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

FINAL REPORT

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Explanatory notes

Reference to dollars ($) are to United States dollars.

Reference to tons are to metric tons, unless stated otherwise.

Use of a hyphen between dates (e.g., 1960-1965) indicates the full period involved, including the beginning and end years.

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands and millions.

CONTENTS

Part one. Report of the meeting

INTRODUCTION

Background information

1. Aluminium, as a result of dramatic growth in the last decades, ranks first by production volume among non-ferrous metals. World primary aluminium production in 1975 amounted to 12.7 million tons, of which 0.8 million tons were produced by developing countries.

2. Aluminium has economically advantageous technical applications in such important fields as electrification, architecture, transport, and packaging.

3. Developing countries have an important potential for aluminium industry development. The bulk of the world's bauxite reserves is in the developing countries. Many of these countries also have considerable untapped hydroelectric resources (Africa, South-East Asia and Latin America).

4. The Second General Conference of the United Nations Industrial Development Organization (UNIDO), held at Lima, Peru, in March 1975, stressed the important role of industrial development and outlined various measures to be undertaken at the national, regional and global levels to enhance the contribution of industry to the introduction of a new international economic order. The Lima Declaration and Plan of Action on Industrial Development and Co-operation (ID/CONF.3/31, chap. IV), adopted by the Second General Conference, established a target: the developing countries' share of world industrial production is to reach a minimum of 25 per cent by 2000. To achieve this objective, efforts will have to be made by all concerned - the developed and developing countries, the United Nations system, and UNIDO. The Lima Declaration and Plan of Action contains a call to the developing countries to establish production facilities covering all branches of industry aimed at meeting the basic needs of their peoples; UNIDO is to prepare a concrete co-operative programme of action to promote the creation, transfer and use of appropriate industrial technology for developing countries, primarily related to specific branches of industry and to social conditions.

5. In the last fifteen years much experience has been gained in the construction and operation of primary aluminium smelters in developing countries. Over this period new smelters were established and started, or existing smelters expanded, in Argentina, Bahrain, Brazil, Egypt, Ghana, India, Iran, Mexico, Surinam, Turkey, United Republic of Cameroon and Venezuela. As a result the developing countries' share of world primary aluminium production roughly doubled in the last decade.

6. The expansion of aluminium smelter capacity in developing countries continues. In some countries (Egypt, Ghana and Iran), plants will be extended; elsewhere new plants, some of them remarkably large ones, will be built in the coming years. Algeria, Brazil, Indonesia, Iraq, the Philippines, United Arab Emirates (Dubai) and Venezuela are among the countries planning such development. A preliminary estimate based on known project figures shows that by 1985 the developing countries' share of world primary aluminium production may be as high as 17 per cent. The target of 25 per cent by the end of this century is therefore not unrealistic as far as the aluminium industry is concerned.

7. Smelter construction and operation in developing countries is subject to specific problems of materials, infrastructure, climate, manpower, peculiarities of the market, and the like. As a result a specific approach may be needed to factors such as: adjustment to local climatic conditions (through ventilation and protection of personnel from heat); construction and start-up planning; scheduling of operations; preparation of manning tables; management and organization; training of staff; and financing arrangements. The effect of these factors on specific investment and production costs is of interest to future investors or prospective partners in smelter ventures.

8. In the effort to develop national capabilities and capacity,co-operation between the industrialized and the developing countries, and especially between the developing countries themselves, is of fundamental importance, because it would help bring about an exchange of information and the sharing of relevant experience and know-how at all levels.

9. In line with the above considerations, and keeping in mind that developing countries should devote every attention to the development of basic industries, UNIDO convened a Workshop on Case Studies of Aluminium Smelter Construction in Developing Countries, held at Vienna, Austria, from 27 to 29 June 1977.

