

**IFAS AGENCY for the GEF PROJECT**

**ARAL SEA BASIN PROGRAM  
WATER & ENVIRONMENTAL MANAGEMENT  
PROJECT**

**COMPONENT C:  
DAM SAFETY AND RESERVOIR MANAGEMENT**

**NUREK DAM  
SAFETY ASSESSMENT REPORT**

**MARCH 2000**

**GIBB**

**LAWGIBB Group Member** 

In association with



# NUREK DAM SAFETY ASSESSMENT REPORT

## CONTENTS

Chapter	Description	Page
1	INTRODUCTION	1-1
	1.1 Background to Project	1-1
	1.2 Safety Assessment Procedures	1-2
	1.3 Scope of Safety Assessment	1-3
2	PRINCIPAL FEATURES AND DIMENSIONS OF THE DAM	2-1
	2.1 Location, Purpose, and date of Construction	2-1
	2.2 Description of the Dam	2-1
	2.3 Hazard Assessment	2-2
3	DESIGN CONSIDERATIONS	3-1
	3.1 Hydrology	3-1
	3.2 Geology and Seismicity	3-1
	3.3 Construction Materials and Properties	3-1
	3.4 Seepage Control Measures	3-2
	3.5 Reservoir Draw-off Works	3-2
	3.6 Performance Monitoring Instrumentation	3-2
	3.7 Hydropower Facilities	3-3
4	DAM CONDITION AND PERFORMANCE	4-1
	4.1 Comments Arising out of Inspection	4-1
	4.2 Assessment of Performance Monitoring Results	4-2
	4.3 Dam Safety Incidents	4-3
	4.4 Maintenance Procedures and Standards	4-3
	4.5 Existing Early Warning & Emergency Procedures	4-3

5	SAFETY ASSESSMENT	5-1
	5.1 General	5-1
	5.2 Structural Safety	5-1
	5.2.1 General	5-1
	5.2.2 Embankment performance monitoring	5-2
	5.3 Safety against Floods	5-2
	5.3.1 Discussion on the exceedance probability of design hydrographs	5-2
	5.3.2 Factors which reduce the dam safety during floods	5-3
	5.3.3 Conclusions and recommendations	5-4
	5.4 Provision for Emergency Draw-down	5-5
	5.5 Safety against Earthquakes	5-6
	5.5.1 Seismic design criteria	5-6
	5.5.2 Liquefaction of fill and foundation materials	5-7
	5.6 Other Safety Matters	5-7
	5.6.1 Downstream tailwater levels	5-7
	5.6.2 Security of access	5-7
	5.6.3 Security of electricity supply	5-7
	5.7 Safety Assessment - Summary	5-8
	5.7.1 Principal matters of concern	5-8
	5.7.2 Safety statement	5-8
	5.7.3 Safety aspects of reservoir management	5-9
6	RECOMMENDED STUDIES, WORKS AND SUPPLIES	6-1
	6.1 General	6-1
	6.2 Additional Surveys, Investigations, Inspections and Studies	6-1
	6.2.1 General	6-1
	6.2.2 Surveys	6-1
	6.2.3 Ground Investigations and Inspections	6-2
	6.2.4 Additional Engineering Studies	6-2
	6.3 Construction Works	6-3
	6.4 Equipment and Supplies	6-4
	6.5 Emergency Planning Studies	6-4
	6.6 Safety Measures - Priorities	6-5
7	CONCLUSIONS	7-7
8	REFERENCES	8-1

**APPENDIX A List of Data Examined**

**APPENDIX B Hazard Assessment Procedure**

**APPENDIX C            Report by Instrumentation Specialist**

**DRAWINGS**

- 1.     Nurek Dam Location Plan**
- 2.     Schematic Site Plan**
- 3.     Dam Cross Section**
- 4.     Power Station - Cross Section**
- 5.     Deep and Surface Spillway**

## UNITS AND ABBREVIATIONS

ASBP	Aral Sea Basin Program
CA	Central Asia
CMU	Component Management Unit
EA/EIA	Environmental Assessment/Environmental Impact Assessment
EC-IFAS	Executive Committee of IFAS
FSL	Full Storage Level
FSU	Former Soviet Union
FAO/CP	Food and Agriculture Organisation/World Bank Co-operative Programme
GDP	Gross Domestic Product
GEF	Global Environment Facility
ICB	International Competitive Bidding
ICOLD	International Commission on Large Dams
ICWC	Interstate Commission for Water Co-ordination
IDA	International Development Association of the World Bank
IFAS	International Fund to Save the Aral Sea
JSC	Joint Stock Company
LDL	Lowest Drawdown Level
M & E	Monitoring and Evaluation
NCB	National Competitive Bidding
NGO	Non-governmental Organisation
O & M	Operation and Maintenance
PIP	Project Implementation Plan
PIU	Project Implementation Unit
PMCU	Project Management and Co-ordination Unit
PMF	Probable Maximum Flood
RE	Resident Engineer
TA	Technical Assistance
TOR	Terms of Reference
SIC	Scientific Information Centre (of the ICWC)
SU	Soviet Union
SW	Small Works
VAT	Value Added Tax
WARMAP	Water Resource Management and Agricultural Production in CA Republics
masl	metres above sea level
Mm <sup>3</sup>	million cubic metres
km <sup>3</sup>	cubic kilometres = 1000 Mm <sup>3</sup>
m <sup>3</sup> /s	cubic metres per second
ha	hectare
hr	hour

# 1 INTRODUCTION

---

This report is one of ten reports prepared under Component C: Dam and Reservoir Management, of the Water and Environmental Management Project (WAEMP). The WAEMP is supported by a variety of donors, such as the Global Environment Facility (GEF) via the World Bank, the Dutch and Swedish Governments and the European Union, and is being implemented by the IFAS Agency for the GEF Project under the Aral Sea Basin Program.

---

## 1.1 Background to Project

---

In general, the WAEMP aims at addressing the root causes of overuse and degradation of the international waters of the Aral Sea Basin, and to start reducing water consumption, particularly in irrigation. The project also aims to pave the way for increased investment in the water sector by the public and private sectors as well as donors. The project addresses this aim in several components. Dam and Reservoir Management, the assignment with which this report is concerned, is one of them. The other components are: Water and Salt Management, the leading component, to prepare common policy, strategy and action programs; Public Awareness to educate the public to conserve water; Transboundary Water Monitoring to create the capacity to monitor transboundary water flows and quality; Wetlands Restoration to rehabilitate a wetland near the Amu Darya delta; and Project Management. The components have close links with each other.

The Dam and Reservoir Management Component focuses on four activities as follows:

- a) Continuing an independent dam safety assessment in the region, improve dam safety, address sedimentation and prepare investment plans;
- b) Upgrading of monitoring and warning systems at selected dam sites on a pilot basis;
- c) Preparing detailed design studies for priority dam rehabilitation measures; and
- d) Gathering priority data and preparation of a program for Lake Sarez.

The activities are grouped for work process purposes into two packages and will be executed simultaneously, according to an agreed schedule of works:

- Dam safety and reservoir management (including activities "a", "b" and "c");
- Lake Sarez safety assessment (covering activity "d").

The Dam Safety and Reservoir Management package covers the following areas: dam safety, natural obstructions, silting of reservoirs, control of river channels etc.

The activity covers the following 10 dams, two in each country:

Kazakhstan: Chardara and Bugun dams;  
Kyrgyzstan: Uchkurgan and Toktogul dams;  
Tajikistan: Kayrakkum and Nurek dams;  
Turkmenistan: Kopetdag and Khauzkhan dams; and  
Uzbekistan: Akhangaran and Chimkurgan dams.

