2 is in the bottles. They need to be weighed and refilled periodically.

6.1.3 Mechanical Auxiliaries Equipment Recommendations

Mechanical equipment wears out with age. As the equipment gets old, frequent repairs and replacements will be needed. NEPA needs to make ongoing investments into repairing and replacing inefficient and aged equipment. Failure of any of these auxiliary systems can inhibit generating capability and reduce plant and/or availability. The cost of this equipment is not high, relative to generating equipment, but a strong effort is needed to get spare parts, overhaul the equipment or replace items before failures occur.

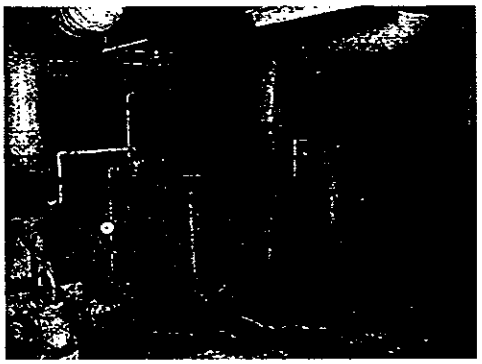

Figure 14. *Badly corroded and leaking raw water pumps.*

Plant maintenance and operating personnel know best what the condition of this equipment is and should prioritize work items. Procurement and location of parts has been a problem in the past, so communication equipment improvements and procurement process changes are needed.

7.1 POWERHOUSE ELECTRICAL EQUIPMENT

7.1.1 Generators Description

Units 5 & 6 are Hitachi generators rated at 126,000 kVA at .95 power factor (PF), 16 kv, with a maximum continuous duty rating of 145,000 kVA. The units were installed in 1978. Units 7 through 10 are Asea generators rated at 85,000 kVA, .94 PF, and 16 kv. They were installed in 1968. Units 11 & 12 are also Hitachi generators rated at 100,000 kVA at .95 PF, 16 kv, and a maximum continuous duty rating of 115,000 kVA. They were installed in 1976.

7.1.2 Generator Condition

Unit 5: The condition of the Unit 5 generator is not known, but it is suspected that much damage has occurred internally. It had 5,749 service hours of operation on it before the run-away event in November 2000. Just by looking at the buckled housing, one can determine that the unit was moving vertically and horizontally beyond the limits of its bearings and thereby causing severe damage to the rotor, stator, exciter, and bearings. Before consideration is given to restoring Unit 5 to service, a complete structural inspection should be made for damage to the concrete and movement and damage of the sole plate.

Unit 6: The Unit 6 generator is fully operable and has 99,308 service hours of operation on it as of 11 July 2001. This unit was noted to have slightly elevated temperatures on all the bearings and the highest operating hours. This might be the reason that temperatures are running slightly higher than the other units, except for Unit 9. There were no reported problems with rotor, stator or other generator components.

Unit 7: The Unit 7 generator is unavailable due to a transformer failure. It has 43,730 service hours of operation on it as of 11 July 2001. Alstom Power is replacing the transformer, unit circuit breaker, and the governor. One rotor pole has been removed reportedly for use at another project.

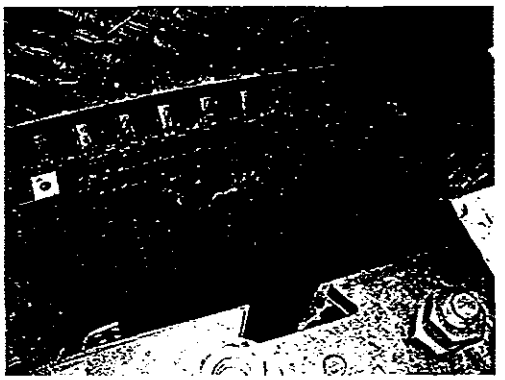

Figure 15. *Missing rotor pole from Unit 7 generator.*

Where the pole had been removed there was a "pasty, greasy substance" (right center of Fig. 14) on the surface of the wedges. This is probably due to activity in the area when removing the rotor pole. This unit has been down for some time for partial rehab and the cover plates have been removed from most of the stator/rotor.

Unit 8: The generator for Unit 8 is also unavailable due to transformer failure. Units 7 and 8 share the same transformer. It has 14,598 service hours of operation as of 11 July 2001. Since the transformer failure, this Unit has been used to supply station service generation. The condition of this unit is thought to be similar to that of Unit 7. There was stator coil failure on some of the coils in 1984 that was repaired in 1998. The stator windings on this unit are also open and exposed making it vulnerable to moisture from the air and should be dried by a heat run before returning to service.

Unit 9: The Unit 9 generator is fully operable. It has 71,605 service hours of operation on it as of 11 July 2001. Two stator coils were reported to have failed in 1998. These were repaired in 1999 and the unit has since tripped off on ground faults several times. The windings were also wetted on 9August 1997 from rainwater. It was noted from charts provided by the plant staff that all the bearing temperatures on this unit are significantly higher than the other units. This could be partly, but not totally, due to the unit being run more than the others except Unit 6, which had only slightly elevated temperatures. Other than the coil failures mentioned above, there were no other reported problems with rotor, stator or other generator components.

Unit 10: The Unit 10 generator is unavailable because of a re-commissioning effort that is in progress. It has 52,287 service hours of operation on it as of 11 July 2001. Almost 19 years into the generator service life (23 April 1988) stator coil failures occurred and the brake ring on the rotor had "fallen." Repairs were made in- house by splicing coils in and the unit returned to service. Almost nine years later an isolator burned up, causing more stator coil damage. Then, one year and two months later (2 June 1988), water leaked from the roof into the unit causing more stator coil failures. Repairs were again made in-house and the unit restored to service. There were more coil failures four months later when flexible links on the transformer burned up. Coils were damaged on 24 June 1999 during a system disturbance. On 19 February 2001 a 330KV fault tripped all units offline and damaged stator coils. Other than the coil failures and brake ring trouble there were no other reported problems with the rotor, stator or other generator components.

Unit 11: The generator for Unit 11 is unavailable and undergoing a major rehabilitation with refurbishing of the rotor, new stator core, new stator coils, new circuit breaker, new static excitation, new starter board, and new transformer. This unit has 40,596 service hours of operation on it as of 11 July 2001. It is expected to return to service in November 2001.

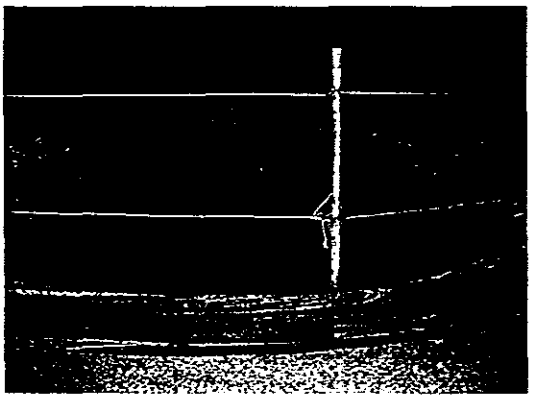

Figure 16. *Unit 11 generator stator windings being refurbished.*

Unit 12: The generator for Unit 12 is fully operable. It has 27,046 service hours of operation on it as of 11 July 2001. Rainwater flooded the stator windings on 9 August 1997. On 24 April 1997 a leaking cooler (radiator) was repaired. There have been numerous other incidents of this unit tripping off line or shutting down for other reasons not related to the generator. There were no other reported problems with the rotor, stator or other generator components.

7.1.3 Generator Recommendations

Kainji generators should receive thorough testing and inspection to determine their present condition. The inspections performed by the TAT were more of a survey inspection, looking at the surface, without condition indicator tests. The USACE has developed a program called Repair, Evaluation, Maintenance and Rehabilitation Research Program (REMR). In the evaluation part of REMR, there are condition indices developed to give a snapshot evaluation of a piece of major equipment such as a generator. For generators, the parameters that are tested and measured are Corona Probe Test, Insulation Resistance Test (usually 2500 V meggar), Ozone measurements, Partial Discharge Analysis (PDA), Reduced Rating (indication of weakened components), End turn and circuit ring inspection, slot inspection, Core inspection, DC Hi-Pot; and Blackout Test. These standardized tests and measurements are then used to determine an overall Condition Index of the generator and to show if it needs major work. In addition to TAT visual inspection, there were discussions with plant personnel and the review of two papers written by plant personnel on the condition and recommendations for equipment at the Kainji Hydropower Station. Outages and Trouble Reports for the year 1997 were also provided and considered in the TAT analysis of the generator condition.

The recommendations for these units are based on the above-mentioned factors of onsite inspection, the 1997 reports, plant personnel papers, and plant personnel interviews. From this perspective the following recommendations by the TAT are offered:

(1) All Units - The temperature monitoring equipment should therefore be replaced as a priority item. Temperature equipment used to monitor the bearings is antiquated, and hard to read. The meter and temperature recorder were located on the Governor/starter board and are read by an attendant at this board and recorded on a log. The control room operator needs constant access to these temperatures as they determine the operation of the units, e.g. the operator may have to reduce load on a generator or transformer to try to bring temperatures down, or shut the unit down. It wasn't determined if the stator, rotor, and transformer temperatures were sent to this same board or not. However, these temperatures are critical to the operation of the unit within the ratings of the generator and transformer. Exceeding these temperatures greatly affects the life of the equipment.

(2) It is recommended that all generator, transformer, station, switchyard, and line relaying be replaced as a priority item. It is imperative that someone with relay the expertise in Engineering evaluate all the system parameters and provides the proper settings to the project personnel commissioning the relays. It was also found that several units are experiencing coil failures and other damage as a result of system troubles and faults. These external problems should be resolved with the replacement of the generator, transformer, line, and switchyard protective relaying. The relaying at Kainji is all located in a single room across a hall, in back of the control room. There is a test crew that tests and maintains this equipment. However, these are all electro-mechanical components with more than 33 years of service. They are antiquated, aged, and difficult to set and maintain. Looking at the number of apparent faults and system troubles that ended up causing stator coil failures in 1997, it appears that the relaying is inadequate. New relaying is now available that covers all the needed generator relaying in one box. Also, transformer and line relaying is available in a single box.

