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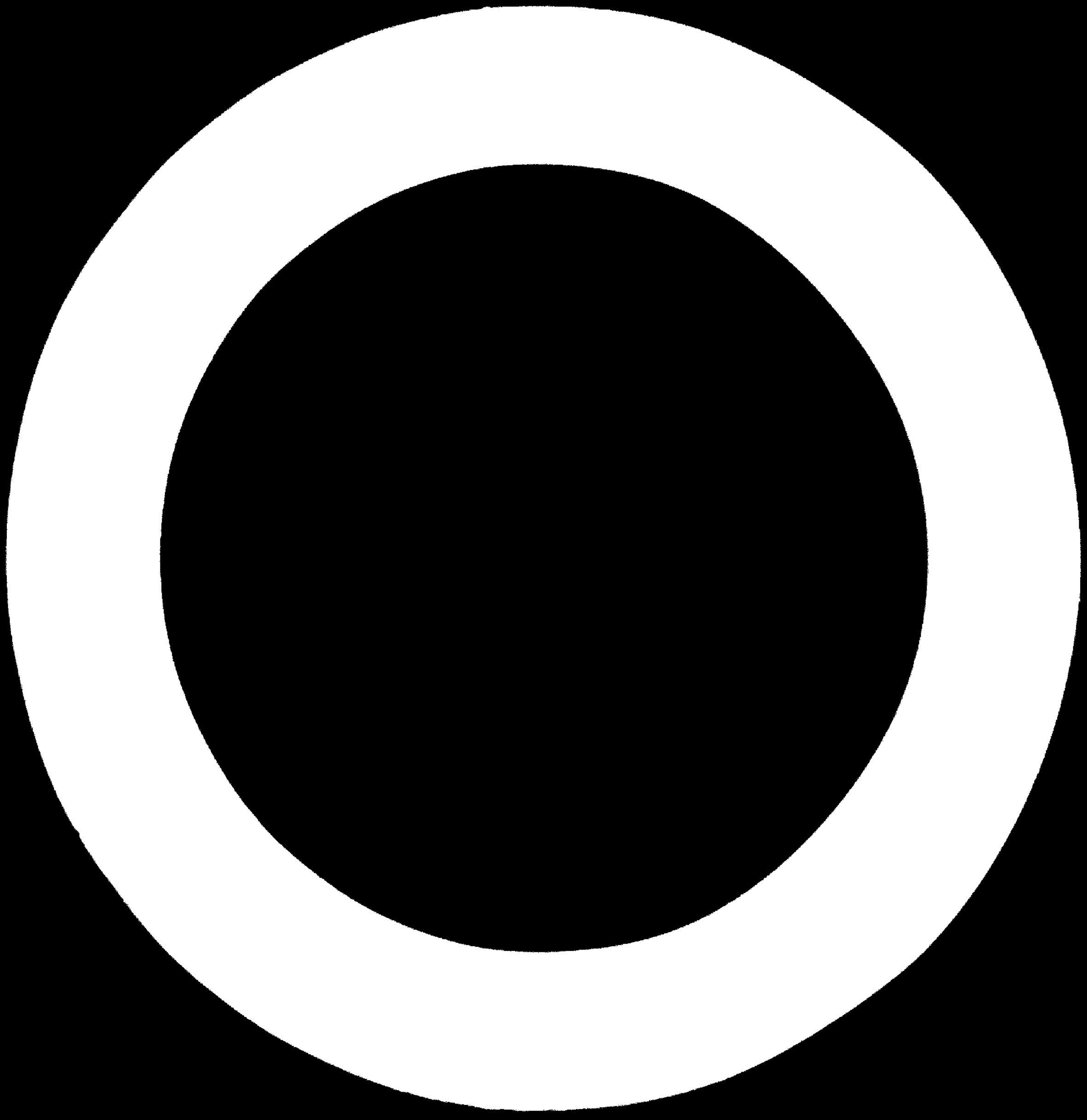

Summary

The air pollution caused by a primary aluminium smelter mainly refers to the emission of fluorides, both gaseous and solid, and dust. Due to the different levels of toxicity which may be attributed to the various compounds emitted, the emission control for gaseous fluorides is of primary importance.

Collection and cleaning of pot effluents may be effected in various manners. By using the potroom as "hood", a high collection efficiency may be achieved, but large volumes with a relatively low concentration of hazardous compounds must be treated. Individual hoods mounted on each pot yield small volumes of highly concentrated gases, but collection efficiency is lower.

Collected gases may be treated in various ways by using dust removal equipment, wet scrubbers or dry scrubbers. Hydrogen fluoride is readily removed by wet scrubbers, but solid fluorides, low in particle size, often require the installation of special cleaning equipment. Dry scrubbing removes both gaseous and solid fluorides. In each case, the overall control efficiency is determined by the collection efficiency of the collection system and the cleaning efficiency of the removal equipment. Depending upon these two variables, the overall control efficiency may vary within a very wide range.

The costs for investment and operation of emission control installations depend upon plant type and size and degree of emission control to be achieved. Investment costs may vary from 3 to 11 % of the total investment and operating costs may amount to 2 to 7 % of the price for aluminium.

Standards on environmental control are still scarce in the developing countries. Therefore, the installation of highly elaborate cleaning equipment in plants located in developing countries does not seem to be appropriate in the immediate future.

The trend for dislocating production increase to developing areas is not obvious for 1972 - 1980. Thus, total emission in such areas is only determined by the normal production increase forecast. However, the rate of distribution of production increase may be significantly switched in favour of the developing countries by emission control standards being tightened up in highly industrialized areas.

CONTENTS

INTRODUCTION

Since the Stockholm Conference on Environmental Control sponsored by the United Nations in 1972 a worldwide discussion has emerged as to what extent the unused capacities of natural resources in developing countries could be used to erect new basic industries. This consideration is also of great importance for the siting of alumina plants and aluminium smelters in tropical countries where bauxite reserves and/or unused energy resources invite the erection of large new industrial complexes of aluminium industry. Some of the developing countries have even been described as being at present pollution "heavens" because no emission control is required.

Following this line of thought, polluting industries would have a tendency to migrate with new installations according to the economic advantage of developing areas. Sometimes a step by step approach is visualized, in as much as stricter environmental rulings are to be applied in later years when the cost from damages by emission begins to exceed the benefits of the new plant for the country in question.

Another way to put this same reasoning is the following:

Some developing countries argue that even the polluting industries in the highly industrialized countries had very little emission control installed in the first decades of their existence, thus enabling these plants to derive a greater benefit compared to plants with a highly sophisticated emission control installed. There is, however, more and more reasoning against the pollution "heavens", the more important ones being the following:

- Large companies and also international organizations come to the conclusion that pollution as a competitive element should be ruled out to avoid that specific tariff barriers are erected by countries with high pollution control standards to avoid the import of raw materials, for instance aluminium, produced in highly polluting units at therefore lower costs in other countries.

- A polluting plant, even in a developing country, might after a number of years come under public criticism. The owners of this plant might then be in considerable trouble to change the plant over to a non-polluting process which may be very costly.