Because of the need to safeguard human life, early priority is being given to safety reviews at each of the dams, which is the subject of this report.

---

## 1.2 Safety Assessment Procedures

---

The dam safety assessments are the first stage in the evaluation (including costing and economic justification) , analysis, design and implementation of measures aimed at ensuring safe operation of the selected dams. They have been prepared based on a brief reconnaissance visit to each dam, discussions with the operating staff and a perusal of such information and data as was found to be readily available. No attempt has been made at this stage to analyse any of the data. A data collection and cataloguing procedure was initiated before commencement of the assignment but this process (to be carried out by National Teams) is still at an early stage in implementation.

The field visits were made and the reports prepared by a team of international experts specialising in dam engineering and dam safety procedures. The team comprises experts from GIBB Ltd (United Kingdom) and its associate for this assignment, Snowy Mountains Engineering Corporation (SMEC) from Australia, together with members of a team of regional experts who have been contracted as individuals to work with the Consultants for this project. This team is referred to here as the International Consultants (IC). The International Consultants have been supported during the field visits by members of National Teams appointed for this project from each of the five Central Asian republics.

The principal members of the international team, who are the authors of this report, are the following: -

- Jim Halcro-Johnston (GIBB Ltd) – Team Leader
- Gennady Sergeevich Tsurikov (Uzbekistan) – deputy Team Leader
- Edward Jackson (GIBB Ltd) – Dam Engineering Specialist
- Ljiljana Spasic-Gril (GIBB Ltd) – Geotechnical Engineer/Dam Structures Specialist
- Pavel Kozarovski (SMEC) – Hydrologist/Hydraulic Engineer
- E.V. Gysyn – Dams Specialist (Kazakhstan)
- E.A . Arapov – Hydraulic Structures Specialist (Turkmenistan)
- G.T . Kasymova – Energy Expert (Kyrgyz Republic)
- R. Kayumov – Hydrostructures Specialist (Tajikistan)
- R.G. Vafin – Hydrologist, specialising in reservoir silting (Uzbekistan)
- V.N. Pulyavin – Dam Instrumentation Specialist (Uzbekistan)
- N.A. Buslov - Dam Specialist (Turkmenistan)
- Y.P. Mityulov – Cost and Procurement Expert (Uzbekistan)
- N. Dubonosov – Mechanical Equipment Expert (Kyrgyz Republic)

Most of the above team members have contributed in the preparation of this report.

---

## 1.3 Scope of Safety Assessment

---

The safety assessments are made based on superficial evidence observed during the site visits, discussions with operating staff and subsequent discussions with members of the National Teams and an examination of supporting design and construction documents as has been made available to the IC for review. (A full list of the documents reviewed is included as Appendix A )

The safety evaluation of the dam has required an assessment of the following factors:

- (1) The **characteristics of the reservoir and dam site**, which includes the flood regime for the river, and the geological conditions at the site;
- (2) The **characteristics of the dam**, covering its design and present condition;
- (3) The expected **standards of operation and maintenance** of the dams ,its performance, and the implications for safety;
- (4) The **effects on the downstream** area resulting from a failure of the dam or an excessive release of water.

The structure of this report reflects the scope of safety assessment. Chapter 2 presents a general description of the dam, including location, purpose, principal dimensions and assessment of its hazard rating in relation to the impact that a safety incident would have on the adjacent community. Chapter 3 discusses the design factors that principally affect the safety of the dam.

Comments on the condition and performance of the dam are given in Chapter 4 and in Chapter 5 an assessment of its safety is given.

Chapter 6 gives recommendations for studies, works and supplies to be undertaken in the interests of ensuring the safety of the dam and the downstream community. Conclusions and recommendations are summarised in Chapter 7.

The recommendations for safety measures given in this report must be regarded as tentative as their precise scope will depend on the outcome of further studies which are outside the scope of the present assignment. No attempts has therefore been made at this stage to evaluate the cost of the required remedial works or to carry out an economic justification for the works proposed, which will be necessary to support an application for funding. This will be carried out when the necessary studies and detail designs have been completed.



## 2 PRINCIPAL FEATURES AND DIMENSIONS OF THE DAM

---

### 2.1 Location, Purpose, and date of Construction

---

Nurek dam is situated in Tadjikistan Republic on Vakhsh river 75 km from Dushanbe city. Access to the dam is possible at any season by asphalted road Dushanbe-Nurek (Figure 1).

The purpose of the water reservoir is:

- a) seasonal and partly long term runoff regulation of Vakhsh river for irrigation,
- b) power generation.

The construction work was completed in 1978. The design was carried out by SAO "Hidroproject" in 1957-1960.

---

### 2.2 Description of the Dam

---

Main structures of the dam are (Figure 2):

- dam
- power station with water conduit tunnels
- outlet structures

The rockfill-earth dam has a central core (Figure 3). The dam shells are constructed of gravel/pebble material. The vertical core consists of clay and sandy silt with inclusion of stones up to 200 mm in size. The transition from the core to the side shells is made through variable thickness filters constructed of specially selected material. There is a surcharge on the slopes constructed from large stone - upstream surcharge layer is 20-40m thick, downstream surcharge layer is 5-10m.

In the lower narrow part of the canyon a massive concrete saddle is placed to function as the core base. The saddle consists of massive concrete 157 m long, along the river bed, its width between the canyon slopes varies from 30 to 60 meters. In the heavily jointed rock of the dam foundation, continuous grouting to a depth of 8 m was arranged.

The power station consists of an intake, head water conduits and power house. The triple-sectioned intake tower is 86m in height, three pressure tunnels lined with reinforcement concrete 10m in diameter, each of them 400m long. The tunnels are terminated in underground Y-tubes. There are emergency and guard gates on the entry of each pressure tunnel (10x10m). The operation of these gates is carried out by gantry crane with capacity 2x140t. There are nine steel lined underground conduits 6 m in diameter, 500 m long. The power house with vertical axis hydropower units, each 330 MW, is situated at the downstream foot of the dam, and is 200 m x 50m in plan (Figure 4). Height of the power house is 40 m.

The outlet structures consist of a surface spillway with a high-level intake and an emergency spillway with a low level intake (Figure 5). The surface spillway with high-level intake with capacity 2,020 m<sup>3</sup>/s at FSL, has a spillway intake at a depth of 12.3 m below the FSL. Two spillway bays, each 12m wide, are equipped by radial gates

and emergency slide gates, which are operated by gantry crane with capacity 2x15t. The spillway discharge chute is made in form of non-pressure tunnel, 10 m wide, 11 m high and 1,110m long. The tunnel discharges onto a surface chute terminating in a flip bucket energy dissipator. Concrete lining of the tunnel is equipped by drainage holes.

The emergency spillway with low-level intake has a capacity of 2,020 m<sup>3</sup>/s. The sill of the intake is located 100 m below the FSL. Some 280 m away from the intake portal the spillway path is made in the form of a tunnel, 10m wide and 10m high. The shaft for the emergency gate is 145 m away from the intake portal. Emergency gate is a roller gate 8m x 11.5m x 100m. It is operated by a cable elevator with capacity of 100t. After the emergency gate the spillway tunnel divides into two parts each containing service and emergency gates. Emergency gate - Caterpillar gate B x H = 3.0 x 9.5m with theoretical head of 101.3 m. Service gate - radial gate B x H = 5.0 x 6.0m with theoretical head 101.5m. Operation of these gates is carried out by a hydraulic elevator. The power supply of drives of all elevators is realized from its power resources.

The principal dimensions of the reservoir and the various components of the dam are given in Table 2.1.