(3) A breaker coordination study needs to be accomplished for Kainji. This effort, again, require someone Engineering with the expertise to evaluate all circuit breakers at Kainji from 330 KV down. When this is accomplished, then the relaying or breakers can be set to trip only when they should, e.g., a 16KV breaker should not trip when the 400V breaker should have cleared the fault.

(4) The Unit 5 generator should not be abandoned completely, but replacement should be considered before any consideration of installation of units in bays 1-4. The unit should be disassembled under contract and all parts thoroughly inspected by non-destructive testing (NDT), such as ultrasound, x-ray, etc., and dimensional checks made against the original design drawings. Some portions such as rotor poles, stator core and coils should be replaced without inspection, as it is certain these are destroyed. The generator foundations (concrete and sole plates) should be inspected for damage and repairs made. It is the opinion of the TAT that the generator and turbine can be rebuilt by restoring or replacing damaged components.

(5) There were no reported problems on the Unit 6 generator, but the unit alignment and bearing clearances should be checked at a convenient time since bearing temperatures

are elevated. Unit 6 was commissioned in 1978 and now has 23 years of service. Generator stator and rotor components should have a service life of at least 35 years. So this unit should be good for another 10-15 years unless outside factors causes outages for the unit. Protective relaying and temperature measuring equipment should be replaced as priority items.

(6) The stator windings on Unit 7 have been exposed and moisture has accumulated inside the unit. This exposure is due to the unit being down for rehabilitation of components external to the generator. One rotor pole has been removed and will need to be replaced. A heat run before returning to service should dry the unit. Unit 7 was commissioned in 1968 and now has 33 years of service. As mentioned above, the generator stator and rotor components should have a service life of at least 35 years. Since there were no reported failures of stator coils, rotor or cooling trouble, this unit should be evaluated with a condition index to determine if it should go on for another 10-15 years or rebuilt by core replacement, rewind, rotor rejuvenation etc. Therefore, this unit could have several more years of reliable service but should have an in-depth evaluation within the next 3 to 5 years. Protective Relaying and temperature measuring equipment should be replaced on this unit as priority items.

(7) Unit 8 condition appears to be similar to that of Unit 7. Though there were coil failures in 1984, no other generator problems have been reported. Unit 8 should be evaluated with a condition index to determine if it can provide reliable service for another 10-15 years or rebuilt by core replacement, rewind, rotor rejuvenation etc. This unit could continue to operate reliably for a few more years but should be evaluated in more depth within the next 3 to 5 years. Protective relaying and temperature measuring equipment should be replaced on this unit as priority items.

(8) The failure of coils on Unit 9 seems to have been caused by external factors such as system disturbances, system ground faults, and wetting by roof leakage. This unit particularly would benefit by replacing the old relays with new generator protective relaying. The condition of Unit 9 is suspected to be worse than that of Units 7 and 8. It should be investigated to determine why all the bearing temperatures are higher on this unit than the others. When possible, the alignment of the unit and bearing clearances should to be checked to see if they are correct. The unit should be thoroughly evaluated now with a condition index to determine if it could provide reliable service for a few more years or be rebuilt by core replacement, rewind, rotor rejuvenation etc. Protective relaying and temperature measuring equipment should be replaced on this unit as priority items.

(9) Unit 10 has had many coil failures caused by several different factors. This unit appears to be ready for a complete major rehab, replacing the core, stator windings, cooling system and rehabilitating the rotor. Also, the protective relaying and temperature measuring equipment need to be replaced during the rehab.

(10) Unit 11 is currently undergoing a major rehabilitation effort. It is not known whether the protective relaying or the temperature measuring equipment is also being replaced. If not, then it needs to be included in the rehabilitation of the unit.

(11) There were many interruptions on Unit 12 during the 1997 Trouble Log. This unit was commissioned in 1976 and has provided 25 years of service. As stated above, generator stator and rotor components should have a service life of at least 35 years. So this unit should be good for another 10-15 years unless outside factors causes outages for this unit. Protective relaying and temperature measuring equipment should be replaced on this unit as priority items.

8.1 EXCITERS

8.1.1 Exciter Description

Units 5 and 6 are equipped with Hitachi Rotating Exciters that were installed in 1978. Units 7 through 10 are equipped with Asea Rotating Exciters that were installed in 1968. Units 11 and 12 have the same type of exciters as Units 5 and 6 but were installed in 1976.

8.1.2 Exciter Condition

The exciter on Unit 5 was shredded during the run-away event and doesn't appear to be salvageable. Unit 6 exciter is probably in better shape than the rest since it does not have an oil head with leakage into the exciter area like the other units. Therefore this exciter probably should be the last scheduled for replacement.

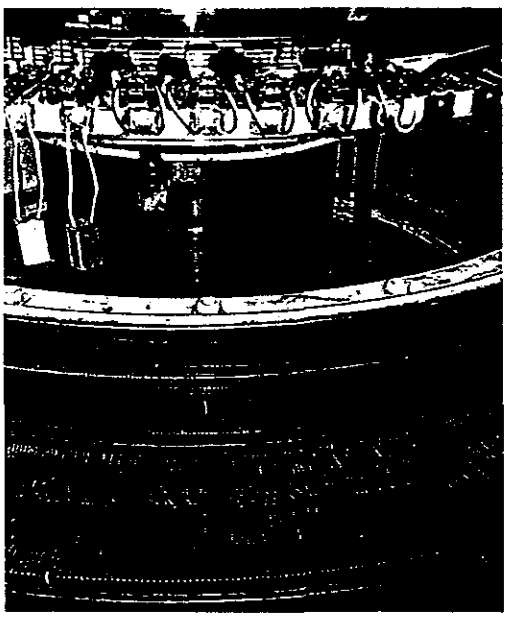

Figure 17. *Unit 5 exciter.*

8.1.3 Exciter Recommendations

All exciters should be replaced with static excitation starting with Units 7 through 12, since there is a problem with oil leakage into the exciters from the Kaplan oil heads. This forms a semi-conductive paste when combined with brush dust. The USACE also had this problem at one of its projects. As an interim measure, the electricians fastened felt material around the shaft just above the exciter (inside the exciter enclosure) to trap as much oil as possible. This minimized the oil leakage into the exciter somewhat but the felt material had to be changed frequently, every week in some cases.

9.1 UNIT CIRCUIT BREAKERS

9.1.1 Unit Circuit Breaker Description

Units 5, 6, and 12 have 330 KV SF6 breakers in the Switchyard. Units 7 through 11 each have a 16KV air-blast type breaker. Units 7 through 11 also have "isolators" or disconnect switches for maintenance or repair isolation from the transformers.

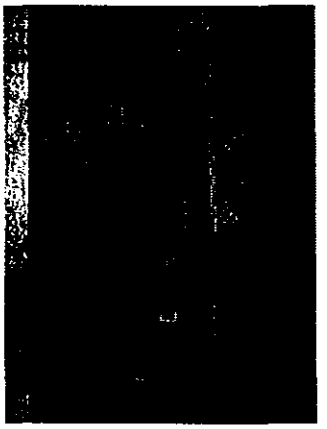

Figure 18. *16 kV air-blast type circuit breaker.*

9.1.2 Unit Circuit Breakers Condition

Units 5, 6 and 12 have 330 KV SF6 breakers and were reportedly not having any problems. Kainji project personnel have no jurisdiction or maintenance responsibilities for these breakers since they are located in the switchyard. A new ABB SF6 breaker is replacing Unit 7 air-blast circuit breaker. Unit 8, 9, and 10 air-blast circuit breakers are old, obsolete, and are prone to having serious problems related to phases not opening, air supply and efficient operation. Spare parts are not available to completely rebuild these breakers. Failure of this type breaker will be catastrophic, probably causing a fire and associated damage to surrounding equipment. Most of the isolators have been "strapped-around" due to catastrophic failures that were occurring.

Figure 19. *New 16 kV SF6 circuit breakers.*

9.1.3 Unit Circuit Breaker Recommendations

The SF6 breakers for Units 5, 6, and 12 are in good condition. Unit 7 breaker is being replaced with a 16 KV SF6 breaker as well as Unit 11. Units 8, 9, and 10 also need to be replaced with new SF6 breakers. It is sometimes difficult to accomplish, but it is recommended to order all these circuit breakers with one supply contract, so that they would be the same across all the units. This has some advantages in terms of maintenance, training of personnel, and spare parts. After delivery to the site, the breakers could then be installed as a unit becomes available. If the breakers are on site, installation should not take more than four weeks and could be accomplished by plant personnel.

10.1 TRANSFORMERS

10.1.1 Transformer Description

Units 5 and 6 each have a three phase, unit connected, Trafo Union Transformers rated at 145,000 kVA, 16/330 KV, forced oil water (FOW) cooled. The date of manufacture is 1976. Units 7 and 8 have a new ABB transformer that has not been installed that serves paired units in its transformer bay. No nameplate data could be found on this transformer. Units 9 and 10 have an Asea Transformer that serves the paired units rated at 183,600 kVA, 16/330 kv, FOW cooled. The date of manufacture is 1967. Unit 11 has a new ABB transformer that has not been installed in its transformer bay that will be unit connected. No nameplate data could be found on this transformer. Unit 12 has a three phase, unit connected Trafo Union transformer, rated at 115,000 kVA, 16/330 kv, FOW cooled. The date of manufacture is 1974.

10.1.2 Transformer Condition

Unit 5 Transformer has not been in service since the unit failed in November 2000. It is thought to be operable, but its condition is not known.

Unit 6 Transformer has primer paint showing through on the top. The outage list for 1997 shows that there was a "flash over on yellow phase" on this transformer on 29 March 1997. There were no other reported problems with this transformer.

Unit 7-8 Transformer is the third transformer that these units have had. It is currently being replaced by ABB. The original transformer exploded and burned in 1996. A reconditioned replacement transformer was then installed and subsequently also burned.

