APPRAISAL REPORT

VORDUFELL PUMPED-STORAGE PROJECT

BY THE

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED FOR
THE STATE ELECTRICITY AUTHORITY
GOVERNMENT OF ICELAND

JUNE 1963

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VORDUFELL PUMPED-STORAGE PROJECT

SUMMARY OF REPORT

The State Electricity Authority
P. O. Box 40
Reykjavik, Iceland

Gentlemen:

General

We have appraised a pumped-storage development at Vordufell designed primarily to provide a reserve to the Southwest Iceland Power Supply System (Sog System). The possible need for reserves in connection with the Burfell Project serving an aluminium smelting load was discussed in our Project Planning Report of January 1963.

Reserve power and energy would be stored as water in Ulfsvatn on the top of the mountain, Vordufell, for immediate generation in the event of an outage of the Burfell Project. The water would be pumped into this high level storage from the Hvita, using secondary energy. A reversible pump-turbine installation would accomplish both pumping and generation. The installation, thus, is merely a special adaptation of the pumped-storage principle which is coming rapidly into world-wide use for capacity installation in large power systems.

Inasmuch as the requirement for reserves cannot be accurately predicted, cost curves were prepared for ranges of plant capacity and of reservoir storage. These curves were then used to determine the cost of assumed required reserves for three alternatives of smelter installation: 1, 1 1/2, and 2 potlines. These costs for Vordufell pumped-storage were then compared to that for reserves provided alternatively by gasturbine installations.

Details of the study are presented in the five Chapters of the main body of this Report, and in the ten Exhibits which amplify the text.

Assumptions

The following assumptions were made as to the normal and emergency load requirements to establish an estimate of the required power and energy Reserves:

1. The level of System loads and generation resources was taken as that estimated for the year 1970.
2. Reduction of loads during emergency conditions were taken at 100 percent for the NATO Base and the Fertilizer Plant, at 50 percent for the Aluminium Smelter, and at 10 percent for the General Load.
3. An emergency period of two weeks was assumed for energy requirements.
4. The normal power requirement of one potline was taken at 60, 000 kilowatts.
5. The existing generation, other than Burfell which is assumed to be out of production, would be operated on base load, with the Reserve installation absorbing the peaks only for the two weeks.

The results of our estimates of Reserve requirements at Reykjavik are given in the table below.

RESERVE POWER AND ENERGY REQUIREMENTS

	Normal Aluminium Load		
	1 Potline 60 MW	1 1/2 Potlines 90 MW	2 Potlines 120 MW
Capacity - MW	18	33	48
Energy - Million Kwh	0.8	2.2	4.2

The above capacity values determine the size of the Reserve installation whereas the energy values determine the storage required or the amount of fuel needed.

Vordufell Project Description

The excellent natural conditions for a pumped-storage development at Vordufell were recognized in our Advisory Report of March 1960. Field investigations carried out during the summer of 1962 have provided the data necessary for the present appraisal estimate, which has been prepared essentially for the purpose of providing a basis for policy decisions on future investigations and studies.

The Vordufell Project will be located about 65 kilometers east of Reykjavik at the west side of the mountain, Vordufell, and near the left bank of the Hvita. It will utilize about 261 meters of natural head between the lake, Ulfsvatn, located at the crest of Vordufell, and the Hvita. The project will consist of three main components: the reservoir, the pumping plant including water conductors, and the transmission plant. The reservoir will be provided at Ulfsvatn. The initial storage capacity of the lake will be increased as required by the construction of dikes at the south end of the lake.

The pumping-generating plant will be located at the base of Vordufell about 600 meters from the left bank of Hvita. A vertical pressure shaft leading into a near horizontal tunnel will connect the reservoir with the pumping plant. Water supply to the pumping plant will be taken from the Hvita by means of a tailrace canal.

The transmission plant will consist of a transformer and low tension switching at the pumping plant, and a short connection with the 230 Kv line from Burfell to Reykjavik. A solid tie between the two lines was assumed. Consideration should be given to route this main transmission line through the pumping plant location. The total length of line would be very little greater.

Selection of Size of Installation

The Reserves required will depend on many factors which cannot all be estimated accurately at this time. An important factor is the size of the aluminium load which the System will serve. An initial smelter may have from one to two potlines in half-potline increments of about 30,000 kilowatts. We decided, therefore, to prepare estimates for three alternative sizes of installation selected within the range of expected Reserve requirements. The three sizes selected were 30,000, 45,000, and 60,000 kilowatts of dependable capacity at Reykjavik. The rated capacity at the plant will be about five percent larger than the above values because of line losses and draw-down of the reservoir.

The size of the reservoir is related to the Reserve energy requirements which also can not be estimated accurately. Layouts and cost estimates were therefore prepared for a range of reservoir levels from elevation 320 to elevation 340. This range includes all probable storage requirements.

Vordufell Cost Estimates

Detailed cost estimates were prepared for the three plant alternatives selected, for the transmission tie, and for the range of reservoir levels given above. The estimates are discussed in Chapter IV.

The estimates include allowances for contingencies, engineering and overhead, and interest during construction. No allowances were included for working capital, interest reserve, cost escalation, and import duties and taxes. The rate of exchange was taken at 43 Icelandic Kronur to one US Dollar.

Estimates were also prepared for items of annual cost except interest on investment. These items include operation and maintenance costs, and depreciation of assets. Energy required for pumping was assumed delivered at no cost. An allowance of 0.5 percent of the pumping plant construction cost was included as the annual cost of a reserve fund to cover expenses of an extraordinary nature. Compensation for water rights was not considered and does not seem appropriate.

The results of the estimates were presented in graphical form as a convenient means of finding the cost of various combinations of plant capacity and storage.

The costs of providing the Reserves computed above for the three sizes of smelters were estimated from these developed cost curves. Interpolation was necessary to obtain appropriate values. The results of our estimates are tabulated below.

VORDUFELL PUMPED STORAGE
DEVELOPED AS RESERVE FOR BURFELL
(1970 Estimated Conditions)

		Normal Aluminium Load		
		1 Potline 60 MW	1 1/2 Potlines 90 MW	2 Potlines 120 MW
Capacity - MW*		18	33	48
Energy - Million Kwh		0.8	2.2	4.2
Reservoir Elevation - m		317	322	327
Cost of Pumping Plant and Transmission Tie -	$1000	2900	3800	4700
Cost of Reservoir -	$1000	150	250	650
Total Project Cost -	$1000	3050	4050	5350
Cost per Kilowatt -	$1000	170	123	111
Annual Cost of Pumping Plant and Transmission Plant -	$1000	125	145	178
Annual Cost of Reservoir -	$1000	4	5	8
Total Annual Costs -	$1000	129	150	186

* Dependable capacity at Reykjavik. Rated capacity of plant about five percent larger.

The above values of annual charges do not include interest on investment because the rate that would apply is not known at this time. Instead we elected to estimate the annual interest costs for a range between four and eight percent of total investment. The results were then plotted on a graph, attached as Exhibit A. The total annual costs of Reserves for each of the three potline alternatives selected are shown in solid lines thereon.

Thermal Alternative

Gasturbines were selected as a "yardstick" for evaluating the economics of the Vordufell Project. The capital cost for the gasturbines fully installed was taken at $100 per kilowatt. The annual charges including fuel costs but without interest on investment were estimated as follows for the three alternatives of reserve requirements selected:

	Normal Aluminium Load		
	1 Potline	1 1/2 Potlines	2 Potlines
Capacity - MW	18	33	48
Energy - Million Kwh	0.8	2.2	4.2
Annual Cost other than Interest - $1000	118	192	272

The interest costs were estimated for the range between four and eight percent and added to the above charges. The total annual costs thus obtained are shown in dashed lines on Exhibit A.

Cost Relationship

A comparison of the annual costs shown on Exhibit A indicates that the Vordufell Pumped-Storage Project is more economical than gasturbines for a two-potline smelter, whereas the gasturbines are more economical for a one-potline smelter. The two alternatives are about even for the 1 1/2 potline requirement of 33,000 kilowatts. This general conclusion will be true also if the energy required for pumping is included at a reasonable cost.

The unit cost of $100/KW for a gasturbine installation may be somewhat liberal. A unit cost of $90/KW would lower annual costs about 8.5 percent. Such a reduction would make a gasturbine installation slightly more favorable than pumped-storage for the 1 1/2 potline smelter under 1970 conditions.

The requirements for Reserves on the basis of the assumptions presented above will increase in proportion to the load served by Burfell. The annual increase will amount to about 90 percent of the increase in the General Load. By 1975 with one potline the Reserve requirements would total about 63 MW, or 3 1/2 times that for 1970. Similarly with two potlines, Reserves required by 1975 would approach 100 MW unless more severe load shedding becomes feasible.

The cost analyses tended to indicate that, considering the Reserve function alone, a gasturbine installation is cheaper for Reserve requirements less than 30 - 35 MW, with Vordufell Pumped-Storage more economical for larger Reserve requirements. The load projections tend to indicate a Reserve requirement more favorable to Vordufell within about 5 years from the time Burfell begins to serve any size of initial smelter load. On the other hand, gasturbines may possibly be more adaptable to smaller installation increments. They may also possess some advantages with respect to use for power factor correction. However, Vordufell as a pumped-storage capacity plant provides important advantages to the Iceland Power Supply System on a long range basis.

Vordufell as Pumped Storage Capacity Plant

The studies of Vordufell as a Reserve station revealed that it is also exceptionally attractive as a more conventional pumped-storage development to provide daily peaking capacity. Storage requirements in relation to installed capacity are much less severe than required for Reserve purposes. Our analyses showed that a 200 MW plant operating on a daily four-hour continuous peak would require only 1.5 million cubic meters of storage. Similarly, a 1,000,000 kilowatt plant would require 7.2 million cubic meters of storage, or a reservoir to about elevation 327 meters. Ulfsvatn has a much larger potential by several times. The relative cost of the storage reservoir is almost negligible for a large capacity installation at Vordufell.

We estimate that, on the basis of present day prices, a large pumped-storage capacity installation at Vordufell would cost between $90 and $100 per installed kilowatt. The potential of the site is well over one million kilowatts. With a very large installation it will probably be necessary to provide a low level reservoir in the Hvita for regulation purposes. This could be accomplished by a relatively inexpensive dam such as proposed for the Hestvatn Project or as might be required for the diversion of the Hvita to the Thjorsa above Urridafoss.

This relatively cheap cost for capacity at Vordufell suggests that it should be considered as a principal source of peaking capacity in the Iceland Power Supply System in future years. This could mean that conventional hydro developments on the Southwest Iceland rivers might be designed as energy plants primarily.

Conclusions

The studies pointed to the very great attractiveness of the Vordufell Project for pumped-storage capacity and that, in general, it is competitive with alternative sources for Reserve purposes. We conclude that, at least initially, any development of Vordufell can serve economically both Reserve and daily system peaking purposes. The decision with respect to a choice between Vordufell and gasturbines for initial Reserves must await specific evaluations at such times as they may appear to be required. This Appraisal indicates that Vordufell for Reserves and for pumped-storage capacity is far superior on a long range basis.

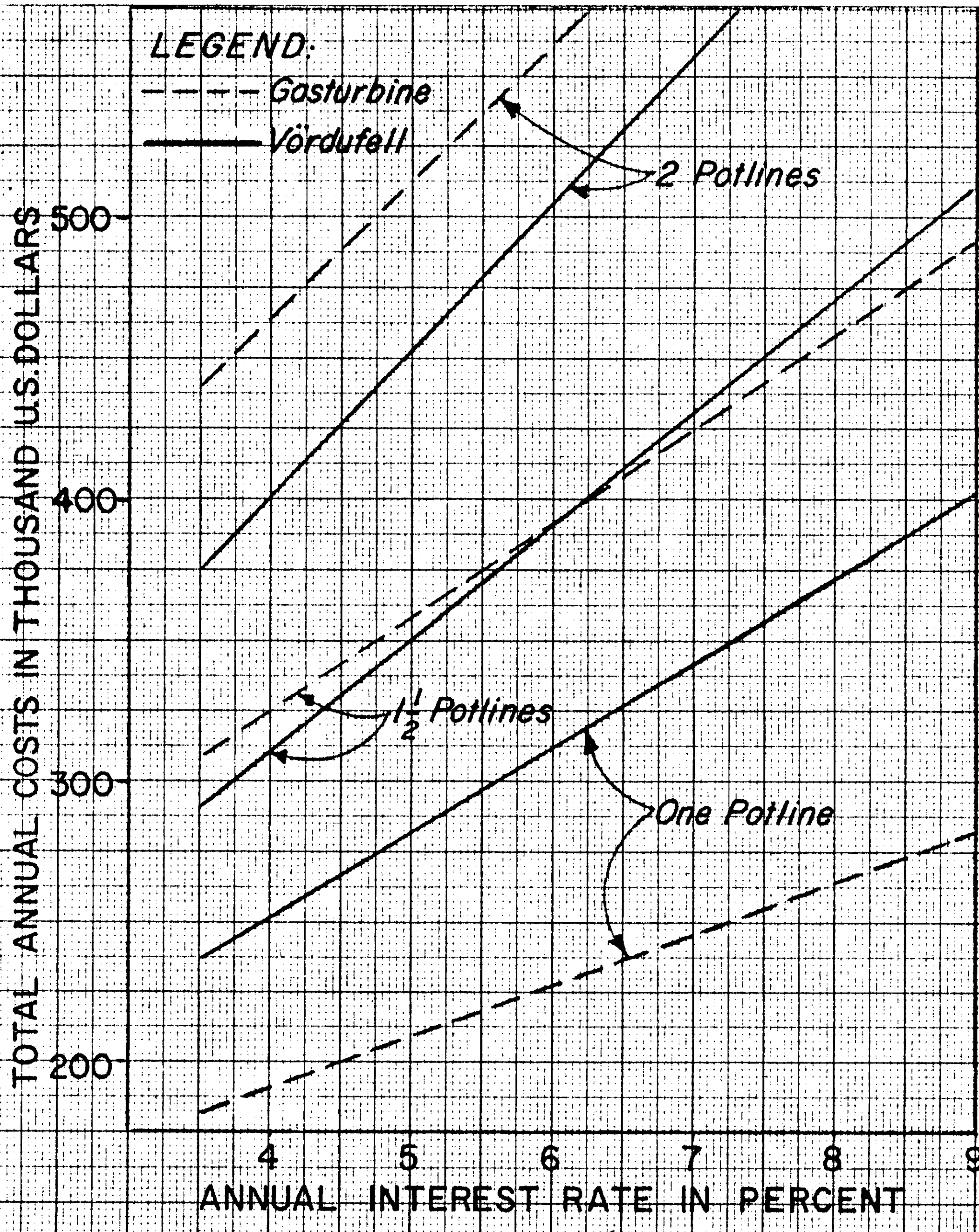
Very truly yours,

HARZA ENGINEERING COMPANY
INTERNATIONAL

E. Montford Fucik

E. Montford Fucik
President

EXHIBIT A



NOTES:

