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United Nations Industrial Development Organization

Workshop on Case Studies of Aluminium Smelter Construction in Developing Countries

Vienna, Austria, 27 - 29 June 1977

ALUMINIUM SMELTER CONSTRUCTION IN DEVELOPING COUNTRIES [1]

Prepared by
the secretariat of UNIDO

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Corrigendum

Page 5 - the Table at the bottom of the page should read:

Aluminium Production

Group of Countries	(1974) Population million	Aluminium Production 1000 t	Aluminium Production kg/c
Industrial countries (market economies)	662	10,247	15.5
Centrally planned economies	1,187	2,650	2.2
Developing countries	1,845	805	0.44
World	3,694	13,729	3.7

A. GENERAL PROBLEMS AND OPPORTUNITIES FOR ALUMINIUM PRODUCTION IN DEVELOPING COUNTRIES:

Aluminium is the second industrial metal of the world

World Production of Main Metals in 1973 By Weight and By Volume

Metal	Million Metric Tons	Million Cubic Metres
Steel	696	89.2
Aluminium	12.8	4.7
Copper	7.5	0.84
Zinc	5.5	0.78
Lead	4.1	0.35

Source: Revue de l'Aluminium, March 1975, p. 117.

Aluminium has the highest growth rate among industrial metals

Increase of Main Industrial Metals Production; 1974 Compared to 1938 as 100%

Steel	640%
Aluminium	2700%
Copper	380%
Zinc	408%

Source: R. Escherich, Paper Presented at VI Internationale Leichtmetalltagung, Leoben, Vienna, 1975.

Present world production of primary aluminium: 1000 metric tons

1970	1974	1975
10,210	13,809	12,699

Present world consumption of primary aluminium: 1000 metric tons

1970	1974	1975
10,029.9	13,837	11,650

Actual and expected growth rates of aluminium consumption World consumption forecasts till the year 2,000

The historical growth rate of aluminium consumption between 1950 and 1976 (only market economies) was 8.7% p.a.

"Western world" growth of aluminium consumption should slow down slightly from 9% per year before 1973 to 6.5 - 7% per year after 1976.

Source: Revue de l'aluminium, May 1976, p. 209.

The demand could show 9% average growth rate from 1976 through to 1980

Source: Stewart Spector quoted in Metal Bulletin
Monthly, November 1976. p. 45.

D. Prym indicates these forecast figures:

	1975	1980	1985	1990
World primary aluminium consumption, million tons	15	21	30	40
Annual kg/capita	3.7	4.7		

The assumed expected average growth rate is 6.8%.

Source: D. Prym, Aluminium (Düsseldorf)
1974, 10. p. 679.

A recent paper of the U.S. Bureau of Mines (Bulletin 667, 1975) indicates these annual average growth rates of primary aluminium metal consumption for the period 1973 to the year 2,000:

USA	4.6%
Rest of the world	5.3%
World	5.1%

The same source presents these primary aluminium demand forecasts expressed in thousands of metric tons:

	1973	Year 2,000 Forecast Range		Probable	
		Low	High	1985	2,000
USA	5,005	12,519	21,863	8,890	17,055
Rest of the world	9,181	22,680	43,545	17,871	37,104
World	14,188	35,199	65,409	26,762	54,160

Mueller of Swiss Aluminium anticipates in a tentative way for developing countries a growth rate of 11% per annum versus figures between 1.4% per annum and 2.9% per annum for developed countries.

Source: Paul H. Mueller, Paper Presented at VI
Internationale Leichtmetalltagung,
Leoben, Vienna, 1975.

The share of developing countries in world aluminium production

In 1975, in terms of so-called western world production, developing countries furnished 7.8% of primary aluminium delivery. Argentina, Bahrain, Brazil, Cameroon, India, Iran, Mexico, Surinam and Venezuela produced altogether over 800,000 tons.

The growth rate of aluminium production in developing countries

	1960 1000 t.	1970 1000 t.	Increase 1960/1970 %
Primary aluminium production in developing countries	88.6	538.2	507.4

The growth is likely to continue. New capacities (new plants and extensions) are planned in Algeria, Argentina, Brazil, Dubai, Ghana, India, Iran, Mexico and Venezuela. In a longer range of time Guinea, Guyana, Indonesia, Iraq, Paraguay, the Philippines, Trinidad and Tobago, and Zaïre are also planning to contribute to this development.

Source: Metal Bulletin, 9 September 1975,
p. 22 and others.

Recent opinion on aluminium smelter construction in developing countries

Location may be influenced by the availability of large quantities of power in developing countries in the form of untapped hydraulic resources, or natural gas in the Middle East countries, however, it is not possible with any degree of accuracy to estimate the eventual operational capacities by the developing countries in 1980, but if all the present known plants should be realized these countries could be accounting for a significant proportion of world primary aluminium production in 1980 - 1985.

Source: OECD - Industrial Adaptation and the
Aluminium Industry, 1976.

Especially the Middle East, Brazil, Indonesia and Venezuela are likely to contribute with big, new capacities.

If all projects in developing countries would materialize their shares would grow to 20% by 1985 (of "western world" capacities).

Source: Revue de l'Aluminium, May 1976. p. 209.

Aluminium consumption in developing countries and its development

	1960 1000 t.	1970 1000 t.	Increase 1960/1970 %
Aluminium consumption in developing countries (only non-socialist)	119.5	479.1	300

The share of developing countries in aluminium production and aluminium consumption, expressed in per capita figures

Aluminium Production
(1974)

Group of Countries	Population million	Aluminium Production 1000 t.	Aluminium Production 1000 t.
Industrial countries (market economies)	662	10,247	15.5
Centrally planned economies	1,187	2,650	2.2
Developing countries	1,845	805	0.44
World	3,694	13,729	3.7

Aluminium Consumption
(1972 Data)

Group of Countries	Population million	Aluminium Consumption 1000 t.	Aluminium Consumption kg/c
Industrial countries (market economies)	662	10,499.3	15.9
Centrally planned economies	1,187	2,133.2	1.8
Developing countries	1,845	605.6	0.33
World	3,694	10,499.3	2.8

Aluminium consumption in developing countries by main areas

Africa	0.14 kg. per capita
Asia	0.25 kg. per capita
Latin America	1.1 kg. per capita

Source: P.H. Mueller, Paper Presented at the VI
Internationale Leichtmetalltagung,
Leoben, Vienna, 1975.