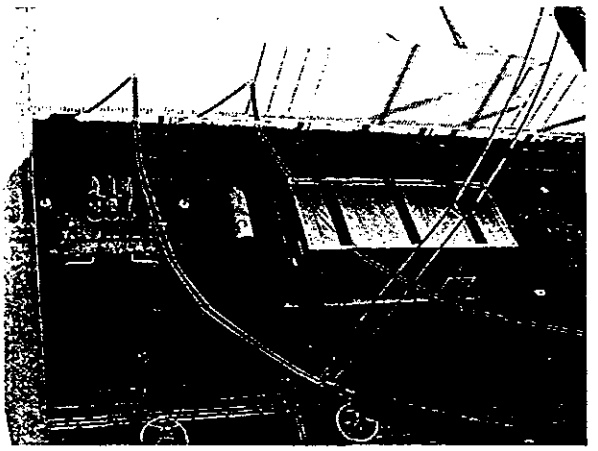

Figure 20. *Unit 6 transformer and new diesel generator building viewed from the dam crest.*

Unit 9-10 Transformer (see Fig. 18) leaks oil and has a very bad hum that has been reportedly getting progressively louder in the last few months.

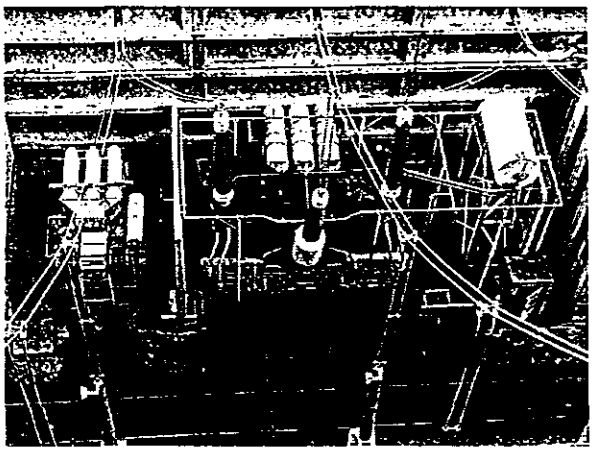

Figure 21. *Unit 9-10 transformer viewed from the dam crest.*

Unit 11 Transformer has a new ABB transformer that has not been installed in its transformer bay that is unit connected. The transformer is being replaced due to fire damaging the original transformer in 1986.

Unit 12 Transformer also has primer paint showing through on the top. An oil seal was replaced on a low voltage bushing (replacement date unknown). Also several problems were noted with

the transformer heat exchangers from the 1997 log where there were "blockages," "oil leaks," and "heat exchanger fault" problems.

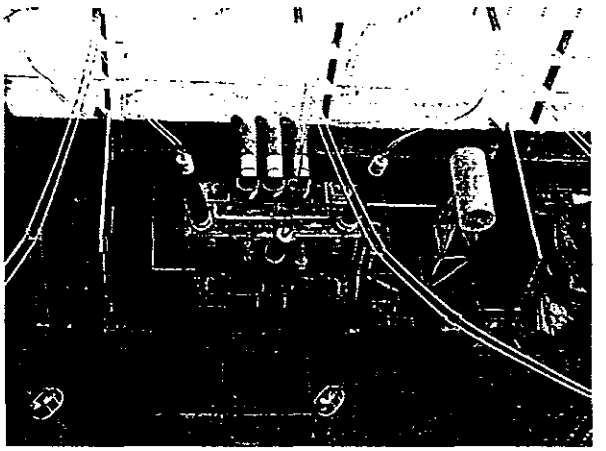

Figure 22. *Unit 12 transformer viewed from the dam crest.*

10.1.3 Transformer Recommendations

All of the transformers at the Kainji Hydropower Station are an area of concern. The temperature equipment used to monitor the transformers was not found, though it was said to exist. The control room operator needs constant access to these temperatures as they determine the operation of the units. For example, the operator may have to reduce load on a generator to try to bring transformer temperature down, or shut the unit down. These temperatures are critical to the operation of each transformer to maintain them within design ratings. Exceeding these temperatures greatly affects the life of the equipment. The temperature monitoring equipment, if it is antiquated or does not work reliably, should be replaced as a priority item. Kainji has had far too many transformer failures for their age. There have been at least four transformer failures ranging in age of operation from 12 to 24 years. This warrants further investigation as mentioned in the Generator section, such as a relay and breaker coordination study. Also, all transformers need to have a quadrennial inspection and special tests to see if they are in good condition.

Before returning Unit 5 Transformer to service, it needs to be tested and inspected thoroughly, protective relaying replaced, and temperature monitoring equipment (readable by the operator) replaced.

Unit 6 Transformer needs painting, testing, protective relaying replaced, and the temperature monitoring equipment (readable by the operator) replaced.

Unit 7-8 Transformer is already being replaced. However, it also needs the protective relaying replaced and temperature monitoring equipment (readable by the operator) replaced. It is already assumed that testing will occur before the transformer is placed in service to ensure it is serviceable and to get a benchmark for future trending of condition.

Unit 9-10 Transformer is in immediate need of testing and investigation to see if it should remain in service or planned for replacement. Also, the protective relaying should be replaced, and the temperature monitoring equipment (readable by the operator) replaced.

Unit 11 Transformer, similar to Transformer 7-8, is being replaced. However, it also needs the protective relaying replaced and temperature monitoring equipment (readable by the operator) replaced. Again, it is already assumed that testing will occur before the transformer is placed in service to make sure it is serviceable and to get a benchmark for future trending of condition.

Unit 12 Transformer needs painting, testing, protective relaying replaced, and the temperature monitoring equipment (readable by the operator) replaced.

11.1. POWERHOUSE MAINTENANCE

11.1.1. Power Station House Cleaning

The Kainji Hydropower Station is very dirty and needs a thorough cleaning. Primarily, because of the inoperable ventilation system, dust and dirt in the station contribute significantly to difficulty in spotting and diagnosing problems and loss of maintenance productivity, faulty controls, improper operation and overheating of equipment. This leads to equipment failure, downtime and costly equipment repairs.

Dewatering after the November 2000 station flooding left a coating of oil on floors, walls and equipment. Portions of the plant have been cleaned but there is still much to do.

Figure 23. *Unit 6 Turbine Pit showing dirt, grease and grim on the equipment parts.*

The cleaning of floors, walls and exterior of equipment could be performed fairly inexpensively by unskilled labor with a minimum of supervision.

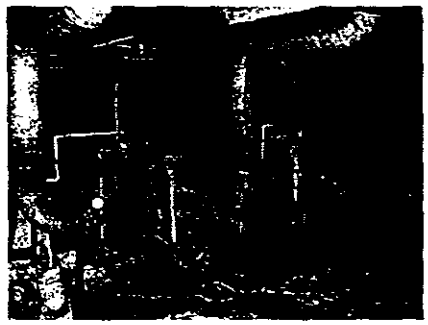

Figure 24. *Corrosion and dirt on raw water pumps.*

Skilled powerhouse personnel could then go through the plant and clean the interior of equipment and electrical panels. After the cleaning, a check should be made of the controls, operability and condition of equipment. Inoperable controls should be repaired immediately. Repairs and replacements should be prioritized and fixed accordingly.

11.1.2 Procurement of Supplies and Spare Parts

The availability of replacement and spare parts and maintenance supplies is poor. The equipment is old enough that original manufactures and suppliers of equipment are often no longer in business, have been bought out by other companies or have changed their names, addresses and phone numbers. Also, if the original manufacturer is located, the specific model of equipment is most likely no longer available. This makes it difficult for procurement people to locate needed supplies and parts.

Figure 25. *Control panel fire damage.*

It is necessary for the technical managers and skilled workers at the project to contact companies and find replacement or substitute parts. Vendors and technical representatives for industrial equipment usually have run across similar problems with other utilities and are a wealth of information in solving replacement part problems. To fully utilize these outside resources, the project needs at least a functioning phone system. The Internet would give Kainji staff easy access to vendors and parts manufacturers. Communication with vendors and manufacturers helps in developing a technical library with up-to-date catalogs for equipment on site. The O&M manuals received at the end of construction have contacts for manufacturers and spare parts that need to be updated.

NEPA and the projects are currently isolated from the hydropower community and are not utilizing industry knowledge and resources. International conferences are held yearly with attendance from other utilities, manufacturers and contractors that share knowledge and experiences. Attendance at these conferences and membership in industry organizations provide project personnel exposure to valuable technical papers written on subjects similar to problems NEPA is experiencing. The technical papers also provide names and phone numbers of the authors so they can be contacted and share their experience to help solve problems at Kainji and other NEPA stations.

Also available are industry periodicals such as *Hydro Review, Water Power and Dam Construction, Power Engineering, Cranes Today, Pumps and Systems (Rotating Equipment), EC&M (Electrical Design, Construction & Maintenance), IEEE Power Engineering Review.* These periodicals not only have state-of-the-art developments in the power business, but also provide information on upcoming conferences and have advertisements for many companies in the business.

One of the most important spare parts needed at Kainji is an additional set of draft tube bulkheads. The project currently has only one set. Because of this, only one unit can be dewatered for maintenance and repairs at a time. One set is needed for overhauls and repairs. A second set is needed to do emergency repairs and routine maintenance. Many maintenance tasks are now being deferred because the draft tube bulkheads are being used for the ABB work on Unit 11 and are not available for routine maintenance.

11.1.3 Powerhouse Maintenance Recommendations

The TAT recommends that the following actions be taken immediately:

1) Procure an additional set of draft tube bulkheads for maintenance use.
2) Develop new processes for obtaining spare parts. Have the technical people at the project find the parts needed through direct communications with manufacturers, vendors and other utilities. Provide this specific information to the NEPA procurement people for purchasing.
3) Provide phone service to the projects. Even satellite phones are inexpensive relative to downtime losses due to generating unit unavailability. Reliable phone service also provides internet access that really opens up communication capability.
4) Update contacts listed in the O&M manuals. This could be done from Abuja where phone service is somewhat more reliable.
5) Obtain up-to-date manufacturer catalogs for equipment on site. Replacement equipment alternatives can easily be determined with the availability of these catalogs.
6) NEPA should allow the project staff to network more with the hydropower industry by attending international hydropower conferences and subscribing to industry periodicals.