10. The Workshop was opened the Director of the Industrial Operations Division of UNIDO.

Objectives of the Workshop

11. The Workshop had the following three main objectives:

(a) To assess up-to-date experience in activities related to the planning, construction and operation of aluminium smelters in developing countries;

(b) To provide a forum for the first-hand exchange of the above experience;

(c) To help identify fields of priority for UNIDO technical assistance for the primary aluminium smelter industry.

The Workshop was attended by 26 participants from 17 developing and developed countries and UNEP. (For list of participants see ID/WG.250/11/Rev.1).

I. ORGANIZATION OF THE MEETING

Election of Chairman and Vice-Chairman

12. Mr. Youssef Ismail (Egypt), Chairman of the Aluminium Company of Egypt, was elected Chairman of the Workshop. Mr. R. de Campos Machado (Brazil), Consultant, Companhia Vale Rio Doce, and Mr. H.F. Robey, Jr. (United States of America), Vice President - Construction, Aluminum Company of America, were elected Vice-Chairmen of the Workshop. The Chairman and Vice-chairmen were elected by acclamation.

Adoption of the agenda

13. The Workshop adopted the following agenda suggested by the UNIDO secretariat:

Election of officers

Adoption of the agenda

Presentation of cases by participants

Detailed discussion of the main issues

Discussion on conclusions and recommendations, including those concerning UNIDO's technical assistance in the aluminium smelter sector

Adoption of the draft report of the Workshop

Organization of work

14. Eleven background papers on case studies of aluminium smelter construction, including one paper by the UNIDO secretariat, had been prepared and were distributed to the participants well in advance of the meeting. Another two papers were distributed on the first day. Participants who had presented background papers elaborated on their main statements and ideas; each presentation was followed by a discussion. Annex II of this report contains a list of the background documents and part two gives summaries of a number of them.

15. After presentation by the Chairman of the main points of the case history of the Aluminium Company of Egypt, delegates from the following countries gave information on their experiences in the planning or establishment of aluminium smelters: Brazil, Canada, France, Guyana, Hungary, India, Indonesia, Iran, Iraq, Italy, Mexico, Philippines, Switzerland, United Arab Emirates and United States of America. Part one of this report covers the discussion of the main issues and includes material from a lecture given by Mr. D. Altenpohl and a background paper prepared by the UNIDO secretariat.

16. After the attention of participants had been drawn to some points of the background papers and project case histories, the sessions were devoted to a detailed discussion of the following five issues:

(a) General problems of and opportunities for aluminium production in developing countries;

(b) Planning of smelters;

(c) Selection of technology and equipment;

(d) Fitting a smelter in to the environment;

(e) The human factor.

17. A preliminary report (ID/WG.250/16) summarising the main points of the discussions was prepared by the secretariat and adopted by the participants at the last meeting of the Workshop on 29 June 1977.

II. SUMMARY OF THE DISCUSSIONS

A. Aluminium smelter construction in developing countries: general considerations

Current situation and trends in the production and consumption of aluminium

18. Aluminium has become the second industrial metal of the world. Its production has overtaken that of all other metals except steel. World production of aluminium in 1975 was 12.7 million tons, while that of copper was only 7.5 million tons. Aluminium production also has the highest growth rate of industrial metals. Between 1938 and 1974, aluminium production increased by 2,700 per cent, while steel production increased by only 640 per cent and copper by 380 per cent. The growth rate of aluminium consumption between 1950 and 1970 (market economy countries only) was 8.7 per cent a year. The growth of aluminium production will undoubtedly continue, albeit at a slightly reduced rate. Because of population growth, even "zero growth" in *per capita* consumption requires increased production.

19. Because of the various assets of the developing countries and the constraints affecting developed countries, most of the development of aluminium production is likely to occur in the developing countries. A tendency for this to happen can already be observed. In 1960, the amount of aluminium produced in the developing countries was 88,600 tons; in 1970 output was 538,200 tons - an increase of 507 per cent. According to the latest statistics available, between 3.5 and 5 million tons of aluminium smelter capacity are now under consideration, study, contract, or construction in developing countries, far more than existing projects in developed countries. In the period between 1960 and 1970, aluminium consumption in developing countries increased by 300 per cent. Nevertheless, if the absolute production and consumption figures (*per capita*) are considered, rather than growth rates, it is evident that the developing countries are still much behind the industrialized nations, as can be seen from the following table.