Per capita aluminium consumption in developing countries, related to GNP figures

Group of Countries	GNP Per** Capita US $	Aluminium Consumption kg/capita	Gram Aluminium Per 1 US Dollar GNP
Industrial countries (market economies)	3,670	15.9	4.3
Centrally planned economies	580	1.8	3.1
Developing countries	280	0.33	1.2
World	1,118	2.8	2.5

** 1972 figures on market prices

The third column shows that the market of developing countries, on the average is undersaturated by aluminium, even compared to their modest average standard of living.

Size of the effort needed to establish more equitable production and consumption shares of developing countries within the world picture

The boosting of aluminium consumption in developing countries from the actual average of 0.4 kg. per capita to a level of 1.4 kg. per capita in the year 1990, the construction of a 3.2 million tons per year new smelter capacity is necessary.

Source: P.H. Mueller, Vienna, 1975.

The pertinent capital needed only for the smelter stage without source of power, alumina plant and infrastructure is equivalent to about US $6.5 billion.

Another global approach provides a target figure for the rest of this century starting from a probable world primary metal demand figure of 54 million metric tons for the year 2,000. Keeping in mind an equitable share of developing countries as 25% world capacities and regarding the existing aluminium smelter capacities in developing countries to be around one million metric tons, the construction of 12.5 million tons smelter capacity appears only in developing countries. On estimating capital cost needed per one ton metal (including alumina plant, energy source and infrastructure) at a round US $4,000 at a 1974 price level, a total of US $50 billion appears as a good guess for total investment in this sector of industry, needed in the developing countries for the rest of this century.

B. PLANNING OF SMELTERS:

Here we attempt to survey basic considerations related to the establishment of aluminium smelters.

Market, abundance of cheap energy and of raw material (bauxite, alumina) are the main factors which favour smelter construction.

Existing plants in developing countries can be classified in this sense:

Plant:	Condition Favoured:
Cameroon	hydro-power, prospective source of raw material, an increasing market
Egypt	hydro-power, market
Ghana	hydro-power, prospective source of raw material, increasing market
Bahrain	energy (natural gas)
India	raw material, market
Iran	hydro-power, market
Argentina	hydro-power, market
Brasil	energy, raw material, market
Mexico	market, energy
Surinam	hydro-power, raw material
Venezuela	hydro-power, increasing market

Decisions are to be taken on:

- to go ahead, or not;
- capacity, stages of construction, product mix (ingots, slabs, billets, cast rolled wire rod and strip);
- location;
- technology;
- details of design (layout, supplies, etc);
- financing and corporate set-up;
- approach to market;
- timing and scheduling of construction.

The main inputs needed for consideration are:

(i) judgement of internal and external markets and channels to these;

(ii) possibilities of alumina supply;

(iii) possibilities of supply by electric energy;

(iv) resources of manpower;

(v) information on possible sites (geographic, climatic, infrastructurals, soil characteristics, environmental requirements);

(vi) expected plant economy (needs techno-economic feasibility study);

(vii) established priorities, as self-sufficiency, defence aspects, lack of other non-ferrous metals, maximum employment policy, etc.

Comments on the market aspect:

Domestic consumption capacity depends besides the GDP per capita level also on a lot of other factors, such as:

(a) availability of fabrication plants, which are the main channel of primary aluminium to the market;

(b) the domestic availability of aluminium has a boosting effect on consumption itself;

(c) an organized and systematic aluminium application promotion programme can have an important impact.

Regional planning should receive strong emphasis. Developing countries with good energy potential, with availability of alumina, or with both, may have little or practically zero market potential. In such cases the regional market, taking into account the neighbouring countries, can provide full justification for smelter construction. A promising example of the first steps towards the organic build-up of such a regional market is the UDEAC area in Africa. Here, based on virgin metal from Cameroon a well designed network of semis' and finished products' plants is getting shape.

Comments on plant capacity:

The capacity unit is the potline. Its production capacity is determined by the A.C. current value and the number of pots. In a new plant potline capacities are now between 50 - 100,000 tons per year. Minimum size and economic capacity should be decided from case to case. It can be the equivalent of at least 1 - 3 potlines.

In specific cases of some developing countries as energy "islands" or economy "islands" limiting factors of financing, or of the market absorption capacities, combined with difficulties of transport may propound the idea of a "mini-smelter". Such plants were considered in some cases within the last period of the industry's history, but no actually implemented project seems to justify such an approach.

Comments on plant economy:

The production cost of primary aluminium and its structure have undergone considerable changes in the last decade. A cost analysis dating back to January 1975 projected these rough breakdown figures:[1]

	Time Period 1965/1969	Time Period 1975/1979
Bauxite/alumina	30%	30%
Capital costs	17%	27%
Energy	15%	23%
Labour	35-40%	20%

---

[1] Metal Bulletin, 7 January 1975. p. 18

The same source stated that "In actual terms, capital costs and energy costs have tripled, bauxite/alumina has doubled, while labour has risen by 50%". (This apparently refers to conditions in the USA).

Production cost is rather sensitive to changes of the operational rate. This function is illustrated by an estimate of S. Spector[1] published in 1971 for the case of a 136,000 t.p.y. smelter:

Operational rate	88%	90%	100%
Production cost, gross c/lb.	22.08	21.47	20.45
Cost increase, v/s the 100% case in per cent	7.97	4.99	-

When elaborating on the price equation for the export of ingot, specific case-to-case factors must be considered. Such are: identity of the foreseen markst(s), their price system and their price trends, the size of relevant duties, of transport, loading and unloading costs, of insurance costs, etc.

The cost and price developments in the last decade resulted in a changing pattern of profitability for aluminium smelters. The operation of a primary aluminium smelter in itself, without backward integration into bauxite and/or alumina production and without forward integration into the production of semis and possibly also of finished products, may involve an economic risk. This can be diminished to some extent by appropriate forward integration.

The economic evaluation of a smelter project, which is expected to provide metal mainly for a domestic (or regional) market should take into consideration also other factors than the size of accountable profits. The substitution of otherwise necessary aluminium imports, the added value produced in domestic aluminium fabrication, the substitution of other, possibly imported non-ferrous metals (as copper) by aluminium should be all taken into consideration.

Comments on training and scheduling:

Realistic schsduling should take into account local conditions and problems as lack of infrastructure, of skilled manpower, bottlenecks in local construction capacities and in the availability of local construction materials, etc. Construction time itself in developed countries may be about 18 months (example Vlssingen), in developing countries about 30 months (e.g. the ALBA - smelter in Bahrain). Essential is the appropriate scheduling and timing of staff training as well. This should be well co-ordinated with the construction schedule. It is a sound idea to assign technical and skilled staff of the plant's future maintenance departments to construction management and supervision jobs.