12.1 OTHER SUGGESTED MAINTENANCE IMPROVEMENTS

12.1.1 Automated Maintenance Management System

The Kainji project staff uses written schedules and procedures for performing maintenance on equipment. Records on maintenance and repairs are recorded on paper logs stored in file cabinets. These paper records were the only maintenance and repair history available for the generating units. Drawings are kept in a vault remote from the powerhouse. USACE electricians and mechanics use a maintenance checklist for preventative maintenance on each unit. The maintenance intervals are annual, biennial, & quadrennial; with increasing maintenance work performed when progressing from annual to quadrennial. A clean set of forms is used for each inspection of each unit with notations made for later review and reference. The TAT was shown a list with dates for when the Kainji units were scheduled for checks, but it is not known whether the inspection results is actually recorded. These inspections appeared to be mainly for the purpose of checking alarms and protective devices. The TAT will provide a copy of the USACE Mechanical and an Electrical Maintenance Checklist to the Kainji staff at a later date that could be used as a model for unit maintenance inspections.

The Automated Maintenance Management Software (AMMS), such as Maximo and Dynastar, is available off-the-shelf to help managers and work crews optimize maintenance performance. AMMS uses a database of the power station equipment to store equipment specific information, schedule maintenance, track progress and man-hours needed for tasks, keep inventory and vendor records of spare parts, and reference drawing and manual information. Many AMMS systems scan in drawings and manuals so they are readily available to view on a computer monitor. The maintenance crews can easily print portions of the drawings for later use. The AMMS can be set up to automatically provide work orders for equipment maintenance on a pre-described schedule (weekly, monthly, or yearly) for required maintenance tasks. After the maintenance is performed, data entry on man-hours, supplies used, and notes for future repairs can be entered for future maintenance. The AMMS system is a great tool for maintenance managers in tracking what work is accomplished and what still needs to be performed. Tracking man-hours for maintenance tasks develops a knowledge base for scheduling maintenance and optimizing available resources. The automatic listing of needed tasks helps managers decide which items are most important and what items can be deferred if manpower and material resources are not available. Status reports of equipment can be used by operators to modify needed operating procedures as necessary.

The AMMS is a great scheduling tool for scheduling different crews and can be used by multiple managers. Cleaning tasks and crews, routine maintenance tasks, repairs and major rehabilitation projects can all be scheduled and tracked separately and reported as needed. AMMS helps increase productivity and use of manpower and dollar resources to keep the plant better maintained and increase reliability and availability. Most power utilities worldwide now use automated maintenance management systems. It is highly recommended that NEPA purchase, configure and use off-the-shelf automated maintenance management software to optimize maintenance resources.

12.1.2 Availability of "As-Built" Drawings

Maintenance staff and operators need access to as-built, as-modified, up-to-date drawings. It is difficult, if not impossible, to know the current status of equipment and controls without having an up-to-date set of drawings, especially schematics, readily available for operators and the maintenance staff. Logs need to be kept on equipment condition and availability so operators can make appropriate maintenance decisions. Maintenance staff needs to know what the operable condition of all equipment is all times. Drawings should have any notations or mark-ups of any changes so that maintenance managers can effectively assign and track maintenance work orders and keep operators informed of equipment operating status. Failure to do so could lead to operator misuse of equipment and subsequent damage, extended outages and costly repairs.

12.1.3 Retirement or Service Life

The USACE publishes regulations related to the life cycle of equipment for capitalizing and recovering the cost of major items of equipment. A list of the major items and their life cycle is provided in Appendix D.

12.1.4 Ten year plan

In Appendix E is a drafted recommendation for a ten-year plan showing the major items of equipment, the priority of replacement and approximate cost for the Kainji power station. **(This appendix will be added at a later date).**

13.1 HYDROLOGY AND HYDROPOWER OPERATIONS

13.1.1 General

The TAT met with Generation and Hydrology personnel at the Kainji Hydropower Station to evaluate how the project utilizes available flows and storage to produce hydroelectric power. Hydropower is one of three primary purposes for the operation of the project. The other two purposes are navigation and flood control. Currently, the project is not operated for navigation because of the lack of navigation commerce and the poor operating condition of the navigation lock. The flood control operation is normally guided by a flood control rule curve. The rule curve allows the reservoir to be at or near minimum operating pool in late July to capture the peak runoff from the White Flood, one of two annual peak runoff events. The July-August period is the peak inflow period for the Kainji reservoir. The second peak runoff event, the Black Flood, occurs in early December but is of less magnitude than the White Flood. The reservoir is normally full from December to March. The flood control drawdown period normally occurs from late March to July.

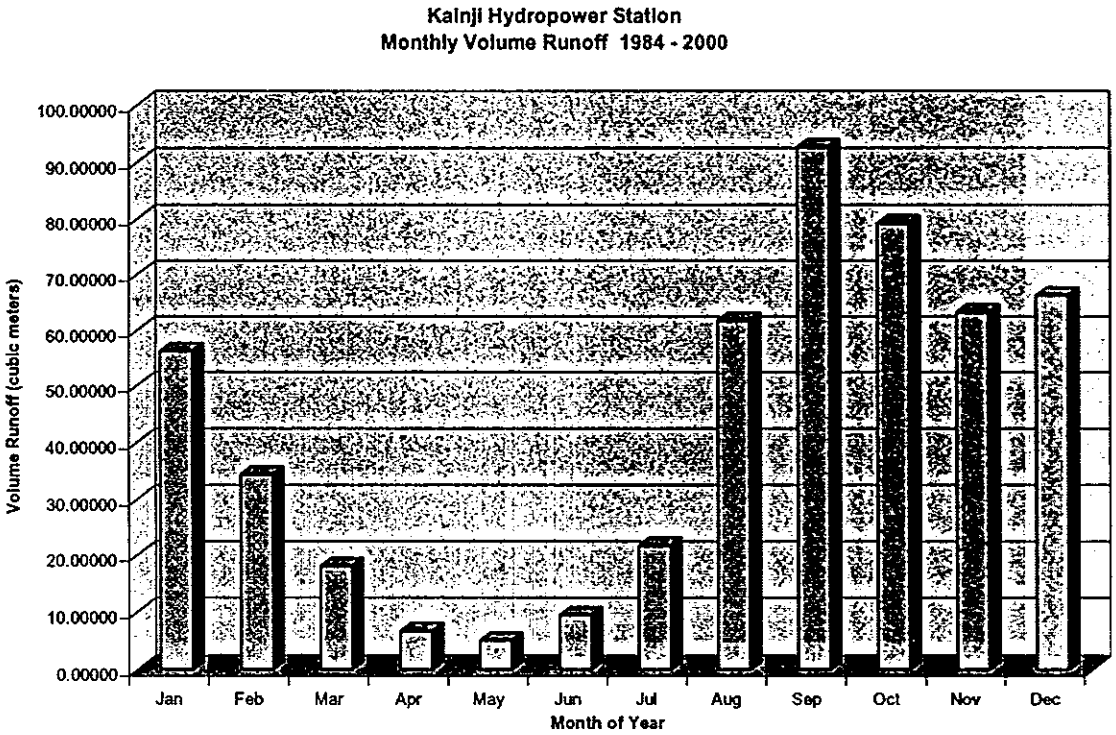

Figure 26. *Monthly volume runoff into Lake Kainji*

Hydropower is a secondary purpose to flood control in regulating releases from Lake Kainji. But because of Nigeria's electrical system reliability and capacity inadequacy problems, Kainji has been forced to generate power during periods when it normally shouldn't. In June 2001, only twenty-six (26) out of NEPA's seventy-nine (79) thermal and hydropower generating units were available for service. The unavailability of generating units places an added stress on the available units to meet a power demand that far exceeds NEPA's generating capability. A conservative estimate of the national peak power demand is approximately 3200 MW. This total does not include an estimated 4,000 MW expensive off-the-grid generation that has emerged in Nigeria because of chronic reliability and voltage stability problems with the national grid. Large diesel generators providing backup capability to businesses are primarily producing this off-the-grid generation. The most recent highest sustained peaking capability measured on the national grid was 2,600 MW in January 2001. Because of the lack of adequate system capacity, the consequence for Kainji is that the project is forced to utilize it's fuel, the inflow from the Niger River, in a less than efficient mode of operation.

The current hydropower operation of the Kainji hydroelectric units is neither an optimal or economical utilization of the water resources available in the project's drainage area. Kainji powerhouse units are forced to produce too much base load generation during non-peak hours and are stretched beyond their peak operating range during peak demand periods. This inefficient use of inflow and stored water prematurely draws down the reservoir, reducing the

project's capability to generate during peak demand periods, putting the electrical system at a further risk of an inadequate power supply for future periods. Unnecessary base load and extended peak operation of the generating units increases wear and tear thereby accelerating unit deterioration and increasing maintenance costs.

Figure 27. *Lake Kainji looking upstream from the dam crest.*

The lack of adequate capacity in the NEPA system is not allowing the Kainji units to operate at their economic optimum. During peak demand periods, these units should be displacing expensive high fuel cost thermal generation to maximize benefits from capital investments made in the project.

13.1.2 Powerhouse Operation

Typically, a hydro station the size and capacity of Kainji would operate at an average annual plant factor of approximately forty to forty-five percent. The average annual plant factor for the Kainji powerplant over the last twenty-five years is twenty-nine percent. The average annual energy generation produced by the Kainji units over the last twenty-five years is approximately 1,906,300 MWh. At a forty-five percent plant factor, the Kainji units should produce approximately 2,995,900 MWh of energy, an additional thirty-six percent over present production. In recent years, sufficient water has been available to adequately operate the units at Kainji. Volume runoff into Lake Kainji for the past three years (1998,1999 and 2000) was above the sixteen (16) year average with the 1999 runoff being the highest for the 1984 – 2000 period of record (see Fig. 27 and Table 1).