Group of countries	Aluminium production kg per capita (1974)	Aluminium consumption kg per capita (1972)
Industrial countries (market economies)	15.5	15.9
Centrally planned economies	2.2	1.8
Developing countries	0.44	0.33

20. It was mentioned during the discussions that the world market for aluminium has lost its traditional stability. Two slumps have recently been observed. The number of decision-making points has increased and if there is no world-wide planning, instability will continue. It was stressed that a global mechanism is desirable. The London metal exchange is unable to solve the problem.

General assets and related problems of the developing countries

21. Several developing countries possess important assets for the creation of aluminium smelters but also face special problems that must be solved. A favourable site (with suitable access routes), raw materials, properly qualified manpower, know-how, and equipment should all be available together. A proper infrastructure should be created and a market for the product must be assured somewhere. An uninterrupted supply of power and raw materials should be provided for the operation. The problem of financing all these operations must be solved. The political stability of the country is also of fundamental importance.

Site

22. The selection of a site for a smelter may be governed by purely economic and also by other considerations (e.g. regional development or defence). As the production of aluminium involves the transport of a large volume of materials, raw materials and products, and electrical energy, the smelter must have easy access routes and should not be far from the power station. From this point of view, a site at or near a deep water port seems to be the most favourable location. This is particularly important for developing countries, since in some cases (e.g. the VALCO plant in Ghana) only part of the production of a 100,000 or 150,000 tons/year smelter is absorbed by the local market and that of neighbouring countries. The rest must be transported to more distant markets; so the cost of transportation has to be added to the production cost. Sometimes the raw materials also come from distant sources e.g. from Australia to Argentina or Bahrain.

23. Reasons other than economic ones may sometimes influence the selection of a site. For developing countries, the preferential development of a particular region is the most likely factor. This was one of the reasons for selecting Nag Hamadi, in Egypt, in the desert as the site for a smelter. If the consideration of this or any other argument leads to a selection of an economically less favourable site, then a corresponding additional item will appear in the production costs.

24. The most favourable site for a smelter is where electric power and bauxite are close to each other and where most of the product is absorbed by nearby markets. The power station, in any case, should not be too far away. In selecting a site, the human factor should not be neglected. Areas are acceptable only if properly skilled people are willing to live there.

Electric power

25. A 100,000 ton smelter needs roughly 200 MW of electric power. The most important asset of several developing countries is a vast untapped hydroelectric power potential (or in some cases e.g. Bahrain, natural gas) in their territory. Consideration must also be given to whether the power potential is needed for other purposes. Participants mentioned specific examples where there was no alternative user (Patagonia, or northern Brazil); while in southern Brazil there is a "better use" for power from the Itaipu hydroelectric power station.

26. There is an enormous amount of untapped hydroelectric power (HEP) in the world. The percentage and absolute figure of unused HEP (usable under average annual flow conditions) in various continents are shown below (data presented at the World Energy Conference in 1974):

Continent	Unused percentage	Megawatts
Africa	98	429,000
South America	93	269,000
Asia (excluding USSR)	93	637,000
North America	73	240,000
Europe (excluding USSR)	52	111,000

27. It has been established that South America could produce 10 times the present world production of aluminium, and in Africa, Zaire alone could treble present world production.

28. Hydroelectric power is the cheapest form of electric power and also the most favourable for the protection of the environment. The construction of a power station requires a large investment and credits on favourable terms.

29. An aluminium smelter requires a stable, uninterrupted power supply. Power failures can have very serious consequences. For this reason, it must be ascertained whether seasonal changes (e.g. drought) jeopardize the continuity of the power supply. Such cases were reported by several participants.