1. Cost of energy required for pumping not included.

2. Two weeks operation annually.

VORDUFELL AND GASTURBINE ANNUAL COSTS

MAY, 1963

VORDUFELL PROJECT

TABULATION OF SIGNIFICANT DATA

	Dependable Capability		
	30,000 kw	45,000 kw	60,000 kw
Number of Units	1	1	2
Minimum Dependable Capability at Reykjavik - kw	30,000	45,000	60,000
Reservoir			
Maximum water surface elevation - meters		varies	
Minimum water surface elevation - meters	313	313	313
Usable Volume - million cubic meters		varies	
Minimum gross head - meters	260	260	260
Dikes (as shown on drawing)			
Crest elevation - meters		327	
Total length - meters		800	
Total volume of fill - cubic meters		80,000	
Spillway (as shown on drawing)			
Crest elevation - meters		325.2	
Width of crest - meters		12	
Discharge capacity - $m^{3/5}$		16	
Intake Canal (as shown on drawing)			
Bottom width - meters	5	6	10
Maximum velocity - m/s	0.4	0.5	0.5
Intake (as shown on drawing)			
Invert elevation	307	307	307

TABULATION OF SIGNIFICANT DATA (Continued)

	Dependable Capability		
	30,000 kw	45,000 kw	60,000 kw
Shaft			
Diameter - meters	1.9	2.2	2.5
Length - meters	160	160	160
Concrete lining			
minimum thickness - meters	0.35	0.35	0.35
average thickness - meters	0.50	0.50	0.50
Max. velocity - m/s	5.8	6.6	6.8
Tunnel - Concrete Lined			
Diameter - meters	1.9	2.2	2.5
Length - meters	550	550	550
Concrete lining			
minimum thickness - meters	0.35	0.35	0.35
average thickness - meters	0.50	0.50	0.50
Max. velocity - m/s	5.8	6.6	6.8
Tunnel - Steel Lined			
Diameter - meters	1.7	2.0	2.3
Length - meters	125	125	125
Concrete lining			
minimum thickness - meters	0.40	0.40	0.40
average thickness - meters	0.60	0.60	0.60
Max. velocity - m/s	7.2	8.0	8.1
Penstock			
Diameter (main section) - meters	1.7	2.0	2.3
Length (including bifurcation and branch pipes) - meters	340	340	340
Max. velocity - m/s	7.2	8.0	8.1

TABULATION OF SIGNIFICANT DATA (Continued)

	Dependable Capability		
	30,000 kw	45,000 kw	60,000 kw
Powerhouse			
Type	Conventional - indoor		
Length - meters	25	27	40
Width - meters	13	14	13
Height - meters	29	30	29
Tailrace Canal			
Length - meters	600	600	600
Bottom elevation - meters	48	48	48
Bottom width - meters	12	20	28
Max. velocity - m/s	0.55	0.55	0.55
Pump-Turbines			
Number	1	1	2
Max. operating head, generating - meters	266	270	273
Max. operating head, pumping - meters	280	284	287
Min. operating head, generating - meters	240	240	240
Min. operating head, pumping - meters	265	265	265
Rated head - meters	260	260	260
Turbine output at rated head - hp	49,000	73,600	2 x 49,000
Turbine output at minimum head - hp	44,000	65,400	2 x 44,000
Full gate discharge at rated head - m^3/s	16.6	25.0	2 x 16.6
Normal discharge at average head - m^3/s	15.4	23.0	2 x 15.4

TABULATION OF SIGNIFICANT DATA (Continued)

	Dependable Capability		
	30,000 kw	45,000 kw	60,000 kw
Pump capacity at rated head - m^3/s	11.0	16.0	2 x 11.0
Speed - rpm	500	428	500
Generator - Motors			
Number	1	1	2
Rated capacity as generator - kva	35,000	52,000	2 x 35,000
Rated capacity as motor - hp	45,000	68,000	2 x 45,000
Power factor	0.9	0.9	0.9
Voltage - kv	13.8	13.8	13.8
Phases	three	three	three
Cycles per second	50	50	50
Speed - rpm	500	428	500
Transformers			
Number	1	1	1
Type	OA/FA/FOA	OA/FA/FOA	OA/FA/FOA
Rating - megavolt-amperes	21/28/35	31.2/41.5/52	42/56/70
Voltage - kilovolts	13.2-230	13.2-230	13.2-230
Main transmission line			
Length - km	4	4	4
Voltage - kilovolts	230	230	230
Construction		wood poles	

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THE REPORT

CHAPTER I

PURPOSE OF PROJECT

General

A pumped storage development at Vordufell as presented herein is primarily for the purpose of providing Reserve capacity and energy for the Burfell Project serving an aluminium smeltering load. Such Reserve capacity may be needed in the case of a complete or partial outage of the Burfell Project caused by transmission failure or operational difficulties at the plant. The amount of Reserves required will depend largely on the size of the industrial load which may range from 60, 000 to 120, 000 kilowatts depending on the number of potlines provided.

The Burfell Project will be interconnected with the power system in Southwest Iceland, also called the "Sog System." The generating capacity and the loads in the overall System and its load shedding capability under emergency conditions will therefore also have an important bearing upon the amount of reserves required.

The various factors mentioned above have been studied to arrive at estimates of capacity and energy requirements for the Vordufell Pumped Storage Project. These estimates are only approximations since they are based on many assumptions with respect to future conditions which cannot be accurately determined at this time. Furthermore, the reserve requirements will change from year to year with the System loads and installations. It is also conceivable that Vordufell may ultimately be operated fully or in part to provide capacity to the System during peak hours. For these reasons it was decided to estimate the Project for three alternative installations which were selected more or less by judgement.

For the purpose of economic evaluation it was necessary to make an economic comparison of the Vordufell Pumped Storage with alternative means of providing Reserve capacity, such as gasturbines, steam capacity, diesel units, geothermal plants, or other hydro developments. Of these the gasturbine alternative appears to be the most economical. Estimates for the gasturbine alternatives are presented in Chapter V.

Reserve Requirements

The estimated loads and generating facilities in the year 1970 was more or less arbitrarily selected as the time basis for evaluation of the Reserve requirements. It was assumed that the Burfell Project would be in operation in 1967, but that the controlling need for Reserve capacity would develop a few years later as a result of an increase in the general loads.

1970 Load

The Sog System power and energy demands in 1970, as estimated by the SEA, is shown in Table I-1 below.

TABLE I-1

ESTIMATED 1970 POWER AND ENERGY LOADS

	Peak Loads Megawatts	Annual Energy Million Kwh
General	124	534
NATO Base	12	79
Fertilizer Plant	6	195
	142	808

The aluminium loads, not included above, were assumed at 60,000, 90,000, and 120,000 kilowatts, representing a 1, 1 1/2, and 2 potline smelter respectively, as discussed in our Burfell Planning Report of January 1963.

Load Shedding

In discussions with the SEA the following load shedding criteria were decided upon:

1.	General Load	10%
2.	NATO Base	100%
3.	Fertilizer Plant	100%
4.	Aluminium Load	50%

The total emergency peak loads will then be as shown on Table I-2 below:

TABLE I-2

EMERGENCY POWER REQUIREMENTS

	One Potline Peak Load MW	1 1/2 Potlines Peak Load MW	2 Potlines Peak Load MW
General	112	112	112
NATO Base	0	0	0
Fertilizer Plant	0	0	0
Aluminium Plant	30	45	60
Total	142	157	172

The emergency energy requirements were estimated on a weekly basis by means of assumed load duration curves for a typical week in 1970. Curves for normal loads as well as emergency loads are presented graphically on Exhibit 1 as a function of time expressed in percent. The graphs shown are for a 1 1/2 potline smelter. The graphs for one and two potline smelters would be similar except that the aluminium loads would be different. In plotting the curves the maximum normal loads during peak hours were taken as shown in Table I-1. The fertilizer plant was assumed to require 6,000 kilowatts during peak hours and 28,000 kilowatts during off-peak hours. The weekly load factors were assumed at 58 percent for the General and NATO loads and at 98 percent for the Aluminium load.

The load curves for emergency conditions were derived from the normal load curves as adjusted in accordance with the load shedding assumptions outlined above. The NATO load and the Fertilizer load do not appear on the graph because complete shedding of these loads was assumed.

1970 Generating Facilities

To determine the Reserve requirements, it was necessary to make an estimate of the generating capacity other than Burfell available in 1970. The following table is based on the information given in the Burfell Planning Report:

TABLE I-3

1970 GENERATING FACILITIES IN SOUTHWEST ICELAND

Development	Capacity in Megawatts	
Sog		
Steingrimsstod	26.4	
Ljosafoss	21.6	
Irafoss	46.5	94.5
Ellidaar, hydro	3.2	
Andakill, hydro	3.5	6.7
Ellidaar, thermal	19.0	
Westman Island, thermal	3.9	22.9
Total Hydro and Thermal		124.1

All of the above generating facilities were assumed available under emergency conditions. The assumption was made that the boilers of the steam plant at Ellidaar would be heated up at times of possible ice trouble to be ready for quick operation if required. The Diesel capacity at the NATO Base was not included because this capacity would be needed to supply the Base whenever the power from the Sog System would be curtailed, as was assumed herein.

Reserve Requirements

The Reserve capacity requirements were obtained by a comparison of Tables I-2 and I-3. The requirements would be about 18,000, 33,000, and 48,000 kilowatts for a 1, 1 1/2, and 2-potline aluminium loads, respectively. All of the above values are based on the assumption that the normal load of one potline is 60,000 kilowatts.

For the estimate of energy requirements it was assumed that the Sog hydro plants would operate at up to 98 percent capacity factor during emergency periods except when limited by the load. This is considered feasible because of the relatively large storage provided by the lake, Thingvallavatn. An increase in the capacity factor from 70 percent to 98 percent over a two week period represents an estimated 0.75 meters drawdown of the lake. This amount of storage can probably be held in reserve after Burfell is connected to the System. The thermal plants were assumed to operate at a high capacity factor whenever feasible as governed by the load.

The power and energy supplied by the Sog hydro and the Ellidaar steam plants was then plotted on the load curves shown on Exhibit 1. The hatched area represents the amount of energy that must be supplied from the Reserves when Burfell is out of operation.

The results of the above estimates of reserve energy requirements are presented in Table I-4 below.

TABLE I-4

RESERVE ENERGY REQUIREMENTS

IN MILLION KILOWATTHOURS - 1970 LOADS

ONE WEEK OPERATION

	NORMAL ALUMINIUM LOAD		
	1 Potline 60 MW	1 1/2 Potlines 90 MW	2 Potlines 120 MW
Requirements			
Aluminium	4.9	7.4	9.9
General	11.0	11.0	11.0
Total Requirements	15.9	18.4	20.9
Generation			
Sog Hydro	14.3	15.6	16.6
Ellidaar Thermal	1.2	1.7	2.2
Subtotal	15.5	17.3	18.8
Reserve Requirement	0.4	1.1	2.1

Two weeks operation will double the above values.

CHAPTER II

VORDUFELL PROJECT

Project Site

Location and Access

The Vordufell Pumped-Storage Project will utilize the head potential between the lake, Ulfsvatn, located near the crest of the mountain, Vordufell, and the Hvita, which flows past this mountain about 600 meters to the west of its base. The natural head is about 261 meters between the lake at elevation 311 and the river at about elevation 50.