- It is possible today to build aluminium smelters equipped with appropriate pollution control installations where the production costs are only little higher compared to the production costs of pollution releasing process. The cost for the original investment however, may be significantly higher for the clean plant. Investment, however, is not the only cost factor determining the final production costs.

I. AIR POLLUTION FROM PRIMARY ALUMINIUM SMELTING

A. General

The air pollution problems created by a primary aluminium smelter plant operated in conjunction with a casthouse, an anode plant and a cathode repair shop are manifold due to the fact that various production processes are proceeded. In each operation, different raw materials are processed thus creating pollution by dust and tar in the paste plant and the cathode repair shop, emission of tar, soot and fluorides from the anode baking furnace, emission of soot and chlorine containing compounds from the casthouse and air pollution by fluorides and dust originating from the potroom.

The most important source of emission in a primary aluminium smelter plant will undoubtedly be the potroom. For this reason, air pollution from the potroom and its abatement will be stressed in this paper.

Air pollution from potlines is created by several facts, the major ones being:

- operation of a reduction cell containing a bath of molten salts
- emission of gaseous compounds, e.g. CO_2 and CO saturated with volatile material rich in fluorides
- frequent service on the reduction cell by breaking the crust and exposing the surface of the bath to atmosphere
- pot operation depending upon occurence so-called anode effects taking place generating a multiple amount of gaseous fluorides of the C_xF_y type.

- anode changes in pots using consumable prebaked anodes.

  Replacing an anode exposes a considerable area of the molten bath to atmosphere for a limited time.

- frequent charging of alumina to the pot, thus creating a certain amount of alumina dust

- tapping of metal through tap-hole.

B. Composition and Quantity of Pot Effluents

The main pollution compounds generated in and emitted from the pots are

- HF)
- CF_4) gaseous fluorides
- fluorides such as $NaAlF_4$, Na_3AlF_6, $Na_5Al_3F_{14}$ and AlF_3
- SO_2
- CO_2
- CO
- carbon dust
- alumina

During normal operation of the pot, gaseous compounds, e.g. CO_2 and CO are formed and are released from the bath. Fluorides in the gas bubbles and evaporated from the surface of the bath are emitted into the atmosphere surrounding the pot. $NaAlF_4$ is the most volatile of the compounds present in the bath. Due to its instability, $NaAlF_4$ decomposes, forming $Na_5Al_3F_{14}$ and AlF_3. Subsequently, HF is formed by the reaction of AlF_3 with moisture originating from the atmosphere. During the time of an anode effect, fluoro-carbon compounds are known to be formed, mainly CF_4.

Sulphur present in the anode is gradually oxidized to SO_2 while the anode is consumed.

Burning of the anode may cause the formation of particulate carbonaceous matter which is either dispersed in the liquid bath or is entrained by gas bubbles and emitted from the pot as carbon dust.

Finally, the charging of the pots with alumina generates dust emission, the amount of which depends upon the grain size distribution of the alumina.

The amount of effluents emitted by the pot vary within wide limits among aluminium smelters and are strongly influenced by a number of parameters, e.g.

- composition of the bath (bath ratio)
- bath temperature
- general pot operation
- frequency of anode effects

Industry surveys conducted in recent years both in US (1) and Europe (2) indicate that information on the quantity of fluoride effluents emitted from the pot is not uniform (see table 1).

Another marked difference refers to the composition of effluents from various pot types. The effluents of a prebake pot roughly correspond to a 50 : 50 distribution between HF and solid fluorides. For Soederberg pots, this ratio is changed to 90 : 10 in favour of HF, probably due to the availibility of greater quantities of hydrogen from the Soederberg anode.

Reference (1) quotes a pot emission of 6.5 kg SO_2/t Al for European practice. This value, corresponding to a sulfur content in the anodes of approx. 0.7 % seems to be rather on the low side. Present sulfur contents in anode carbon are 1.1 - 1.7 %, thus yielding a SO_2 pot emission of 10 - 15.5 kg SO_2/t Al.

The information given in references (1) and (2) is compiled in table 1. For further considerations in this paper, pot effluent composition according to (2) was used.

The fact should be stressed that the toxic effect of the different fluorides emitted from a primary aluminium smelter plant vary significantly. Damage to vegetation by HF will be significantly higher than by fluorides in dust (3). Herbivorous animals show an essentially higher resorption of fluorides contained in the forage originating from gasecus fluorides than for fluorides originating from dust (4).

For this reason, with regard to preventing damage to vegetation and animals the emission control of gaseous fluorides is of much higher importance than the emission control of fluorides in dust.

Table 1 Quantity and Composition of Pot Effluents

All values are in kg/metric ton Al

	Reference (1)		Reference (2)	
	European	US	Soederberg	Prebake
Total Fluorides	16.6	22.5	20	16
F gaseous	10.3	13.1	18	8
F solid	6.3	8.8	2	8
Total solids	25-63	45.6	*	*
SO_2	6.5	30	*	*
CO	250	*	*	*
CO_2	1500	*	*	*

* no numerical values indicated

II. EXISTING SYSTEMS OF AIR POLLUTION ABATEMENT AND THEIR EFFECTIVENESS

A. Collection of Pot Effluents

It would be well beyond the scope of this paper to consider the abatement of all of the pollutants mentioned earlier. For this reason further consideration will only be given to fluorides. SO_2 at present is still a minor problem to the primary aluminium industry bearing in mind that the rate of SO_2 emitted from the primary aluminium industry is considerably below 0.5 % of the total amount of SO_2 emitted by other industries and consumers.

The abatement of air pollution from an aluminium reduction potline consists of two different technologies:

- the technology of controlling the emission by volume, i.e. by collecting the fumes emitted from the pot and
- the technology of treating the collected pot effluents adequately, i.e. removing hazardous compounds and nuisance dusts by appropriate cleaning installations before release to the atmosphere.

Collecting fumes from the pot may be effected in two ways which differ significantly: either by using the potroom as a hood for the entire potline or by hooding each pot individually.

When collecting <u>ventilation air</u> by the potroom, collection efficiency may be assumed to be 100 % provided that the ventilation system is properly designed and precautions have been taken to prevent adverse wind conditions which carry potline effluents out to the ambient atmosphere. This design is frequently applied with potlines consisting of unhooded prebake pots. In the case of Soederberg pots or hooded prebake pots, this design may serve as a "secondary" system, collecting the pot fumes which may escape on one occasion or the other due to opening of the hoods for pot operation or leaking hoods.

The system of collecting pot emissions within the potroom suffers the disadvantage that large volumes of ventilation air, e.g. up to 1.7 x 2.2 x 10^6 m_n^3 per ton of aluminium produced, have to be handled. Such large volumes of exchanged air are necessary in order to obtain acceptable working conditions by dilution of the pot emission, HF and CO, and by reduction of temperature at the work place.

Collecting pot fumes with a "primary" system by mounting skirts or hoods on each individual pot has been common practice with Soederberg pots, and is becoming increasingly important with prebake pots.