30. All known projects in developing countries are based on local hydroelectric power or natural gas. In some developed countries, there are plans to build smelters based on fossil fuel (e.g. lignite). To operate a

smelter economically, all raw materials can be imported from great distances if cheap transport - large-capacity bulk-cargo vessels, for example - is available, but there must be an electric power station somewhere near the site of the plant.

Raw materials

31. For the production of each ton of aluminium, roughly 2.85 tons of raw material - mainly alumina (70 per cent), anode carbon and fluorides - must be transported to the smelter. The shipping of alumina by bulk carrier vessels from a distant country may sometimes prove more economical than the use of local bauxite if the bauxite deposit is not easily accessible.

32. Large variations in the physical quality of alumina may cause difficulties in potline operations, because automatic feeding is based on volume, and different aluminas may have different bulk weights.

33. According to a cost analysis made in 1975, about 30 per cent of the production cost of primary aluminium is the cost of alumina.

34. The production of anode carbon, especially the blocks used in modern smelters, is expensive. For this reason, co-operation between developing countries on the joint production of anodes seems to offer several advantages. One participant mentioned that the quantity of suitable quality petroleum coke available is diminishing. The problem of increasingly high sulphur content of petroleum coke also has to be faced and solved.

35. Several developing countries (Iraq and Tunisia, for example) have started to construct facilities for the production for export of the fluorides necessary for aluminium production.

People

36. An aluminium smelter, like any factory, needs a permanent staff with a wide variety of special knowledge and skills. A modern aluminium smelter employs about 1,000 people representing hundreds of different jobs.

37. In the developing countries, as distinct from the developed ones, there is generally enough manpower available. Although it is cheaper, the workers generally lack the experience, know-how, skills and knowledge needed for their job. In addition, they have often grown up in an agricultural area, and the discipline and routine work needed in a modern factory may be alien to them.

38. It follows from this that (a) training is of special importance, (this is dealt with seperately elsewhere), and (b) the cultural background may give rise to special problems and difficulties to be dealt with appropriately. This may account for occasional increased absenteeism and an increased number of drop-outs. For this reason, it was considered an accepted fact that smelter operation in developing countries needs more staff than in developed areas.

Recent characteristic data concerning smelter staff numbers

	Working hours/ton (total)	Staff for every 100,000 tons/year capacity
Plants and projects in developed industrial countries	8.1 - 17.4	423 - 906
Plants and projects in developing countries	18.2 - 67.2	952 - 3,500

39. The data in the above table may well indicate orders of magnitude only. A comparison of the average figures for developed and developing countries indicates that staff requirements in developing countries are more than three times greater than in developed countries.

40. The "productivity gap" may be attributable to:

(a) Objective causes: the level of average skill, the physical stature and strength of the workers (which depend on such factors as traditional diet);

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

(c) Subjective factors: work morale, the psychological effects of a comparitively low level of wages and salaries, elements of motivation, management and of organisation;

(d) The application of "appropriate" technology: the use of simple robust equipment requires a minimum of spares and maintenance but implies a lower degree of mechanization and automation and the use of a less sensitive technology.

41. One of the representatives from a developing country reported that it had proved as a wise policy, despite warnings to the contrary, to start with excess personnel of up to 70 per cent of the scheduled staff. Another delegate [illegible], however, that the temporary presence of excess staff may result in complaints of overwork when the number of staff is reduced to a normal level.

42. It may be an asset if staff in a developing country are dedicated to this work. "People can do wonders" mentioned one of the delegates. Enthusiasm may partly offset deficiencies in practice and education.

43. The in-plant training of local staff abroad is expensive. It is part of the investment costs.

44. The employment of the staff of an aluminium smelter requires a corresponding infrastructure, which may already exist but more often has to be created along with the construction of the smelter (see section on infrastructure below).