Vordufell is located at the north end of the Skeid which is a flat plain bordered by three rivers: the Hvita to the west, the Stora-Laxa to the north and east, and the Thjorsa to the south and east. The general location is shown on the Key Map of Exhibit 2. The area is about 65 kilometers due east of Reykjavik and about 30 kilometers from the south coast of Iceland. It is served by a main road which connects with the east-west highway from Reykjavik about three kilometers west of Urridafoss. Several farms are located around Vordufell, but not on the west side in the immediate project area. The nearest farm is about 2.5 kilometers south of the powerhouse site.

General Topography

Vordufell is an isolated mountain rising 340 meters above the surrounding plain to its highest point at elevation 391 meters. It extends about six kilometers in a north-south direction and about 3.5 kilometers in the east-west direction at the south end where it is widest. The slopes are steep on all sides except somewhat less to the southwest which offers the most favorable route for road access. The top of the mountain is relatively flat with a depression in the middle, partly occupied by Ulfsvatn. This depression is rimmed by low hills on all sides except to the south and northeast where relatively low saddles break their continuity. The outlet from the lake is at the south end through the narrow gorge, Ulfsgil.

The lake has a surface area of about 250,000 square meters at its natural level of 310.9 meters. Most of the lake is from five to eight meters deep; the greatest depth is in the northeast end where 12 meters have been sounded.

The project area between Ulfsvatn and the Hvita may be divided topographically into three segments: (1) the Vordufell including the steep west slopes down to elevation 150; (2) the base of the mountain having relatively gentle slopes; and (3) a 500 to 600 meter wide bog extending to the left bank of the Hvita and elevated only a few meters above the river. The total horizontal distance from the lake to the river is about 1700 meters.

General maps in a scale of 1 : 50,000 and with 20 meter contours were available for the planning of access roads and transmission lines. The immediate project area including the sites of all structures was mapped by aerial methods in a scale of 1 : 5,000 with 2 meter contours. A few soundings made in Ulfsvatn provided general information as to the depth of that lake. A hydrographic map with one meter contours was available of the Hvita at the outlet of the tailrace channel.

Project Arrangement

General

A pumped-storage scheme usually includes five main elements: (1) an Upper Reservoir, (2) a Lower Reservoir, (3) Water Conductors,

(4) a Powerplant including Equipment, and (5) Transmission Plant. Water is pumped from the Lower Reservoir into the Upper Reservoir where it is stored until released for power generation as required. The energy required for pumping must come from an outside source not normally considered part of the pumped-storage plant.

The Vordufell Pumped-Storage Project conforms in principle to this concept and includes all of the elements mentioned above. The purpose of the Project under study is, however, somewhat different than for the usual type of pumped-storage scheme which is designed to provide peaking capability to a system, operating generally on a daily basis with the pumping cycle accomplished during off-peak hours at night and the generating cycle during peak hours in the morning and/or evening. The Vordufell Pumped-Storage, as presented herein, is not planned for this purpose, but mainly as a Reserve in conjunction with the Burfell Project serving an aluminium smeltering load. The principal difference affecting the design is that a much larger upper reservoir must be provided because the plant may be required to draw almost continuously on the stored water for several days. The depression in which Ulfsvatn is located is a suitable and economical site for a large upper reservoir at Vordufell.

The Lower Reservoir for the Vordufell Pumped-Storage is provided by the Hvita which has an adequate supply for any foreseeable needs.

It would be entirely feasible to design the Project as a peaking plant only, or as a combination peaking-reserve station. The general layout would be similar in all cases; the difference would be in the plant capacity, size of water conductors, and the amount of storage required in the Upper Reservoir.

The general layout of the Vordufell Pumped-Storage Project is shown in plan on Exhibits 2 and 3. It will consist of the following elements:

(1) an Upper Reservoir provided at Ulfsvatn by means of dikes across Ulfsgil and the low saddles to the south and northwest; (2) an Intake Structure at the west end of the lake; (3) a Headrace Conduit consisting of a vertical Pressure Shaft, a near horizontal Tunnel, and a Penstock, leading from the Intake to (4) the Powerhouse located at the base of Vordufell; (5) a Canal connecting the Powerhouse with the Hvita at a point approximately opposite the confluence of the Bruara; (6) the principal Electrical and Mechanical Equipment; (7) the Transmission Plant; and (8) Access Roads.

This general plan of development is so clearly indicated by topographic and geologic relationships that no attempt was made to study other possible alternatives at this time. Variations would mainly be in respect to the location and arrangement of the headrace conduits. The final selection would be on the basis of improved geologic conditions and economic advantages. These are not now considered to be very great relative to the presently proposed plan.

A one-unit plant providing a dependable capability of 45,000 kilowatts at Reykjavik and with a maximum normal level of 325 meters for the upper reservoir was selected for presentation on the drawings. However, since the requirements for Reserves are somewhat uncertain, cost estimates were also prepared for installations providing 30,000 and 60,000 kilowatts dependable capacity at Reykjavik.

The 30,000 and 45,000 kilowatt alternatives would represent the approximate requirements in the case of a 1 1/2 and 2 potline smelter respectively. The 60,000 kilowatt alternative may be considered as a future extension of the 30,000 kilowatt plant for the purpose of providing for a larger aluminium smelter, added peaking capacity to the system, or both.

The requirements for storage are proportional to the energy requirements given in Table I-4, essentially. One cubic meter of water stored in the reservoir at Ulfsvatn produces about 0.55 kilowatthours of energy, as discussed in Chapter III. However, since an accurate estimate of the energy requirements is not feasible at this time, estimates have been prepared for reservoir elevations 320, 325, 330, 335, and 340 representing a range in net storage from three to 18 million cubic meters of storage, assuming a dead storage of about 2 million cubic meters in all cases. The reservoir elevation of 325 meters was selected for presentation on the drawings. This alternative will provide about 6 million cubic meters of net storage, which will have an energy potential of about 3.3 million kilowatthours, sufficient for three weeks operation in the case of a 1 1/2 potline smelter or 1 1/2 week's operation in the case of a two potline smelter.

In the following is given a description of the alternative selected for presentation on the drawings.

Ulfsvatn Reservoir

The general layout of the Ulfsvatn reservoir features is shown on Exhibit 2. The structures will include several dikes and an emergency spillway. Two of the dikes and the emergency spillway will be located south of Ulfsvatn. A third dike will be required in the saddle northwest of the lake.

The dikes will all have a crest at elevation 327 and be of a rockfill type construction with a central core of impervious materials protected by filters on each side. The rock will be quarried from basalt breccia or suitable tuff available within a short haul distance. The impervious core material will come from deposits of loess which occur in isolated patches approximately one meter thick on the south end of the mountain. The filter material will be crushed from quarried rock.

The dikes will be founded on bedrock which is close to the surface everywhere except in the depressions at the south end of the lake where a one to three meter thick layer of bog deposits overlay the rock. This layer will be removed under the entire section of the dike. Some rock excavation will be required for the core, but no grouting is anticipated except locally along fissures that may be potential paths of leakage.

The spillway is designed for a capacity equal to the maximum pumping capacity of the plant, or approximately 15 cubic meters per second. The requirements based on the natural inflow to the lake is estimated to be less than this amount. The drainage area is very small and the relatively large reservoir permits a high degree of self-regulation.

The spillway will consist of a low concrete weir flanked by two retaining walls to contain the dikes on both sides, as shown on Exhibit 2. The weir will be 12 meters long with crest at elevation 325.2. The design discharge capacity will be reached with the reservoir at elevation 326.0, or one meter below the crest of the dikes.

Intake Structure

The intake structure forming the entrance to the pressure shaft is shown in plan and section on Exhibit 2. It will be of concrete construction with a deck at elevation 314 from which emergency stoplogs may be inserted in slots provided at the front of the intake opening. A short approach canal with the bottom sloping from elevation 306 to elevation 309 will extend from the intake into the lake. The general elevation of the intake is tied in with the minimum reservoir level, which in turn was selected on a judgment basis to achieve the most economical arrangement overall.

Trashracks and closure gates are not considered necessary and have not been provided. The reservoir area will be cleared when construction is completed and little or no debris is expected to enter the reservoir thereafter. Inspection of the pressure shaft and penstock, and maintenance of the valve in front of the pump-turbine will be carried out behind the stoplog closure. Such closure can only be accomplished during low reservoir stages, but this arrangement is considered acceptable since the need for it will be very infrequent.

The intake will also serve as the outlet into the lake during pumping operations when the flow is reversed.

Headrace Conduit

The headrace conduit leading from the intake to the powerhouse will consist of three different sections: (1) a vertical pressure shaft from the intake at elevation 307 to a nearly 90 degree bend at approximately elevation 150 which will connect to (2) a pressure tunnel which will surface on the west slope of Vordufell where it connects with (3) a steel penstock leading to the pump-turbines. The conduit is shown in profile and sections on Exhibit 3. The total length will be about 1175 meters, of which 160 meters are pressure shaft, 675 meters pressure tunnel, and the remaining 340 meters steel penstock.

The pressure shaft will be 2.2 meters in diameter and lined with reinforced concrete throughout. Maximum velocities will be about 6.6 meters when generating and about 4.0 meters when pumping. It was assumed for the purpose of cost estimating that the shaft would be excavated from below. The working platform was assumed suspended from a cable extending to the surface through a 10-centimeter drilled pilot hole.

The pressure tunnel will be lined with steel plate, backed by concrete, for 125 meters at the downstream end. The remaining 550 meters will be lined with reinforced concrete. The internal diameter will be 2.2 meters in the concrete lined section and 2.0 meters in the steel lined section. The maximum velocities are estimated at 6.6 and 8.0 meters per second, respectively.

No subsurface drilling has been carried out in the location of the pressure shaft and tunnel. Surface exposures indicate, however, that the rock will be mostly palagonite-tuff and basalt breccia of adequate strength for the relatively small openings that are required. Local zones of weak rock that will require steel supports are expected in both the shaft and the tunnel. Rock bolts will be used to provide additional temporary supports.

The steel penstock will be placed in a shallow trench excavated in the rock to a point about 30 meters upstream of the powerhouse, where it will be in a short inclined tunnel. The steel penstock will be embedded in concrete throughout, and insulated with a layer of soil in order to prevent the water from freezing during cold weather. The diameter will be 2.0 meters throughout.

Powerhouse

The designation "powerhouse" as used herein refers to the buildings and the structures for housing of the pump-turbine, the motor-generator, and their accessory equipment.

The location of the powerhouse is shown on Exhibit 3. It was selected as near to the Hvita as feasible with respect to the foundations in order to keep excavation quantities to a minimum. The surface of the bedrock was located by soundings and is shown in profile on Exhibit 3. It was found to dip below foundation levels about 50 meters downstream of the selected powerhouse location.

The powerhouse will be of the indoor type and of concrete construction, essentially. The structure will be 28 meters long, 16 meters wide, and 30 meters high. It will house one vertical unit of the reversible type with the pump-turbine set at elevation 39, or 11 meters below the minimum tailwater level. This setting, necessary for efficient operation of the units, has resulted in a very deep powerhouse. The walls have been designed to withstand water pressures up to elevation 55, one meter above the estimated maximum flood level.

Access to the powerhouse will be from the south end where an erection and unloading bay will be provided at elevation 51. This bay and the parking area outside will be protected from flood waters by rock left in place up to elevation 55.

The powerhouse will be served by a 90-ton bridge crane supported by beams and columns along both longitudinal walls. Draft tube closure will be made by a vertical lift gate operated from a movable crane located on a deck at elevation 51 downstream of the powerhouse. Trash-racks will be installed at the draft tube outlet to prevent entry of debris into the pump-turbine during pumping operations. Space for the electrical auxiliary equipment will be provided on the upstream side of the power-house. The main transformer will be located directly above. Drainage, heating, ventilation, lighting, water supply, and other auxiliary services will be provided in accordance with established practice for powerhouses of this type.

Tailrace

The tailrace canal connecting the powerhouse with the Hvita is shown in plan and section on Exhibit 3. It will be about 600 meters long and 20 meters wide with side slopes of three horizontal to two vertical. The bottom will be horizontal at elevation 48, which is slightly below the level of the riverbed at this point. The excavation will be mostly in peat, but will also include some rock excavation near the powerhouse where the canal will be deepened to connect with the draft tube outlets at elevation 34.

It is likely that some sediment will be carried into the canal by waters from the Hvita. Maintenance by dredging may, therefore, be required periodically to keep the canal open. Such dredging may be reduced or even eliminated by suitably placed bunds in the river. The effectiveness of bunds is, however, somewhat in doubt and they have, therefore, not been included in the present plans. Model tests may be required to determine if bunds should be included in the final design.

Principal Electrical and Mechanical Equipment

The type of unit was selected from preliminary studies based on experience with similar pumped-storage plants and on information given by pump-turbine manufacturers. These studies indicated that a reversible Francis type pump-turbine connected directly to a synchronous motor-generator would be feasible for unit sizes down to 20,000 kilowatts, but also that they should be as large as feasible for economic reason.