The cathode lining repair crew of the coming operation period should, under the supervision of the contractor, take an active role in the first lining of the pots.

1/ Aluminium, September 1971.

C. SELECTION OF TECHNOLOGY AND EQUIPMENT:

1. The State of the Art:

At present practically all primary aluminium is produced by the Hall-Heroult electrolytic process.

Potline current intensities in commercial plants are generally between 100 and 170 kA. Experience above 200 kA is available with some producers as ALCOA, Swiss Aluminium,[1] the USSR.[2] Over 200 kA specific energy consumption rates and specific investment costs are claimed to increase.

The carbon anode system of the pots most widely used are:

- Soderberg with horizontal studs;
- Soderberg with vertical studs;
- Prebake.

In new plants mainly prebake is gaining ground, whereby these advantages are claimed:

- Easier to automize and mechanize;
- Potroom atmosphere better;
- Electric energy consumption lower;
- Fluoride consumption lower.

Specific investment costs are claimed to be in the case of over 100,000 tons per year plant size more favourable for prebake. An extensive study, conducted in the USSR[3] has established that the breakeven point of production costs between Soderberg and prebake is around 165 kA potline current. In the range above this value prebake was found to be the more economic.

The number of pots in modern potlines varies between 120 (e.g. Chiba in Japan 128) up to over 240 (e.g. Eastalco in the USA, Vlissingen in the Netherlands 256).

New potline capacities are planned generally around 75,000 tons per year. With higher current values they are approaching the 100,000 tons per year figure (Massena in the USA 91,000 tons per year).

Potline design can follow two extreme tendencies as to current density:

(i) high current density in the anodes (0.9 A/cm^2), and
(ii) low current density (0.75 A/cm^2) in the anodes.

Variant (i) is justified in case of cheap electric energy. This design, which was mainly used in the USA before the energy crisis, requires 1 - 2 Kilowatt hours of energy more per kg. of aluminium. Variant (ii) was mainly used in European practice, where energy prices were traditionally more on the high side.

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[1] Ersmetall 10. 1974. p. 461

[2] Kalushskii et alia: Tsvet Met., also Tsvetmet 5. 76. p. 11

[3] A.S. Derkac: Paper presented at the 3rd Aluminium Symposium in the CSSR, 21 - 23 September 1976.

Pot and busbar design over 100 kA needs careful compensation of the magnetic forces. This problem is fully tackled up to about 170 kA. Satisfactory solutions over 200 kA are also commerically proven.

Specific energy and material consumption figures in modern plant (case of prebake anodes):

Electric energy, D.C.	13,100 - 15,000 kwh/t.
Alumina	1,930 - 1,950 kg/t.
Carbon, net	450 kg/t.
Aluminium fluoride	23 - 27 kg/t.

Cathode lining life can be about 1500 - 2000 days. There is a tendency to diminish the electric resistance of cathodes.

Mechanization and automation of most potline operations is extensively solved. In the USA, where only tapping and the replacement of anodes were not automized, potroom work needs only 2 man hours per ton.

Under conditions of partly automized European smelters, 3 man hours were quoted for this.[1]

Computer control of potline operations is widely used for functions as:

- control of current;
- detection of pots with lability of electric resistance;
- prophylactic and normal detection of anode effects, their elimination;
- crust breaking and feeding by alumina;
- establishment of tapping schedule;
- printing or workshop reports.

The D.C. feed of the potlines is generally supplied through silicon rectifiers. D.C. busbars are made mainly by horizontal casting. They are assembled by welding.

The pollution of potroom atmosphere and of plant environment by fluorine containing gas effluents could be reduced to acceptable levels. Whilst fluorine emission from the pots (gas and dust) is between 14 and 19 kg. per ton of aluminium produced, pot hooding efficiencies in the excess of 98% are reported for prebake anode potlines.[2]

The cleaning of the collected smelter gas through wet processes, or alternatively through the adsorption by alumina, combined with a recovery of fluorine, the so-called dry process - is well proven on a large industrial scale. As a result, plant emissions with a fluorine content lower than 1 kg. per ton of aluminium produced could be attained.

---

[1] Wittner: Elektrowärme International, June 1973.
B.3. p. B. 124

[2] Gary L. and alia. Light Metals, 1976
(AIME, Volume II, page 467).

Modern anode plants are widely automated and have excellent ducts and fume exhaust systems. Commercial processes for the elimination of hydro-carbon fumes from anode burning kilns were developed. Many anode plants use forming by vibration. The processing of spent anodes and rodding operations are strongly mechanized.

Casthouse operations are designed to produce high-quality, large-size slabs and billets. Modern safe degassing and fluxing methods and equipment are applied eliminating chlorine gas emissions. Energy consumption and metal losses are kept low, semi-continuous direct casting is generally used. The application of electro-magnetic moulds was also introduced on a commercial scale.

2. Specific Investment Costs:

By the end of 1974, US $1,600 per one ton annual capacity was regarded as a medium figure for aluminium smelters.

Present estimates are over US $2,200 (e.g. new Brazilian smelter - 2281[1], ALCAN's Port Alfred project - 2390 US Dollars[2]). Within these global figures the cost of fluoride emission control equipment ranges between 2 and 11%. The actual average share indicated by IPAI was 6.6%[3]. Figures between US $121 and US $143 as investment cost increment for pollution control systems were indicated by the end of 1975.[4]

The anode plant is an important investment cost element. An information by the end of 1975 indicated about US $270 for the anode plant and US $100 for the rodding workshop, both referred to one ton prebaked anode, as specific investment cost figures. This means about US $180 of 1974 value per ton of aluminium metal production capacity.

The construction of aluminium smelters in developing areas is in cases, when local steel construction and machine-building capacity is non-available, more expensive, compared to construction in industrialized areas. For example, a recent estimate claims that smelter construction in the Near East is by 20 - 25% more expensive than similar plant construction in the USA (Metal Bulletin, 11 April 1975).

3. "Appropriate Technology" in Primary Aluminium Production

The idea is that whilst in developed industries the selection of technology is governed primarily by considerations of plant economy, whereby some other factors as compliance to sanitary and pollution standards also play a role and as a result the "up-to-date" plant appears, under conditions of developing countries, the choice may be somewhat different. The selection of technology to be found "most appropriate" in developing areas can be influenced by factors and priorities which are specific for such areas, as:

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[1] Metal Bulletin. 8 April 1975. p. 23

[2] Metal Bulletin. 13 April 1976. p. 23

[3] IPAI Environmental Committee Report: Fluoride Emissions Control Costs for New Aluminium Reduction Plants. 1975.