Equipment

45. A modern smelter needs a variety of equipment in the rectifier, potroom, cast-house, and maintenance workshop, to mention the main areas only. In exceptional cases, a developing country may be largely self-sufficient in the production of the necessary equipment, especially if only an extension by simple duplication of existing facilities is planned, as was reported for Brazil and India. In general, however, the necessary equipment, or most of it, has to be purchased from a foreign supplier, together with the corresponding know-how.

46. In some developing countries, because of particular geographical and climatic conditions, special equipment may be needed. It was reported, for example, that the smelter under construction in Dubai will include a desalination plant. At a desert site, sand storms may occur. In monsoon regions, the occurrence of heavy rainfall must be considered.

47. One important problem with imported equipment is spare parts, on which the survival of the plant may depend. The distance of the plant from the supplier must be borne in mind. One participant mentioned that spares took six months to arrive. Because of this and the sometimes complicated purchase and delivery procedure of ordering one year in advance, the following special measures are needed: the organization of the continuous production of certain non-standard spare parts, and the maintenance of a larger than normal inventory of spares that must be imported. In some cases an expensive delivery by air will be necessary.

Infrastructure

48. If a smelter or any other industrial plant is set up in a developed country, the project can rely on the existing infrastructure of the country. In developing countries this is not so. When the plant is being built, the necessary infrastructure must be set up and then maintained continuously.

49. The following is a simplified check-list:

(a) Electrical energy supply. A high degree of security of operation is needed because freezing of the electrolyte in the pots causes heavy and costly damage. Stand-by units and security junctions to the national grid should be considered;

(b) Water supply. In one case a desalination plant had to be built;

(c) Transport for materials. Unloading and loading facilities are necessary. The material inflow of a 100,000 ton/year smelter is about 285,000 tons a year. The outflow is more than 100,000 tons/year;

(d) Transport for personnel. It was reported that in one case the bus-drivers were on the smelter's pay-roll;

(e) Housing. The accommodation required will depend on the nature of the area selected (existance of nearby towns etc.). Proper care in housing is a main factor that helps to stabilize the work-force and is therefore of the utmost importance;

(f) Health service for employees and their families. Facilities have sometimes included clinics where operations can be done (the need for this has been seen in several instances). The health service also has to provide a regular health check for the workers;

(g) Nursery and primary schools. For the children of employees. (This also depends on the nature of the area of the smelter.)

50. The need to create an infrastructure has several important consequences. First, it increases the investment cost and second, it increases the personnel needed to run the plant. The additional cost above the battery limit investment should be regarded as a separate contribution to national development so as to avoid conflicts in judgement that may lead to unjustified shelving of the project. In other words, sacrifice is needed and should be treated separately from comparable cost increments. This additional and more general role of the smelter in developing countries should be taken into consideration when the man-hours needed to produce one ton of aluminium are compared.

The market

51. The products from the aluminium smelter must be sold somewhere; so a safe potential market is a prerequisite to the construction of a smelter. On the other hand, if a market exists that cannot be supplied with aluminium from elsewhere, then provided that other conditions can be met, this might be one of the reasons for the construction of a smelter. Any feasibility study should include a chapter on the market.

52. It was the participants' opinion that, in judging the domestic market situation in developing countries, the boosting factor of the metal's availability on aluminium consumption had to be taken into account when planning the establishment of an aluminium industry in a developing country. This was proved by examples such as Cameroon and Iran, where aluminium consumption *per capita* rose to levels of 1.5-2 and 3-4 kg respectively after the establishment of a smelter. The availability of manufacturing plants and an

organized and systematic aluminium applications promotion programme can have an important effect.

53. In many developing countries, even if the situation is viewed in regional dimensions, the domestic markets are often small compared with minimum economic plant capacities (about 100,000 to 150,000 tons/year). Consequently, the judgement of the market may often be the judgement of the export market. For example, all the aluminium produced at the VALCO smelter in Ghana, 80 per cent of the planned production of the Dubai smelter, 75 per cent of the production of the expanded Arak smelter (Iran) and 66 per cent of the production of the planned Asahan smelter (Sumatra, Indonesia) is expected to be exported under contract.