One important factor that may limit the size of the units is related to the fact that the turbine, when operating as a pump, will require substantially full power at all times. In the case of the Vordufell Pumped Storage the pumping is planned to be achieved with secondary and off-peak power as available from the System. The magnitude of this power can not be estimated with confidence at this time, since it will depend on many factors which cannot be foreseen. The only guide for judgement is the estimated load curve shown on Exhibit 1 which indicates a maximum difference between peak load and off-peak load of about 85,000 kilowatts in 1970. The size of the units should be somewhat less than this, probably not more than 50,000 which is indicated to be available about 50 percent of the time. On this basis one unit was selected for both the 30,000 and the 45,000 kilowatt plant whereas two units were selected for the 60,000 kilowatt plant.

The unit for the 45,000 kilowatt plant shown on the exhibits will be of the reversible type with the pump-turbine connected to the motor-generator by a vertical shaft. The pump-turbine will be of the Francis type, sized for a maximum output of 73,600 metric horsepower at 260 meters rated head. The speed was selected at 428 rpm. The pumping capacity of the unit was estimated at about 16 cubic meters per second operating at the rated head, and at about 14 cubic meters per second at the maximum head of 284 meters.

The generator-motor was rated 52,000 kva, 0.9 power factor, 13.8 kv, three-phase, 50 cycles, as a generator, and 68,000 metric horsepower as a motor. The power factor during the pumping cycle will be about 0.94.

A 3000 metric horsepower induction motor for starting up pumping operations will be built integrally with the generator between the generator rotor and the exiter. Power will be supplied from the 13.2 kv bus. A compressed air system will be provided to depress the water level in the draft tube during starting up of the pumping operations.

A one-line diagram for the Vordufell Pumped-Storage Project is shown on Exhibit 4. The plant was assumed to be operated by remote control.

Transmission Plant

The power transmission will be accomplished by a line connecting with the 230 kv line from Burfell to Reykjavik by means of a solid tie. The Burfell-Reykjavik line as now planned will pass just south of Vordufell so that the length of transmission line required will be only four kilometers. The line will be 230 kv, single circuit and of wood pole construction. Consideration should be given to rerouting the main transmission line to pass close to the pumping plant.

The substation at Vordufell will include the main transformer of the OA/FA/FOA type rated 13.2-230 kv, 31,200, 41,500, and 52,000 kva. A line disconnecting switch will normally be in open position. An independent power supply from the local net may be desirable but was not included in the present estimate. The starter motor will take its power from the 13.2 kv bus.

Access Roads

Access to the project area will be from the main road at Husatottir where a farm road branches off to Fjall, located near the southwest end of Vordufell. New roads will be required from Fjall for access to the powerhouse area and to Ulfsvatn. The road to the powerhouse will be in easy terrain along the west side of Vordufell. The road to Ulfsvatn will be on a steep grade up the southwest slope of the mountain and will probably require considerable excavation in side cut. The total length of new roads is estimated at about eight kilometers. Some improvements may be required on the five-kilometer farm road between Husatottir and Fjall for the purpose of project access.

The total road distance to Reykjavik will be about 95 kilometers.

CHAPTER III

POWER AND ENERGY

Peaking Capability

The dependable peaking capability at Reykjavik may be estimated from the formula: $kw = n \times H_n \times Q \times 9.8$, where n is the overall efficiency factor which reflects the losses in the turbine, generator, main transformer, and the transmission line, H_n is the minimum net head, and Q is the full gate turbine flow capacity at that head. The following values were assumed for the 45,000 kilowatt alternative:

$$n = 0.86 \times 0.97 \times 0.99 \times 0.97 = 0.80$$

$$H_n = 313 - 53 - 20 = 240 \text{ meters}$$

$$Q = 25 \times \left(\frac{242}{260}\right)^{1/2} = 24.0 \text{ cumecs}$$

With these values the formula gave as a result 45,000 kilowatts which agrees with the basic assumption for the selection of the plant capacity. The above n and H_n values are also applicable to the 30,000 and 60,000 kilowatt alternatives. The discharge, Q, will be proportional to the size of the units.

Pumping Power

The power input required at the rated head to operate the pump-turbine as a pump was taken at 50,000 kilowatts, or 53,000 Kva at 0.94 power factor. The input will be only slightly different for other operating heads within the range required.

The pumping capacity is estimated at about 16 cubic meters per second at low reservoir elevations and at about 14 cubic meters per second at high reservoir elevations. The pumping capacity of the 30,000 and 60,000 alternatives would be proportional to the unit ratings, essentially.

Energy

The energy potential of one cubic meter of water stored in the Ulfsvatn Reservoir is estimated at 0.55 kilowatthours delivered at Reykjavik. This estimate is based on an average reservoir elevation of 320, 20 meters of hydraulic losses, and an overall efficiency of equipment and transmission line of 0.82. To produce one kilowatthour of energy will, conversely, require about 1.8 cubic meters of water. These energy values are more or less independent of the size of the plant.

The energy required at the plant to pump one cubic meter into the storage is estimated at 0.87 kilowatthours, or in other words, one kilowatthour will pump about 1.15 cubic meters of water. This estimate is based on an average reservoir elevation of 320, 10 meters of hydraulic losses, and 0.85 overall efficiency of the motor, pump, and main transformer.

CHAPTER IV

PROJECT COSTS

Capital Costs

Cost estimates have been prepared for the Vordufell Pumped-Storage Project for the following reservoir elevations: 320, 325, 330, 335, and 340 meters, and for three alternative sizes of plant capacity: 30,000, 45,000, and 60,000 kilowatts. The detailed estimates for the 325-meter reservoir alternative and the three plant alternatives including transmission plant are presented in Exhibit 5. The estimates of the other reservoir alternatives have been prepared in the same manner, but are not presented.

The construction costs have been estimated on the basis of detailed quantity surveys from the drawings referred to above and additional sketches as necessary. The unit prices were developed essentially on the basis of estimates for similar type of work for the Burfell Project. Adjustments were made as appropriate to reflect differences in quantities and construction procedures. The unit prices do not include import duties and taxes.

The costs of the pump-turbine and generator-motor are based on prices obtained recently from American manufacturers. The prices were adjusted downward about 10 percent to account for the somewhat lower European price level. Costs of other equipment such as transformers and circuit breakers are based on information from European manufacturers obtained for the Burfell Project in late 1962. Import duties and taxes were again not included.

Contingency allowances of 10 percent for equipment and 20 percent for all other work were added to the subtotal of direct costs. Engineering and overhead were taken at eight percent of the total direct cost including contingencies. This addition gave total construction costs. An allowance to cover interest during construction was added to obtain total project investment. Since financing terms are not known, this allowance was taken at seven percent of the project investment for the estimated two-year construction period.

Allowances for cost escalation and working capital were not included.

The estimated costs for the reservoir are shown graphically on Exhibit 6 for reservoir elevations between 316 and 340 meters. This graph and the reservoir-volume curve were then used to estimate the total project investment in relation to net storage as shown on Exhibit 7. The costs are shown graphically by curves for each of the three plant capacity alternatives selected and for a range of net storage between 0.5 and 14 million cubic meters. A scale showing the energy potential of the storage has also been included for convenience.

Annual Costs

The annual costs of the Vordufell Pumped Storage Project may be separated into four components:

1. Operation and Maintenance
2. Depreciation of Assets
3. Reserves, and
4. Interest on the Investment

The annual operation and maintenance cost for the Vordufell Project will be relatively low since the station will be controlled remotely and will be operating only for short periods. Maintenance cost of the reservoir and the waterways will also be low except for possible dredging requirement in the tailrace canal. An annual allowance of $15,000 was included for such dredging.

Depreciation costs were based on 100-year life for the reservoir and 50-year average life for the power features and transmission plant. The water conductors and the structures should have a useful life of about 75 years whereas the mechanical and electrical equipment may average 35 to 40 years.

An allowance of 0.5 percent of the pumping plant construction cost was made in the estimate of annual charges for any reserves that may be needed to cover expenses of an extraordinary nature. Water rights were not included, nor cost of energy for pumping.

The principal item of annual costs will be interest on investment. Since the financing terms are not known, it was decided to estimate the interest costs for three different annual rates: four, six, and eight percent.

The estimate of annual costs for the Reservoir Features are shown in Table IV-1, and for the Pumping Plant and Transmission Plant in Table IV-2. The results of these estimates are presented in graphical form on Exhibits 8 and 9 for annual interest rates ranging from four to eight percent.

Estimates were also made for developments that would conform to the Reserve requirements given in Chapter I for the 1, 1 1/2, and 2-potline smelter alternatives. The estimates are given in Table IV-3. The annual costs for the 18,000, 33,000, and 48,000 kilowatt power requirements were interpolated from the estimates of the 30,000, 45,000, and 60,000 kilowatt alternatives selected previously. These interpolations are considered to be reasonably accurate for the present purposes. Two weeks of operation, all in one continuous period, was assumed for the purpose of estimating the energy and storage requirements.

The results of the estimates of annual costs are presented by the solid lines on Exhibit 10.

TABLE IV-1

ANNUAL COSTS IN THOUSAND US DOLLARS
RESERVOIR FEATURES

	Reservoir Elevation in Meters			
	320	325	330	335
Operation and Maintenance	2	2	3	4
Depreciation - 100 year life	2	4	10	20
Interest				
At 4% annual rate	7	17	40	76
Total Annual Cost	11	23	53	100
At 6% annual rate	11	25	60	116
Total Annual Cost	15	31	73	140
At 8% annual rate	15	35	80	155
Total Annual Cost	19	41	93	179
Net Storage in Million m^3	3.0	6.0	9.6	14.0

TABLE IV-2

ANNUAL COSTS IN THOUSAND US DOLLARS
POWER FEATURES INCLUDING TRANSMISSION PLANT

	Dependable Peaking Capacity at Reykjavik		
	30 MW	45 MW	60 MW
(Total Investment)	3600	4400	5900
Operation and Maintenance	50	60	70
Depreciation - 50 year average life	72	88	118
Reserves - 0.5% of Construction Cost	17	21	28
Subtotal	139	169	216
Interest			
At 4% annual rate	144	176	236
Total Annual Cost	283	345	452
At 6% annual rate	216	264	354
Total Annual Cost	355	433	570
At 8% annual rate	288	352	472
Total Annual Cost	427	521	688

TABLE IV-3

TOTAL ANNUAL COSTS IN THOUSAND US DOLLARS
TWO WEEKS OPERATION

	Aluminium Smelter Installation		
	One Potline	1 1/2 Potlines	Two Potlines
Reserve Requirements			
Capacity (MW)	18	33	48
Energy (Million kwh)	0.8	2.2	4.2
4% Interest Rate			
Pumping Plant	240	295	365
Reservoir	10	15	35
Total Annual Costs	250	310	400
6% Interest Rate			
Pumping Plant	295	370	460
Reservoir	15	20	45
Total Annual Costs	310	390	505
8% Interest Rate			
Pumping Plant	355	445	550
Reservoir	15	25	60
Total Annual Costs	370	470	610

CHAPTER V

THERMAL ALTERNATIVE

General

Gasturbines are one of the most economical means of providing Reserve generating capacity because of their relatively low initial cost. Preliminary information indicates that European manufacturers can deliver gasturbine units for about $60 per kilowatt FOB European port. Fuel consumption is rather high in cost, but this is of minor importance if the gasturbines are used primarily for Reserve purposes as was assumed in this study. Gasturbines were, therefore, selected for comparison with the Vordufell Pumped-Storage Project for the purpose of providing Reserves in conjunction with the Burfell Project serving an aluminium smelter.

Capital Costs

A cost of $100 per kilowatt was assumed for a fully completed gasturbine plant at Reykjavik. This price is based on the FOB cost mentioned above and was assumed to include the cost of freight, installation, site preparation, foundations and buildings, fuel storage, engineering, and interest during construction.

Annual Costs

The annual costs will consist of (1) Operation and Maintenance Costs, (2) Depreciation, (3) Reserves, (4) Interest on Investment, and (5) Fuel Costs.

Operation and maintenance costs will be relatively low since operation will be infrequent. The units would, however, need to be started up occasionally and run for a few hours in order to keep them in good operating condition. An allowance of 0.5 percent of the estimated construction cost was included as an annual cost of a reserve fund to cover expenses of an extraordinary nature.

Depreciation is based on a useful life of 30 years.

The fuel cost was taken at $0.01 per kilowatthour of generation based on 27 percent overall efficiency and a fuel price of $26 per metric ton.

Since financing terms are not known, the annual costs of interest on investment were estimated for interest rates of four, six, and eight percent.

The estimates of annual costs for the gasturbine alternatives are shown on Table V-1 below. The costs have been prepared for the Reserve requirements of the 1, 1 1/2, and 2-potline smelters as estimated in Chapter I. Generation each year was assumed to be of two weeks duration.

The results of the estimates are shown graphically on Exhibit 10 for interest rates ranging from 4 to 8 percent.