The primary collection system of <u>VSS Soederberg</u> pots consists of a gas collecting skirt which is permanently installed round the bottom of the anode. By sealing the outside of the skirt to the electrolyte crust by a layer of alumina, escaping of pot fumes is restricted and collection efficiencies of 70 - 95 % (1) and 60 - 80 % (2) respectively are indicated. Collection efficiency of course strongly depends upon skirt maintenance and pot operation as well as type of alumina used. Fine grain ("floury") alumina will provide a better sealing effect than coarse grain ("sandy") alumina.

The primary collection systems of the VSS Soederberg pots handle only rather small gas quantities. A reported value (1) is approx. 34 m^3 per hour of pot gas which is mixed with approx. 680 m^3 per hour of combustion air injected in two burners. The pot gas finally drawn from the cell may amount to 680 m^3 per hour. Assuming a 90 000 amp cell this colume equals a volume of approx. 27 000 m^3 per ton of aluminium produced.

The concentration of fluorides in VSS Soederberg pot gas is high, due to the rather limited amount of pot gas drawn from the pot.

VSS Soederberg anodes emit a certain quantity of volatile material originating from the baking of the green anode mass in the pot. Due to the lack, for operational reasons, of a suitable pot hood, these volatile materials are not collected and are emitted to the potroom and carried away be the ventilation air.

The design of the HSS Soederberg pots allows that hoods covering the pot and the side of the anode casing may be installed, thus collecting both, pot gases and the part of the volatile matter from the anode baking process escaping through the stud channels. However, for pot operation, the primary hood has to be frequently opened thus allowing pot gases to escape to the potroom air. Collection efficiency will reach an average of about or slightly below 90 % (1). Pot gas volumes drawn from the cell may vary in a wide range between 3400 - 13 600 m^3/h (1). According to the increased volume, the fluoride concentration in the HSS pot gas is considerably lower than that found in VSS Sceder-berg pot gases.

Hooding of prebake pots has become increasingly important in the recent past. For pot operation, hoods have to be opened at certain intervals for crustbreaking, alumina charging and anode change. Pot effluents may escape to the potroom atmosphere during this period as is the case with HSS Soederberg pots. The amount of pot gas drawn from the cell varies within the range mentioned for HSS Soederberg pots. Hooding efficiencies have been reported to be 40 - 95 % (2) and 71 - 98 % (1) with an average slightly above 90 % (1).

Considerably amounts of ventilation air have to be handled in any of the cases mentioned, the volumes ranging from 0.2×10^6 m_n^3/t Al to 2.0×10^6 m_n^3/t Al.

B. Treatment of Pot Effluents

Treatment of the pot effluents accumulated in pot gases or in ventilation air is effected by various techniques, taking into consideration the following criteria:

- physical state of compound to be removed
- chemical behaviour of such compounds
- concentration of compound to be removed in the pot gas or ventilation air
- rate of removal to be achieved
- kind of product yielded by the cleaning process

Hydrogen fluoride is the major pollutant present in pot gases and ventilation air. It is highly soluble in water and may readily be removed by wet scrubbing. Dry scrubbing by sorption on alumina is also an adequate means of removing HF from pot gases, presumed that a so-called active alumina with a large sorptive surface area is used. In a dry scrubbing process, contacting pot gas with alumina is followed by a mechanical separation of solids from the gas phase, by means of cloth filters.

Fluorides in dust originate from volatilization of the molten salts in the bath. The process of formation of solid fluorides implies that the grain size of solid fluorides is extremely low and may even be submicron.

Analytical data on this subject are rather limited as measurement of particle size distribution is rather difficult below 5 micron. Removal may be effected by wet scrubbing and dry process. Due to the limited grain size of solid fluorides, wet scrubbers usually do not perform at extremely high efficiency rates unless equipment with elevated energy consumption, e.g. a venturi scrubber, is used.

Total solids include alumina dust emitted during alumina charging to the cell, carbon particles from the anode and fluoride containing particles from volatilization of the bath. Particle sizes may range from submicron to 80 microns. Limited data available indicate that the submicron part of the dust, usually rich in fluorides, may amount to 40 - 50 % of total dust, depending upon the type of cell operated (1).

C. Removal Equipment Efficiency

A vast variety of equipment exists for removal of gaseous fluorides, solid fluorides and total solids. It would be beyond the scope of this paper to present data on each type of equipment commercially available. A limited selection had to be made which is based mainly on equipment currently used in Europe and the U.S. Further and more detailed information may be obtained from reference (1).

The selection of cleaning equipment to treat ventilation air is determined by the large volume of air handled. For this reason dry scrubbing is not appropriate. Wet scrubbers used are usually of the spray screen or floating bed type. Cleaning efficiency for both types is high for gaseous fluorides, 90 - 95 % and about 45 % for solid fluorides (1). Total solids may be somewhat higher, approx. 55 - 60 %.

Cleaning of pot gases from VSS Soederberg pots is normally executed in two stages. The use of dry electrostatic precipitators or cyclones is common practice for removal of particulates including solid fluorides. A cleaning efficiency of 98 % may be achieved with dry electrostatic precipitators. Removal efficiency of multiple cyclones is considerably lower, about 50 % for total solids and presumably somewhat lower for solid fluorides. Wet scrubbing by use of a spray tower is frequently applied for removal of HF, achieving a cleaning efficiency of 99 %. Floating bed scrubbers are reported to achieve cleaning efficiencies of 97 % for gaseous fluorides.

The venturi scrubber may be applied to VSS Soederberg pot gases, acting as a single stage cleaning unit be removing hydrogen fluoride and solid fluorides simultaneously. Cleaning efficiency again is high for gaseous fluorides, 98 - 99 % and is slightly lower at 96 % for solid fluorides. Dry scrubbing by alumina and bag filtration may be applied to pot gases from VSS Soederberg pots. Data reported (1), (2) for cleaning efficiencies are 97 - 98 % for solid fluorides and 98 - 99 % for gaseous fluorides. When applying dry scrubbing to VSS Soederberg pot gases, special care must be taken in order to maintain proper operation of the burners to prevent fouling of the dry scrubber unit by excessive tar.

For HSS Soederberg pot gases, the selection of equipment is rather limited.

Spray towers and floating bed scrubbers are frequently applied to take care of both, gaseous and solid fluorides. The spray tower is somewhat less efficient than the floating bed scrubber with regard to both gaseous fluorides and solid fluorides. Solids removal may, however, be improved by the use of a wet electrostatic precipitator installed in first stage. Such equipment frequently operates with a 98 % efficiency on solids.