---

## 2.3 Hazard Assessment

---

In many countries a formal classification system is used to define the risk a dam represents, in terms of the potential for loss of life and/or damage to property which could result in the event of flooding caused by failure of the dam or an extensive release of water. The magnitude of the risk depends partly on the characteristics of the dam and reservoir and partly on the conditions downstream of the dam. Risk factors based on the procedure set out in ICOLD Bulletin 72 (Reference 1) are shown in Tables B1 and B2 in Appendix B.

Based on the Tables in Appendix B, the total risk factor of 36 points (Table 2.2) puts the Nurek dam in Risk Class IV, that is the highest risk category.

**Table 2.2 Nurek Dam – Risk Factor**

		<b>Points</b>
Reservoir Capacity (Mm <sup>3</sup> )	10,000	6
Dam Height (m)	300	6
Downstream Evacuation Requirements	>1000	12
Potential Damage Downstream	High	12
	<b>TOTAL</b>	<b>36</b>

Table 2.1 Nurek Dam – Principal Dimensions

<b>Reservoir</b>	
Catchment Area	30,700 km <sup>2</sup>
Reservoir Volume at FSL	10,500 Mm <sup>3</sup>
Dead Storage at LDL	6,000 Mm <sup>3</sup>
Full Storage Level (FSL)	910 masl
Lowest Drawdown Level (LDL)	857 masl

<b>Dam Type</b>	Rockfill embankment
Crest Level	920 masl
Crest Length	714 m
Crest Width	20m
Height of Embankment	300 m
Upstream Slope	1:2.25
Downstream Slope	1:2.2

<b>Spillway</b>	
Design Capacity (both spillways)	4040 m <sup>3</sup> /s
Turbines	1120 m <sup>3</sup> /s

### 3 DESIGN CONSIDERATIONS

---

#### 3.1 Hydrology

---

The Vakhsh river is formed by the confluence of Surkhob and Obi-Khingou rivers and discharges into Amudarya. The river is supplied with water from the glaciers, snowmelt and partially from ground water. The catchment area is 30,700 km<sup>2</sup>. The length is 372 km. The average annual discharge is 645 m<sup>3</sup>/s. Maximum flood discharge is 3,900 m<sup>3</sup>/s. There is lowest water discharge is 120 - 200 m<sup>3</sup>/s in the middle of October.

Theoretical maximum discharge at the dam site (0,01% exceedance probability) by the observations in 1932-1962 - 5400 m<sup>3</sup>/s, and by some observations in 1932-1972 - 5,700 m<sup>3</sup>/s. The average annual run-off of sediments is 76.3 Mm<sup>3</sup>.

For the whole period of observations the maximum discharge was 4,290 m<sup>3</sup>/s.

---

#### 3.2 Geology and Seismicity

---

The dam is situated in the middle course of the Vakhsh river in the narrow Pulsanguin canyon. The canyon is 300 m deep. The channel width is about 40 m. The canyon bottom and sides are composed of hard sedimentary rock of the cretaceous period, viz siltstone and sandstone with slope 30-35° to the upstream. The rock is slightly fractured- fracturing of the rock decreases with depth. The surface layer of the siltstone, 1m thick, is weathered. On the flat area the canyon slopes are covered by deluvium sediment, with thickness 20- 25 m in some of the places. The thickness of alluvium in the river bed is from 13 m to 20 m. There is a tectonic deformation in sedimentary rock.

The seismicity of this area - earthquake Intensity VIII, but design seismicity of the dam and structures is IX.

---

#### 3.3 Construction Materials and Properties

---

The dam shell is built of gravel/pebble material. During constructing of the shell the compacted soil density was 2.25 - 2.3 t/m<sup>3</sup>. The clay core was compacted in 25 cm-30 cm layers with the compacted density of 2.03 - 2.13 t/m<sup>3</sup>. There is no risk of liquefaction for the embankment material.

---

### 3.4 Seepage Control Measures

---

There is a grout curtain at a depth of 40m to 130m in the heavily fractured rock of the dam foundation. Three grouting galleries have been built to control the condition of the dam foundation.

---

### 3.5 Reservoir Draw-off Works

---

Before the USSR collapse, the operating regime was subject to the needs of irrigation of Republics of Tadjikistan, Uzbekistan and Turkmenistan. At the present time the operating regime is oriented to power generation. The operating rules of the dam stipulate the flood passing through the Vakhsh river without exceeding the FSL. That is why at the inflow exceeding the capacity of the power station units, the overflow spillway gates, and in case of necessity, the emergency bottom spillway gates are opened.

---

### 3.6 Performance Monitoring Instrumentation

---

At the Nurek dam, instrumentation has been installed to observe the deformation and displacement of the dam-foundation system, and also the seepage regime. At the present time a substantial part of the instrumentation does not work for several reasons. The observations are carried out not at full volume and not regularly. Not all piezometers are in working order.

15 nos inclinometers with total length of 2400m, about 700 nos of various detectors (95nos for ground stress, 107nos for pore pressure, 32nos for line deformation), 57 double pipe and 50 built-in piezometers were installed in the dam. The main part of remote instrumentation is placed on the dam site on 7 instrumentation profiles. The rest of the pressure cells are installed mainly on the contact of core or near abutments

The observations for the dam foundation settlements are carried out by means of leveling the marks installed in joint and 3 cement inspection galleries of the concrete saddle. The observations are carried out on 70-75 marks once every three months.

After 20 years of installation of the instrumentation, 21% of the total number of the instruments installed are out of order. Instruments for measuring line deformations are the ones which have been damaged the most.

### 3.7 Hydropower Facilities

#### Hydropower Equipment

N	Item	Units	Qu-ty	Type
1	Hydraulic turbines	Nr	9	PO-310/957-B-475
	Capacity	MW	341	
	Diameter	m	4.75	
	Number of operating blades	Nr	15	
	Number of guide apparatus blades	Nr	24	
	Design head	M	230	
	Design head water discharge	m <sup>3</sup> /s	158	
	Speed	R/min	200	
II	Generators	Nr	9	ПГCBΦ-940/235-30
	Power	MWA	390	
	Power factor	-	0.85	
	Voltage	KV	15.75	

The power station works in power generation regime. Long term average power generation is 13,000 million kW/h.

## 4 DAM CONDITION AND PERFORMANCE

---

### 4.1 Comments Arising out of Inspection

---

The IC, in company with representatives from the Tajikistan National Team and Engineers from the site visited the dam on 5 October 1999. Areas inspected included the whole of the embankment and the draw-off works.

The reservoir level at the time was 910 masl.

During the visit of experts of the project «Dam Safety and Reservoir Management» there was no possibility to realize the detailed inspection of the units and equipment of the dam. Some part of information about the condition of the dam was obtained from operating staff of the dam, and another part from «Expert judgement about condition of the main structures and equipment of Nurek power station and problem of its modernization» composed by the group of specialists AO «Institute Hydroproject» Moscow from 11.05.1997.

On the basis of received information the following is found out:

- The observations for the dam condition are realizing not in full volume and not regularly.
- The IC were told that the seepage the dam and foundations has stabilized.
- There is a dent in the middle of tunnel on the chute concrete 2m away from right wall 0.5m long, 0.3m wide and 0.15m deep without reinforcement outcrop at the emergency spillway with overflow intake.
- The concrete saddle of the construction transport tunnel coming from the right side, is eroded with reinforcement outcrop:
  - Close to the tunnel chute.
  - In the upper parts to reinforcement.
- There is a crack at a distance of 80-90 cm from the end portal having opening on the chute of 10 to 30 mm, on the wall of 10 mm and closing on the arch. The crack depth is 500 mm.
- On the emergency spillway with bottom intake:
  - There are 3 cracks at 5m intervals between each other and at 100 cm distance from the end portal of the tunnel from 150 mm to 350 mm width. The depth is more than 500mm. On the walls the visible cracks go vertically and close on the top.
  - The bridge connecting the intake tower to the road with 58 m span is in emergency condition.
  - There is no opportunity to inspect turbine conduits from inside as still no device that enable to carry out the inspection of conduits.
- The 220kV switchyard area is exposed to intensive washing by overflow and ground water. There are some holes 2-3m deep in the ground.