TABLE V-1

ANNUAL COSTS OF GAS TURBINES
IN THOUSAND US DOLLARS

	Normal Aluminium Load		
	One Potline (60MW)	1 1/2 Potlines (90 MW)	2 Potlines (120MW)
Capacity Required (MW)	18	33	48
Energy Required (Million Kwh)	0.8	2.2	4.2
Capital Cost	1800	3300	4800
Annual Costs			
O & M	42	45	47
Depreciation (30 years)	60	110	160
Reserves (0.5% of Construction Cost)	8	15	23
Fuel Cost (10 mills/Kwh)	8	22	42
Subtotal	118	192	272
Interest			
4% Annual Rate	72	132	192
TOTAL COST	190	324	464
6% Annual Rate	108	198	288
TOTAL COST	226	390	560
8% Annual Rate	144	264	384
TOTAL COST	262	456	656

THE EXHIBITS

Exhibit No.	Title
1	1970 Loads and Generation
2	General Plan and Reservoir
3	Power Features
4	One-Line Diagram
5	Cost Estimates - 5 Sheets
6	Cost of Reservoir
7	Total Project Cost
8	Annual Costs - Reservoir Features
9	Annual Costs - Power Features and Transmission Plant
10	Vordufell and Gasturbine - Annual Costs

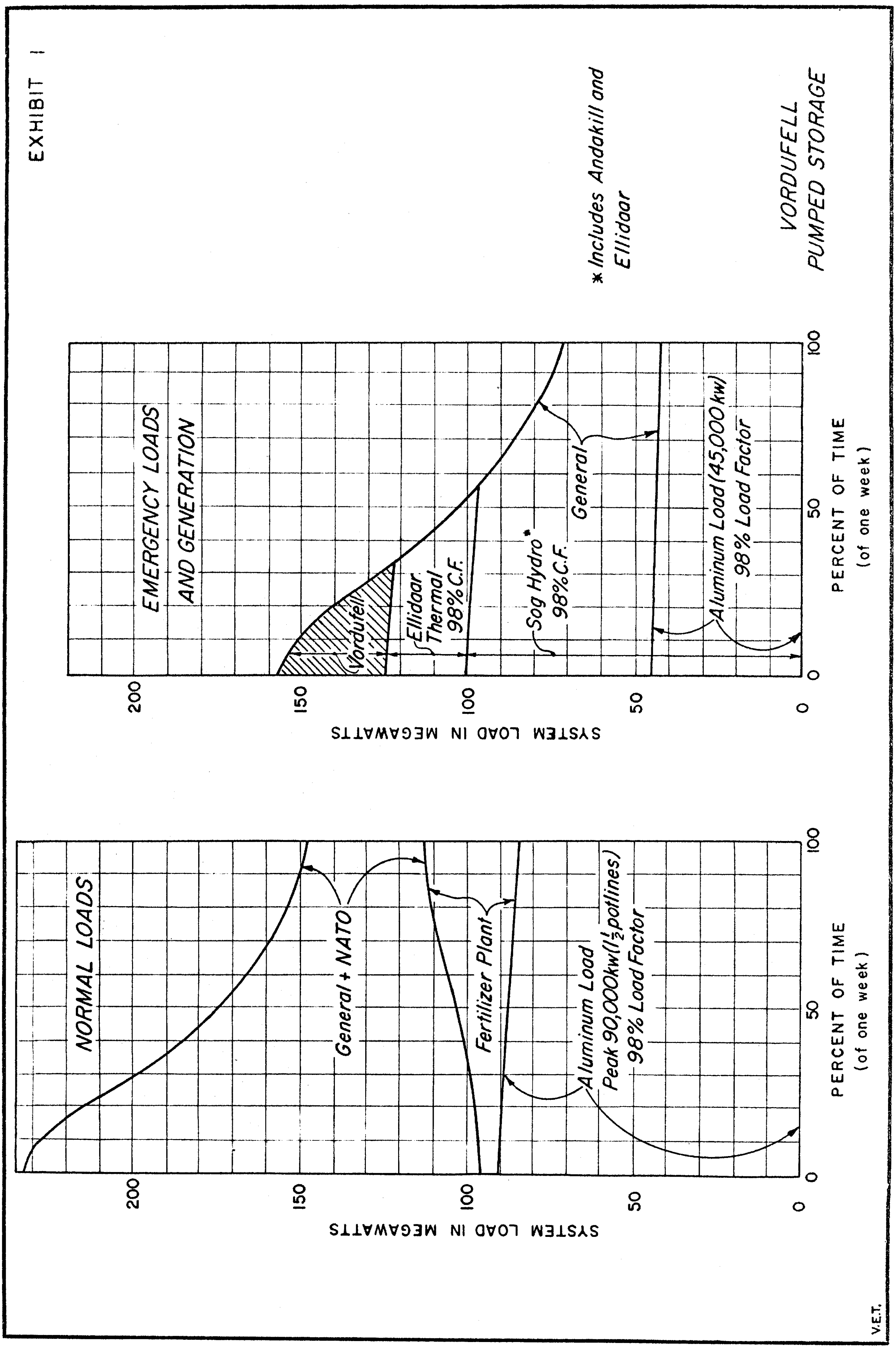
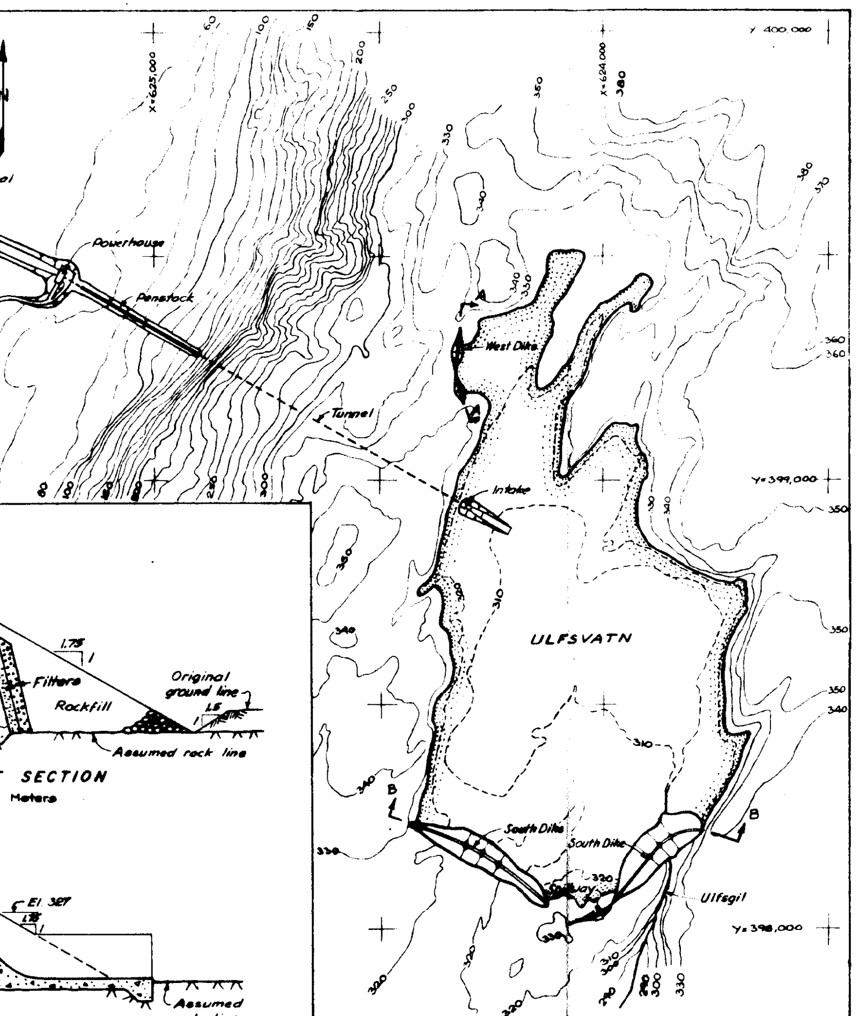
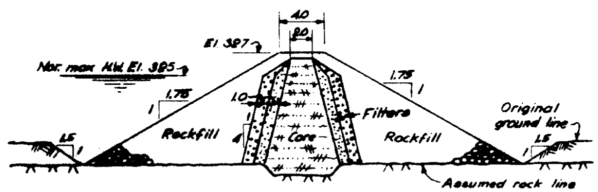


EXHIBIT 1
NORMAL LOADS
General + NATO
Fertilizer Plant
Aluminum Load
Peak 90,000kw(1½ potlines)
98% Load Factor
EMERGENCY LOADS
AND GENERATION
Vordufell
Ellidaar
Thermal
98% C.F.
Sog Hydro*
98% C.F.
General
Aluminum Load (45,000 kw)
98% Load Factor
* Includes Andakill and
Ellidaar
VORDUFELL
PUMPED STORAGE
SYSTEM LOAD IN MEGAWATTS
PERCENT OF TIME
(of one week)
0
50
100
150
200
V.E.T.

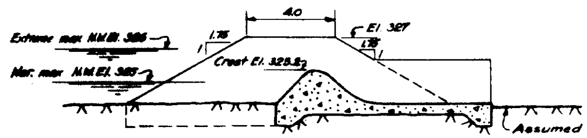
EXHIBIT 2



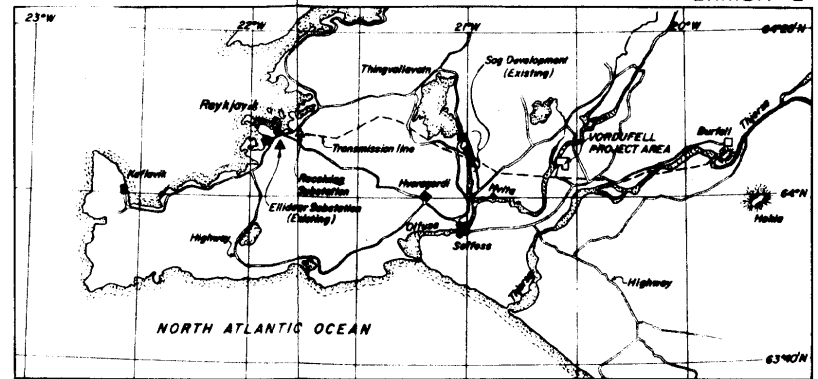
GENERAL PLAN
Scale 0 100 Meters



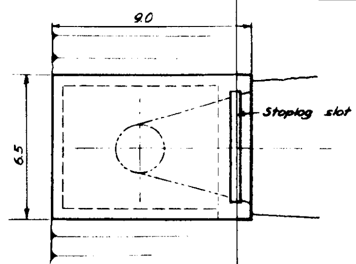
TYPICAL DIKE SECTION
Scale 0 5 Meters



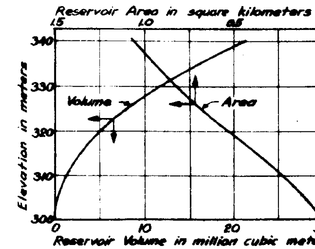
SPILLWAY SECTION



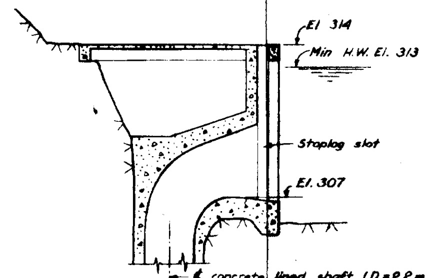
KEY MAP
Scale 0 10 Meters



INTAKE-PLAN



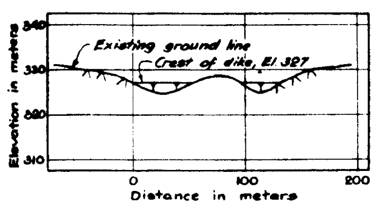
RESERVOIR AREA-VOLUME CURVES



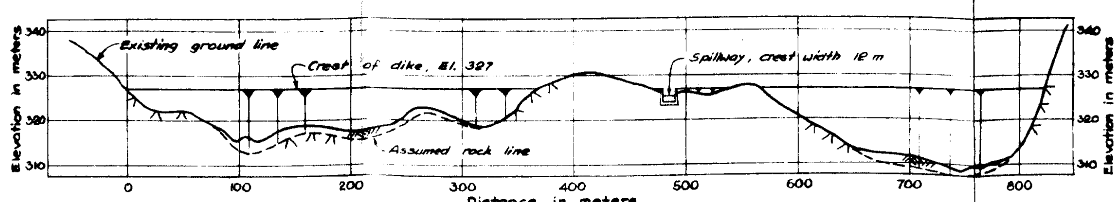
INTAKE-SECTION

NOTE:
Development shown is for a plant of 45,000 kilowatt dependable capacity delivered at Reykjavik, and with a net storage of 6 million cubic meters.