Treatment for pot gases from prebaked pots may be designed as a single stage or two stage installations. In the latter case, dust is removed by use of dry electrostatic precipitators or multiple cyclones. Multiple cyclones will remove dust at a rate slightly below 80 %. The performance of dry electrostatic precipitators varies in a wide range (60 - 99 %), depending upon various conditions, e.g. gas humidity and operating voltage. Assuming proper design and operating conditions, an average cleaning efficiency of 94 % for solids may be expected. HF removal is effected by wet scrubbers. Spray towers or floating bed scrubbers achieving 90 - 98 % efficiency are frequently used. Single stage wet scrubbing installations are usually designed as spray towers or floating bed scrubbers. Both types are high in efficiency, 94 - 98 % for gaseous fluorides. Reported data for cleaning efficiency is 80 % for the spray tower on solid fluorides and 80 % for the floating bed scrubber on total solids. Dry scrubbing may be applied to pot gases from prebake pots. Average cleaning efficiencies of 98 % for both hydrogen fluoride and solid fluorides as well as for total solids may be assumed.

A summary of cleaning efficiencies of various removal equipment is given in table 2. The data compiled in this table have been reported by references (1) and (2). They will be used for model calculations following later in this paper.

D. Efficiency of Model Control Schemes

Based on the efficiency data compiled in table 2, the emissions of a few selected models have been calculated. The selection was made to demonstrate the various emission levels which may be achieved rather than to qualify the performance of each cleaning unit. It should be borne in mind that besides the models evaluated in this paper, a great number of further possibilities exist for selecting adequate equipment.

Table 2 Cleaning Efficiencies of Various Removal Equipment

		F_{gas}	F_{solid}	F_{total}	Solids
<u>VSS</u>					
primary	multicyclone		50 (n)		50
	dry electrostatic precipitator		98		
	wet electrostatic precipitator		95 (n)		95 (a)
	spray tower	99	75		
	floating bed scrubber	97		97	78
	venturi scrubber	99	96		
	dry alumina scrubber	98	98		98
secondary	spray screen	88	42		
<u>HSS</u>					
primary	spray tower	92 (a)	70 (a)		
	floating bed scrubber	98	78		
secondary	spray screen	80	42		
<u>Prebake</u>					
primary	multicyclone				78
	dry electrostatic precipitator		94 (a)		94 (a)
	spray tower	94 (a)	80		
	floating bed scrubber	98			80
	dry alumina scrubber	98	98		
secondary	spray screen	80	25		
<u>Ventilation</u>					
without	spray screen	93	45		60 (p)
primary	floating bed scrubber	90 (a)			75

(a) average from ref. (1)

(c) calculated from ref. (1)

(p) company information

(n) no detailed data available, assumed

The following models have been evaluated:

Pot type	primary control	secondary control
VSS	none	none
	spray tower	none
	dry electrostatic precip. + spray tower	none
	dry alumina scrubber	none
	dry alumina scrubber	spray screen
HSS	none	none
	spray tower	none
	spray tower	spray screen
PB	none	none
	spray tower	none
	dry alumina scrubber	none
	dry alumina scrubber	spray screen
	none	spray screen

Pot effluents were assumed as indicated in table 1, reference (2).

Various collection efficiencies have been included in the model evaluation in order to demonstrate the influence on the total emission exercised by a properly maintained collection system.

Model emission values for gaseous fluorides, solid fluorides and total fluorides have been compiled in tables 3, 4 and 5.

Table 3 Total Emission from VSS Soederberg Plants at Various Control Levels
kg F/metric t Al

Primary	Secondary	Collection efficiency for primary syste														
		0			70			75			80			85		
		F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t
none	**none**	18	2	20												
spray tower					5.5	1.0	6.5	4.6	0.9	5.5	3.7	0.8	4.5	2.9	0.7	3.6
dry electrostatic prec. + spray tower	**none**				5.5	0.6	6.1	4.6	0.5	5.1	3.7	0.4	4.1	2.9	0.3	3.2
dry alumina scrubber	**none**				5.7	0.6	6.3	4.8	0.5	5.3	3.9	0.4	4.3	3.0	0.3	3.[illegible]
dry alumina scrubber	**spray screen**				0.9	0.4	1.3	0.8	0.3	1.1	0.7	0.3	1.0	0.6	0.2	0.8

Table 4 Total Emission from HSS Soederberg Plants at Various Control Levels
kg F/metric t Al

Primary	Secondary	Collection efficiency for primary system														
		0			70			75			80			85		
		F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t
none	none	18	2	20												
spray tower	none				6.4	1.0	7.4	5.6	1.0	6.6	4.8	0.9	5.7	3.9	0.8	4.7
spray tower	spray screen				2.1	0.8	2.9	2.0	0.7	2.7	1.9	0.7	2.6	1.8	0.7	2.5

Table 5 Total Emission From Prebake Plants at Various Control Levels
kg F/metric t Al

Primary	**Secondary**	Collection efficiency for primary system														
		0			70			80			90			95		
		F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t	F_g	F_s	F_t
none	**none**	8	8	16												
spray tower	**none**				2.7	3.5	6.2	2.0	2.9	4.9	1.2	2.2	3.4	0.9	1.9	2.8
dry electrostatic prec. **+** **spray tower**	none				2.7	2.5	5.2	2.0	1.7	3.7	1.2	0.9	2.1	0.9	0.5	1.4
dry alumina scrubber	none				2.5	2.5	5.0	1.7	1.7	3.4	0.9	0.9	1.8	0.6	0.6	1.2
dry alumina scrubber	spray screen				0.6	1.9	2.5	0.4	1.3	1.7	0.3	0.7	1.0	0.2	0.5	0.7
none	spray screen	0.6	4.4	5.0												

E. Conclusion

The results obtained by the model calculation lead to the following conclusions:

- with all pot types, the difference in emission between uncontrolled systems and systems with the best primary control is remarkably high. Even with collection efficiencies of 70 , the reduction in emission amounts to approx. 65 - 70 % with all pot types. Thus, even a system with a low standard of maintenance is better than no system at all.

- changes effected in the cleaning equipment of a primary system for VSS pots do not necessarily result in a drastic reduction of the emission. All primary systems for VSS pots evaluated yield about the same performance data, the main reason for this being the fact that the predominant fluoride compound present in VSS pot gas is HF, which is readily removed by water scrubbing.

- contrary to VSS pot gases, an improvement in emission may be achieved with prebake pot gases by changing to equipment with a high cleaning efficiency for solid fluorides. This is due to the different composition of prebake pot gases.

- with VSS pot gases, a better overall control efficiency may be achieved by changing to a higher collection efficiency.

- improving the overall control efficiency for prebake pot gases may be achieved in two ways:

  - changing to a more efficient cleaning system
  - improving the efficiency of the primary collection system

  Up to a collection efficiency of about 90 %, the effect of upgrading the cleaning equipment is about equal to the effect of increasing collection efficiency by 10 %.

- With prebake pots, the emission control for total fluorides achieved by a spray screen for ventilation air alone is about the same as with a primary system including modern dry scrubbing and operating a 70 % collection efficiency. The emission control for gaseous fluorides obtained by a secondary spray screen is even better and equals the performance of todays available technology for primary equipment alone when operated at a collection efficiency of 95 %.

  This fact is of primary importance when considering the prevention of any possible damage to areas being used for farming. As already mentioned gaseous fluorides are far more hazardous to plants and animals than solid fluorides.