- Around the 550kV switchgear there are settlements of ground, caused by change of ground water regime.
- Due to unfinished construction works on the damaged dam, the power station , turbine house, access road to the dam, intake and outlet structures are not protected from sediments.
- There are some bank failures along the reservoir and Vakhsh river bed , some 100 m from the dam. Intensive silting is in a process in the tail part of the water reservoir , the edge of the silt is 35-40 km away from the dam.
- Condition of supplying electric cables is not satisfactory and cables do not stand the loading due to the isolation disturbance.
- Cracks at maintenance roller gates made operation of the gates under loading extremely difficult. Although the cracked rollers were replaced by the new ones, the fact of the cracks' appearance says about unreliability of the service parts of the gate, and finally about the gate itself.

---

## 4.2 Assessment of Performance Monitoring Results

---

Observations of the main structures of the dam are carried out in accordance with the Observations programme and manual for seepage, geodetic and remote instruments, produced in 1982-1983. Besides, there is a schedule of permissible values for satisfactory operation and condition of the main structures. Inspection reports for conduits and the intake are presented in tables and graphs together with the data on instrumentation and the data processing of the observations. These data are kept on the dam.

The condition of Nurek dam is characterised by the following factors (Appendix C) according to the previous years results:

- Maximum settlements of the upper and central sections of the concrete saddle are 140 mm. The low section had an average settlement of 180 mm at the end of construction; the settlement range was 85 to 280 mm. An average section settlements increase is 20-25 mm.
- The result of observations on deep survey bench marks showed that total deformation of two lower layers of foundation (20-40 and 40-60 m) did not exceed 1.5 mm.
- The largest construction settlement of the core in central section was 13.7 m or 4.7% height of embankment. In the central cross-section construction settlement of upstream shell axis is 11.9 m, or 5.8% of the height of embankment, downstream shell - 6.5 m, or 3% of the height of embankment. The vertical displacements are 3.3 - 3.6 and 2.2 m respectively for upstream and downstream shell.
- Operating settlements of the dam core in central cross-sections on July 1986 were: on the level of the 1st gallery - 0.37 m; 2nd gallery - 0.48 m; crest - 0.63 m.



- Horizontal displacements of all dam zones, except the upper part of the core, were directed towards the downstream. The largest displacements of the core and low shell, to the end of construction, were 0.8 - 0.9m.
  - Maximum pore pressure in the core (3.6 MPa) was measured in 1979. After this there was a gradual decrease of the maximum value of pore pressure: at the end of 1982 - to 3 MPa, at the end of 1984 - to 2.9 MPa, the end of 1986 - 2.7 MPa.
  - The excessive pore pressure, which can be defined as the difference between measured pressure and design pressure, and indicate completion of consolidation decreased from 2.0 - 2.2 MPa at the end of 1980, to 1.7 MPa at the end of 1986.
- 

### **4.3 Dam Safety Incidents**

---

There has not been any emergency situation since the moment of going into operation.

---

### **4.4 Maintenance Procedures and Standards**

---

Operation rules for Nurek dam, power station and spillway structures are available. They are composed on the basis of Technical Operation Rules of Stations and Networks of MinEnergO USSR. Moscow 1976, and also rules of using water reservoir of Nurek Water Reservoir at the Vakhsh river, Tashkent, 1979.

---

### **4.5 Existing Early Warning & Emergency Procedures**

---

An early warning system is not available. There is telephone connection, which allows contact between the personnel and regional centres. The actions of operating staff are set up by the order of chief of the dam.

## 5 SAFETY ASSESSMENT

---

### 5.1 General

---

The safety assessment is based on the following general criteria:

- (1) **Structural safety**  
The dam, along with its foundations and abutments, shall have adequate stability to withstand extreme loads as well as normal design loads.
- (2) **Safety against floods**  
The reservoir level shall not rise above the critical level (maximum flood level) for the largest possible flood. Gate mechanisms and power units must remain fully operational and accessible at all times.

The dam should have adequate facility for rapid lowering of the reservoir level in case of emergency.

- (3) **Safety against earthquakes**  
The dam shall be capable of withstanding ground movements associated with the maximum design earthquake (MDE) without release of the reservoir. The selection of the appropriate value of MDE is based on an assessment of the consequences of dam failure (Section 2.3).

- (4) **Surveillance**  
Arrangements for inspection, surveillance and performance monitoring of the dam should ensure that a danger arising from damage, defect in structural safety or an external threat to safety is recognised as soon as possible, so that all necessary measures can be taken to control the danger.

Adequate emergency planning, early warning and communications facilities shall be in place to ensure the safety of the downstream population in case of emergency.

In the light of the review of the design and performance of the Nurek dam, the findings of the condition assessment, and the review of the hydrological and geological conditions, the following conclusions are drawn regarding the safety of the dam:

---

### 5.2 Structural Safety

---

#### 5.2.1 General

It is not within the scope of the present study to make a detailed assessment of the structural safety of the Nurek embankment, currently the world's highest dam, and the information which has been made available for the IC's study regarding the design criteria, material properties, design analysis and performance monitoring data falls far short of what is needed for a full safety review.

Nevertheless, the IC see no reason to doubt that the embankment as designed meets all the requirements for static stability that could be expected.

However, from the brief review carried out there are two matters which the IC consider should be more fully examined, these are:

- (1) the seismic design, particularly the expected behaviour of the embankment under the effect of the Maximum Design Earthquakes (MDE), as discussed in Section 5.5; and
- (2) the safety implications of allowing the reservoir to exceed the normal full storage level of 910 masl (1997 World Bank Report, Annex 9, paragraph 7.3.2).

## 5.2.2 Embankment performance monitoring

Information on results from performance monitoring instruments was obtained from the National Team after the IC's inspection of the dam. This is discussed in Appendix C to the Report and summarized in Section 4.2 above. It is not known now how these results compared with the design predictions and a full analysis of the results is outside the scope of the present study.

The 1997 World Bank Report on the Expert Review Visit drew attention to certain deficiencies in the performance monitoring system which appear to be still applicable, viz:-

- (1) the instrumentation is deteriorating with age, though sufficient remains in working order for routine monitoring;
- (2) the number of suitably skilled and experienced staff available to maintain the performance monitoring is diminishing;
- (3) since 1993/4 the analysis and interpretation of the instrumentation readings has been inadequate, with particular reference to geodetic movement monitoring of the embankment;
- (4) seismic monitoring has been suspended.

---

## 5.3 Safety against Floods

---

### 5.3.1 Discussion on the exceedance probability of design hydrographs

The aim of this section is to discuss the conservatism involved during derivation of design hydrographs in accordance with SNIP and how these hydrographs compare with PMF.

Nurek outlet structure was designed using 0.1% exceedance probability hydrograph and checked against 0.01% hydrograph. No routing of the design hydrograph was envisaged and the dam outlet structures were designed to pass the 0.01% peak. There is approximately 5 m reserve between the FSL (910 masl) and the crest level of the clay core (915 masl) with approximate storage of  $500 \times 10^6 \text{ m}^3$ . If this space can be utilised, the combined effect of the available storage and the current outlet structure capacity (including turbines) would be able to pass even larger floods than 0.01% exceedance probability flood. However, it is reported (Reference 1) that to

utilise this space it would be necessary to conduct additional investigations covering all aspects of the dam stability during the periods of higher than FSL levels.