Scale 0 5 Meters
Except as noted



WEST DIKE-PROFILE A-A



SOUTH DIKES - PROFILE B-B

DATE	NO.	DISTRIBUTION

PRINTS

	BY	DATE	CHKD.	DATE
DSGN.				
DWN.	VT	May 1963	VT	May 1963
DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD	
CIVIL				
MECH.				
ELECT.				
PLNG.	VT	ARE		
STAFF			CHIEF ENGINEER	

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

THE STATE ELECTRICITY AUTHORITY
ICELAND

VORDUFELL PROJECT

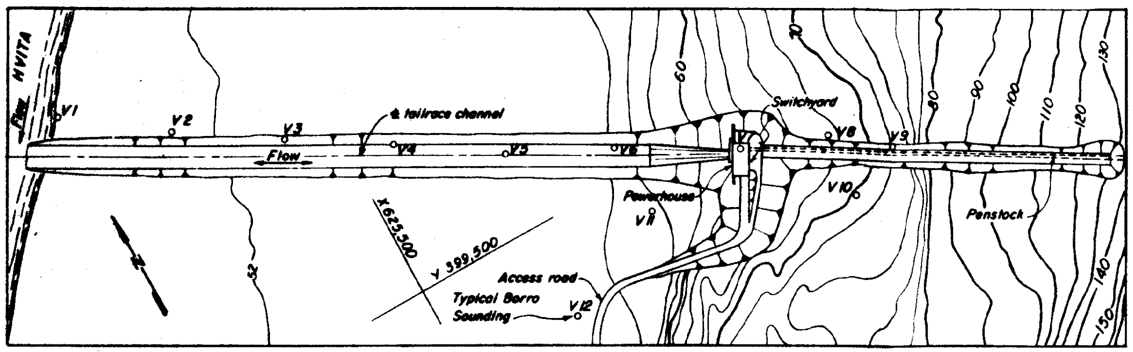
GENERAL PLAN AND RESERVOIR

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED ____________

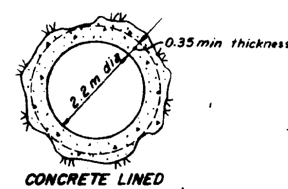
CHICAGO, ILLINOIS | DATE MAY, 1963 | DWG. NO. 290 P 67

EXHIBIT 3



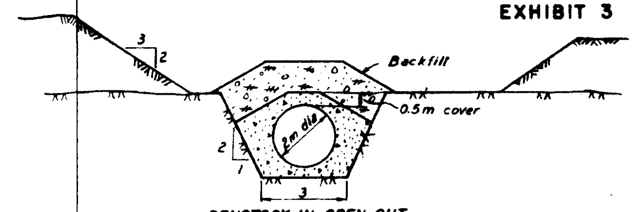
POWERHOUSE AND TAILRACE-GENERAL PLAN

Scale 0 50 Meters



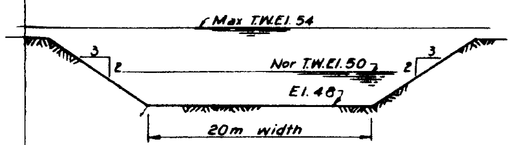
CONCRETE LINED TUNNEL SECTION

Scale 0 1 Meter

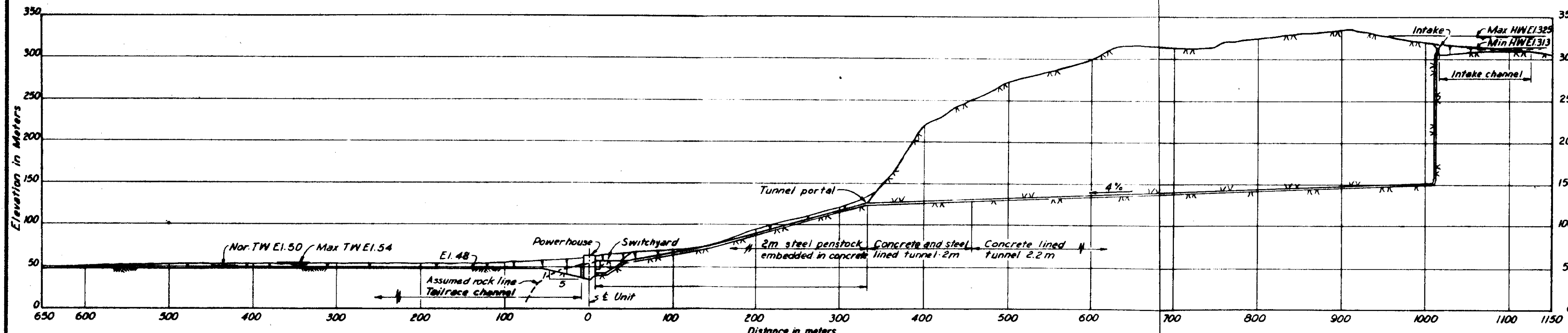


PENSTOCK IN OPEN CUT

Scale 0 2 Meters

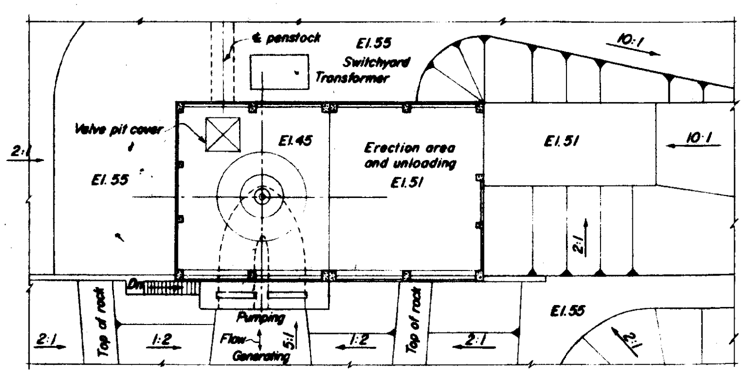


TAILRACE CHANNEL - TYPICAL SECTION

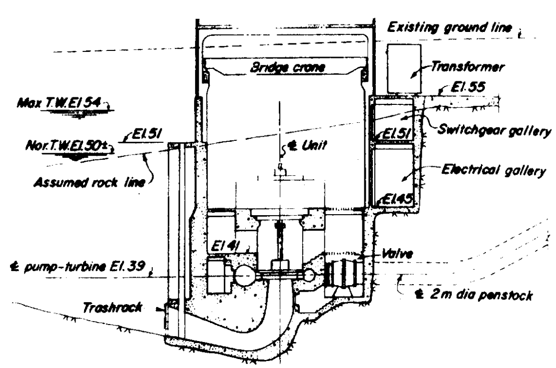


PROFILE

NOTE: Development shown is for a plant of 45,000 kilowatt dependable capacity delivered at Reykjavik, and with a net storage of 6 million cubic meters.



POWERHOUSE PLAN (Typical)



POWERHOUSE - TRANSVERSE SECTION (Typical)

Scale 0 5 10 Meters
Except as noted

THE STATE ELECTRICITY AUTHORITY
ICELAND

VORDUFELL PROJECT

POWER FEATURES

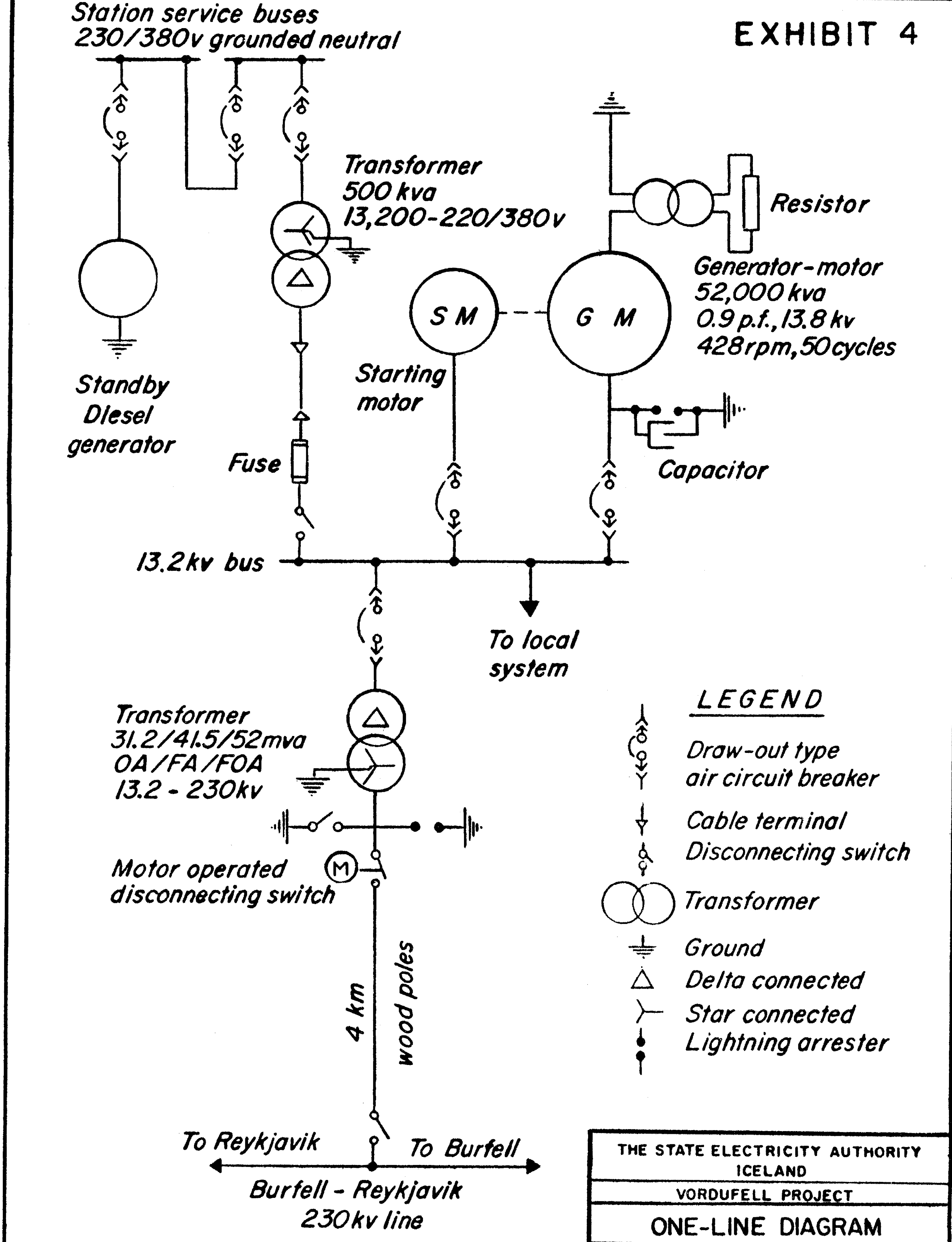
HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY HARZA ENGINEERING COMPANY

APPROVED ....

CHICAGO, ILLINOIS | DATE May, 1963 | DWG NO 290 P 68

PRINTS

EXHIBIT 4



THE STATE ELECTRICITY AUTHORITY
ICELAND

VORDUFELL PROJECT

ONE-LINE DIAGRAM

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING CO., CHICAGO
APPROVED_____________

DATE MAY, 1963	DWG. NO. 290 P 84

VET

K+E PHOENIX N188 TRACING CLOTH

ESTIMATE | **HARZA ENGINEERING COMPANY**
CHICAGO, ILLINOIS

EXHIBIT 5
Sheet 1 of 5

Project: Vordufell Date: Feb. 6, 1963 Page ____ of ____ Pages

Structure: Reservoir - El. 325 Estimated by: VT Checked by: ARE

Item No.	ITEM	Quantity	Unit Price	Amount
	Dikes			
	Excavation, overburden	35,000 m^3	1.00	35 000
	Excavation, rock	7,500 m^3	5.00	37 500
	Foundation treatment	7,500 m^2	2.00	15 000
	Impervious core	24,000 m^3	2.00	48 000
	Filters	18,000 m^3	3.50	63 000
	Rock shell	38,000 m^3	2.50	95 000
	Subtotal Dikes			293 500
	Spillway			
	Excavation, rock	200 m^3	10.00	2 000
	Foundation treatment	200 m^2	5.00	1 000
	Concrete	100 m^3	85.00	8 500
	Subtotal Spillway			11 500
	Subtotal Dikes Plus Spillway			305 000
	Contingencies, 20% ±			65 000
	Subtotal Direct Cost			370 000
	Engineering and Supervision, 8% ±			30 000
	CONSTRUCTION COST			400 000
	Interest During Construction, 7% ±			30 000
	PROJECT INVESTMENT			430 000

HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

ESTIMATE

EXHIBIT 5
Sheet 2 of 5

Project VORDUFELL Date April 19, 1963 Page ____ of ____ Pages

Structure Pumping Plant and Transmission Estimated by ARE Checked by V T

Summary

Item No.	ITEM	30 MW Capacity * Quantity	Unit Price	Amount U.S. $	45 MW Capacity * Quantity	Unit Price	Amount U.S. $	60 MW Capacity * Quantity	Unit Price	Amount U.S. $
		(one unit)			(one unit)			(two units)		
	PUMPING PLANT									
	Waterways			891 000			1 092 000			1 308 500
	Power House Structures			315 000			359 000			455 500
	Generator - Motors and Pump-Turbines			940 000			1 185 000			1 880 000
	Accessory Electrical Equipment			110 000			130 000			180 000
	Miscellaneous Powerplant Equipment			245 000			295 000			385 000
	Access Roads			50 000			50 000			50 000
	Subtotal Direct Cost			2 551 000			3 111 000			4 259 000
	TRANSMISSION PLANT			175 000			205 000			240 000
	Subtotal Pumping Plant and Transmission Plant			2 726 000			3 316 000			4 499 000
	Contingencies									
	Equipment 10% ±			138 000			182 000			255 000
	All others 20% ±			236 000			302 000			346 000
	Total Direct Cost			3 100 000			3 800 000			5 100 000
	Engineering and Overhead 8% ±			250 000			300 000			400 000
	TOTAL CONSTRUCTION COST			3 350 000			4 100 000			5 500 000
	Interest During Construction			250 000			300 000			400 000
	TOTAL INVESTMENT			3 600 000			4 400 000			5 900 000