- A marked emission reduction in all systems may be achieved by combining a primary and a secondary cleaning system.

  However, it is unlikely that the installation of such sophisticated systems will be necessary for primary aluminium plants built in developing countries in the next few years.

III. COST OF MODEL CONTROL SCHEMES

A. Cost Structures

Information on costs of cleaning equipment is rather scarce and only limited data are available.The only extensive compilation of cost data known today has been published in reference (1). This study, however, refers to U.S. conditions. Major deviations may be encountered when applying these data to conditions in the developing countries. For this reason, the data developed in this paper using base data given in reference (1) should be used for comparison rather than to determine actual costs.

All costs given refer to 1970 prices and are based on US $ at 1970 rates.

The costs data used for model calculations are listed in table 6. They have been converted to US $/annual metric ton Al and rounded off to the next decimal.

The cost elements given in table 6 are based on the following assumptions:

The pots to be considered are of the 100 000 amps. type.

The volumes of pot gas and ventilation air to be cleaned are:

850 m^3/h·pot	potgas for VSS Soederberg pots	(= 3.1×10^4 m^3/t Al)
5 100 m^3/h·pot	potgas for HSS Soederberg pots	(= 1.9×10^5 m^3/t Al)
4 250 m^3/h·pot	potgas for prebake pots	(=1.56×10^5 m^3/t Al)
42 500 m^3/h·pot	ventilation air for prebake pots	(=1.56×10^6 m^3/t Al)
59 500 m^3/h·pot	ventilation air for Soederberg pots	(= 2.2×10^6 m^3/t Al)

Investment costs include purchase cost, direct installation costs varying with the type of equipment installed and indirect installation costs amounting to 30 % of the sum of purchase cost and direct installation cost.

Table 6 Cost Elements for Various Pollution Abatement Equipment

Pot type	Equipment	Invest. US $/mtpy	Operat. US $/mtpy
VSS	primary		
	primary collection	21.10	6.10
	spray tower	4.20	1.70
	dry electrostatic precip.	13.90	4.00
	dry alumina scrubber	12.30 (a)	4.40 (a)
	water treatment	5.90	2.90
	secondary		
	spray screen	57.20	19.90
	water treatment	8.80	3.50
HSS	primary		
	primary collection	37.50	11.10
	spray tower	12.40	4.20
	water treatment	6.70	3.20
	secondary		
	spray screen	57.20	19.90
PB	primary		
	primary collection	25.00	7.50
	spray tower	7.10	2.60
	dry electrostatic precip.	19.00	5.50
	dry alumina scrubber	39.90 (b)	13.20 (b)
	water treatment	3.40	1.80
	secondary		
	spray screen	40.90	14.30
	water treatment	6.30	2.60

(a) Average of two systems, varying approx. ± 6 %

(b) Average of two systems, varying approx. ± 11 % for investment and ± 15 % for operating costs

Operating costs include labor and materials for operation and maintenance, power, water, chemicals and royalties, where applicable. Depreciation, interest, taxes and administration are set at 23 % of the capital costs.

For credits, a pot emission as indicated in table 1, reference (2) is assumed. Collection efficiencies applied to the calculations were 80 % for VSS pots, and 90 % for prebake pots. Fluorides were estimated at US $ -.55 per kg F. Costs were calculated for the models as used in table 3, 4 and 5, and are compiled in table 7.

B. Conclusions

Relating the model costs for investment and operation of air pollution abatement installations to total investment of primary aluminium smelter plant and the unit price for aluminium respectively, is rather difficult for the following reasons:

- The capital costs for a primary aluminium smelter vary within a wide range, depending upon the capacity of the smelter as well as the product mix produced in the casthouse.

- Plants with an extended product mix ("sophisticated plant") will require investment costs of US $ 1000 - 1600/mt Al capacity depending upon capacity.

- Plants with a limited product mix will require capital costs of US $ 750 - 1250 ("unsophisticated plant").

- Reference (2) quotes a capital investment of US $ 1000 - 1100/mtpy for a 100 000 tpy plant.

- Soederberg plants may required a somewhat lower capital investment [illegible] the reason that the anode baking and rodding facilities included in the prebake plant layout are not necessary. This reduction however is partially equalized by higher investment costs for the Soederberg pot.

Table 7 Comparison of Costs for Various [illegible] Installations

Pot type	Control and cleaning equipment primary	Control and cleaning equipment secondary	Total fluoride emission F_g	F_s	F_t	Costs US $/mt Al Investment	Costs US $/mt Al Operating	Credit for F-recovery US $/mt Al
VSS	none	none	18	2	20	-	-	-
	hooding (80%) + spray tower (+ water treatment)	none	3.7	0.8	4.5	25 ([illegible])	- (11)	-
	hooding (80%) + dry electrostatic precip. + spray tower (+ water treatment)	none	3.7	0.4	4.1	39 (45)	12 (15)	1
	hooding (80%) + dry alumina scrubber	none	3.9	0.4	4.3	33	1[illegible]	9
	hooding (80%) + dry alumina scrubber	spray screen (+ water treatment)	0.7	0.[illegible]	1.0	91 (99)	[illegible] (34)	9
HSS	none	none	18	2	20	-	-	-
	hooding (85%) + spray tower (+ water treatment)	none	3.9	0.8	4.7	[illegible] (37)	15 (19)	-
	hooding (85%) + spray tower (+ water treatment)	spray screen	1.8	0.7	2.[illegible]	10[illegible] (114)	35 (6)	-
PB	none	none	[illegible]	8	16	-	-	-
	hooding (90%) + spray tower (+ water treatment)	none	[illegible]	2.2	3.4	[illegible]	[illegible] ([illegible])	-
	hooding (90%) + dry [illegible] prec.+spray tower(+w.treatm.)	none	[illegible].2	0.9	2.1	[illegible] ([illegible])	1[illegible] (17)	4
	hooding (90%)+dry alumina scr.	none	[illegible].9	[illegible].9	1.6	65	21	9
	hooding (90%)+dry alumina scr.	spray screen (+wat.treat.)	0.[illegible]	0.7	[illegible].0	1[illegible]6 (112)	[illegible] (6)	9
	none	spray screen (+wat.treat.)	0.6	4.4	[illegible]	41 (4[illegible])	14 ([illegible])	-

- Relating the operating costs of gas cleaning plants to the price of aluminium again is difficult. The unit price of aluminium again depends upon capacity and product mix of the plant. In addition, price of labor, power and raw materials may vary depending upon the location of the plant.

- An "unsophisticated plant" may produce aluminium at a price of US $ 425 - 530/metric ton Al produced.

- In a "sophisticated plant", production costs will vary within the range of US $ 475 - 600/metric ton Al produced.

- Reference (2) reports production costs of US $ 530 - 610/metric ton Al.

- It is unlikely that in the near future, plants with an extensive product mix will be built in the developing countries. Therefore, an investment of US $ 1000 per metric ton Al capacity and a price for aluminium of US $ 475 per metric ton of Al produced is assumed. It is also unlikely that water treatment installations will be included in the control equipment at first instance.