The design hydrographs are determined through a statistical analysis of historical records. A theoretical curve, based on a 3-parameter gamma distribution, is fitted to maximum annual peak discharge values and design peak discharges for various exceedance probabilities are determined. The 0.01% discharge value is subject to a correction, which is approximately 20% higher than the original value. The correction itself brings the exceedance probability of the obtained value to 0.005% or 1 in 20,000 years.

The volume of the hydrograph is also defined through frequency analysis of annual maxima. The coincidence of all historical peaks and maximum flood volumes would result in the two variables (peak discharge and flood volume) to be totally dependent, with the exceedance probability of the combined hydrograph equal to the exceedance probability of the peak discharge value. However, the ranked historical peak discharge values do not necessarily coincide with the ranked maximum volumes. In other words these two variables are partially dependent, resulting in a hydrograph with exceedance probability lower than the exceedance probability of the peak discharge.

During the practical fitting of the theoretical frequency curve, a coefficient of asymmetry  $C_s$  is calculated from the recorded series of annual maxima. This coefficient is then used to fit an appropriate curve. Higher the coefficient, more skewed is the theoretical curve, resulting in higher discharge values for low probabilities of exceedance. This practice introduced an additional conservatism into the derivation of the design discharge values, which results in some overestimation of the design discharge value.

The above three factors result in the design discharge hydrograph with exceedance probability significantly lower than 0.01% (1 in 10,000 years). It is expected that the resulting exceedance probability of the design hydrograph would be in the range of 0.001% or 1 in 100,000 years. Further investigations into this matter are required to support this statement. If the results confirm the above statement it can be concluded that the conservatism introduced during the design calculations results in the outlet structures of the dams to have been designed for a 1 in 100,000 years events instead of 1 in 10,000 years events, which in general approaches the exceedance probability of a PMF event.

The Uzbekistan "Gidro-Met" (Bureau of Meteorology) provides forecasts of expected streamflows at the beginning of the wet season (early spring). The forecast is based on the snow deposits in the catchments of particular rivers. The Bureau of Meteorology of Uzbekistan is currently developing a methodology for estimation of snow extent and water equivalent using satellite images. Based on the forecast, the central authority, which regulates the dam operation, issues a request for the initial level in the reservoir prior to the beginning of the melting season. In the cases of extremely wet years the requested initial level can be lower than the FSL. This mechanism might make additional storage available for flood routing, increasing the dam safety during extreme floods.

### **5.3.2 Factors which reduce the dam safety during floods**

There are several factors that affect the performance of the Nurek dam during large flood events. The following factors have been identified during the assessment:

- (1) Estimates of extreme floods used for design of outlet structures are based on statistical analysis of 30 years long records. Analysis of longer records following the dam construction resulted in 0.01% exceedance probability peak discharge with correction to change from 5,400 m<sup>3</sup>/s to 5,700 m<sup>3</sup>/s. In order to make meaningful extrapolation of events with exceedance probability of 0.1% the extrapolation would have to be based on regionalized parameters with records in excess of 100 years. As this is not a case, the extrapolation beyond 0.1% exceedance probability must be considered to be beyond the credible limit. In order to establish the exact relation between the 0.01% exceedance probability discharge hydrographs developed in accordance with SNIP and the extreme flood hydrographs based on PMF estimates a PMF study must be undertaken for this site.
- (2) The design of the dam is based on a release of water during extreme flood events through a combined outlet consisting of a bottom outlet (2,020 m<sup>3</sup>/s), emergency spillway (2,020 m<sup>3</sup>/s) and turbines (1,120 m<sup>3</sup>/s), totalling 5,160 m<sup>3</sup>/s. The release through turbines is based on an assumption that all turbines are operational, the power lines are capable to transfer the generated energy and that the demand centres are able to consume the generated power during the extreme flood event. In order to assess the safety of the dam during an extreme flood, it is reasonable to assume that the turbines will not be operational due to one of the factors mentioned above. In this case the maximum outlet capacity is thus 4,040 m<sup>3</sup>/s. The reservoir water level would rise to R.L. 915.8 masl for a duration of approximately 3 days in order to pass the 0.01% event, exceeding the present maximum allowable water level in the reservoir (910 masl) for a period of 8 to 9 days.
- (3) For the current situation, assuming that the 0.01% discharge hydrograph is representative of the PMF flood, the following reservoir levels would be achieved for different combinations of the outlet capacities:

Scenario Description	Max reservoir level if starting level is at FSL	Initial reservoir level for max level not to exceed FSL
Q <sub>bottom</sub> +Q <sub>surface</sub> +Q <sub>turbine</sub>	910.9	908.7
Q <sub>b</sub> +Q <sub>s</sub> +5/9Q <sub>t</sub>	912.0	905.0
Q <sub>b</sub> +Q <sub>s</sub>	915.8	861.5
Q <sub>b</sub> +Q <sub>s</sub> (Turbines closed at Q <sub>i</sub> =3,000 m <sup>3</sup> /s)	914.6	-
Q <sub>b</sub> /2+Q <sub>s</sub>	925.5	812.0 (max level=918.0)
Q <sub>b</sub> +Q <sub>s</sub> /2	924.5	840.0

Note 1: reservoir levels above 915 masl exceed the level of the top of the core zone, and levels above 920 masl exceed the embankment crest level.

Note 2: the above values were obtained by routing the 0.01% exceedance probability flood through the reservoir storage for corresponding to the scenarios, stage-discharge curves and the stated initial level in the reservoir.

### 5.3.3 Conclusions and recommendations

It can be concluded in general that the adopted design procedure in accordance with SNIP provides a relatively conservative estimate of large floods. The exceedance

probability of the design flood is lower than 0.01% and is expected to approach 0.001% or 1 in 100,000 years.

The assumption that the turbines will be operational during an extreme flood event is optimistic, so during a 0.01% flood event with turbines closed, the water level will encroach into the space above FSL above 915.0 masl, which could be an unsafe condition. If turbines are not working and if one of the radial gates on the outlet structures could not be opened the dam would be overtopped. There are four independent power lines (2x500 KV and 2x220 KV) leaving the site, which are linked to different demand centres, so it is likely that some flow through the turbines would always be possible.

It is therefore recommended that:

- (1) A PMF study be carried out, taking into account the combined effect of an extreme snow (glacier) melt and an extreme rainfall (PMP).
- (2) The PMF hydrograph be routed through the storage using the bottom outlet and the emergency spillway only, commencing at FSL; the maximum reservoir water levels identified for various circumstances, and the dam stability for those levels assessed.
- (3) The adequacy of the existing outlet structures be re-assessed for the cases if one of the segment gates is not operational, and appropriate measures to ensure dam safety are identified and implemented.
- (4) The possibility for some turbines to be operational during the PMF event be investigated by analysing the power supply grid and the likelihood for simultaneous load rejection in all demand centres.

## 5.4 Provision for Emergency Draw-down

Facilities for reservoir draw-down for flood discharge or an emergency comprise:

- (1) **Surface spillway**  
2 nr radial gates 12 m wide, cable operated  
2 nr maintenance gates, gantry operated;
- (2) **Low level sluices**  
Single conduit:  
1 nr repair gates, cable operated;  
Double conduit:  
1 nr emergency gate, hydraulically operated  
1 nr radial gate, hydraulically operated

There was no opportunity for the IC to inspect either the surface spillway or the low level sluices, but their condition and state of readiness was discussed with the dam manager.