[4] Revue de l'Aluminium. December 1975. p. 529.

- difficulties in the recruitment of skilled workers, craftsmen and technicians;
- the desire to provide a maximum of job opportunities;
- a low level of wages;
- difficulties in obtaining maintenance spares;
- climatic problems, like heat or sand storms.

An interesting description of smelter construction case experience could be read recently on the Bahrain smelter[1].

A few highlights of this paper, reflecting principles kept in view at planning and some actual experience are briefly presented:

- Process and technology should be simple, sophisticated mechanization and automation should be held at a minimum. Where possible, certain services should be added in a second stage only.
- At the time of decision-making pot size between 130 - 160 kA was world-wide under design and construction, but it was not yet proven in operation long enough to be introduced in a developing country. Result: 105 kA was selected. A low anode current density (0.776 A/Cu^2) was chosen because this involved a higher anode-cathode distance and therefore less sensitive operation.
- In-place relining of cathodes was selected because of its simplicity.
- Difficulties were encountered because of many prototype equipment which had to be debugged.
- Operation in summer heat (over 40°C) caused difficulties. Machinery changes and the introduction of local cooling enabled to reduce the heat exposure of workers.
- Unexpected problems of increased CaF_2 content in the electrolyte were caused through contamination by incoming desert limestone sand. As a counter-measure, the excess AlF_3 content in the electrolyte had to be reduced.
- A programme of further optimization was established after a few years of operation. This concerned:
  - (i) automatic pot control with computer;
  - (ii) increase of the anode cross section by 10%;
  - (iii) increase of the rectifier voltage.
- Following the gradual training of manpower and the improvement of working conditions, man hours per ton of aluminium could be reduced from 13.5 in 1972 to 7.2 by the end of 1975.

The above example illustrates that problems and solutions are determined by specific local conditions, therefore, no generally valid "appropriate" technology can be defined. It is thought as useful to establish a checklist of issues in technology selection to be considered and decided upon. Here we attempt to provide such a list:

---

[1] **K. Baltensperger:** **Selection and Operation of a Reduction Process for a Developing Country in the Middle East (Light Metals 1976 (AIME) Volume I, page 57)**

(a) Potline and pot characteristics:

anode system (Soderberg horizontal,
Soderberg vertical,
prebake).

current intensity;

number of pots per potline;

current density;

cathode design;

busbar design;

mechanization of potroom operations;

automation and computer control;

work and health safety devices.

(b) Gaseous effluents handling:

hooding;

exhaust and gas cleaning system;
(to be sought as a compromise of cost saving and efficiency).

(c) Cast-shop technology:

capacities and types of holding and cast furnaces;

refining of the metal;

casting, lifting, stacking devices, etc.;

equipment for semis production (e.g. cast rolling of rod and strip - if any).

(d) Anode plant design

anode operation workshops (rodding, spent anodes handling, etc), design.

(e) Maintenance workshop design
(Spares supply, etc).

(f) The energy supply system
(e.g. gas turbine versus steam plant).

4. The Future of the Electrolytic Plant: Alternatives to the Hall-Heroult Process:

4.1 The Toth Process:

This belongs into the category of thermic reduction process. Aluminium chloride is reduced by manganese metal:

$$3\,Mn + 2\,AlCl_3 \longrightarrow 2\,Al + 3\,MnCl_2$$

The manganese and the chloride are claimed to become recycled. The process was announced in 1973. No commercial installation works yet.

Opinion on this process: only little relevant information is available, generally scepticism was expressed regarding technical and economic feasibility. On commercial scale difficulties can arise mainly because of the contamination of the produced aluminium by manganese and from the side of the reactions in solid phase.

4.2 The ALCOA Aluminium Chloride Electrolysis Process:

In 1973 the Aluminium Company of America (ALCOA) reported that it has developed an electrolytic process for aluminium production from aluminium chloride dissolved in alkali and alkaline earth chloride melts. This process was considered promising so that the company decided to build a plant with an annual capacity of 15,000 tons of aluminium, to be increased to 30,000 tons per year. This plant is being built in Anderson County, Texas. The plant started operation in July 1976. This chloride process was developed over a 15 year period and at a cost of US $25 million.

If the preliminary production turns out successful, it is planned to increase annual production to 300,000 tons of aluminium.

The ALCOA process works in three steps. First aluminium oxide (alumina) is produced, secondly the oxide is reacted with carbon and chlorine gas to form aluminium chloride. The last step is the electrolysis of the chloride, whereby aluminium is produced. The chlorine is recycled.

The electrolysis is conducted in the molten salt phase. The cell works with bipolar graphite electrodes at a temperature of around 700°C. The energy consumption has been reported to be 8.9 kwh/kg. Al. This means that nearly 30% of the energy is saved, compared to present industrial practice in modern plants. The produced metal is claimed to have high purity.

Opinion on the process: It seems to be technically feasible. The electrolysis cell is a very concentrated production unit with a large production per reactor volume. As the production of aluminium chloride from the oxide appears as an additional step in technology, this brings new increments of cost and energy consumption. In such a way it is still dubious if the gross production cost and energy consumption of the process will be competitive compared to the traditional Hall-Heroult electrolysis. If the pollution problem by chlorinated hydrocarbons can be avoided, it appears as a great advantage to replace the fluorides by chlorides, which cause much less concern from the environmental point of view.

Research work on the line of chloride electrolysis is going on also in Japan. Professor Y. Tsumura of Tokyo is claimed to have improved upon a process for the production of primary aluminium, developed by Professor R. Midorikawa of Hokkaido. A mixture of $AlCl_3$ - NaCl - KCl is electrolysed at 120 - 150°C temperature to yield aluminium sponge.

4.3 General Outlook:

Among the new processes the Toth process seems to have little chance to attain commercial importance. The ALCOA process appears as feasible and having advantages. Its final evaluation, however, will be possible only on the basis of the just started pilot operation.

Carbothermic and other similar processes proved until now as unsuccessful.