Bearing in mind the above mentioned, the following conclusions may be drawn from the cost analysis of the selected models:

With VSS pots, a control efficiency of approx. 78 % may be achieved by investing between US $ 25.- and US $ 40.- per metric ton capacity, excluding water treatment. This equals a rate of 3 to 4 % of the total investment. The corresponding operating costs amount to roughly 2 to 3 % of the price of primary aluminium. Highly sophisticated air pollution control equipment achieving 95 % overall cleaning efficiency is unlikely to be installed in plants which otherwise have a low degree of mechanisation. However, for comparison, the respective rates may be assumed to be approx. 9 % of investment and 6 - 7 % of production costs. The credit for fluoride recovery would amount to 2 % thus leaving net operating costs of 4 - 5 % of the price of aluminium.

With HSS Soederberg pots, pollution control of a similar performance level (77 %) is slightly more expensive. Capital costs would amount to 5 % of total investment and operating costs would total about 3 % of the price of aluminium. Including a secondary cleaning system and thus achieving an overall control efficiency of 88 % would raise the investment to approx. 11 % of total investment and operating costs to approx. 7 % of the metals cost price.

Emission control from prebake pots at a level of approx. 80 % may be achieved by an investment rate of about 3 - 4 % of the total investment. The effect of operating costs upon price of primary aluminium will be in the range of 2 - 3 %.

Upgrading the emission control to 85 - 90 % will require an investment rate of 5 - 7 % and affects the price for aluminium by 4 - 5 %. Credits of 1 - 2 % may be achieved by fluoride recovery, decreasing the net operating cost to 3 % of the aluminium price.

Best available technology, achieving 94 % overall control efficiency, which again is unlikely to be installed in an otherwise unsophisticated plant, would cost about 11 % of the investment, operating costs would be approx. 7 % of the aluminium price. The credit for fluoride recovery of 2 % would reduce net operating cost to approx. 5 % of the aluminium price.

Installing a secondary cleaning system only would require approx. 4 % of the total investment and would affect the price of aluminium by approx. 3 %.

Table 8 gives a summary of the above mentioned.

Table 8 Influence of Costs of Cleaning Installations on Total Investment and Price of Aluminium

Pot type	Approx. Overall Control Efficiency	Invest. as % of total Investment	Net operat. costs as % of Aluminium price
VSS	78 %	3 - 4	2 - 3
	95 %	9	4 - 5
HSS	77 %	5	3
	88 %	11	7
PB	80	3 - 4	2 - 3
	85 - 90	5 - 7	3
	94	11	5
second. only	69	4	3

IV. STANDARDS ON ENVIRONMENTAL CONTROL IN DEVELOPING COUNTRIES

During the Stockholm conference, evidence was given that the problems of environmental control are by no means identical in the developing countries and in industrialized nations.

Highly industrialized areas, run the risk of being tainted by effects of human activity such as pollution of air, water and soil. To prevent this, legal prescriptions and standards are currently being issued in such areas, in order to protect the quality of life.

Contrary to this, in many of the developing countries it is not quality of life which is endangered but rather preservation of life itself. Environmental problems are related to lack of food, insufficient water supply systems, absence of sanitary installations and preservation of agricultural utilization of the soil rather than to environmental pollution. Pollution control, for this reason, is of minor importance to these countries and the release of legal prescriptions and standards is not considered to be necessary at present. On the contrary, the environment is considered as a "natural resource" and use should be made of it. Disadvantageous effects should be prevented by reasonable planning, which on the other hand should not adversely affect the development of the country.

In addition, consideration must be given to the fact that in many instances, technology offered to the developing countries includes means for environmental control. This supplemental technology regarded as being superfluous, by many authorities is considered to unnecessarily increase the investment thus deteriorating the competitive situation of the country in question.

A minor number of developing countries often already in the process of industrialisation have in the recent past attempted to legalise environmental control. However, it has also been clearly stated by such countries, that environmental control standards should by no means delay the economic development.

The number of developing countries with established standards or legal prescriptions is small. For the reasons explained above, it is rather doubtful whether this number will increase significantly in the course of the 10 years to come.

V. PERSPECTIVES OF AL-PRODUCTION INCREASE AND POLLUTION ABATEMENT AT THE PLANTS

A. Estimated Production Increase

In the past, the production of primary aluminium has continuously increased. Limited data on world production for 1960 - 1969 and world capacity 1970 are available from reference (1). These data include a number of assumptions for communist countries.

During the period 1960 - 1969, world production increased by an annual average of approx. 8.5 % and was close to 9.1×10^6 mt in 1969. The corresponding figure for the western world was 7.5×10^6 mt. During the period of 1963 - 1969, the production of the western world accounted for approx. 80 % of world production.

From the 1969 production of the western world, approx. 91 % (= 6.8×10^6 mt) originated from industrialized areas (Europe, North America and Japan) and only approx. 9 % (= 0.67×10^6 mt) were produced in areas with a lower level of industrialization.

The 1972 production of the western world amounted to approx. 9.2×10^6 mt Al. Assuming an annual growth rate of 9 %, the production figures for the western world as compiled in table 10 may be anticipated for coming years.

A break down of capacity expansion in the western world for the period 1969 - 1974 is also quoted in reference (1). This information, reproduced in table 9, has been slightly modified in as much as Japan, originally included in Asia has been separated and capacities have been distributed between Japan and Asia. This distribution was based on company information.

The distribution of the 1969 capacity is similar to production in that year with approx. 90 % of the capacity installed in highly industrialized areas and approx. 10 % situated in areas with a lower level of industrialization.

The information compiled in table 9 was published in 1976. Most likely the depression encountered by the aluminium industry in the recent past has not been taken into account. For this reason, the absolute values for capacity increase given in table 9 will probably be somewhat high. However, the proportional distribution may still be assumed to be correct.

According to table 9, the capacity increase in North America is almost evenly distributed between plant expansion (45 %) and new plants (55 %). In Europe, about 30 % of the capacity increase is attributed to plant expansions and about 70 % to new plants.

The average ratio in all areas with a high level of industrialization is approx. 35 % in expansion of already existing plants and 65 % in new plants. Similar values apply for areas with a lower level of industrialization.

The following partition has been applied in order to determine the distribution of production increase:

Highly industrialized areas:	85 % of total production increase
Areas with lower level of industrialization:	15 % of total production increase

This distribution may be applicable for the immediate future but may gradually be changed in favour of the areas with a low level of industrialization due to environmental control regulations being tightened up in the highly industrialized areas.

The assumed capacity and production increase in developing areas has been compiled in table 10.

