BURFELL PROJECT
THJORSA RIVER, ICELAND

Summary Report
Nov. 4, 1961

Safn I

HARZA ENGINEERING COMPANY INTERNATIONAL

HARZA ENGINEERING COMPANY INTERNATIONAL
CONSULTING ENGINEERS
RIVER PROJECTS

OFFICES
TEHRAN, IRAN
BAGHDAD, IRAQ
SAN SALVADOR, EL SALVADOR
TEGUCIGALPA, HONDURAS
BANGKOK, THAILAND
VIENTIANE, LAOS
LAHORE, WEST PAKISTAN
AMMAN, JORDAN
TAIPEI, TAIWAN

REPRESENTED IN THE UNITED STATES BY
HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

CABLE ADDRESS "HARZINT"

ADDRESS REPLY TO
HARZA ENGINEERING COMPANY
FOR THE ACCOUNT OF
HARZA ENGINEERING COMPANY INTERNATIONAL
400 WEST MADISON STREET
CHICAGO 6, ILLINOIS

TELEX NUMBER CG 1-4385

Nov. 4th, 1961

File 247

SUMMARY REPORT
ON
BURFELL PROJECT
THJORSA RIVER
ICELAND

LOCATION

The Burfell Project will be located on the middle reaches of the Thjorsa River in Southwest Iceland, as shown on Drawing No. 247P8. The river, together with its principal tributary, The Tungnaa, originates at the glaciers, Hofsjokull and Vatnajokull, and flows southwesterly to the North Atlantic Ocean. The drainage area upstream of the Project is about 6380 square kilometers. The Project, as currently conceived, will develop about 102 meters of gross head as the Thjorsa follows a semi-elliptical course around the southern end of the mountain, Burfell. Transmission facilities would extend to near Reykjavik, the country's principal and capitol city.

The location of the Burfell Project with respect to other proposed power and storage projects on the Thjorsa and Hvita Rivers is shown on Drawing No. 247P8. Detail data with respect to these proposed projects are shown on Drawing No. 247P13. This general master plan of development is described more fully in the report by the Harza Engineering Company International, entitled, "Advisory Report - Hydro-electric Power Resources - Hvita and Thjorsa River Systems - Southwest Iceland", dated March, 1960. It is important to point out that the presently proposed plan for the Burfell Project differs from the plan presented therein in that no initial storage is provided. The present plan is limited to a run-of-river development which permits the future provision of a storage dam and reservoir.

DESCRIPTION OF PRODUCTION FACILITIES

The general layout of the Burfell Project is shown on Drawing No. 247P18. It will consist of (1) a diversion weir and spillway crossing the Thjorsa River about two kilometers upstream from the low waterfall, Trollkonufoss; (2) a diversion intake structure on the right (west) bank of the river connecting to; (3) a diversion canal leading diagonally southwestward to; (4) a combined tunnel intake and sluice structure at the upstream end of; (5) a headrace tunnel extending through the mountain, Burfell, with a surge tank near the downstream end, and terminating in individual penstocks which lead to; (6) an underground powerstation; (7) a tailtunnel and channel extending to the Thjorsa near the mouth of the Fossa River; (8) an operators village; (9) and access facilities.

It is important to point out that this specific plan of development, while considered technically feasible, is only one of a number of generally similar alternatives for developing the head available in the Thjorsa River in the vicinity of Burfell. Other alternatives are yet to be investigated and studied. Any final selection would be on the basic of improved geologic conditions and economic advantages. These are not now considered to be very great relative to the presently proposed plan.

1. Dam, Spillway and Diversion Structure

A general plan of the dam, spillway and diversion structure, together with typical sections, is shown on Drawing No. 247P16.