Present efforts to elaborate technologies of processing non-bauxitic raw materials, as clay, ashes, schists, anorthozite and alunite to aluminium oxide may have also an impact on developments. If, for example, a direct route for the economic production of pure aluminium chloride from clay could be established, this could be combined with the ALCOA - process. This way would eliminate the production of aluminium oxide (alumina) and open new perspectives of competitiveness. It should be noted in this context that the so called "H-plus" process of Péchiney-Ugine-Kuhlmann, to be developed together with ALCAN, is designed to process clays and clay-like materials to alumina through an acid treatment via the hydrate of aluminium chloride.

Efforts for the substitution of the Bayer process (alumina production) and the Hall-Heroult process (for primary metal production) will continue, but on quoting Professor K. Grjotheim and his co-authors:[1] "Even if all progress today goes faster and faster, one may draw some careful conclusions from the fact that the Hall-Heroult process presently dominates completely. Some of the new processes might be of industrial importance in the future, but they will hardly be able to compete with the steadily improved Hall-Heroult plants in the coming fifteen to twenty years.

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[1] Paper Presented at the Banska Bistrica (CSSR) Symposium in 1976.

D. FITTING AN ALUMINIUM SMELTER TO THE ENVIRONMENT:

1. Size of Building Site Required:

This varies to some degree depending on circumstances, as: the size of workshops and plant buildings, of possible auxiliary production lines serving forward integration on the system of electric energy supply (simple sub-station needed only, or possibly a whole power plant, etc), on the size of the spare area to be reserved for purposes of future extension, on the design of the potrooms, on the storage requirements set for raw materials and for the metal product inventory.

The area required for 100,000 metric tons annual capacity may be set between 21.0 and 44.4 hectares (i.e. between 51.9 and 109.7 acres), whereby the share of the built-in part may attain 20 to 30 per cent. Taking 30 hectares for 100,000 tons per year capacity as a medium, the world's existing 13 million tons annual aluminium smelter capacity would require 3900 hectares, i.e. 39 sq. kilometers only.

The size of the area, which is actually affected by the smelter through the emission of fumes, may be considerably larger, depending on the system of fume collection and treatment selected. In the extreme case of zero treatment as it was often usual in old plants, especially when established in non-agricultural areas, soil, vegetation, human and animal life could be strongly affected in the environment, also depending on micro-climatic conditions. This situation was also reflected in the principles of planning, e.g. in setting the minimum distance between smelter and housing colonies at about 5 kilometers. Modern efficient systems of potline gas collection and treatment, able to meet even the most sever environmental legislation, may change this picture fundamentally.

2. Infrastructure Required:

We confine ourselves here to a simplified checklist:

(a) Electric energy supply: high security of operation is needed because a freeze of the electrolyte in the pots causes heavy and costly damages. Stand-by units, respectively security junctions to the national grid should be considered.

(b) Water supply.

(c) Means for material transport: unloading and loading facilities. The material inflow for the production of one ton of primary metal makes up about 2.85 tons. This consists mainly of alumina and carbon electrode raw materials.

(d) Housing: The size of accommodation capacity required will depend much on the character of the area selected (existing town nearby, etc). Proper care for housing is absolutely important because this is a main instrument which helps to stabilise the workforce.

3. Smelter Effluents - General:

3.1 Gaseous effluents. The main problem is caused by the fumes of the potlines. These contain as main harmful constituents fluorine, partly in gaseous state, partly bound in solid particles, in the case of Soderberg - anodes also hydrocarbons, which are essentially tarry fumes, originating from the cracking and distillation of the binder pitch in the anode paste, also carbon dioxide and sulphur dioxide. This latter is generated by the oxidation of the sulphur content in the anode carbon.

The quantity of fluoride emission from the pots, expressed in kilogrammes per ton aluminium produced[1] depends on the cell type.

Type of Pots	F Gas	F Solid	F Total
Soderberg	19	4	23
Prebake	about 7.5	about 7.5	15

An[illegible]ource of polluting fumes is the anode plant. In case of prebake anodes here beside the hydrocarbons emitted, fluorine also appears having its source in the recycled anode "butts".

3.2 Liquid effluents. The main trouble is caused here by the residual liquors of wet fume treatment systems, containing fluorine and sometimes hydrocarbons. In littoral areas often seawater is circulated in the treatment systems. The effluents may need neutralisation, respectively purification before their discharge to the sea or to rivers.

3.3 Solid wastes. The main item is the material of spent cathode linings, which amounts to 40 - 90 kg. per ton of aluminium. This may contaminate the soil and soil water through leaching by rainfall.

4. The Collection and Treatment of Potline Fumes:

4.1 Legislation and general experience concerning the effect on the environment. Three well defined aspects of air pollution are normally subject to legislative control:[2]

(i) Emission from stacks (regarded as single or multiple point sources), and/or roof vents (line sources);

(ii) Ambient air quality in the neighbourhood of the smelter;

(iii) Conditions in the working environment (industrial hygiene).

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[1] P. Péria. Revue de l'Aluminium. April 1974. p. 225

[2] IPAI - International Primary Aluminium Institute
Survey of Legislation and Regulations for the Control of Air and Water Pollution by Fluorides. 1973.

Emission standards are mostly expressed by using the rate of emission of fluoride as gaseous (Fg) particulate (Fs) or total (Ft = Fg + Fs), expressed as Kg. F. per hour or per day. Standards are frequently set by relating the allowable emission to the rate of metal production, i.e. kg. F/t. Al.

Several pollution agencies in the USA adopted the "process weight rate" concept for dust emission. It relates the emission to the total weight of materials processed. The formula used in this context, relating to areas less than 50% urban, leads to the following allowable emission figures:

Aluminium Production Rate, t.p.a.	Allowable Emission kg/t. Al.
15,600	3.0
93,600	1.7
187,200	1.0

Actual standards exist with few exceptions practically only for industrialized countries. Below, please find a few examples presenting characteristic numerical values, based on the IPAI survey of 1973:

Emission Rates
(examples of the most severe regulations)

	Maximum Emission kg. F/t. Al.	
	Fg.	Ft.
US (Federal, proposed)	-	1.0
Germany (proposed)	1.0	-
Netherlands	0.37	1.12
Norway	-	1.3
Japan (Kagawa)	1.0	-
Japan (Fukuoka)	1.2	-

Working environment. The threshold limit values (TLV), as recommended by the American Conference of Governmental Industrial Hygienists for 1972, are:

	mg/m^3
Fluoride (as F)	2.5
HF	2.0
Fluorine F_2	0.2
SO_2	13
CO_2	9000
CO	55
Coal tar pitch volatiles	0.2

Other recommendations for the working environment.