Table 9 Distribution of Production and Esti[illegible] [illegible] Capacity Increase [illegible]
Estern World (according to reference [illegible])

		1969 Production		1969 Base Capacity		Capacity Increase by plant expansion			by new plants			Total Capacity Increase	
		10^3 mt	%	10^3 mt					10^3 mt				
X	EEC	850	11.4	874	11.[illegible]	[illegible]	[illegible]	14.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
o	EEC-Associates (d)	181	2.4	200	2.[illegible]	[illegible]	4.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
X	EFTA	798	10.7	796	10.[illegible]	[illegible]	[illegible]	41.[illegible]	4.	[illegible]	[illegible]	[illegible]	[illegible]
X	Other Europe	152	2.0	[illegible]	2.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Total Europe (X only)	1600	24.0	1629	24.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
X	North America	4438	59.4	4421	58.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.[illegible]
o	Latin America (excl. Surinam)	69	1.2	93	1.2	[illegible]	4.	34.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
o	Africa (ex.Cameroon)	113	1.5	[illegible]	1.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.
o	Asia (excl. Japan)	160	2.1	[illegible]	2.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
X	Japan	569	7.6	593	7.8	286 (b)	14.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.
o	Oceania	126	1.7	[illegible]	2.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Grand Total	7476	100	[illegible]	100	[illegible]	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Total X	[illegible]	[illegible]	[illegible]	[illegible]	664	62.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Total o	[illegible]	[illegible]	742	9.[illegible]	[illegible]	17.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(a) percentage of total capacity [illegible]
(b) Increase by plant expansion for total Asia [illegible] 44.1[illegible]
(c) Increase by new plants for total A[illegible]
(d) Including Surinam and Cameroon

Table 10 Assumed Capacity and Production Increase in Developing Areas 1972 - 1980

Year	Estimated Production Western World (a)	Increase to Previous Year	Production Increase in Areas with Low Level of Industrialization (total)	Estd. Prod. in Areas wit Low Level of Industrialis.
	10^3 mtpy	10^3 mtpy	10^3 mtpy	10^3 mtpy
1972	9 200			830
1973	10 000	800	120	950
1974	10 900	900	135	1 085
1975	11 900	1 000	150	1 235
1976	13 000	1 100	165	1 400
1977	14 200	1 200	180	1 580
1978	15 400	1 200	180	1 760
1979	16 800	1 400	210	1 970
1980	18 300	1 500	225	2 195
(1985)	(28 200)	(2 300)	(345)	(3 680)

(a) Includes areas with high degree of industrialization and developing areas

B. Air Pollution by Production Increase

There is very little information available with regard to todays' pollution control by primary aluminium smelters in developing areas. Dry scrubbing units are known to be in operation in one plant in Brazil and another one in Mexico (5). Contrary to this, there are a number of plants known to be in operation without any air pollution control installations at all.

An overall control efficiency, based on a 1971 model of the US primary aluminium industry, of 74.3 % has been published in reference (1). It may be expected that similar values would be achieved in other areas with a high level of industrialization.

A further assumption must be made regarding the type of pots which are to be installed in new plants. Between 1959 and 1970, 6 new plants were commissioned in the US out of which only one was a Soederberg plant. In addition, out of another 4 plants under construction during 1971 and 1972, one was a VSS Soederberg plant, all others being equipped with prebake pots.

Plant expansion during the period 1951 - 1969 favoured Soederberg pots in 6 out of 9 cases.

Following the US trend for new plants, the assumption was made that future plants would be equipped with prebake pots.

Table 11 contains estimated F_t^- emissions per year at various overall control efficiencies based on present production and estimated future production increase.

Table 11 Assumed Total F_t-Emission in Developing Areas and in Western World 1972 - 1980

Year	Estd. Prod. in Develop. Areas	Assumed Total F_t-Emission in Developing Areas at Overall Control Efficiencies of all Installations of							Estd. Prod. in Highly Industrialized Areas of Western World	Estd. Total F-Emission in western world at Overall Control eff. 75 %
		0 %	30 %	60 %	70 %	75 %	80 %	90 %		
	10^3 mtpy	10^3 mtpy F	10^3 mtpy F	10^3 mtpy F	10^3 mtpy F	10^3 mtpy F	10^3 mtpy F	10^3 mt	10^6 mtpy	10^3 mtpy F
1972	830	13.3	9.3	5.3	4.0	3.3	2.7	1.3	8.4	33.6
1973	950	15.2	10.6	6.1	4.6	3.8	3.0	1.5	9.1	36.4
1974	1 085	17.4	12.2	6.9	5.2	4.3	3.5	1.7	9.8	39.2
1975	1 235	19.8	13.8	7.9	5.9	4.9	4.0	2.0	10.7	42.8
1976	1 400	22.4	15.7	9.0	6.7	5.6	4.5	2.2	11.6	46.4
1977	1 580	25.3	17.7	10.1	7.6	6.3	5.1	2.5	12.6	50.4
1978	1 760	28.2	19.7	11.3	8.4	7.0	5.6	2.8	13.6	54.4
1979	1 870	31.5	22.1	12.6	9.5	7.5	6.3	3.2	14.8	59.2
1980	2 195	35.1	24.6	14.1	10.5	8.8	7.0	3.5	16.1	64.4
(1985)	(3 680)	(58.9)	(41.2)	(23.6)	(17.7)	(14.7)	(11.8)	(5.9)	(24.5)	(98.0)

The following conclusions may be drawn from this table:

- Assuming an overall control efficiency average of 30 % for plants operated in developing areas and 75 % for plants in industrialized areas, todays F_t-pollution in developing areas would account for approx. 22 % of the total F_t-pollution in the western world. By 1980, this rate would be changed to approx. 28 %.

- Under the same assumption, todays F_t-pollution in developing areas would be increased by approx. 165 % until 1980. For industrialized areas, todays F_t-pollution would be roughly doubled.

- To maintain today's assumed F_t-pollution of 9.3×10^3 mt/year in the developing areas, the overall control efficiency would have to be raised to 60 % by 1976 and to 70 % by 1979.

VI. TECHNICAL ASSISTANCE REQUIREMENTS OF THE DEVELOPING COUNTRIES

In a number of developing countries, new primary aluminium smelter plants have been erected in the recent past or are under study to be realized in the second half of this decade.

In most cases, public bids are put up either by governments or private companies, and a partner is selected by evaluation of the quotations. Most likely, future quotations for a new primary aluminium plant will at least include two different designs with regard to environmental control: on the one side a basic plant equipped to meet the minimum standards of pollution abatement and designed for further addition of abatement equipment as necessary at a later date, and on the other side a more sophisticated plant which will meet environmental control stardards as of the start of operation. The selection of the appropriate plant design will strongly depend upon local conditions.

In general, the primary aluminium industry is in a position to offer many services within a wide range of possibilities.

A contract may be specified in such a way that <u>conceptional design</u> only will be supplied. This would include flow sheets, general and detailed layouts and a list of necessary equipment. Conceptional design would also include the supply of technical descriptions related to building and equipment. The delivery of conceptional design alone will strongly depend upon the availability of local engineering firms familiar with the specific problems of building a primary aluminium plant.

Such firms not being available, the contractor could also be engaged to furnish <u>general engineering</u>. This would include the set up of technical specifications for tender documents as well as the issue of tender documents and evaluation of tenders. General engineering would also include expert advice on contracts for the delivery of all kind of goods, checking of suppliers' documents, issue of shop drawings on special items, edition of operating and maintenance manuals and finally time scheduling and progress control.