* Dependable Capacity at Reykjavik

HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

ESTIMATE

EXHIBIT 5
Sheet 3 of 5

Project VORDUFELL Date February 18, 1963 Page ___ of ___ Pages

Structure Waterways Estimated by ARE Checked by AJF

Item No.	ITEM	30,000 KW Capacity			45,000 KW Capacity			60,000 KW Capacity		
		Quantity	Unit Price	Amount	Quantity	Unit Price	Amount	Quantity	Unit Price	Amount
	Waterways									
	Intake and Intake Canal									
	Excavation	4,000 m^3	2.50	10 000	4,500 m^3	2.50	11 250	5,500 m^3	2.50	13 750
	Concrete	130 m^3	100.00	13 000	150 m^3	100.00	15 000	170 m^3	100.00	17 000
	Pressure shaft									
	Pilot hole		L.S.	25 000		L.S.	25 000		L.S.	25 000
	Excavation	920 m^3	15.00	13 800	1,150 m^3	15.00	17 250	1,350 m^3	15.00	20 250
	Concrete	500 m^3	60.00	30 000	570 m^3	60.00	34 200	650 m^3	60.00	39 000
	Steel Supports	18 MT	500.00	9 000	20 MT	500.00	10 000	22 MT	500.00	11 000
	Pressure Tunnel									
	Excavation	4,600 m^3	20.00	92 000	5,700 m^3	20.00	114 000	6,700 m^3	20.00	134 000
	Concrete	2,750 m^3	60.00	165 000	3,100 m^3	60.00	186 000	3,450 m^3	60.00	207 000
	Steel Supports	75 MT	500.00	37 500	85 MT	500.00	42 500	95 MT	500.00	47 500
	Steel Liner	70 MT	700.00	49 000	100 MT	700.00	70 000	130 MT	700.00	91 000
	Penstock									
	Excavation, common	7,000 m^3	1.00	7 000	8,000 m^3	1.00	8 000	9,000 m^3	1.00	9 000
	Excavation, rock	5,200 m^3	5.00	26 000	5,600 m^3	5.00	28 000	6,000 m^3	5.00	30 000
	Concrete	3,100 m^3	40.00	124 000	3,500 m^3	40.00	140 000	3,900 m^3	40.00	156 000
	Steel Penstock	260 MT	700.00	182 000	350 MT	700.00	245 000	470 MT	700.00	329 000
	Tailrace Canal									
	Excavation, common	80,000 m^3	1.00	80 000	110,000 m^3	1.00	110 000	135,000 m^3	1.00	135 000
	Excavation, rock	7,000 m^3	4.00	28 000	9,000 m^3	4.00	36 000	11,000 m^3	4.00	44 000
	Subtotal Waterways			891 300			1 092 200			1 308 500

EXHIBIT 5
Sheet 4 of 5

HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

ESTIMATE

Project VORDUFELL Date April 19, 1963 Page ____ of ____ Pages

Structure Powerhouse and Equipment Estimated by ARE Checked by VT

Item No.	ITEM	30,000 Kilowatt Capacity (one unit)			45,000 Kilowatt Capacity (one unit)			60,000 Kilowatt Capacity (two units)		
		Quantity	Unit Price	Amount	Quantity	Unit Price	Amount	Quantity	Unit Price	Amount
	Power House Structures									
	Excavation, overburden	14,000 m^3	1.00	14 000	15,000 m^3	1.00	15 000	20,000 m^3	1.00	20 000
	Excavation, rock	9,000 m^3	5.00	45 000	10,000 m^3	5.00	50 000	12,000 m^3	5.00	60 000
	Concrete									
	Substructure	1,100 m^3	60.00	66 000	1,400 m^3	60.00	84 000	2,000 m^3	60.00	120 000
	Superstructure	1,000 m^3	100.00	100 000	1,100 m^3	100.00	110 000	1,300 m^3	100.00	130 000
	Architectural and Miscellaneous		L.S.	50 000		L.S.	100 000		L.S.	125 000
	Subtotal Power House Structure			315 000			359 000			455 000
	Generator-Motors and Pump-Turbines									
	Generator-Motors	1-35,000 KVA	415,000	415 000	1-52,000 KVA	525,000	525 000	2-35,000 KVA	415,000	830 000
	Pump-Turbines	1-49,000 Hp	400,000	400 000	1-73,600 Hp	500,000	500 000	2-49,000 Hp	400,000	800 000
	Starters	1	125,000	125 000	1	160,000	160 000	2	125,000	250 000
	Subtotal Generator-Motors and Pump Turbines			940 000			1 185 000			1 880 000
	Accessory Electrical Equipment		L.S.	110 000		L.S.	130 000		L.S.	180 000
	Miscellaneous Powerplant Equipment									
	Powerhouse Crane	1	65,000	65 000	1	75,000	75 000	1	65,000	65 000
	Penstock Valves	1	50,000	50 000	1	60,000	60 000	2	50,000	100 000
	Ventilation, heating, pumping, water-supply, piping, e.t.c.		L.S.	130 000		L.S.	160 000		L.S.	220 000
	Subtotal Miscellaneous Powerplant Equipment			245 000			295 000			385 000

ESTIMATE

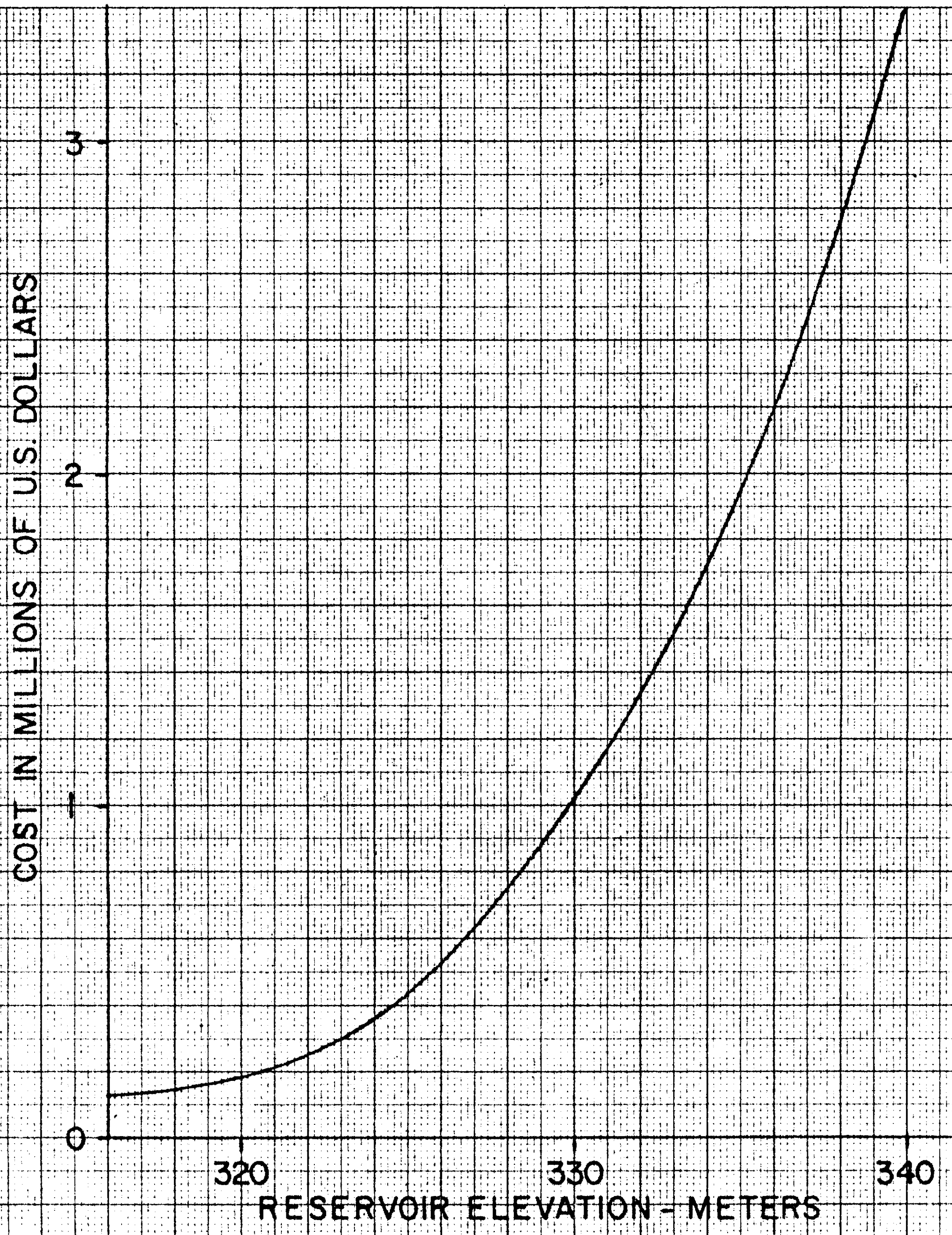
HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

EXHIBIT 5
Sheet 5 of 5

Project Vordufell Date April 19, 1963 Page ____ of ____ Pages

Structure Transmission Plant Estimated by ARE Checked by EAC

Item No.	ITEM	Quantity	Unit Price	Amount
	30 MW PLANT			
1	Transformer - 230-13.2 kv			
	- 35 mva	1	65,000	65 000
2	Lightning arrester	1	4,000	4 000
3	Disc. Switch - 230 Kv	1	3,000	3 000
4	Grounding switch	1	3,000	3 000
5	Structures and Foundations		L.S.	3 000
6	Carrier Current Equipment		L.S.	3 000
7	Grounding, Conduits, Wire		L.S.	2 000
8	Surfacing and Fencing		L.S.	2 000
9	Transmission Line	4 km		60 000
10	Connection with Burfell-Reykjavik Line		L.S.	5 000
11	Supervisory Control Equipment			25 000
	TOTAL DIRECT COST			175 000
	45 MW PLANT			
1	Transformer - 230-13.2 Kv			
	52 mva	1	95,000	95 000
	Other items as for 30 MW Plant			110 000
	TOTAL DIRECT COST			205 000
	60 MW PLANT			
1	Transformer - 230-13.2 Kv			
	70 mva	1	130,000	130 000
	Other items as for 30 MW Plant			110 000
	TOTAL DIRECT COST			240 000

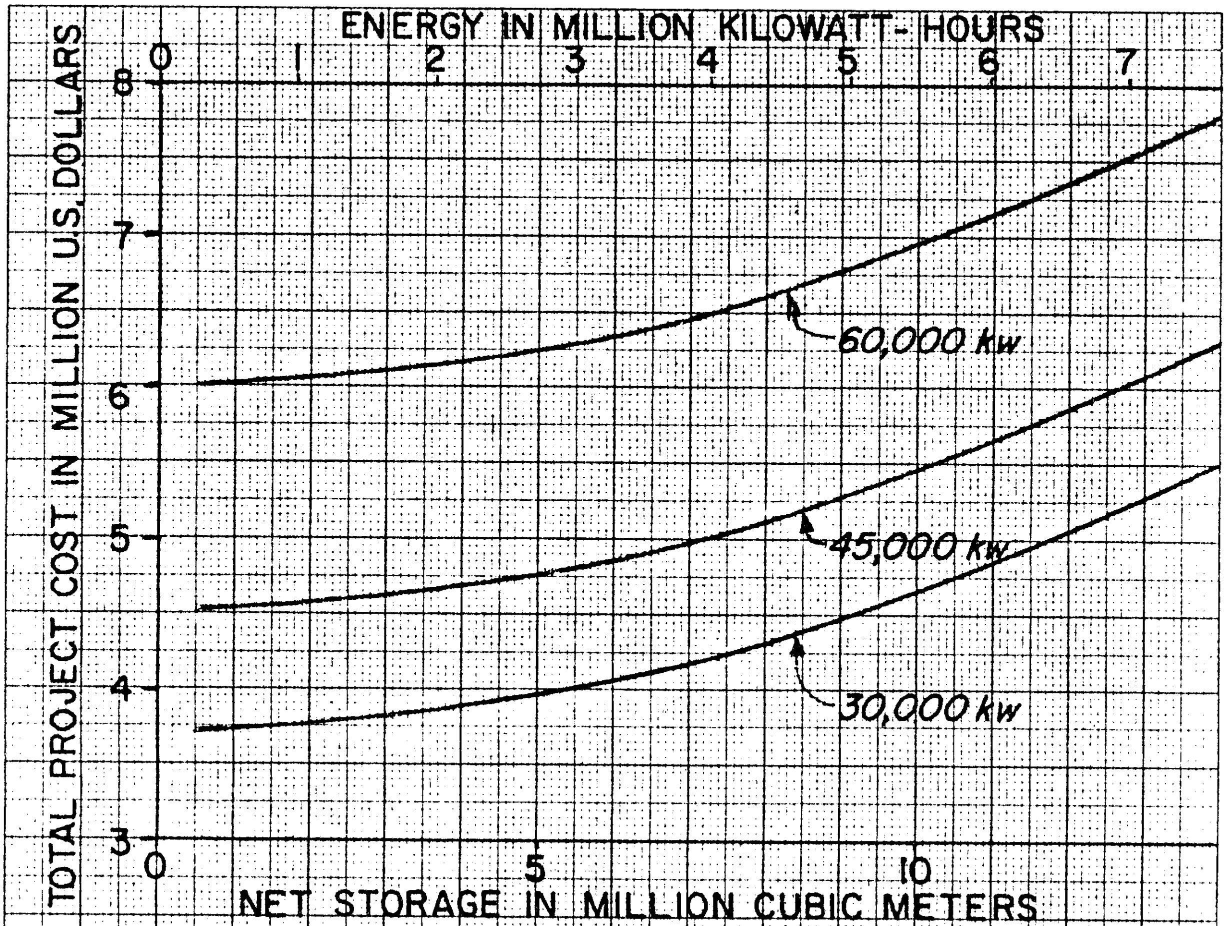


NOTE:
Costs include interest during construction but not import duties and taxes.