### Surface spillway

- The surface spillway is reported to be in good working order, but concern was expressed at the condition of the radial gate cables. A repair contract had been arranged but had recently been terminated.

### Low level sluices

- The report on the experts' visit attached to the 1997 World Bank Report stated that the upstream repair gate was not serviceable. It was reported that this had now been repaired and that the gate was in working order.
- Problems were being experienced with the maintenance gates in that some of the rollers were damaged and no source of replacement could be found;
- The radial gates were subject to vibrations. Repair was said to be within the capacity of local resources, but had not yet been started.
- The steel lining was reported to be damaged, but was not regarded as being in a dangerous state.

The IC understands that the sluices are not tested at full capacity because of the risk of flooding and overfilling the downstream reservoir.

## 5.5 Safety against Earthquakes

### 5.5.1 Seismic design criteria

In the original design seismic input parameters and stability analysis in seismic condition are assumed to have been carried out in accordance with procedure given in the Russian Seismic Standards (Reference 2). According to the Russian Seismic Standard, a seismic design coefficient ( $k_g$ ) is derived for a site based on MSK earthquake intensity scale. The coefficients are derived based on 1:50 year earthquake. The required minimum factor of safety in seismic condition is always greater than unity.

However, the current practice based on the guidelines given in ICOLD Bulletin 72 (Reference 1) is to assess dam safety against two representative design earthquakes that are as follows:

OBE - Operating Basis Earthquake  
MDE - Maximum Design Earthquake

Where:

- OBE, or "no damage earthquake" is the earthquake which is liable to occur on average not more than once during the expected life of the structure (of not less than 100 years). During an OBE, the dam and its ancillary works should remain functional but may need repair. The required minimum factor of safety for the OBE earthquake should be greater than unity.
- MDE or "no failure earthquake" is the earthquake that will produce the most severe level of ground motion under which the safety of the dam against catastrophic failure should be ensured. For dams which are classified to be Risk Class IV a recommended return period of MDE is 30,000 years (Reference 3). For this earthquake displacements of the crest are assessed and compared with the allowable wave freeboard

Although the seismicity of the site is quite high (Intensity Zone 8 on MSK Scale) and the dam is said to have been designed as for Zone 9, its safety has not been assessed for OBE and MDE earthquakes. It is recommended to carry out additional

engineering studies (see Section 6.2.4) to evaluate its performance in those conditions.

A check should also be carried out of the height of seismic waves (seismic seiche) on the reservoir which may occur during a seismic event and which requires additional height to be added to the standard "static" freeboard.

### **5.5.2 Liquefaction of fill and foundation materials**

The embankment is constructed of well compacted sands, gravels and rock, and low permeability loam, on stable foundations. Loss of strength in either the embankment or its foundations as a result of seismic shaking is not regarded as a significant risk.

---

## **5.6 Other Safety Matters**

---

A number of other matters need further examination as part of a more comprehensive safety assessment than has been possible in the present study, for instance:

### **5.6.1 Downstream tailwater levels**

The IC's enquiries have revealed that it was originally intended that the tailrace channel should be enlarged, but this was not done. Insufficient information is available on the present hydraulic characteristics of the tailwater channel and those for the channel as originally designed, to determine whether there is likely to be a significant difference in tailwater levels, and in particular whether a higher tailwater level could cause problems with turbine operation at high flood discharges.

### **5.6.2 Security of access**

Access to all gate actuators is by way of tunnels and surface roads, all of which must remain accessible in all weather conditions, and should not be vulnerable to closure by rockfalls or other reasons due for instance to earthquakes or extreme weather.

Careful study, and possibly some rock stabilising work, is needed to ensure the long term security of all access roads leading to critical components of the dam.

The note of the experts' visit to Nurek attached to the 1997 World Bank Report drew attention to some deficiencies in the access roads, but it is not known whether these have now been made good.

The deck of the access bridge to the intake structure is in a dangerous state and needs urgent repair.

### **5.6.3 Security of electricity supply**

The IC understand that there are four independent power lines leading to the site (two 220 kV and two 500 kV) and it is unlikely that all would be out of action simultaneously and require the complete shut-down of the powerhouse. Detailed arrangements for supplying power to essential components such as the gate actuators are not known, but a totally reliable supply to those critical components is



essential for the safety of the dam. It is understood that the supply to the gates is by means of a ring main for which the cables are laid in the vehicle access tunnels. The security of the cables in these areas needs careful examination.

#### **5.6.4 Security of switchyard**

Section 4.1 draws attention to problems due to erosion and ground settlements in the 220 and 550 kV switchyards, which in the case of the 220kV switchyard is attributed partly to the effect of spray from the spillway discharge. In view of the fact that the dam's capability to control an extreme flood relies on the use of the turbines it is clear that the security of the switchyard is related to the safety of the dam, particularly as it appears that the switchyard is most at risk during periods when the spillway is in operation.

---

### **5.7 Safety Assessment - Summary**

---

#### **5.7.1 Principal matters of concern**

The IC see the following as being principal matters of concern as regards the safety of the Nurek dam:

- (1) the embankment is at risk from possible structural problems due to reservoir water levels exceeding safety levels in the event of an extreme flood;
- (2) there are deficiencies in the embankment performance monitoring instrumentation system;
- (3) the reported failure to complete the excavation of the tailwater channel might have safety implications which need to be evaluated;
- (4) although the seismic design of the dam is reported to have been based on a Zone 9 Intensity (MSK scale) it is not known whether the design has been checked for MDE conditions, or what are the estimated deformations for such conditions;
- (5) while the low level sluices are reported to be currently in working order the IC have no assurance that they have been demonstrated to operate satisfactorily for a sustained period at full capacity under full reservoir head.

#### **5.7.2 Safety statement**

Neither the time available during the site inspection nor the data made available for examination have been sufficient to enable the IC to reach a firm conclusion as to the condition of the Nurek dam. Nevertheless, the IC have no compelling reasons for suggesting that the embankment does not meet adequate safety standards, provided that the reservoir level remains below full storage level of 910 masl.

The dam is, however, exposed to danger from floods in that, depending on the availability of the flood discharge facilities (surface spillway, deep sluices and turbines) an extreme flood could result in the reservoir exceeding the safe level. The safety implications of exceeding the full storage level must be evaluated.

The safety of the dam against floods depends wholly on the operation of the hydromechanical plant, but some doubt exists regarding the operation of the low level sluices, which have not been tested fully open under full reservoir head. Therefore the ability of the dam to control a major flood cannot be regarded as being assured.

### 5.7.3 Safety aspects of reservoir management

It is essential to recognise that the reservoir impounded by the dam has immense strategic importance and that a component of provision for flood storage within the reservoir provides the security against flooding that the downstream communities have become accustomed to, and have a right to expect. For this reason, reservoir management procedures must be formulated in a way that gives priority to control of flood releases, and not to other more commercial interests. It is suggested that, to avoid any possible conflict of interest, the power to authorise reservoir impoundment levels prior to the start of the annual flood season should be vested in a flood safety commission, made up of technical experts, which is established independent of the management structure of the present operator of the dam. Such an arrangement would have the advantage of protecting the present operator from liability for maloperation of the dam in the event of releases generated by exceptional flood conditions.

## 6 RECOMMENDED STUDIES, WORKS AND SUPPLIES

---

### 6.1 General

---

The review of the design of the dam, information obtained during the site inspections, and discussions with the site manager has enabled the IC to arrive at certain conclusions regarding the safety of the dam, which are discussed in Section 5. These conclusions, along with considerations of requirements for emergency management have provided the basis for an assessment of the need for additional studies, investigations, construction works and supplies necessary to bring it to an acceptable and sustainable standard of safety. However, it must be recognized that the need for further work might still become evident as an outcome of this work, as the preliminary conclusions are refined.