	USSR (1966)	CSSR (1969)
Fluoride (as F), mg/m^3	1.0	1.0
HF, mg/m^3	0.7	1.2

In cases of lasting and heavy exposure considerable damages of vegetation and animal life, especially of cattle were observed. On the basis of actual experience, it is claimed, however, that no damages are caused to vegetation and animals if fluorine emission from the plant does not exceed a level of 600 - 900 kg. per day.[1] This means that in case of agriculturally cultivated environment, the larger a plant, the more efficient fume treatment is needed, respectively the maximum plant size may be limited under such conditions.

4.2 Alternative techniques available. The source of contaminant-bearing gases are the electrolytic cells (pots). These are hooded in order to collect the gases. The concentrated gases, collected under the hoods can be:

(i) Blown out through a stack (no treatment);
(ii) Treated in a wet washing system;
(iii) Treated in a dry system (adsorption of alumina, plus bag filter).

The above cases (ii) and (iii) are called the primary gas cleaning cycle.

A part of the gases escapes to the working atmosphere of the potrooms. If necessary, the whole potroom air before leaving through vents, is passed through a wet scrubber system on the roof of the potrooms. This is called secondary cleaning system.

The efficiency of hooding is different for the three main types of pots:[2]

	Collection Efficiency (in %)
Soderberg, vertical	75
Soderberg, horizontal	85
Prebake hooded	95 (also 98% reported)

When comparing the dry and wet treatment of gases in the primary cycle, the dry system appears to have these advantages:

(i) Absence of liquid effluents;
(ii) High efficiencies (about 98 - 99%);
(iii) Fluorine becomes recycled, therefore economy appears. (when installed in existing plants ultimately, a payback period of three years was reported).

Some authors mention that the recycling of volatile contaminants through adsorption on the alumina appears as a disadvantage. In practice this does not seem to cause serious troubles however.

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[1] P. Péria. Revue de l'Aluminium. April 1974. p. 225

[2] Ivar Nestaas. A Survey of the Pollution Problems in the Aluminium Industry (UNEP, Paris, 6 - 8 October 1975).

The secondary wet scrubber system is very costly, therefore, its application should be avoided if possible. The extreme increase of hooding efficiency is the best way for this.

From the technical point it is possible to meet the most severe requirements on effluent purity, however, the less pollution, the more costly the investment and the operation. This correlation is expressed below in figures:[1]

Comparison of Smelter Gas Effluent Treatment Systems

Effect and Cost (only closed prebake cell-case)

Case No.:	System Applied Primary Cleaning	 Secondary Cleaning	Emission Fkg/t.Al. (case of 95% hooding)	Investment Cost of Gas Cleaning Equipment US$/t. Al. - annual	Operation Cost Increment US$/ton aluminium
1	none	none	16	-	-
2	wet scrubber	none	3.8	66	23
3	Alumina + bag filter (dry system)	none	1.3	89	20
4	Alumina + bag filter (dry system)	spray screen	0.7	141	40

The costs of alternative solutions for smelter gas emission control were also elaborated by IPAI.[2] According to their findings, if the investment cost of one ton annual smelter capacity is assumed to be US $2,000, the fluorine emission control equipment will cost an additional 2 to 11% of this, in the average 6.6%. The additional operating cost increment, due to emissions control, in case of pre-bake anode cells will amount from:

US $6.17 per metric ton aluminium (dry primary system only)
to
US $52.75 per metric ton aluminium (wet primary plus wet secondary system, including multi-purpose cryolite recovery plant).

Ergo the additional operating cost increment in percent is between 0.8 and 6.6.

For new plants, two main classes of emission control emerge:

(i) Hooded prebake cells plus primary control;
(ii) Hooded cells plus primary plus secondary control.

For "remote" areas, and this may well apply to non-agricultural sites in developing countries, hooded cells plus a tall stack is also a viable alternative, whereby a scrubber can be added at a later date.

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[1] I. Nestaas. UNEP. 1975

[2] IPAI - International Primary Aluminium Institute
Fluoride Emission Control: Costs for
New Aluminium Reduction Plants. April 1975.

In the case of old, existing plants, an ultimate introduction of gas collection and treatment may cause technical difficulties and additional cost. Menegoz and Sala[1] reported on the cost impact of such plant reconstructions. They quote these increments of investment costs:

	Investment Cost Increment US Dollars Per Ton Annual Capacity
Gas collection only	17.87
Roof screen only	39.00
Collecting, plus secondary system	60.75 - 63.60

The treatment of the carbon anode plant fumes needs a separate system. A highly efficient system consists of electrostatic precipitator, a venturi-scrubber and a spray tower in series. The dry alumina adsorption method was also adapted for this purpose, whereby the hydro-carbons get incinerated before the aluminium adsorbent is fed to the pots.

5. Recommendations on Decisions to be Taken:

(i) As the environmental protection may increase investment and operation cost considerably, if extremely strict standards are applied, plant location should be preferred in non-cultivated, possibly even desert-like areas.

(ii) Pollution control systems can be installed also in more stages, whereby first a cheap, but less efficient way can be selected, e.g. hooding, plus high stack. In such cases, however, proper provision should be made to secure the possibility for an ultimate easy adaptation of a more efficient system.

(iii) The necessity to establish the expensive secondary control system should be avoided by all means. This can be done through proper location, through selection of a cell type, which enables maximum good hooding (e.g. prebake with central crust breaking) and through the limitations of ultimate plant capacity.

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[1] D.C. Menegoz and J.M. Sala
Light Metals (AIME) Volume I, p. 125.

E. THE HUMAN FACTOR IN ALUMINIUM SMELTER CONSTRUCTION AND OPERATION:

1. Work Hygiene:

This aspect is partly also related to the system selected for pot fume treatment.

Potroom workers are exposed to a big variety of harmful factors. We quote in this context I. Nestaas.[1]

> "Working conditions in potrooms tend to be unpleasant and in some cases unhealthy, due to a number of factors, such as:
>
> Shift work;
> Exposurs to polluted air;
> Heat exposure;
> Draught;
> Noise;
> Dirt;
> Poor light;
> Heavy work;
> Accidents.
>
> The quality of the working environment varies considerably between plants, owing mainly to design of pots and potrooms, ventilation and operational procedures. New plants tend to offer better working conditions than old ones, and many companies take great care to design their plants for good working conditions. Fluorosis is normally not a health problem at modern plants. Potrooms with closed prebake pots have better general atmospheric conditions than others. Heat exposure may be a problem in several cases, for instance for people working between closely spaced pots."