54. In the United States 75 per cent of the aluminium produced is taken by the following four sectors: architecture (26 per cent), transportation (22 per cent), packaging (13 per cent) and the electrical industry (12 per cent). In Europe these sectors account for 67 per cent of aluminium consumption. A more detailed breakdown, for leading developed countries, is given in the table.

Western world aluminium consumption: breakdown by end-use 1973

	Western world		Western Europe		United States		Japan	
	'000 tons	%	'000 tons	%	'000 tons	%	'000 tons	%
Transport	3 036	22	1 154	28	1 200	21	344	18
Mechanical Engineering	828	6	330	8	345	6	87	5
Electrical Engineering	1 656	12	454	11	670	12	226	12
Building and Construction	3 589	26	700	17	1 590	28	654	35
Packaging	1 794	13	454	11	970	17	28	2
Domestic and office appliances	966	7	330	8	415	7	141	8
Other	1 933	14	700	14	546	10	381	20
Total	13 803	100	4 123	100	5 736	100	1 862	100

Source: Figures provided by D. Altenpohl.

55. The end-use pattern for developing countries is very different. A more elaborate United Nations study of this subject could be helpful in the forecasting of domestic aluminium consumption in the developing countries.

Finances

56. Several of the necessary factors mentioned above (know-how and equipment for example), are lacking in the developing countries and have to be imported. This requires appropriate financing through, for example, a foreign exchange loan on suitable terms. Proper financial arrangements must be made to cover the costs of civil works, locally produced equipment, transportation, and other items.

57. Former estimates of the specific investment costs of the smelter within the battery limit are between $2,000 and $2,500 for each ton of annual capacity (new Brazilian smelter $2,281 (1975), ALCAN's Port Alfred project $1,900 (1976)) excluding inflation, interest during construction, provision for expansion etc. During the discussions the figure of $4,000/ton was mentioned as an overall cost, proving that indirect costs vary considerably and may even reach double the battery limit cost. Considerably lower values are possible if much of the equipment needed can be produced in the country as happened in India, where the cost was $2,000/ton. (In Brazil, in contrast, locally-made equipment proved to be more expensive.)

58. $1.22/kg (55 cents/lb) was mentioned as the lowest current price for primary aluminium that can provide the minimum return on investment necessary to make a new smelter attractive. One participant expressed the opinion that nowadays, however, the establishment of an aluminium smelter would not usually be profitable unless the selling price was substantially above this figure.

59. If the country does not possess large foreign exchange reserves, the lack of finance may delay the realization of feasible projects. Such difficulties were encountered in financing the construction of a hydroelectric power station and smelter in Guyana.

60. It was pointed out by one of the participants that capital had become one of the scarcest raw materials. Vast sums were simply not available to build an additional one million ton capacity a year to maintain the rate of growth experienced so far. It was added that if the necessary mine, alumina plant, extrusion and rolling capacities are also considered, the cost is more likely to be $8 billion.

B. Planning of smelters, selection of technology and equipment

Motives to construct an aluminium smelter

61. Different countries may have different fundamental reasons for building an aluminium smelter. The primary motive may come from one or both ends of the "raw material energy - primary aluminium - market" system.

62. The motive may be pressure from the front, from an abundance of electrical energy or bauxite, or both, if other conditions can be met. (The necessary capital and market can be found or created.) This is the case in several developing countries (Brasil, Indonesia and others). The motive force may also come from the other end of the system. It may be a result of the absorption effect of an expanding market: there may be an established need for an amount of primary aluminium that, for one reason or another, cannot be purchased on the world market. Naturally, the necessary electrical energy, raw materials, and capital should also be available. In some cases, an improvement of the balance of trade by curbing imports and increasing exports is an important consideration.