Post-glacial Thjorsa lava extends in a near horizontal attitude for about two kilometers between the slopes of Burfell and Hekla, but is separated therefrom by the lava-marginal streams of Ytri-Ranga on the east and Bjarnarlaekur on the west. The Thjorsa at the site of the structures flows on the surface of the latest lava flow and is confined to its channel even during floods by more recent sediments, mostly lapalli, up to about 10 meters thick. There is no evidence that the Thjorsa even during great floods has ever flowed even in part into the lower level lava-marginal streams, probably partially because of the development of a natural riprap along its banks. The surface of the lava and of the sediments slopes gently southward and the river slope conforms thereto.

All of the structures conprising this part of the project will be founded on the surface of the Thjorsa lava, which appears entirely competent. The main spillway will cross the river as a low weir of concrete gravity construction only about 3 to 4 meters high up to a crest elecation of 223 meters. It will raise the water surface only about two meters. Two tainter gate bays will be located to the right of the weir and adjacent to the diversion intake structure. Each will contain a tainter gate 12 meters wide by 4 meters high operated by an individual hoist located at the deck level, elevation 230 meters. Operation will be by remote control from the powerstation. The gate sill is set at elevation 219,5, the approximate present river bottom. Inasmuch as it is expected that the Thjorsa will, by sedimentation, establish a new grade upstream of the weir, the principal purpose of the gated section is to sluice sediment and ice from in front of the diversion intake structure. Minor flow regulation will also be permitted. The spillway structure will be designed to have little backwater effect upstream during high floods.

A gravity retaining wall at the left end of the weir will serve as a terminus of the left bank rockfill dike. This dike will extend in an upstream direction to high rock and be graded in conformity with the expected water surface profile for the design flood of 9,000 cubic meters per second (cms). A freeboard allowance is provided. The rockfill dike will have a central impervious core protected by graded filters.

The diversion intake structure will be located along the right bank of the river upstream from the gated spillway. It will contain thirteen low level ports for entry of water into the diversion canal. Each port will be 10 meters wide by 1.5 meters high. The continuous wall above the ports will serve as a "shear" wall to guide floating ice towards the spillway and prevent its entry into the canal. The top of the wall will be graded upwards in an upstream direction generally parallel with the expected water surface during a moderate flood. The base of the ports will be approximately one meter above the present riverbed and will be likewise graded to correspond with the expected normal water surface level. The structure will be of reinforced concrete construction except for the base slab which will be of mass concrete. A curved concrete gravity retaining wall terminating in a short rockfill dike, both located beyond the upstream end of the diversion structure, will prevent all but great floods from entering the diversion canal. Reinforced concrete retaining walls on the downstream end will serve as a terminus for the right bank rockfill dike, which forms the left side of the diversion canal.

2. Diversion Canal

A plan of the diversion canal is shown on Drawing No. 247P15. It will extend from the diversion intake structure southwestward to the Bjarnarlaekur. Inasmuch as most of the lapalli will float in water, all of the sediments within the channel limits and under most of the dike will be removed. Some of the underlying Thjorsa lava surface may also require removal to provide adequate depth and hydraulic cross-section. The containing rockfill dike on the left side will be of the cross-section shown on Drawing No. 247P15. It will have a central impervious core protected by graded filters. The shells will be built with tunnel muck and other required rock excavation, expected to be more than adequate in quantity. The lapalli backslope on the right side of the channel will be ripraped with rock from required excavations. The top of the dike will be level at elevation 230 and be provided with a roadway. This will be above the maximum design flood level, expected at the spillway, by a freeboard allowance.

3. Tunnel Intake and Sluice Structure

The plan of the tunnel intake and sluice structure is shown on Drawing No. 247P15. Details are shown on Drawing No. 247P17. The tunnel portal is considered part of this intake structure. The sluice structure is contiguous to the intake on the left side.

The intake structure will form a transition between the diversion canal and the headrace tunnel. It will be designed to minimize hydraulic losses. Concrete construction will be utilized. The upstream end will consist of a curtain wall with low level intakes covered by trashracks. Removal of the trashracks will permit insertion of step logs to block the openings. Four openings, each 4 meters high, are to be provided. A moveable hoist will be positioned on the deck at elevation 230. The sill elevation of 216 meters is dictated by the general natural level of the approach canal.