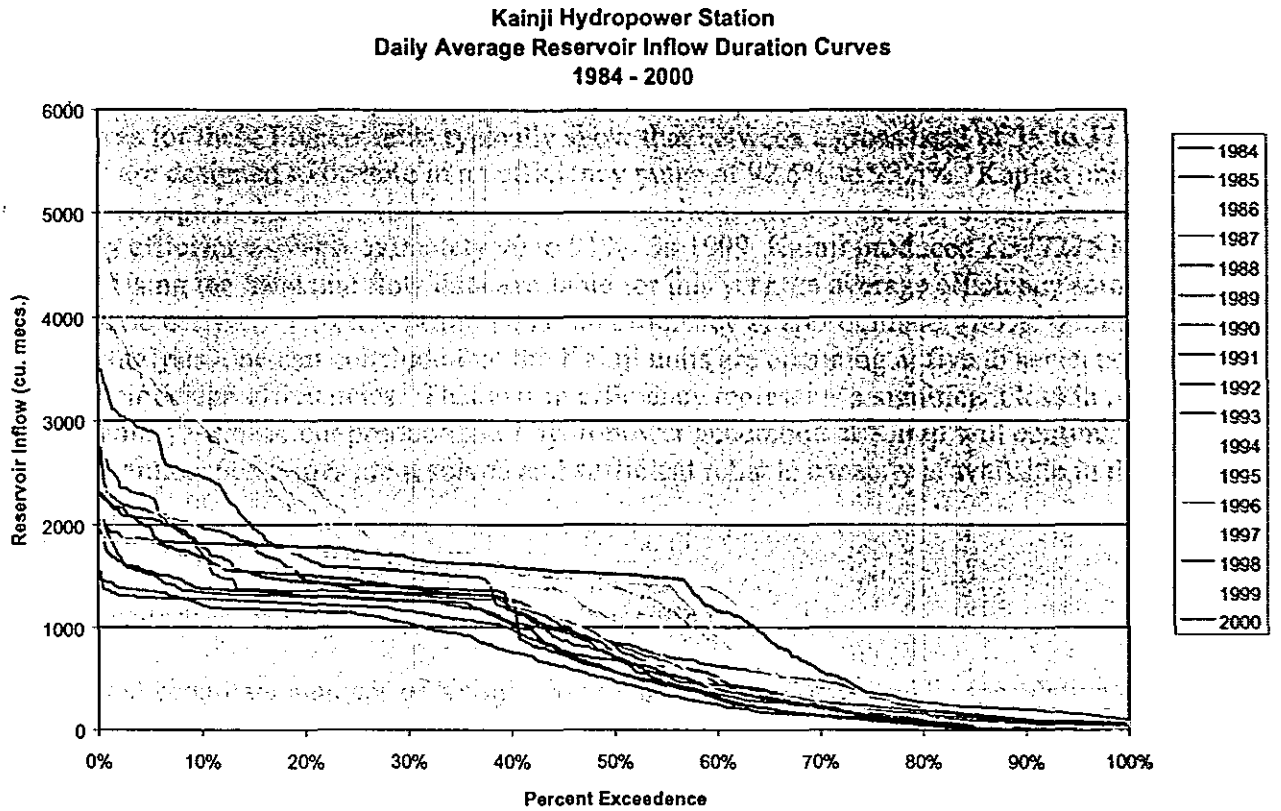

Figure 28. *Yearly Lake Kainji Inflow Duration Curves.*

TABLE 1.
Lake Kainji Volume Runoff

Year	Vol. ($m^3 x 10^6$)
1984	18.61239
1985	24.32653
1986	24.63282
1987	21.12766
1988	31.68125
1989	28.85035
1990	22.63318
1991	29.03732
1992	26.96234
1993	23.02025
1994	37.32006
1995	37.27554
1996	34.64555
1997	29.81838
1998	42.90582
1999	45.00051
2000	37.09430
Average	**30.29084**

The Generation Department provided the TAT with unit performance curves for Units 5 and 6. The curves for these Francis units typically show that between a gross head of 35 to 37 meters, the units are designed to operate in an efficiency range of 92.5% to 93.5%. Kaplan units of Kainji's vintage in the 80 to 100 MW range at rated head and horsepower usually have an operating efficiency of approximately 90 to 91%. In 1999, Kainji produced 2,377275 MWh of energy. Using the head and flow data available for this year, an average efficiency across all the units can be derived. This derivation yields an efficiency of approximately 86%. From this cursory analysis, one can conclude that the Kainji units are operating at five to seven percent below their design efficiencies. This loss in efficiency represents a significant loss in revenue and capability. Inefficient production of hydropower generation at Kainji will continue until critical maintenance issues are resolved and sufficient reliable capacity is available in the national grid.

13.1.3 Economics of Kainji Hydropower Generation

An optimal economic analysis of Kainji's hydropower operation would be speculative at best given the present economic environment in which the powerplant operates. Attempting to compute a representative value for Kainji's energy and capacity in the present energy market would not be prudent. Presently, NEPA is losing money on every kilowatt of power it generates. This situation is brought about because of three primary reasons. First, prices for electricity from NEPA's power generating resources, including Kainji, is heavily subsidized. This practice makes it extremely difficult to realize the true market value of the Kainji generation. Secondly, the manner in which the water is released through the turbines is inefficient. Generation from Kainji units is produced "as needed" as calls for it is made from the National Control Center (NCC). These uneconomical calls from NCC are motivated by the unavailability of adequate capacity in the NEPA system. In some months, water is spilled from Kainji when units are not available, to provide adequate flows for the Jebba Hydropower Station downstream. In a capacity adequate system, the optimal use of Kainji's generation would be used to displace expensive thermal resources during peaking periods. Third, unmetered consumption of electrical power and the collapse of the revenue collection system make it extremely difficult to recover actual cost to produce power at Kainji. These situations need to be rectified immediately in order for the Kainji Hydropower Station to realize it's true economic value.

13.1.4 Generation Expansion

The Kainji Hydropower Station has four empty bays, with penstocks already installed, in which additional units could be installed. It would not be prudent at this time to consider expanding into the existing empty bays because of chronic reliability problems and the instability of economic conditions. Once maintenance, reliability and unit availability problems are adequately addressed, there might be some additional benefits of utilizing an additional unit primarily as a synchronous condenser to improve voltage stability on the national grid. Stabilizing the grid and preventing outages can be a significant economic benefit weighed against the cost of an additional unit. Furthermore, if the capacity adequacy problem is resolved in the near future, an additional unit at Kainji could be utilized as a peaking unit during peak demand periods. A more detailed analysis would be required to determine if additional flows are

available to operate another unit in any mode.

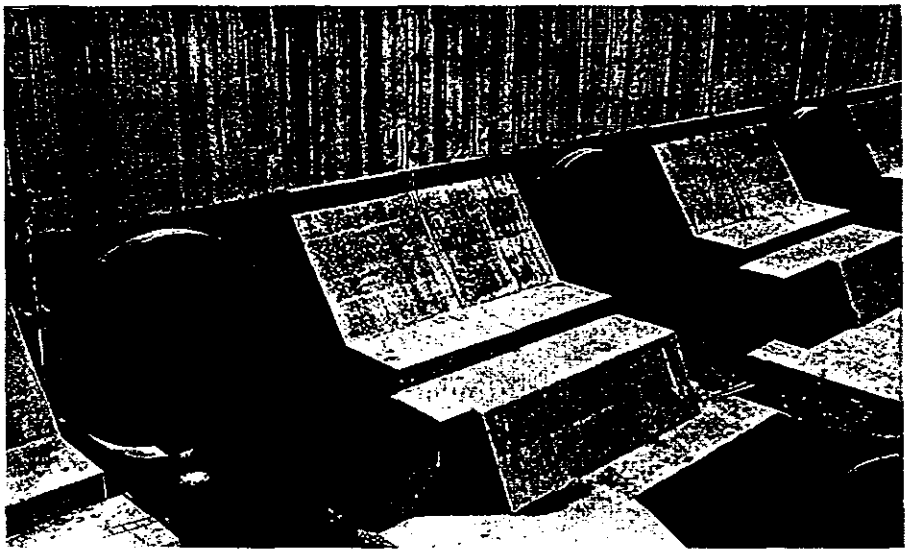

Figure 29. *Empty unit expansion bays showing installed penstocks.*

13.1.4 Hydropower Operations Recommendations

The operation at the Kainji Hydropower Station is being severely impacted by the lack of adequate capacity in the NEPA system to meet the country's demand for power. The unavailability of existing installed capacity is further aggravating the efficient operation of the Kainji units. If and when the mechanical and electrical recommendations in this report are implemented and unit availability is improved at NEPA's thermal plants, some efficiency improvements could be realized in the operation of the Kainji units. These recommendations are made with the above considerations in mind:

1) Releases from Lake Kainji should follow the operating rule curve as much as available flows would allow.
2) The primary hydropower mode of operation should be for daily peaking to displace expensive thermal generation.
3) Spill for the Jebba Hydropower Station should not occur if Lake Kainji is below its operating rule curve.
4) A detailed hydrologic, economic, and load growth analysis should be performed to determine the feasibility of adding units in the empty unit bays.
5) Hydrologic and generation data management at both Kainji and Jebba should be updated and modernized to improve data analysis, operational planning and water/reservoir management. Appropriate computer technology, including computers, printers and color plotters, should be acquired immediately. This should be a priority item because data collection is continuing on an hourly basis.
6) Modern hydrology measuring equipment should be acquired as soon as possible to ensure the most accurate data collection as possible. This equipment should include electronic flow/current meters for tributary measurements and project discharges, and porcelain enameled iron staff gages for elevation readings.

14.1. DAM MONITORING AND SAFETY INSPECTION

The Kainji Dam safety inspection was carried out in conjunction with a comprehensive evaluation of the powerhouse. The dam safety inspection focused on the physical conditions of the project, an evaluation of the project's instrumentation and an evaluation of the instrumentation readings, and an evaluation of the Dam Safety Program.

14.1.1 Project Description

The Kainji Project was designed by a joint venture of NEDECO and Balfour Beatty Company Ltd. during the 1950's and early 1960's. The dam was constructed between 1964 and 1968 by IMPREGILO a consortium of three Italian companies. The project consists of a right and left embankment section separated by the concrete intake structure and spillway section.