If necessary, local engineering may also be provided by the contractor. This added service would mainly consist of adjusting tender and suppliers' documents to local conditions, supervising construction and erection and issuing terms of delivery and installations. Quality control of all goods and control of payment would also be included in local engineering as well as the initial start-up of the plant.

Finally, a contractor may offer to supply a turn key plant. In this case the contractor would not only furnish conceptional design, general and local engineering, but would also bear the entire responsibility and all risks involved in plant erection and initial start-up.

In most cases, a contractor will not be limited to providing the technical know-how for building and initial starting up of a primary aluminium smelter plant. Most likely the parties will agree upon a contract arranging for further technical assistance to plant operation. Such assistance may include the training of key personel in the contractors' own plants and the dispatch for a limited period of time, of experts to the new plant. In addition, technical assistance may include a long term continuous advisory services contract on operation and supervision of all equipment. Under such terms, general information on production of primary aluminium and related items will be made available to the new plant and assistance in operating the plant will be granted. If necessary, certain key positions of the management may be filled by the contractor for a limited time.

Technical assistance demonstrated above refers to primary aluminium smelting in general but may obviously be interpreted accordingly for environmental control.

VII. CONCLUSIONS

Perspectives of locating primary aluminium smelters in developing countries may be concluded as follows:

In highly industrialized areas, considerations relating to environmental control are becoming more and more important. Therefore the possibilities of locating primary aluminium smelters in densely populated areas are limited, even when considering to equip such plants with sophisticated environmental control facilities.

Most of the developing countries have large unused natural resources, such as labour potential, energy and unharmed environmental conditions. In addition, very often there is a fierceful interest of such countries to attract basic industries, and therefore it is quite natural to carefully evaluate the possibilities of erecting new plants in developing countries. When analyzing production and capacity increase forecasts for the immediate future, the trend to dislocate primary aluminium smelters to developing countries is not obvious at first sight.

However it must be expected that as from the end of this decade, a growing part of the capacity increase will be installed in developing countries.

Plants to be built in developing countries may be designed in two different ways:

A plant with a very little or no environmental control facilities may be put up and operated. Environmental equipment may be added as necessary, either depending upon legal requirements gradually released or to prevent damage to areas with agricultural utilization. However, care should be taken that such plants are designed in such a way that environmental control installations may be added at a later date without excessive costs.

As a second possiblity, a plant may be built with initial environmental control facilities of a comparatively high standard. This plant would not encounter any difficulties with meeting future legal requirements, but might possibly find some trouble with regard to the competitive situation.

Average environmental control may be achieved by modest capital investments amounting to approx. 3 - 5 % of total investment. Such control would affect the price of aluminium by 2 - 3 %.

Installing elaborate environmental control may require investments in the range of 5 - 11 % of total investment and would increase metal production costs by 3 - 7 %.

As already mentioned, the decision referring to the degree of environmental control to be achieved will predominantly be determined by legal requirements. However, local conditions of existing natural systems will also have to be carefully considered before taking any decision.

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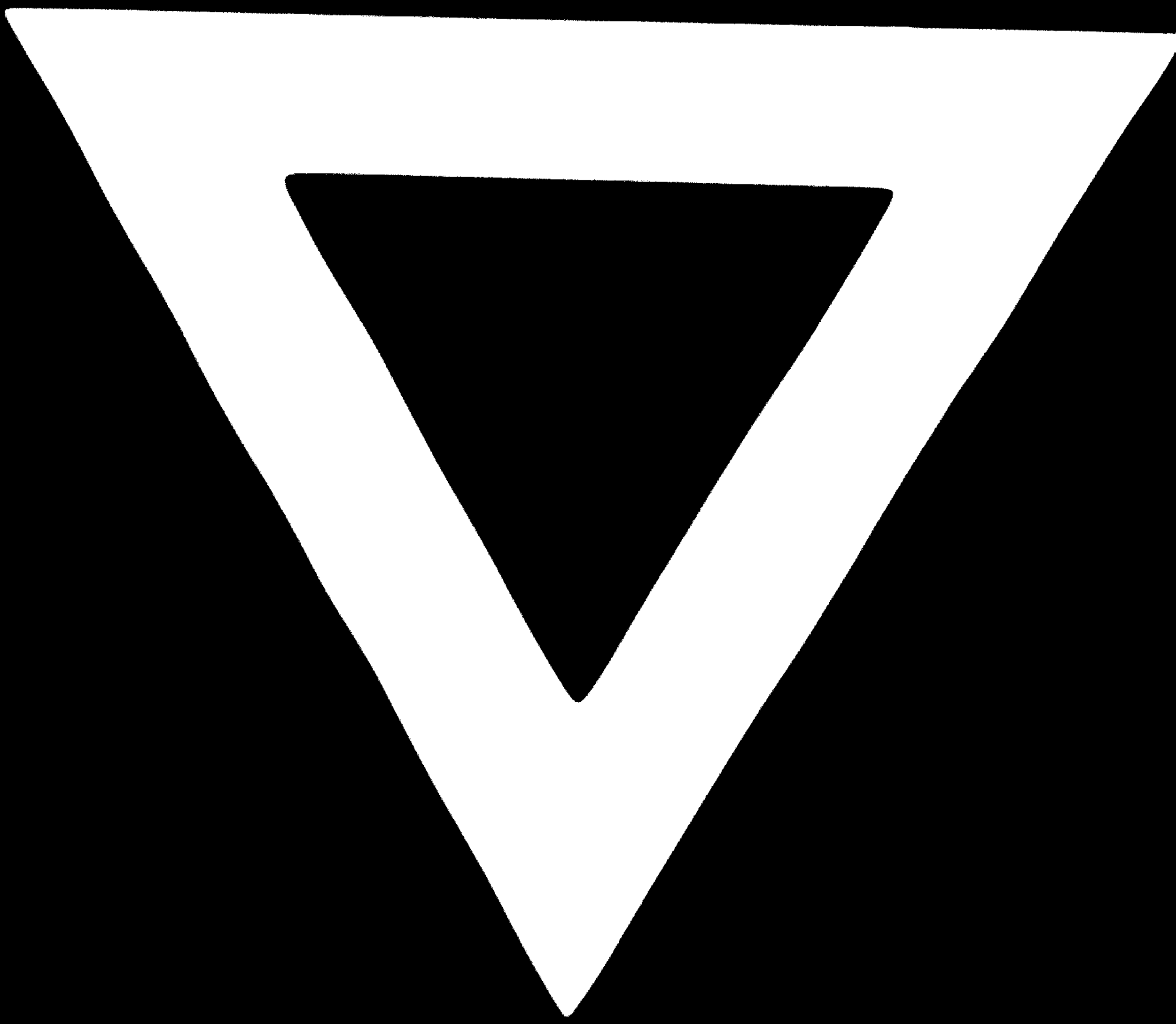

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