The transition will narrow towards the tunnel portal and the bottom will grade downward to elevation 211,5, the bottom of the tunnel. The portal will contain a wheeled gate for tunnel closure. It will be operated by a fixed hoist located at deck level.

The sluice structure will be designed to permit passing floating debris and ice over a weir at elevation 221.5, and sediment through an undersluice with the sill at elevation 214, two meters lower than the tunnel intake sill. Both openings are to be 6 meters wide. A wheeled gate will provide control for the undersluice. The wheeled crest gate will be of the split-leaf type, with each leaf 3 meters high. A moveable-trolley, fixed frame hoist, located at deck level will operate all gates, using a lifting beam. The hydraulic capacity of the opening will be equal to the total turbine capacity in the power station. Water from the sluices will discharge to the Bjarnarlaekur.

A concrete gravity section will extend eastward from the sluice structure to serve as a wrap-around for that end of the right bank dike. A temporary low level opening will be provided for construction diversion purposes. This wall will be surmounted by a road deck connecting to the top of the dike. This will permit access to the river diversion works, described above.

4. Headrace Tunnel

The location of the headrace tunnel, typical tunnel sections, and a profile near the downstream end are all shown on Drawing No. 247P18. The main tunnel, including the vertical shaft section, will be of 7.5 meter diameter and fully concrete lined, supported and reinforced where necessary. It will slope gently downwards from the upstream portal to past the surge tank, then drop vertically to distributor level when the rock cover becomes insufficient. A construction adit will be provided for the downstream end at high level.

The 20-meter diameter surge tank will be in excavation and concrete lined. The excavation will open out to the surface, and the tank will be roofed with concrete and provided with a vent.

The horizontal portion at distributor level will be steel-lined with concrete backing. This portion will be driven to full diameter to provide access for the steel "cans". However, the steel-lined section will gradually reduce near the powerstation as each steel penstock takes off to its respective turbine spiral case.

5. Powerstation

The powerstation will be of the underground type located under the west side of the mountain, Burfell, as shown in plan and section on Drawing No. 247P18. Details of construction are shown on Drawing No. 247P19. A vertical setting of the units is planned.

The main generator hall and erection bay will be 15 meters wide and 80 meters long between concrete curtain walls. The erection area will be on the left end. A control and service area of equal width and 11 meters long will be located on the right end. A concrete roof arch will be provided. The generator hall will house the planned four units. The turbine setting will be at minimum tailwater in order to permit the economy of high specific speed. Each turbine will be protected by a butterfly valve located at the inlet end of the spiral case. An overhead bridge crane will be provided.

A tailrace surge chamber is to be provided at the end of the draft tubes. A draft tube gate structure will be located within this surge chamber. A monorail hoist will be used for gate operation. The surge chamber will be vented to the surface. Access to the draft tube deck will be by a short tunnel from the erection area, with protection provided by a watertight bulkhead door.

Access to the powerstation is shown in plan and section on Drawing No. 247P18. The primary access will be by a relatively short 6-meter tunnel, concrete lined where necessary, entering the erection area at elevation 131. A fan room will be located above the roof adjacent to the erection bay. Additional access is provided by the 4-meter cable adit extending from the switchyard to enter the control area a short distance below the roof. This tunnel will carry the generator low tension leads and the controls. It will also serve for ventilation and personnel access.

6. Tailrace

The tailrace is located as shown on Drawing No. 247P18. It will be in tunnel from the left end of the surge chamber to the portal, a distance of about 130 meters. An open channel will be provided from the tunnel portal to the river. The tunnel will be 10 meters wide by 11,5 meters high, and will be unlined except where required for structural support. A concrete portal with stop log slots will be provided. The excavation from construction operations in that vicinity will be spoiled to elevation 130 meters or higher in the area upstream from the tailrace channel to prevent the entry of sediment from the river.