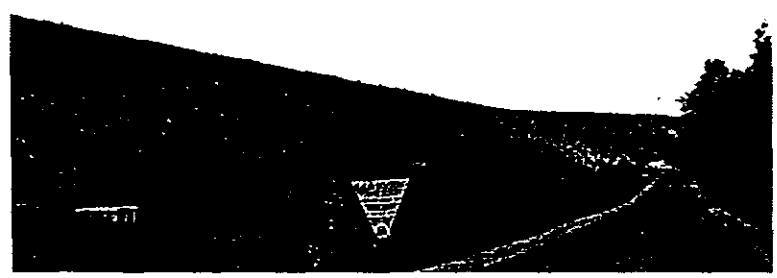

Figure 30. *Right embankment dam with seepage monitoring station at lower left.*

There is also a 4.1 kilometer (km) long saddle dam located approximately 1.6 km northeast of the project. The right embankment dam consists of a 1.1 km long earth filled section with a maximum height above the foundation of about 15 meters (m). Relief wells have been incorporated along the toe of this section to control seepage. The right earth fill section transitions into the right earth and rock fill section. This section is 1.3 km long with a maximum height of 73 m. The rock fill embankment dam and adjacent concrete sections are founded on rock, as is the left embankment dam. The right and left embankment dams abut the concrete intake and spillway structure. The concrete structure is 550 m long and with a maximum height of 63 m at the spillway section. The concrete section consists of the abutment blocks, the power intakes, and the gated spillway section. The concrete intake section contains 12 penstock intake gates for the powerhouse, the spillway consists of four 18 meters high hydraulically activated radial tainter gates. The left embankment dam abuts the spillway section. It is a 1,220 m long earth and rock fill embankment founded on rock with a maximum height of about 42 m. A navigation lock is located about midpoint along this section. The lock has a maximum lift of

41.2 meters. A 4.1 km long saddle dam is located approximately 1.6 km northeast of the left embankment dam. The saddle dam is an earth fill embankment founded on residual soils. The structure has a maximum height of about 15 m. Under seepage is controlled with a series of relief wells located along the toe of the structure. After operation of the dam it became necessary to install additional relief wells below a portion of the saddle dam to control high water levels that occurred during high pool levels. Numerous foundation and embankment piezometers were installed at ten different embankment sections. An additional 121 piezometers are located under the outlet and spillway structures to monitor uplift on the structure. An internal drainage system was designed into all of the embankment sections. The drainage is drained to the toe of the dam at fifteen different locations and is monitored at eight different locations. In addition to the seepage control and monitoring features, instruments were installed to measure internal settlement and total settlement and deformation. This instrumentation consists of internal settlement gauges and extensiometers located at 3 different sections in the main embankment dams. To measure crest deflection and deformation brass pins were installed at seven locations on the right fill dam and nine locations on the left fill dam, and four monuments on the concrete dams. Permanent monuments were installed downstream of the project as reference points. The concrete sections were equipped with five direct plumb lines and one indirect plumb line for measurement of deflection in the structures.

14.1.2 Conditions at time of Inspection

Rain showers had been falling prior to the inspection but the area was generally dry. Rainfall had been insufficient to start the refill of the reservoir, resulting in a reservoir elevation of 132.35 m, which is near the minimum power pool. The tailwater was at elevation 102.9 m. Sufficient rain had fallen during the past few months to cause regrowth of vegetation on the embankment structures.

14.1.3 Inspection of the Dams

Embankment Dams: At the time of the inspection the relief wells and embankment drains were dry or nearly dry, and no areas of seepage were observed. Weir readings were available up through June 2001. Piezometers in this area are presently out of service due to vandalism in the instrumentation rooms and a malfunctioning readout box.

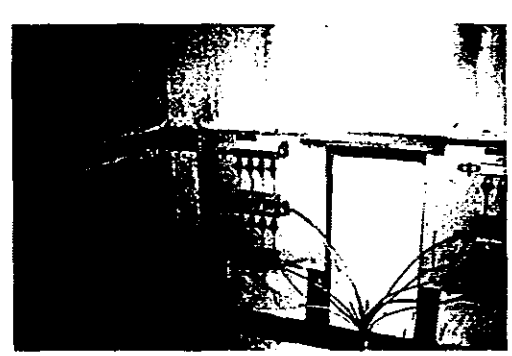

Figure 31. *Piezometer readout panel.*

The last published piezometer readings were from mid-year 1997. The down stream face of all embankments were in good condition, and showed no signs of distress. Some vegetation has started to regrow as a result of recent rains. The growth is reportedly removed annually.

Figure 32. *Right embankment dam crest and wave wall.*

The crest of the dam had a considerable amount of grass growing on the right embankment and saddle dam structures. No signs of excessive deformation were observed. The left embankment dam crest was paved, which would have caused any significant deformations in the crest to be easily detected. None were observed. A wave wall located on the upstream edge of the crest of all embankments was in good shape and shows no signs of deformation.

Figure 33. *Saddle dam crest looking from left abutment area.*

The riprap on the upstream face of the embankment dams was generally in good shape.

Figure 34. *Right embankment and riprap face.*

Some areas of very minor wave erosion were noted.

Figure 35. *Upstream face of left embankment dam.*

The abutments and downstream toe area of the structures were in good condition.

Figure 36. *Right embankment dam abutment with concrete intake structure.*

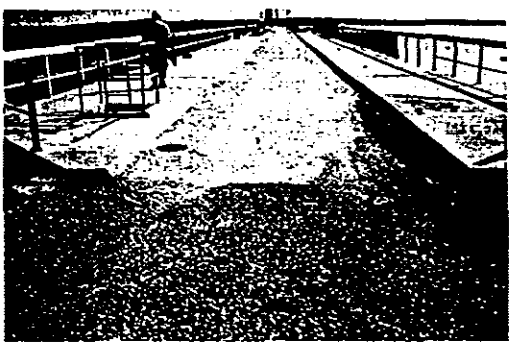

Figure 37. *Left embankment dam abutment with concrete intake structure.*

Some sinkholes have occurred about 100 feet downstream of the left embankment dam. The sink holes are in construction fill material and appear be the result of rain water washing the upper finer grained material into a more open fill material under it. The sinkholes do not appear to be related to the embankment structure in any way.

Intake Structure and Spillway Dam: The Intake Structure and Spillway Dam were inspected for structural integrity and to the extent possible the condition of the mechanical equipment.

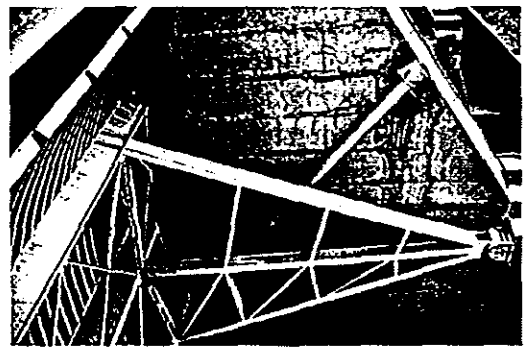

Figure 38. *Spillway gate trunion and hydraulic lift cylinder.*

The decks of the two structures are significantly cracked, but the cracking is in an irregular pattern typical of shrinkage cracking. The cracks do not seem to penetrate the structure more than about one foot.

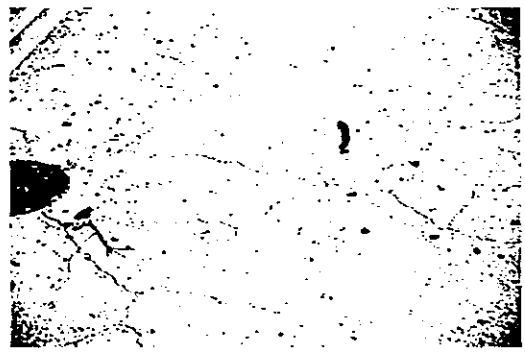

Figure 39. *Typical shrinkage cracking in the concrete intake structure.*

Spalling and other signs of distress at construction joints and around openings were minimal. Some instrumentation had been installed to measure crack displacement, but any displacement that may have occurred did not result in any distress or visible signs of offset. Inspection of the various galleries showed few cracks to be present and none that appeared to be significant. Most cracks that were noted were at lift lines or construction joints, and showed no signs of displacement. Leakage into the galleries through joints or cracks was almost non-existent. Relief wells are producing minimal amounts of flow, and do not appear to have any significant deposits that may be restricting the flow from the drains. Data on flow from the relief wells was not provided. A review of instrumentation for the structures show uplift readings to be fairly consistent and below the design line. Plumb line readings show deflections of less than 26 mm in the downstream direction and 10 mm parallel to the axis of the structure. Triangulation surveys of the structure show total displacement of up to about 40 mm in the upstream direction and 30 mm parallel to the structure. The accuracy of the triangulation surveys is not known but is generally assumed to be within an acceptable tolerance.

14.1.4 Navigation Lock

The navigation lock is not operational due to vandalism of the control system. Structurally, the lock appeared to be in good condition. No signs of significant leakage or cracking were noted. The upstream radial miter gates are in a closed position with the downstream gates in an open position. Since the lock is not being operated, it is recommended that the upstream bulkheads be installed so that the miter gates are in a dry environment to extend their life. Also, the miter gates can be exercised open and closed annually to preserve and inspect the condition of the operating equipment.

14.1.5 Dam Safety and Instrumentation Program

The project has an instrumentation and inspection program in place. The personnel in charge of the program are highly qualified and very knowledgeable, and are performing in a satisfactory manner but are hampered by the difficulty in obtaining repair parts. In addition to project personnel, NEPA has an engineer dedicated to dam safety and instrumentation that works with the personnel at the three different hydropower projects operated by NEPA. To supplement the in-house dam safety program, a private engineering firm is contracted to provide an in-depth review of the projects every five years. The Program in place is sufficient to ensure the safety of the projects, but there is a need to be able to acquire instruments and purchase repair parts for existing instruments.

14.1.6 Dam Safety Recommendations

The TAT would suggest the following dam safety recommendations to enhance and strengthen the existing program.

1) Replace or repair damaged instruments and recorders.
2) Formalize existing dam safety practices and implement others.
3) Place bulkheads or stoplogs in navlock to keep upstream miter gates in a dry environment.

APPENDIX A

Kainji Hydropower Station Hydraulic and Operating Data

Operational and hydrologic data records at the Kainji Hydropower Station are presently being hand-recorded on log sheets. Upon requesting operating data, the TAT was presented with stacks upon stacks of old faded log sheets that are being archived in a file cabinet at the power plant. The TAT was told that this is the only operating data available for the plant. The TAT had twenty-five years (1975 – 2000) of historical operating data from the log sheet photo copied for later analysis. Sixteen years of reservoir inflow data recorded on log sheets was also copied and given to the TAT. The TAT has digitized the operating and reservoir inflow data and forwarded it to the Kainji Hydropower Station Generation and Hydrology departments on compact disk. Below is a summary of some of the data analysis.