The exposure to hydro-carbons in the potroom atmosphere, originating from the binder pitch of Soderberg anodss, according to a recent study[2] seems to cause an increase of cancer rates among potroom workers in the case of Soderberg plants. Compared to male city population as a reference group, the frsquency of respiratory cancer was found 1.7 - 2.6 times higher, that of stomach cancer 2.28 times and of cancer of all localizations 2.3 - 3.0 times higher.

In case of a smelter with prebake cells, cancer frequency was somewhat below that of the male city population selected for comparison.

As the main means to meet the work hygiene requirements of an aluminium smelter, it is advised:

(i) To pay proper attention at plant design to aspects of work hygiene (to avoid too crammed potroom layouts, to provide efficient hooding, a satisfactory change of air in the potrooms and also, if necessary, spot cooling and local fresh air supply).

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[1] Ivar Nestaas: UNEP, Paris 6 - 8 October 1975

[2] V.G. Konstantinov, P.G. Simakhina, E.V. Gotlib, A.I. Kusminykh Problems of the Carcinogenic Hasard in Aluminium Electrolysis Halls. Professional'nyi Rak. 1974. 6 pages.

(ii) To provide monitoring of potroom atmosphere quality and temperature.

(iii) To provide a regular health control of the workers.

(iv) To provide good maintenance of hooding devices, ducts., etc.

2. Quantitative Aspects of Staffing: Productivity:

Reliable data on actual staff requirements of aluminium smelters are scarce and often ambiguous, especially concerning their exact coverage. Sometimes employees' or work force numbers are given, sometimes productivity data, expressed in man hours per ton. We have supposed in our calculations below a sum of 1920 annual man hours per employee. For the sake of easy comparison, we have used staff numbers related to a 100,000 tons per annum unit capacity level.

As a historic background a few figures from UN Report St/CID/9, representing the technical level of around 1960 be quoted and interpreted:

USA, 60,000 tpy smelter	15 hours/t	(781 staff)
Europe	28 hours/t	(1458 staff)
Developing country	130 hours/t	(6770 staff)
Japan, actual 1960	69 hours/t	(3593 staff)
Norway, actual 1958	55.5 hours/t	(2890 staff)
USA, actual 1958	19.5 hours/t	(1016 staff)

A report from the year 1969 indicates:

Hungary	33 hours/t	(1719 staff)
France, new plant	14 hours/t	(1167 staff)

The afore-mentioned staff numbers in brackets are understood to be the total number of employees, projected to a 100,000 tons per year basis.

Recent characteristic data concerning smelter staff numbers reflect an increase of productivity during the last one and a half decade:

	Working Hours Per Ton (total)	Staff Per 100,000 tpy capacity
Plants and projects in developed industrial countries	8.1 - 17.4	423 - 906
The same in developing countries	18.2 - 67.2	952 - 3500

It may be that the above data are not fully representative, however, they may well indicate orders of magnitude. A comparison of the mathematical medium values for developed and developing countries shows that staff requirement in the latter group appears to be more than the threefold compared to the developed group.

A few brief ideas on the causes of this "productivity-gap":

(i) objective causes, as the level of average skill, of the physical stature and force of the workers, etc.,

(ii) factors of deliberate policy, as the creation of maximum employment, objectives of in-plant training and teaching especially with a view to further plant extensions;

(iii) subjective factors, as work morale, the psychological effects of a comparatively low level of wages and salaries, elements of motivation, of management and of organization;

(iv) some increment may be explicitly due to the application of "appropriate" technology, i.e. the use of simple, robust equipment, which requires a minimum of spare supplies and of maintenance, but implies also a lower degree of mechanisation and of automation, also the use of a less sensitive technology.

3. The Importance of Training:

When planning the training of a new aluminium smelter staff, a few remarks may be of interest:

(i) The operation and maintenance of an aluminium smelter needs that a big share of the staff be well trained.

(ii) A smelter needs a big variety of disciplines. This applies to the engineers, the technicians and to the craftsmen, respectively skilled workers, as well.

(iii) Training pays. A smelter represents high investment and a high product value. Damages caused by ignorance may be very costly.

(iv) The in-plant training should be performed under identical conditions of equipment and technology, as foreseen for the new plant to be constructed As a result training uses to be organized by the party, which provides the know-how. A mixing of practices may cause confusion and troubles, especially in the first stages of operation.

(v) It should be decided what degree of staff independence is desired. In this context, different models exist. In some cases a lot of the skilled staff and the technical management consists for a long time of expatriates. In other cases the number of the expatriates can be gradually reduced to a well designed programme of education, training and substitution. In some cases, especially in developing countries, with traditions of technical education and of vocational training, full national independence can be reflected in the staffing, up to the top technical management. Under this type of arrangement only a few technical advisers of the plant's supplier use to stay after commissioning for a limited time.

(vi) Staff should be planned and trained with some reserves. Beside the normal share of dropouts, it should be counted with that in a developing country, people with industrial experience easily get higher and better jobs, e.g. engineers get promoted into governmental posts, etc.

F. UNIDO'S ROLE IN ALUMINIUM INDUSTRY DEVELOPMENT:

UNIDO, in the course of its existence, since 1967, paid great attention to aluminium industry.

In the frame of its technical assistance programms developing countries received information and specific recommendations on the industrialisation of their bauxite deposits, expert assistance was rendered in stages of study work, of pre-investment activities and of plant construction. Pre-feasibility and feasibility studies were prepared for important plants, especially in the smelter field. A list of projects implemented or still operational can be found in Appendix I.

Appendix II supplies a list of general sectoral papers, which were prepared and edited under UNIDO's auspices, as well as of meetings in the aluminium industry field.