VORDUFELL
COST OF RESERVOIR

MAY, 1963

EXHIBIT 7



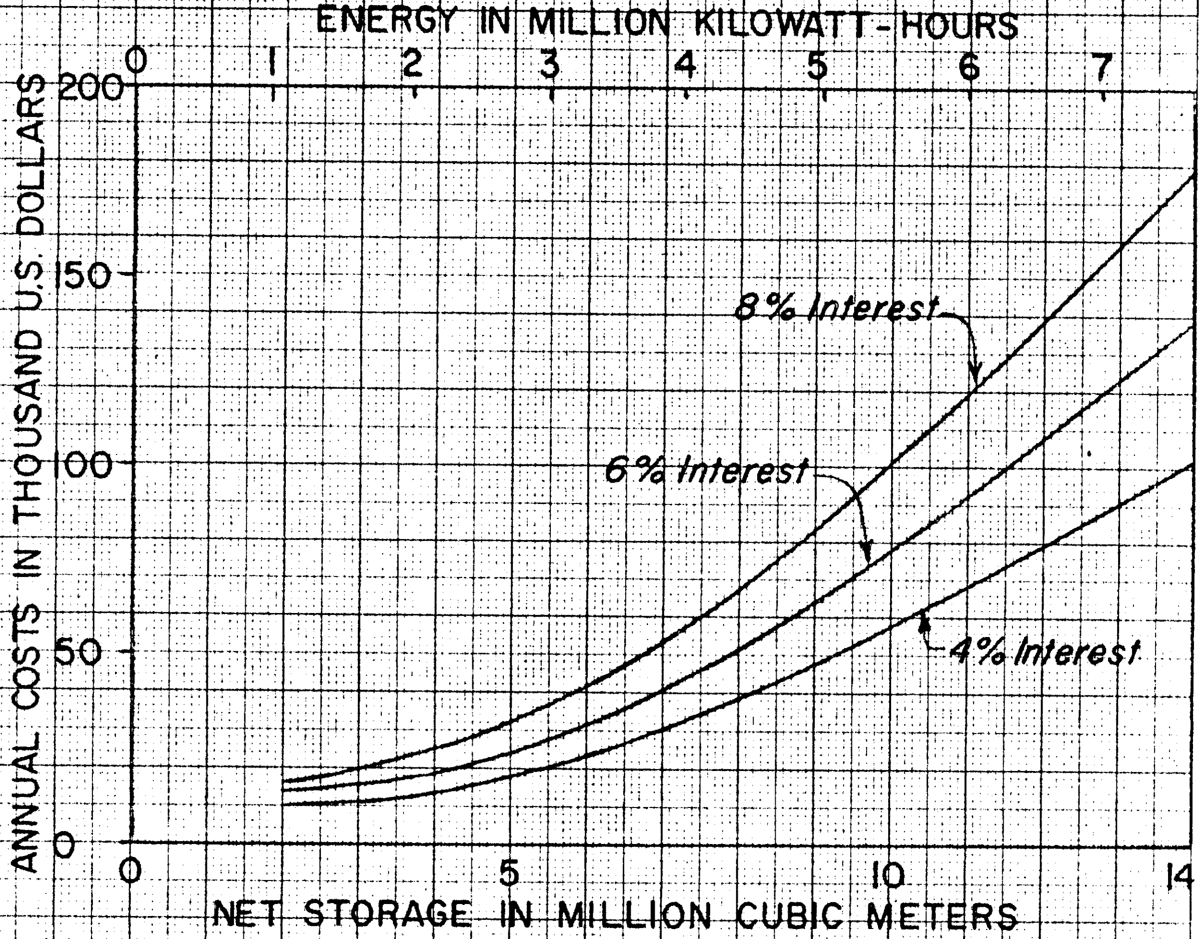
NOTES:

1. *The costs include interest during construction but not import duties and taxes.*
2. *The capacity values shown are dependable at Reykjavik.*
3. *The 30,000 and 45,000 kw alternatives are one-unit plants, the 60,000 kw is a two-unit plant.*

VORDUFELL

TOTAL PROJECT COST

MAY, 1963



NOTES:

1. *Cost of energy required for pumping not included.*
2. *Energy is delivered at Reykjavik.*

VORDUFELL
ANNUAL COSTS
RESERVOIR FEATURES

MAY, 1963

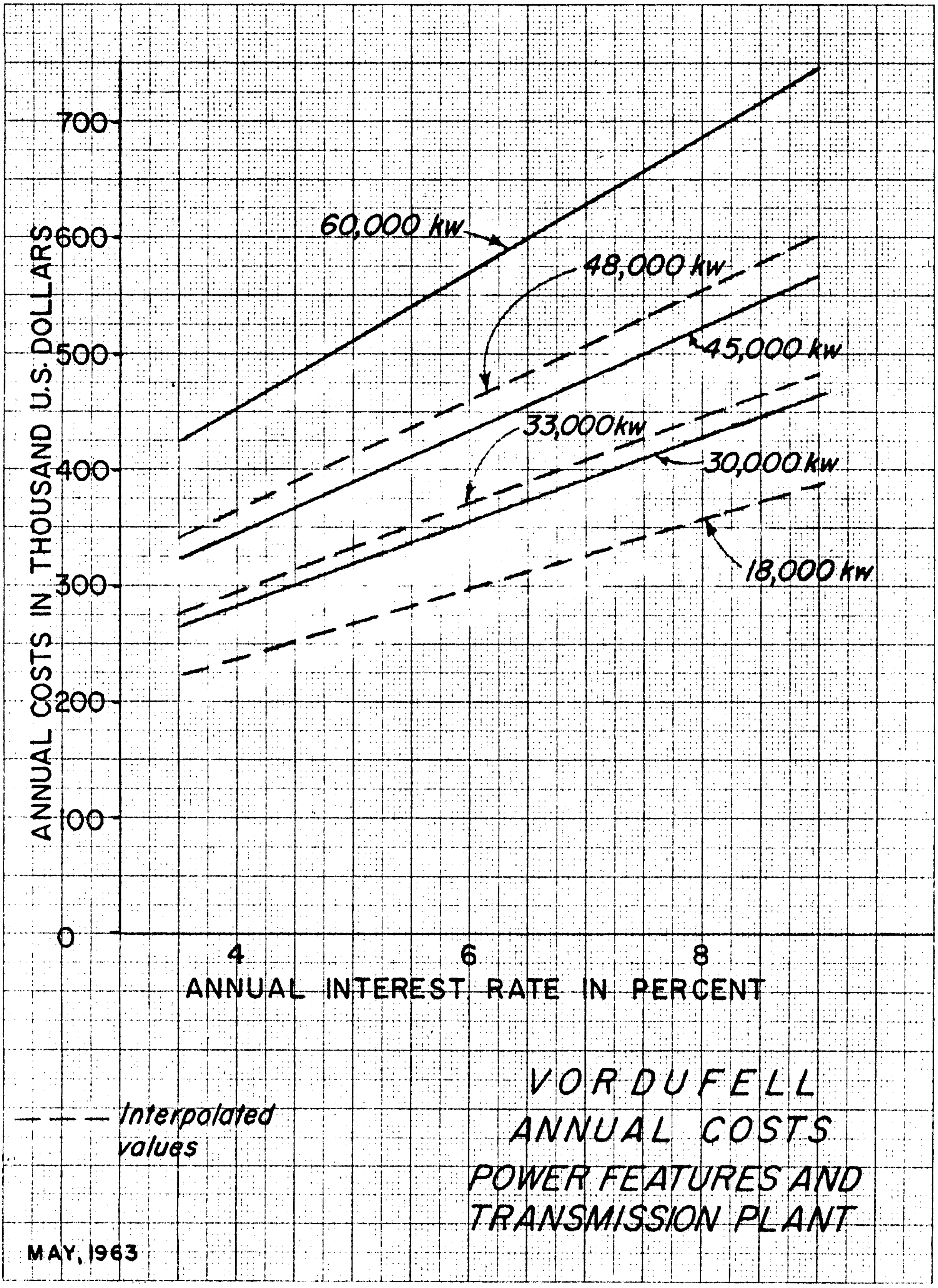
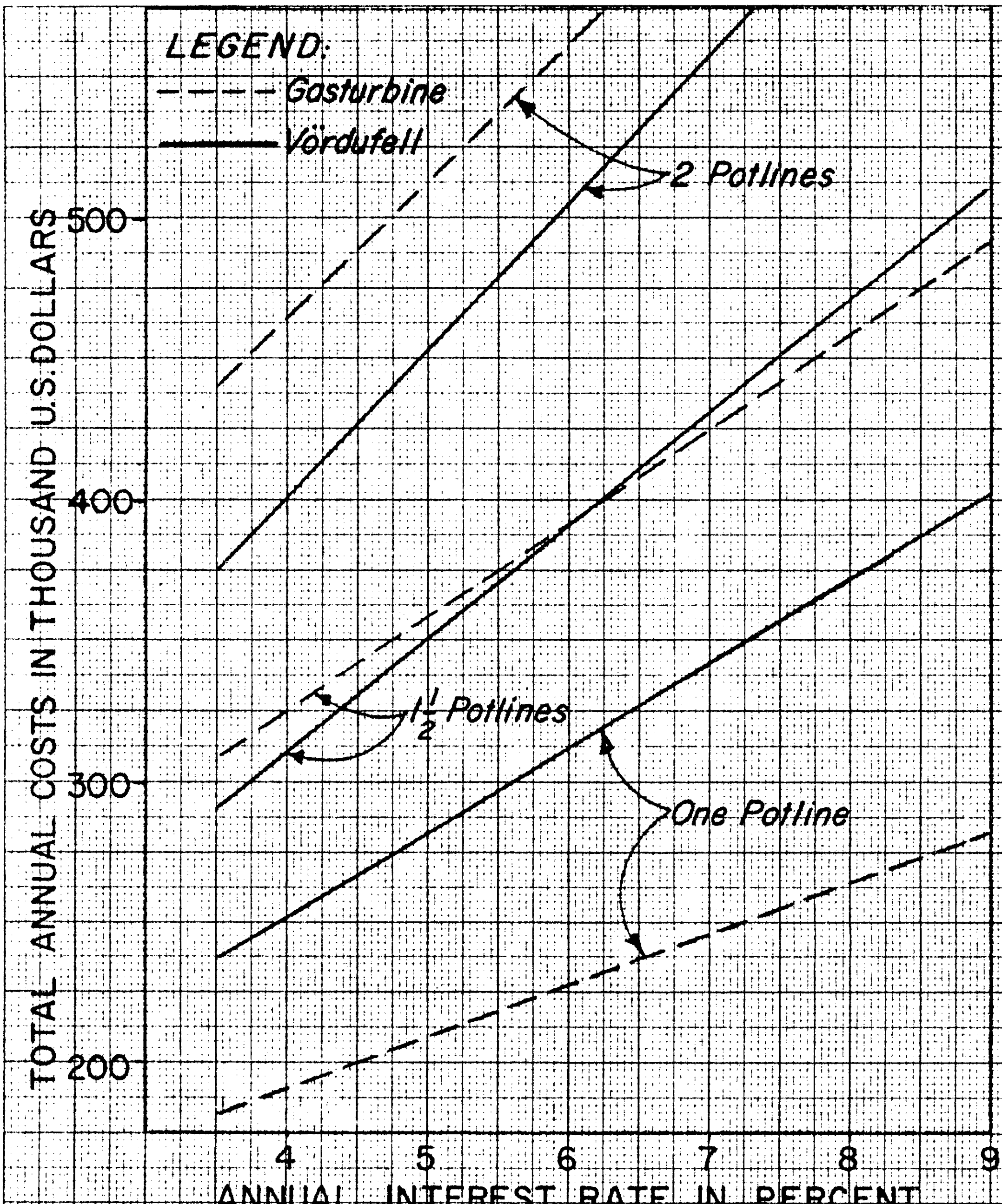

700
600
500
400
300
200
100
0
ANNUAL COSTS IN THOUSAND U.S. DOLLARS
4
6
8
ANNUAL INTEREST RATE IN PERCENT
60,000 kw
48,000 kw
45,000 kw
33,000 kw
30,000 kw
18,000 kw
Interpolated values
VORDUFELL
ANNUAL COSTS
POWER FEATURES AND
TRANSMISSION PLANT
MAY, 1963

EXHIBIT 10



VORDUFELL AND GASTURBINE ANNUAL COSTS

NOTES:

1. Cost of energy required for pumping not included.
2. Two weeks operation annually.

MAY, 1963