Kainji Hydropower Station
Average Annual Energy Generation (MWh)

1975	**1,937,700**
1976	**2,227,686**
1977	**2,518,610**
1978	**1,894,060**
1979	**2,798,212**
1980	2,719,542
1981	2,299,131
1982	2,403,970
1983	1,859,128
1984	1,305,459
1985	1,475,664
1986	1,611,248
1987	1,444,062
1988	1,416,153
1989	1,511,858
1990	1,029,990
1991	1,635,280
1992	1,581,701
1993	1,413,761
1994	2,142,163
1995	2,385,860
1996	1,888,647
1997	1,576,564
1998	2,368,862
1999	2,377,275
2000	**1,741,696**
AAE	1,906,318

* The numbers in bold print were computed from head and flow data provided by the Generation staff at Kainji.

APPENDIX B

List of Industry Periodicals and Publications

1. HYDRO REVIEW. ISSN 0884-0385, HCI Publications. 410 Archibald Street, Kansas City, MO, 64111, USA, (816)931-1311, www.hcipub.com.

2. EM&C, (Magazine of Electrical Design, Construction and Maintenance), A PRIMEDIA Publication, P.O. Box 12901, Overland Park, KS 66212, USA, (800)441-0294, www.ecmweb.com

3. IEEE POWER ENGINEERING REVIEW, ISSN 0272-1724, a publication of The Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, New York, NY 10016-5997, USA, (212)419-7900, www.ieee.org

4. IEEE Computer Applications in Power, ISSN 0895-0156, a publication of The Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, New York, NY 10016-5997, USA, (212)419-7900, www.ieee.org.

5. INTERNATIONAL WATER POWER AND DAM CONSTRUCTION, ISSN-0306-400X, Wilmington Publishing Ltd., PO Box 200, Ruislip, Middlesex HA4 OSY UK, Tel: +44 20 829 7818, www.connectingpower.com.

6. POWER ENGINEERING, ISSN 0032-5961, published by PennWell Corp., 1421 S. Sheridan Rd., Tulsa, OK, 74112, USA, (918)835-3161, www.power-eng.com.

7. PUMPS & SYSTEMS ROTATING EQUIPMENT, ISSN 1065-108X, published by Randall Publishing Company, Inc., PO Box 2029 Tuscaloosa, AL 35403-9836, USA, Fax (800)761-4119, www.pump-zone.com.

8. CRANES TODAY, published by Wilmington Publishing Ltd., PO Box 935, Finchingfield, Essex CM7 4LN UK, Tel: +44 1371 810433, www.connectingcranes.com.

9. Water Power and Dam Construction, published by Wilmington Publishing Ltd, Wilmington House, Church Hill, Dartford, Kent DA2 7EF, United Kingdom, Tel: +44 (0) 1322 277788, e-mail: waterposer@wilmington.co.uk, Web Page: www.connectingpower.com

APPENDIX C

Mechanical and Electrical Maintenance Check Lists

(This appendix is available in PDF format and will be provided at a later date)

Account Number C of E	Account Number FERC	PRIN-CIPAL ITEM	SUB-ITEM	PLANT ITEMS	SERV LIFE YRS	RETIREMENT UNITS	REMARKS
06	(*)			FISH AND WILDLIFE FACILITIES (CONT'D)			
		13.		Lighting System, excluding Lighting Boards and attached Accessory equipment	50	Each Independent System, complete	
		14.		Main Power System, excluding Power Boards, Engine Generator Sets 100-kw and over and Transformers 1,000 kvq and over	50	Each Independent System, complete	
		15.		Main Power, Lighting and Control Boards, complete with attached accessories	35	Board, complete	
		16.		Transformers, Liquid-filled or Air or Gas insulated, 1,000 kva total or more in one or more phases not part of power board	40	Transformer, complete	
		17.		Engine Generator Sets, 100-kw or over	40	Generator Set, complete	
		18.		Air Compressors, complete, 100 cfm and over	25	Compressor, complete	Does not include unattached air receivers.
		19.		Roof Coverings, 3,000 sq. ft. or over per building	20	Complete roof covering for one building	
		20.		Trucks and Fish Transportation Tanks	10	Truck, complete; or Tank, complete including Refrigeration and Aeration Equipment, if applicable	
		21.		Fish Trapping Station, Concrete complete	50	Station, complete	
		22.		Fish Trapping Station, Timber, complete	25	Station, complete	
		23.		As Fingerling By-pass Channels, Systems applicable and Equipment	XX	As applicable	There is extreme variation in the structural and mechanical features of the various types of by-pass facilities provided and recently constructed facilities consist of comparatively experimental innovations. Therefore proposed subunits, retirement units, and estimated service lives will be submitted to HQDA, CECW-OM-O, WASH, DC 20314 for approval by each affected district.
		24.		As Fish Attraction and Guidance Systems; applicable Sonic, Visual, Electrical and Electronic	XX	As applicable	These systems are relatively experimental with extreme variation in physical features of various types of facilities provided. Therefore, proposed subunits with service lives will be submitted to HQDA, CECW-OM-O, WASH, DC for approval by affected districts.
07	-			POWER PLANT			
071	331			POWER HOUSE			
		1.		Basic Structure, excluding other principal items	100	Complete Structure, including subitems a-s	
			a.	Lighting Systems, excluding Boards and attached Accessory Equipment		System, complete	

(*) May be either FERC Account 331 or 332

Account Number Col B	Account Number FERC	PRIN-CIPAL ITEM	SUB-ITEM	PLANT ITEMS	SERV LIFE YRS	RETIREMENT UNITS	REMARKS
071	331			POWER HOUSE (CONT'D)			
			b.	Water Systems, Potable and Raw Water		System, complete	
			c.	Sewer Systems		System, complete	
			d.	Heating and Ventilating Systems		System, complete	
			e.	All Components not listed elsewhere		None	
		2.		Intake Structure (when integral part of powerhouse)	100	Complete structure, including subitems a–f	
			a.	Lifting Beams		Complete Set of all Intake Beams	
			b.	Intake Gates		Gate, complete	
			c.	Machinery, Gate Operating		Complete System for one Gate	
			d.	Stoplogs and Bulkheads		Complete Set of all Gates	
			e.	Crane, complete, excluding Mobile and Crawler types		Crane, complete	
			f.	All components not listed elsewhere		None	
		3.		Elevators, complete with Operating Mechanism, excluding embedded parts	40	Elevator, complete	
		4.		Trash Racks	40	Complete Set for one Generating Unit	Installed cost of the removable portion of trash racks only should be included here.
		5.		Floating Trash Booms	25	Each independent facility, complete	
		6.		Roof Coverings, 3,000 sq. ft. and over	20	Roof Covering, complete for one Structure	
072	333			TURBINES AND GENERATORS (INCLUDING STATION SERVICE)			
		1.		Turbines (excluding components listed separately in Items 4 thru 12 below)	50	Complete turbine, including subitems a–f	
			a.	Wicket Gates		Complete Set for one unit	
			b.	Shaft, including Kaplan Blade Control not located in the hub		Shaft, complete for one unit	
			c.	Butterfly Valves		Complete Set for all units	
			d.	Pressure Regulators		Complete Set for all units	
			e.	Embedded Turbine Parts		Complete Set for one unit	
			f.	All Components not listed elsewhere		None	
		2.		Generators (excluding components listed separately in Items 4 thru 12, below)	50	Complete Generator, including items a–d	
			a.	Stator, complete, excluding winding		Stator, complete	
			b.	Shafts, including Thrust Collar		Shaft, complete	
			c.	Air Coolers and Piping furnished as part of Generator (Main units only)	50	System, complete for one unit	
			d.	All Components not listed elsewhere		None	
		3		Governors (excluding components listed separately in Items 4 thru 12, below)	50	Governor, complete set	
		4		Rotor Windings, complete	50	Winding, complete set for one unit	See additional instructions on next page.
		5.		Turbine Runner, complete	40	Runner, complete	See additional instructions on next page.
		6.		Governor Oil Pressure Pump, complete	40	Pump, or pumps complete for one unit	See additional instructions on next page.

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Account Number C of E	Account Number FERC	PRIN-CIPAL ITEM	SUB-ITEM	PLANT ITEMS	SERV LIFE YRS	RETIREMENT UNITS	REMARKS
072	333			TURBINES AND GENERATORS (COND'T)			
		7.		Generator Stator Windings	35	Complete winding for one Generator, installed	See additional instructions on next page.
		8.		Thrust Bearings	50	Bearing, complete	See additional instructions on next page.
		9.		Exciters, Main and Pilot Direct-connected	35	Complete Assembly for one Generator	
		10.		Governor Air Compressor 100 cfm and over	25	Complete Assembly	
		11.		Compressor, complete, primarily for draft tube water depression while condensing	25	Compressor, complete	Piping and separate air receivers should be included in item f, above.
		12.		Speed increaser	40	Complete assembly for one generator	

Account Number C of E	Account Number FERC	PRIN-CIPAL ITEM	SUB-ITEM	PLANT ITEMS	PERCENT OF TOTAL COST OF TURBINE, GENERATOR, OR GOVERNOR Normal FROM (%)	TO (%)	NOT TO EXCEED (%)	REMARKS
072	333			TURBINES AND GENERATORS SERVICE) (COND'T) The allowable range of percentages of original cost of replaceable components to the total original cost of generators turbines, or governors are indicated below.				
		4.		Rotor Winding	3	7	10	Rotor winding and insulation installed. Does not include pole iron.
		5.		Turbine Runner – Francis	9	13	15	Runner less shaft.
		5.		Turbine Runner – F.B.	9	13	15	Runner including hub and cone less shaft.
		5.		Turbine Runner – Kaplan	17	22	25	Runner, cone, hub, and hub mechanism less shaft and servo mechanism not installed in hub.
		6.		Gov. Oil Pressure Pumps	5	10	15	Pump and Motor only.
		7.		Gov. Ball Head	0.5	1.0	2	The speed control assembly including the fly balls only.
		8.		PMG Assembly	2	3	5	The PMG including the drive assembly (Part of the governor).
		9.		Stator Winding	12	16	20	The installed cost of the winding including the ties, wedges, and similar items and including the circuit rings but excluding the stator iron (a rewound unit will also include the cost of disassembly and reassembly as applicable).
		10.		Thrust Bearing	2	5	8	Includes only the shoes or segments and their supports and adjustment mechanism and the thrust runner.
		11.		Exciters, Main & Pilot	2	5	8	The generator mounted exciters and pilot exciters only. Excitation cubicles containing voltage regulation rheostat, field breakers and miscellaneous controls as well as separately mounted generators sets should be included in principal item 9 of account 73.1.
		12.		Governor Air Compressor	1	2	5	Only compressor units 100 cfm or larger should be included under this item.