A more detailed specification and methodology for the work described in this Section is presented in the accompanying report 'Methodology for Detailed Design of Priority Rehabilitation Measures'.

---

### 6.2 Additional Surveys, Investigations, Inspections and Studies

---

#### 6.2.1 General

To provide the basic data for designing the works described below and for refining the conclusions of the safety assessment, additional information is required which is outside the scope of the present study. This work is described under the following headings:

- ground surveys
- ground investigations and inspections
- engineering studies

#### 6.2.2 Surveys

##### (1) Topographic Surveys

The following ground surveys are recommended:

- embankment longitudinal crest profile;
- typical cross sections of the embankment to verify the 'as-constructed' profile;

##### (2) Reservoir Bed Survey

To provide firm data for an updated review of reservoir sedimentation and its effect on reservoir management it is recommended that a new reservoir bed (bathymetric) survey be carried out at an early date.

To enable a study to be carried out on the hydraulics of the tailrace channel and its effect on tailwater levels, particularly under high flood discharge conditions, it is recommended that a bed survey of the tailrace and downstream river channel be carried out.

### 6.2.3 Ground Investigations and Inspections

The following investigations and inspections are recommended:

(1) Reinstatement of embankment piezometers will involve a considerable amount of drilling in the embankment. It is recommended that during the course of this work in-situ testing should be carried out to verify the properties of the embankment and foundation material, and samples taken for laboratory testing, with particular reference to the material overlying the core zone.

(2) Inspections

To provide information on which to base a detailed assessment of required repairs and equipment, it is recommended that a detailed inspection of the embankment and associated works should be carried out and an inventory of defects, materials and repairs required prepared, covering:

- repairs to embankment upstream face (inspect when reservoir is at a low level);
- repairs to embankment downstream face protection and surface water drainage works;
- interior of all draw-off tunnels, upstream and downstream of gates;

In addition, because of the importance of the gate equipment to the safe operation of the dam and the uncertainty concerning the condition of this equipment, it is recommended that an experienced hydromechanical engineer should carry out a detailed inspection of the equipment, including: -

- gates and hydraulic operating equipment;
- electrical wiring, etc., and lighting;
- steelwork (e.g. bridges, gate tower stairs and landings);

Furthermore, it is recommended that arrangements should be made for a full-scale test of each of the gates under controlled conditions, up to full opening at maximum design head. To do this, it will be necessary to lower the water level of the Baipazinskaya reservoir, downstream of Nurek, to avoid flooding the downstream areas.

### 6.2.4 Additional Engineering Studies

The following additional engineering/hydrological studies are recommended:

1) Review the estimates of extreme flood inflows to the reservoir, taking into account also:

- the effect of other reservoirs in the upstream catchment, under normal conditions;
- the effect of possible failure or malfunction of other reservoirs in the upstream catchment.

2) Review Reservoir Management Procedures using updated flood estimates and reservoir sedimentation data, and freeboard allowance for wave run-up based on updated wind data.

- 3) Study safety implications of allowing reservoir water level to exceed normal full storage level (910 masl) and develop options to enable the flood storage volume between 910 masl and 920 masl to be safely exploited.
  - 4) Review the seismicity of the site and derive estimates of peak ground accelerations for Operating Basis Earthquake (OBE) and Maximum Design Earthquake (MDE); and an appropriate design time history.
  - 5) Review embankment static and seismic stability on the basis of measured properties of the in-situ materials, and determine deformations where factors of safety during seismic shaking are less than unity.
  - 6) Study safety implications and need for enlargement of the tailwater channel.
- 

### 6.3 Construction Works

---

A preliminary assessment of the required construction works is made on the basis of the safety assessment and available data. Final details will depend on the outcome of the studies described above.

#### 1) Embankment

Although the embankment appears to be generally in good condition it is an extremely large structure and it is essential that its performance is properly monitored. The performance monitoring installation should be reinstated where necessary. The following is proposed:

- new standpipe and/or electrical piezometers,
- additional electrical (remote reading) piezometers at critical locations;
- new embankment inclinometer tubes
- network of surface deformation measurement markers and fixed beacons, for precise measurement of horizontal and vertical displacements.

#### 2) Repair or renew deck of access bridge to intake structure

#### 3) Electromechanical Equipment

The safety of the dam relies wholly on the proper operation of the hydromechanical equipment. Any necessary repairs and renewals to gates and operating equipment should be undertaken immediately, and adequate spare parts and workshop facilities established.

Standby electricity generating plant should be provided.

#### 4) Switchyards

The ability of the dam to control an extreme flood depends on the availability of the turbines to contribute to the flood discharge, and hence on the proper operation of the switchyards. Any works necessary to secure the switchyard against malfunction caused by spray, high ground water or other causes should be carried out immediately.

## 5) Miscellaneous

Other matters requiring attention that are discovered during the detailed inspections described above should be rectified.

---

## 6.4 Equipment and Supplies

---

A preliminary assessment of supplies needed, based on the Consultants' inspection and discussions with site managers, is as follows:

- (1) Piezometers - Consideration should be given to installing a number of additional electrical (remote reading) type in critical locations if not already in place.
  - (2) Surface movement measurement fixed beacons and targets, and deformation measuring equipment.
  - (3) Provide supply of spare parts for hydromechanical equipment, along with standby generator(s) and associated housing and wiring.
  - (4) Replace electrical wiring in gate tower.
  - (5) Provide early warning and communications equipment
- 

## 6.5 Emergency Planning Studies

---

Flood routing studies warn that if the hydromechanical equipment is not fully operational, and the turbines are out of use it might not be possible to control all flood events. For this reason a comprehensive emergency plan, supported by an efficient organization and alarm system, is essential.

Given the importance of the dam and the potentially damaging consequences for the downstream population of an emergency which results in the release of a large volume of stored water, it is essential that plans for dealing with such a situation are well prepared, and supported by an efficient organisation, communications and alarm system. Inundation and flood hazard maps showing dambreak wave arrival time and duration of inundation should be prepared, based on dambreak modelling and simulation of dambreak wave propagation in the downstream areas. Flood damage estimates and potential loss of life should be developed on the basis of the above results.

A detailed emergency plan and instruction document should be prepared setting out the procedures to be followed, and the responsibilities of the site managers, regional engineers and civil authorities

---

## 6.6 Safety Measures - Priorities

---

The safety measures identified above are listed in Table 6.1 and assigned to one of three priority levels (I, II, III).

The proposed Priority levels are:

- I - high priority; work to be carried out immediately
- II - intermediate; work to be carried out within three years
- III - low priority; the need to be kept under review.

**Table 6.1 Nurek Dam - Dam Safety  
Priorities for Studies, Works and Supplies**

Item	Studies etc	Construction Works and Supplies		
		Priority I	Priority II	Priority III
1. Surveys (6.2.2)	<input type="checkbox"/>			
2. Investigations and Inspections (6.2.3)	<input type="checkbox"/>			
3. Engineering Studies (6.2.4)	<input type="checkbox"/>			
4. Construction Works (6.3) <ul style="list-style-type: none"> <li>• Instrumentation</li> <li>• Hydromechanical equipment repairs</li> <li>• Intake tower bridge deck</li> <li>• Reconstruction of switchyard</li> <li>• Miscellaneous Repairs</li> </ul>		<input type="checkbox"/>		<input type="checkbox"/>  <input type="checkbox"/>  <input type="checkbox"/>
5. Supplies (6.4) <ul style="list-style-type: none"> <li>• Piezometers and deformation monitoring equipment</li> <li>• Standby Generator(s)</li> <li>• Early warning and communications equipment</li> </ul>		<input type="checkbox"/>  <input type="checkbox"/>  <input type="checkbox"/>		
6. Emergency Planning Studies (6.5)	<input type="checkbox"/>			



## 7 CONCLUSIONS

---

On the basis of the information received and a brief inspection of the dam embankment the IC have reached certain conclusions relating to the safety of the Nurek dam, and the required safety improvement works, as follows:

- 1) While the embankment itself appears to be sound, its safety against damage from floods depends wholly on the proper operation of the hydromechanical plant. The ability of the dam safely to control an extreme flood is seriously prejudiced if the surface spillway, the low level sluices or the turbines are not available to contribute to the flood discharge.