7. Switchyard

The switchyard will be located outdoors in a prepared bench as shown on Drawing No. 247P18. The cable adit from the powerstation will enter near the center of the yard on the uphill side. The main power transformers will be located in the yard.

8. Access and Operators Village

A trail exists on the left side of the Thjorsa River in the vicinity of Burfell. This trail connects to the road net of the populated areas of Southwest Iceland. Improvement of this trail and portions of the connecting road net will be required. A connection to this road would be made as shown on the "Key Plan" on Drawing No. 247P18. This would involve a bridge across a narrow segment of the Thjorsa River at the south end of Burfell. Project access roads would fork from the north end of this bridge to the river diversion structure and to the powerstation. The latter route will pass the operator's village midway between the bridge and the powerstation. The lack of a settled community in this area makes such a village nevessary.

9. Main Station Equipment

Four generators will be provided. They will be of the vertical-shaft, hydraulic-turbine driven type rated 36,000 kVA, 0.9 power factor, 13.8 kV, three-phase, 50 cycle.

The four turbines will each be of the Francis type rated 43,000 metric horsepower at 97.5 meters net head. The speed of the units has been tentatively selected at 273 rpm.

Each of the four outdoor main three-phase transformers will be of the OA/FA type rated 38 MVA, 13.8/230 kV. The low tension leads from the generators will be nondraining cables, two per phase. Six air blast circuit breakers will be located in the switchyard. Drawing No. 3.0843.25 shows the One Line Diagram for the station. Besides power breakers are provided for at the receiving ends and a 70 MVA tie to the Sog System.

TRANSMISSION

A single circuit 230 kV line on wood pole construction will extend from the Burfell switchyard to the load center. Tentative locations to the two possible load centers, Reykjavik and Thorlakshofn are shown on Drawing No. 2.0836.61. The line for the Reykjavik alternative would pass the Sog hydroelectrical plants, while the second alternative would pass Urridafoss and extend also to Reykjavik to provide a tie with the existing generation system.

POWER & ENERGY

1. Stream Flow

The stream flow available at Burfell was described generally in the March 1960 Advisory Report, referred to above. The Thjorsa flows tend to be low except during the summer months from May through August. The average flow has been estimated at about 334 cms. The flow available for 90 percent of the time has been estimated at about 145 cms. The Burfell Project, as presented herein, has been sized to utilize this flow with the four units operating at best efficiency. Approximately 10 percent additional flow, when available, could be utilized by full gate turbine operation.

2. Primary Energy

The primary energy of the Burfell Project has been considered as that produced from a flow up to 145 cms as available. Some load curtailment would be required during the approximately 10 percent of the time when flows may be slightly less than this amount. The estimate of annual primary energy delivered to the load center at high tension after allowance for all losses and a utilization factor of 98 percent amounts to 990 million kilowatt hours. Some secondary energy would be available by turbine operation between best gate and full gate when flows are available, but this has not been evaluated.

3. Peaking Capability

It is expected that the plant can deliver to the load center peaking power up to about 140,000 kilowatts. This might be reduced slightly during periods of high tailwater, including encroachment resulting from ice jams downstream.

PROJECT COSTS

1. Capital Costs

A cost estimate has been prepared for the Burfell Project as described above and is included in summary form. This summary was prepared as the result of a detailed quantity survey based on the drawings referred to above, except for major equipment items discussed hereinafter. Unit prices were established for each class of work based on present day labor and material costs. These unit prices did not include import duties and taxes where otherwise applicable on imported material and equipment, including construction equipment. The only item of profit considered was that to the general construction contractor or contractors.

The estimated cost for permanent equipment is based on that of Western European manufacture. These prices were based on quotations or on recent bid prices for similar equipment from well-known manufacturers. Again import duties and taxes were not included.

A contingencies and omissions allowance of 20 percent was added to the estimated subtotal of direct costs for the production and transmission plants. This allowance is considered reasonable for an appraisal estimate in view of the limited topographic and geologic information available, and the minor amount of subsurface investigations.