Note: In using the above percentages the cost of the water depressing system or the speed increnser should not be included in the cost of the turbines, governors, or generators.

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Account Number C of E	Account Number FERC	PRIN-CIPAL ITEM	SUB-ITEM	PLANT ITEMS	SERV LIFE YRS	RETIREMENT UNITS	REMARKS
073	334			POWERPLANT, ACCESSORY ELECTRICAL EQUIPMENT			
		1.		Miscellaneous Equipment	50	Complete unit, including subitems a-f	
			a.	Generator, Neutral Grounding Equipment including Neutral Breakers		Complete System for all Generators	
			b.	Main Generator Bus or Cable System		Complete System for one Generator or Transformer	
			c.	Station Service Main Bus or Cable System		Complete System	
			d.	Annunciator System, including Switchboard mounted equipment		Complete System	
			e.	Grounding System, including Powerhouse Grounding Mat		Complete System	
			f.	All components not listed elsewhere		None	
		2.		Transformer, Station Service, liquid filled or Air or Gas insulated 1,000-kva or more in one or more phases (excluding those installed as part of Station Service Power Boards)	50	Transformer, complete	
		3.		Antenna Towers, 80-feet and higher	50	Tower, complete	Include in this account when provided primarily for remote control of generating facilities.
		4.		Radio or Microwave Buildings	50	Building, complete	Include in this account when provided primarily for remote control of generating facilities.
		5.		Main Generator Switchgear and Breakers including Air Compressors when applicable	40	Breaker or Switchgear, complete with Accessories	Does not include station service Breakers which should be included under item 7 unless both generator and station service breakers are in the same switchgear.
		6.		Engine Generator Sets 100-kw and over	40	Generator Set, complete	Include here if used for general station service, otherwise include under the feature for which furnished.
		7.		Lighting and Power Boards for Station Service and Unit Auxiliaries, including Breakers, Transformers, and attached Accessories	35	Board, complete	
		8.		Control and Auxiliary Switchboards and Benchboards, including attached Accessories (excluding applicable items listed below)	50	Panel, or Panels, complete, devoted to a single purpose	
		9.		Voltage Regulation and Excitation Equipment including Motor-Generator Set, when required (Main generating units only)	35	Complete System for one Generator	Generally furnished as part of the main generator contract.
		10.		Battery Switchboards including attached accessories	35	Board, complete	Does not include seperately mounted motor-generated sets.
		11.		Control Cable System	35	System, complete for Control Board, Panel, or Panels, devoted to a single purpose	
		12.		Load Control Equipment	15	System, complete for entire plant	

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Account Number C of E	Account Number FERC	PRIN-CIPAL ITEM	SUB-ITEM	PLANT ITEMS	SERV LIFE YRS	RETIREMENT UNITS	REMARKS
073	334			POWERPLANT ACCESSORY ELECTRICAL EQUIPMENT (CONT'D)			
		13.		Recording Annunciator mounted separately from switchboard	15	System, complete	
		14.		Data Logging Equipment mounted separately from switchboard	15	System, complete	
		15.		Electronic Supervisory Control and Data handling equipment	15	System, complete	
		16.		Control Processor, electronic control installation	15	System, complete	
		17.		Radio, microwave, or carrier equipment, complete system at one location including transmitter, receiver power supplies, auxiliary generators, batteries, cables, and antennas, but excluding land and improvements, buildings and towers 50 feet and over	15	Each independent system complete	Include in this account when provided primarily for remote control of generating facilities.
		18.		Storage Battery, 125 volts and over	20	Battery, complete	
		19.		Automatic Recording Oscillographs	15	Oscillograph, complete	
074	335			MISCELLANEOUS POWERPLANT EQUIPMENT			
		1.		Miscellaneous Equipment not listed elsewhere	50	Complete unit, including subitems a–g	
			a.	Bridge or Gantry Crane	50	Crane, complete	
			b.	Tailrace Crane, complete, (excluding Mobile or Crawler types)	50	Crane, complete	
			c.	Lubricating oil systems (excluding oil purifiers listed under item 4)		System Complete	Including piping, transfer pumps, storage tanks and all fixed equipment not listed elsewhere.
			d.	Drainage and Unwatering System, including Pumps		Each independent system, complete	
			e.	Fire Protection, High-pressure Water System, including Pumps		System Complete	
			f.	Station air system, excluding compressors 100 cfm and over		System Complete	
			g.	All components not listed elsewhere		None	
		2.		Antenna Tower, 50-- feet and higher	50	Tower, complete	Include in this account when provided primarily for communications or data transmissions in powerhouse generations.
		3.		Radio or Microwave Equipment Bldgs	50	Building, complete	Include in this account when provided primarily for communications or data transmissions in powerhouse generations.
		4.		Oil Purifiers, Fixed or Portable, Centrifugal, vacuum or Clay Treatment type, 600 gkp or over used for lubricating oil, hydraulic oil or lubricating and insulating oil	35	Purifier, complete	

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Account Number C of B	Account Number FERC	PRIN-CIPAL ITEM	SUB-ITEM	PLANT ITEMS	SERV LIFE YRS	RETIREMENT UNITS	REMARKS
074	335			MISCELLANEOUS POWERPLANT EQUIPMENT (CONT'D)			
		5.		Air Compressors complete, 100 cfm or over	25	Compressor, complete	Does not include unattached air receivers.
		6.		Plant Communication Equipment, including Telephone, Code Call, and Voice Recording Systems	15	Each independent system, complete	Include equipment installed in the power generating station for interplant communication in connection with power plant operation.
		7.		Radio, microwave or carrier equipment complete system at one location including transmitter, receiver, power supplies, auxiliary generators, batteries cables and antennas, but excluding land and improvements, buildings and towers 80 feet and over	15	Each independent system, complete	
075	332			TAILRACE			
		1.		Tailrace, complete	100	Complete Tailrace, including subitems a-b	Include draft tube bulkhead, stoplogs and other facilities used for draft tube unwatering.
			a.	Stoplogs and Bulkheads		Complete Set	
			b.	All other components		None	
076	331			SWITCHYARD			
		1.		Miscellaneous Structures and Equipment	50	Complete Item, including subitems a-i	
			a.	Steel Structures, complete (excluding foundations)		Complete Switchyard Structural System	
			b.	Bus & Insulators, including mounting hardware		Complete System	
			c.	Lighting System, excluding Boards and attached Accessory Equipment		Complete System	
			d.	Conduit, Steel, Power and Control		Complete System	
			e.	Insulating Oil storage and piping system (does not include oil purifiers listed under Item 10)		Complete System	
			f.	Power Transformers, 1,000 kva and over including Auto Transformers	45	Transformer, complete, excluding windings	
			g.	Main Power Cable, 15-kv and over		System, complete for each transformer	
			h.	Grounding System, including Grounding Mat, if separate from Powerhouse Grounding Mat		System, complete	
			i.	All components not listed elsewhere		None	
		2.		Reactors, Shunt or Series, 15-kv and over	50	Reactor, complete	

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Account Number C of E	Account Number FERC	PRIN-CIPAL ITEM	SUB-ITEM	PLANT ITEMS	SERV LIFE YRS	RETIREMENT UNITS	REMARKS
076	331			SWITCHYARD (CONT'D)			
		3.		Lighting Arresters, 15-kv and over per phase	35	Complete three-phase Set	
		4.		Transformers, Instrument, 15-kv and over, PT and CT	45	Transformer, complete	
		5.		Transformer, Regulating	45	Transformer, complete	
		6.		Circuit Breakers, 15-kv and over	50	Breaker, complete	
		7.		Disconnecting Switches, 15-kv and over	50	Switch, complete	
		8.		Coupling Capacitors, including auxiliary equipment	35	Coupling Capacitor, complete	
		9.		Carrier Current Line Traps	35	One unit for all Traps	
		10.		Oil Purifiers, Portable or Fixed, Centrifugal, Vacuum, or Clay Treatment, with or without Filter Press 600 gph or over	35	Purifier, complete	Used only for insulating oil purification.
		11.		Control Cable Systems	35	System, complete	
		12.		Lighting and Power Boards, complete with attached Accessory Equipment	35	Board, complete	
08	336			ROADS, RAILROADS AND BRIDGES			
		1.		Railroads	100	Complete item, including subitems a-e	
			a.	Rails		Rails for complete System	
			b.	Ties and Ballast		Complete System	
			c.	Road Beds, Railroad, including Culverts		Complete System	
			d.	Bridges, Concrete, Steel or Masonry		Bridge, complete	
			e.	All components not listed elsewhere		None	
		2.		Roads	100	Complete item, including subitems a-d	
			a.	Roadway Base and Culverts		Base for each independent road	
			b.	Roadway Surfacing		Surfacing for each independent road	
			c.	Bridges, Concrete, Steel or Masonry		Bridge, complete	
			d.	All components not listed elsewhere		None	
		3.		Bridges and Trestles, Railroad Timber	40	Complete Structure	
		4.		Bridges, Roadway, Timber	25	Bridge, complete	
09	332			CHANNELS AND CANALS			
		1.		Basic Features	100	Complete item, including subitems a-c	
			a.	Concrete Buildings, excluding replaceable Roof Coverings of 3,000 sq. ft. or over		Building, complete	
			b.	Other Concrete Structures		Structure, complete	

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APPENDIX E

Draft Recommendation 10-Year Plan

(To be added at a later date)