APPENDIX I

UNIDO'S TECHNICAL ASSISTANCE PROJECTS IN THE ALUMINIUM INDUSTRY

Country	Year	Short Description
Argentina	1971	Study on possible production of aluminium from local non-bauxitic raw materials.
Argentina	1970	Feasibility study of aluminium smelter.
Argentina	1974/1975	Feasibility studies on aluminium semis plants
Brasil	1970	Assessment of techno-economic implications of adapting electro-thermal reduction of kyanite for the production of aluminium silicon alloys
Brasil	1975	Assistance to the secondary aluminium industry
Sri Lanka	1973	Pre-feasibility study on aluminium semis plant.
India	1973	Study on the utilization of low-grade bauxites
Mali	1972	Pre-feasibility study of establishment of an integrated aluminium industry.
Mali	1974	Expert mission for bauxite development
Quatar	1971	Pre-feasibility study on aluminium smelter.
Turkey	1969/1973	Assistance in construction of integrated aluminium complex - applications of critical path method.
Turkey	1971/1974	Expert on mounting of technological equipment.
Iran	1968	Economic evaluation of an aluminium production plant.
The Maghreb	1970	Study on primary aluminium production.
Egypt	1974/1975	Services of industrial economist of the aluminium production sector.
Costa Rica	1974	Advisory assistance to the aluminium industry.
Guinea	1974	Assistance in metalworking of aluminium
Indonesia	1977/1978	Assistance to aluminium extrusion plants.
Iceland	1974	Pre-feasibility study on alumina plant to utilise geothermal genergy.
India	1973	Testing of sillimanite for purposes of aluminium silicon alloy production by electro-smelter.
India	1975/1976	Assistance in the establishment of an aluminium institute.

APPENDIX I
(continued)

Country	Year	Short Description
Iraq	1974	Pre-feasibility study of aluminium smelter.
Iraq	1975/1976	Expert assistance in the pre-investment stage of an aluminium smelter.
Malagasy Republic	1973/1974	Pre-feasibility assistance in processing local bauxites.
Colombia	1976	Expert assistance to the aluminium industry.

APPENDIX II

SECTORAL STUDIES OF UNIDO IN THE ALUMINIUM INDUSTRY FIELD

1. Pre-Investment Data of the Aluminium Industry.
   U.N. Industrial Development Centre (predecessor of UNIDO).

2. Report of the First Meeting of an Expert Consulting Group
   of the Aluminium Industry. 1968.

3. Utilisation of Non-Ferrous Scrap Metal. Report of the
   Expert Group Meeting on Non-Ferrous Scrap Metals. 1969.

4. Non-Ferrous Metals. A Survey of their Production and Potential
   in the Developing Countries. 1972.

5. The Technology and Economics of Processing Low Grade
   Bauxites. 1973.

6. Model Laboratories for Testing Bauxite, Alumina and
   Intermediate Products in Developing Countries. 1973.

7. Analytical Methods for Testing Bauxite, Alumina and
   Intermediate Products. 1973.

8. The World Primary Aluminium Industry with Special Reference
   to the ECAFE Region. 1973.

MEETINGS

1. First Expert Group Meeting on the Aluminium Industry
   "Alumina Production from Various Ores".
   Vienna, 10 - 16 November 1967

2. Workshop on Case Studies of Aluminium Smelter
   Construction in Developing Countries
   Vienna, 27 - 29 June 1977.

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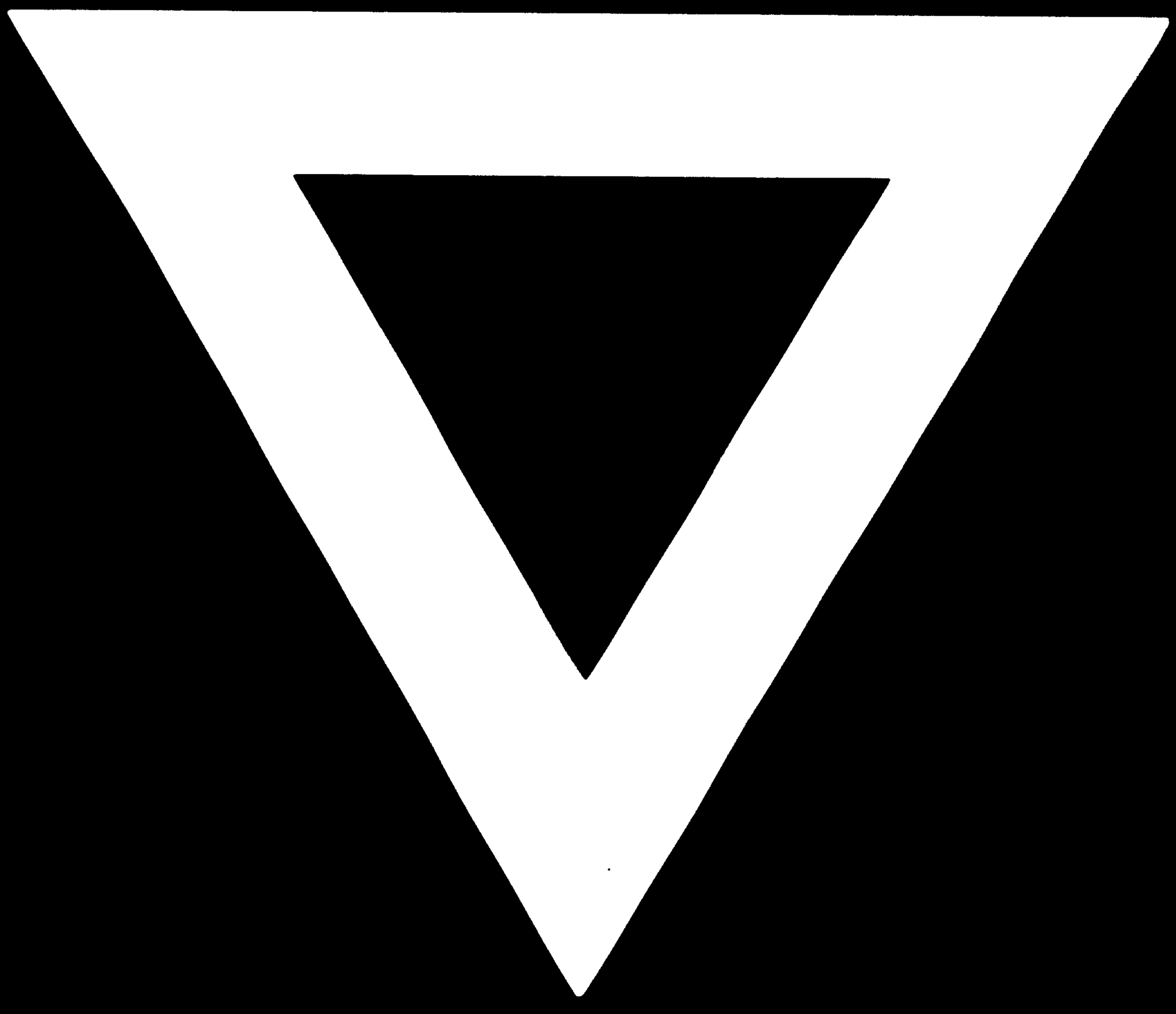

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