An escalation allowance of 5 percent was added to the estimated subtotal including contingencies. This allowance is considered reasonable in view of: (1) recent economic history, (2) frequent practice of equipment manufacturers and, (3) the fact that the estimate is based on present day labor and material prices.

The addition of the escalation allowance resulted in establishing the estimated total direct costs. An allowance of 8 percent of the total direct costs was applied to allow for such indirect costs as design engineering, supervision of construction, and owner overhead. A further allowance of $ 500,000 was made to cover the estimated cost for preliminary planning basic to design and for field investigations whibh are yet to be undertaken. This addition gave an estimated total construction cost of $ 23,575,300 for the Reykjavik load center and $ 24,265,230 for the Thorlakshofn load center.

Financing terms are, at present, not established. Therefore an allowance of 10 percent was made to cover interest during construction for the approximately 3-year construction period. This allowance is considered reasonable.

Capitalization of working capital in the amount of two percent and a reserve of one year's interest (based on 6% coupon rate) was also made. The former is required for operation purposes. The latter provides an allowance for delays in either completion of construction or receipt of power revenue, and is a relatively common practice for financing of this type. If this interest reserve is not needed ultimately it would be reserved for debt service.

2. Annual Costs

The principal item of annual cost will be the expense of interest and amortization of the capital debt (debt service). This cost will not be known until such time as the financing terms may be established.

The annual cost for operation and maintenance has been estimated at $ 400,000 including both the production and transmission systems. No item for insurance premiums has been included in the annual costs. For most usual coverages for projects of this type, the annual costs are usually relatively small.

The return on the value of water rights has been included as an annual cost. This is considered to be the fair return on the value of such rights, which are not now known definitely.

The estimate for Reserves has been taken as about one percent of the estimated total construction cost. This Reserve is required to be established to cover expenses of an extraordinary nature not otherwise covered by promptly paid insurance or normal maintenance. It could be used, for example: (1) to replace equipment failures beyond the guarantee period, (2) for expenses prior to insurance recovery, (3) for rewinding of generators, (4) for other major replacements to structures or equipment in whole or in part, (5) for assessed consequential damages or costs, (5) for delays or failures in revenue collection, and (7) for other unforseen costs.

The estimated annual costs other than debt service are as follows:

1. Operation and Maintenance	$ 400,000
2. Reserves & Water Rights	290,000
Total	$ 690,000

3. Primary Energy Costs

In the evaluation of unit energy costs no consideration has been given to income from the sale of any secondary energy, but all delivered primary energy, as defined above, amounting to 990 million kilowatt-hours per year, has been considered as sold.

Inasmuch as the financing terms have not been established it has been necessary to present an estimate of the unit cost of energy as a graph for a range of annual debt service expressed as a percentage of the total capital requirements of $ 28,140,000 for the Reykjavik alternative and $ 28,963,000 for the Thorlakshofn alternative over a range from 5 to 8%. This graph is shown on Drawing No. 4.1249.20. The other definitely estimated annual costs amounting to $ 690,000 have, of course, been included in determining the unit energy costs as a fixed amount not varying with debt service. However, no allowance for profit has been included in this evaluation. It is also important to point out that no allowance has been made in the capital requirements for any import duties and taxes which might be appropriate.

ACKNOWLEDGMENTS

We wish to extend our sincere appreciation to the Icelandic entities and individuals who have so ably assisted in the basic studies and data which have made this summary report possible. These include the State Electricity Authority; the Icelandic engineering firms of Verklegar framkvaemdir H/F and Almenna Byggingafelagid H/F; Messers Jakob Gislason, Eirikur Briem, Arni Snaevarr, Ögmundur Jonsson, Rögnvaldur Thorlaksson; and many others. Permission to use drawings prepared by Rarik and by the other engineering firms is especially appreciated.

C.K. Willey

Vice President
(Harza Engineering Company)