Certain important repairs to the low level sluices are still outstanding, however, and the IC have not received assurance that they have been tested at full capacity under maximum reservoir head. It is recommended that an experienced hydromechanical engineer should inspect the equipment and that he should be available to witness such tests.

- 2) Under certain flood conditions it would be possible for the reservoir to rise to a level which exceeds the normal full storage level. This is presently thought to be an unsafe situation which requires further study.
- 3) Reservoir management plans should give priority to dam safety and providing flood storage within the reservoir, rather than to maximising the commercial returns from the project.

High priority should also be given to the following:

- 1) reinstatement of piezometers and installation of a comprehensive deformation monitoring system, and thereafter regular monitoring, analysis and interpretation of pore pressures, deformations and seepages;
- 2) review of flood management procedure;
- 3) establishment of a reliable early warning system for the downstream population in the event of an emergency, supported by an efficient organisation and communications system;
- 4) provision of reliable standby electricity generation facilities for gate operation.
- 5) works to secure the switchyard against the effects of groundwater and spray from spillway overflow.

## 8 REFERENCES

---

1. ICOLD Bulletin 72, 1989
2. SNIP 11-7-81 - Russian Seismic Standard
3. Seismic guide for dam design, Building Research Establishment (BRE), UK, 1991

**APPENDIX A**  
**LIST OF DATA EXAMINED**

1. Aral Sea Basin Program, 'Sustainability of Dams'  
World Bank Mission, June 1997, Final Report
2. 'The Nurek Multipurpose Development', Water Power & Dams Constructor,  
September 1978

**APPENDIX B**  
**HAZARD ASSESSMENT PROCEDURE**

**NUREK DAM  
APPENDIX B – HAZARD ASSESSMENT**

<b>Table 2.1 Classification Factors</b>				
	<b>Classification Factor</b>			
	Capacity (10 <sup>6</sup> m <sup>3</sup> )	>120 (6)	120-1 (4)	1-0.1 (2)
Height (m)	>45 (6)	45-30 (4)	30-15 (2)	<15 (0)
Evacuation requirements (No of persons)	>1000 (12)	1000-100 (8)	100-1 (4)	None (0)
Potential downstream Damage	High (12)	Moderate (8)	Low (4)	None (0)

Ref: ICOLD Bulletin 72, (Reference 1)

<b>Table 2.2 Dam Category</b>	
<b>Total Classification factor</b>	<b>Dam Category</b>
(0-6)	I
(7-18)	II
(19-30)	III
(31-36)	IV

Ref: ICOLD Bulletin 72, (Reference 1)

**APPENDIX C**

**NUREK DAM INSTRUMENTATION**

**REPORT BY SPECIALIST MR V. N.PULYAVIN**

**OCTOBER 1999**

## INSPECTION OF INSTRUMENTATION CONDITION AND DAM STRUCTURES OBSERVATIONS NUREK WATER RESERVOIR

**Instrumentation:** The following measures are carried out to control Nurek dam structures condition: measurement of settlements and horizontal displacement of the core and shells, local deformations of the core, seepage regime in the core, in the basis and in mountain slopes, soil stress and porous pressure in the core, and temperature. Besides, the observations are carried out by means of geodetic methods for concrete plug, settlements and horizontal displacement of service galleries.

15 inclinometers with total length of 2400 m, and about 700 sensors for different purposes (including 95 soil stress sensors, 107 pore pressure sensors, 32 linear deformation sensors etc.), 57 double pipe and 50 standpipe piezometers are installed on the dam. Main part of remote instrumentation is placed at the central section on the 7 tiers. Other sensors are mainly installed at contact of core with slopes or near to them.

The dam footing settlement observation is carried out by means of marks leveling, that were installed in a connected inspection gallery and in 3 grouting inspection galleries of concrete plug (the observation was carried out once a quarter), and observation performed for 70-75 marks.

For 20 years since installation period on average 21 % of all kinds of instrumentation went out of order, maximum percentage of sensors that went out of order are linear deformation sensors.

Condition of Nurek dam structures based on previous observation (1986) are characterized by the following figures.

Settlements of upper and central sections of the concrete plug were about 140 mm. Bottom section had 180 mm medium settlement at the time of construction completion and maximum and minimum of settlements at the opposite points of the section were from 85 up to 280 mm. In posterior time average settlement increased only for 20-25 mm. Observation of bottom marks showed, that total deformation of two lower layers for the same period did not exceed 1,5 mm.

Maximal core settlement for construction period – at the central section- was 13,7m, or that means 4,7 % of depth of fill. Maximal vertical displacement – at the middle part of the core – was 3m. Settlement for construction period of the upstream shell was 11,9 m, or that means 5,8 % of depth of fill, and downstream shell – 6,5 m, or that was 3%: vertical displacement correspondingly were 3,3 m and 2,2 m.

The dam core operating settlements at central section at July of 1986 were: at the gallery of first level – 0,37 m, at second level gallery – 0,48 m, at the crest – 0,63 m.

Horizontal displacements of the dam, except upper part of the core, were directed towards downstream. Maximal core displacements and downstream shell made up 0,8-0,9 m to the end of construction.

Pore pressure in the core. Absolute maximum of pore pressure in the core 3,6mPa was fixed in 1979. After that, there was slow decreasing of pore pressure maximal value: towards the end of 1982 – down to 3 mPa; towards the end of 1984 – down to 2,9 mPa; towards the end of 1986 – down to 2,7 mPa. The excessive pore pressure, which can be defined as the difference between measured pressure and design pressure, which was obtained coming from assumption about completion of consolidation but subject to fluctuation of head water level, decreased from 2.0 - 2.2 mPa at the end of 1980, to 1,7 mPa at the end of 1986.



## CONCLUSIONS

1. Accordingly to readings of instrumentation installed in concrete plug, the foundation settlements of Nurek dam have stabilized incompletely, however their increasing for the last 6 years made up only 20-25mm; range of settlement fluctuation is 8-10mm. There is a connection between settlements and head water level. The inclination of lower part of concrete plug in downstream and left side direction is going on. Additional investigations are necessary for determination of the reasons of that occurrence.
2. Operational dam crest settlement in central cross-section for 6 years made up 0,63 m, changing character of core settlement indicates the attenuation of the process. Settlements increased more intensively in lower one third part of the core and ride mainly by continuing core consolidation. Prognosis composed on the basis of core settlements extrapolation, showed, that stabilized crest settlement in the middle part of the dam, can reach 1,5 m , and stabilization duration – 50 years.
3. Horizontal displacements of the dam are practically stabilized, but there is some season fluctuations with amplitude 75-90mm.
4. Pore pressure in the core is continuing to dissipate. Maximal excessive pressure made up 1,7mPa towards the end of 1986.
5. The results of full scale observations on Nurek dam at the beginning of operation testify that condition of the dam meet the designed prognosis does not arouse apprehension.

## DRAWINGS