63. An aluminium smelter may be an important asset for a developing country because:

(a) It may be a source of value added to a raw material. A calculation has shown that in one case $25 remain in a country instead of $10, if the energy content of a barrel of oil is used to reduce alumina to aluminium instead of being exported as oil. (The additional costs or raw materials and other factors have been taken into consideration.);

(b) It may provide permanent jobs to a number of people and could act as an important training centre for several crafts and skills;

(c) It contributes to the diversification of the economy;

(d) It may provide aluminium not available through other channels;

(e) It may be a constant and considerable source of tax revenue (the Brokopondo smelter in Surinam provides 25 per cent of the tax revenue of the country);

(f) It may start or contribute to the industrialisation of a developing region.

64. Where new smelters in developing countries use local raw materials and/or energy and export much of the product, the main problem for the investor Government is usually to assess the competitiveness of the product, the absorption capacity of the world market, and financing.

65. All projects are individual cases. Each requires a special approach, and there are no general formulas that are valid for all cases. Before a final decision is made to build a smelter, a thorough feasibility and market study should be made for each project, covering the following problems: financing, the competitiveness of the product, the judgement of the market's absorption capacity for primary aluminium, the suitability of place and time. In the final judgement, the overall national effect and the secondary benefite of the existence of a smelter in a developing country should be taken into account.

66. Recycled aluminium. It should also be considered that recycled aluminium is an important and comparatively less expensive source of metal. An average of 21-22 per cent of the present aluminium supply is secondary aluminium. This form of energy saving should not be neglected when developing countries design new aluminium industries and desire to boost their domestic aluminium consumption. Efficient secondary plants with proper economy of scale should be provided.

67. Research and development. Proper provisions should also be made for organizing research and development activities, perhaps within the framework of regional co-operation between developing countries.

Inviting offers from different sources

68. Before offers are invited from foreign companies, it is best if the specialists of the country study the technologies and approaches to apply to different problems, so that they can give an expert judgement on the offers received. One of the participants stated that his authorities had no opportunity of checking what was offered and were not even in a position to ask whether they were purchasing the right equipment.

69. Very often an international company or a company from a socialist country is invited to build and operate a smelter. The project must not only meet the justified intention of obtaining maximum benefit for the country, but must also be made attractive. The additional cost of freight and infrastructure, and the excess operation costs specific to developing areas must be offset in some way, for example, by providing the infrastructure or giving tax concessions. A representative of an international company pointed out that it may be more advantageous from a purely economic point of view to build a new smelter in Texas, where the price of electrical power, based on lignite, is 12 mils, than in the jungle in Africa or South America where it is only 9 mils, because the difference is consumed by freight and infrastructure and a private enterprise cannot operate for long at a loss.

70. Where the product, or a considerable part of it, is to be sold abroad at world market price, a subsidy might be necessary, because both the construction and operation of a smelter may be comparatively expensive.

71. Competitive bidding with offers from different countries is advised for the supply of know-how and the plant. Where there is no nucleus of expertise in the country, it might be advisable to use foreign consultants to evaluate the offers received.

Planning, contracting, construction

72. Economic capacity. The economic aluminium smelter capacities are generally assumed to be about 100,000 to 150,000 tons a year or one to three potlines. Since the domestic markets of many developing countries, even in a regional context, are often very small, the judgement of the market will essentially be that of the export market.

73. Location. The location of the plant appears to be mainly a question of economics: it depends on the source of energy and raw materials and the location of the market. Other considerations have been mentioned in the previous chapter.

74. Energy supply. It was noted that proper co-ordination of the construction of smelters and their power supplies deserved special attention and proper scheduling.

75. Joint plants. Because of economies of scale and the minimum economic plant sizes for aluminium smelters, alumina plants and carbon anode plants, the establishment of joint alumina and carbon anode plants for several smelters in neighbouring countries appeared to be a reasonable proposition.

76. Local personnel. It is advisable to involve local personnel, local management and local contractors at all levels from the stage of planning and design of the plant through the different stages of construction and commissioning.

77. Turn-key plants. It was questioned whether a turn-key basis was the best basis for the purchase of know-how and equipment. The ready-made plant is not necessarily the best one under the particular conditions of supply and personnel. The supplier of technology, even if he has the best intentions, cannot know all the problems and assets of the country.

78. Construction management. Experience has proved that efficient construction management can be made significantly easier by the application of proper organizational models for example, having all staff of sub-contractors working on the project on a single pay-roll of the chief contractor or main supplier, as was done on ALCOA's Brokopondo project.

The selection of technology

79. For successful operation, a developing country should select an "appropriate" technology for a new smelter. This is not necessarily the "latest" technology (which may not have been proved on a commercial scale) required by some bureaucrats. On the other hand, there is certainly no point in selecting an evidently outdated technology. The appropriate smelter for a country is the one that can be run and maintained there. Such factors as climatic conditions, a reasonable choice of automation and mechanisation, and proper selection of the product mix in the cast-house have to be carefully considered.

80. All commercial-size primary aluminium producing plants in the world now use some form of the traditional Hall-Heroult process - the electrolysis of a cryolite-alumina melt with a carbon anode. There have been several attempts to replace this process by others or to introduce considerable changes (in electrode materials for instance). Some of these are mentioned below. So far, none of these experiments has reached a stage of development that would justify its consideration as an alternative to the traditional Hall-Heroult process in smelters to be built in developing countries.

The traditional Hall-Heroult process

81. Pot type. At present, the following types of anodes are used in the cells producing aluminium:

(a) Söderberg anode with horizontal stubs;

(b) Söderberg anode with vertical stubs;

(c) Pre-bake anode.

82. It is considered that the advantage of Söderberg cells is the lower investment cost in the carbon plant. A recent study has shown, however, that above 165 kA current, the pre-bake type is more economical. Two arguments may be added to this: firstly the prevailing trend is to build potlines of about 165 kA or higher amperages, and secondly, several independent studies were unanimous in stating that the potroom atmosphere is worse and the frequency of lung cancer is increased by a factor of 2.5-3 in Söderberg potrooms, while in pre-bake potrooms the frequency was below normal. It is therefore reasonable for new smelters to be of the pre-bake design. Other advantages claimed of the pre-bake anode are lower electrical energy and fluoride consumption, and ease of automation and mechanization.

83. A representative of an international company said that his company offered two types of pre-bake cells, a 160-170 kA model in low and high current density versions and a 225 kA high current density model, but no Söderberg cells. It was also announced that Hungary intends to build a new 100,000 tons/year smelter using 150-170 kA centrally fed prebake anode cells with automation and environmental control.

84. The concensus was that for new plants, cells with pre-bake anodes and current intensities around 150 kA (possibly with central feeding) were the best solution.

85. Where plants were to be expanded, the selection of the type of additional cells should be a question of economics. In most cases, identical cells might be preferred since, as one of the participants pointed out, it is expensive to have two different types of cells.

86. There was a discussion about the optimum size of a potline. The following arguments were put forward in favour of shorter potlines (two 100-cell lines rather than one of 200 cells, for example):

(a) If there is any operational trouble and the current supply of the potline is stopped, the loss of production is less for a short potline;

(b) A long potline requires a higher line voltage and consequently more attention to insulation and safety training;

(c) One foreman is usually enough to supervise a short potline, but at least two are necessary for a long one.

87. There are several smelters with long potlines of up to and over 240 cells (Eastalco, United States; Vlissingen, Netherlands). The potline at Chiba (Japan), on the other hand, has 120 pots.

88. Automation. The question of automation was also discussed. Automation is used for feeding alumina, suppressing anode-effects, regulating interpolar distance, and other operations. The general opinion was that extensive automation was advisable but should not be considered to be a prestige item. The potroom crew should be able to handle the cells if the automation breaks down. The objective of automation was primarily not to save labour but to optimize the potroom operation and facilitate environmental control. It is advisable to run the plant first without automation and to switch to automation only after the crews have acquired enough practice in handling the cells.

89. Maintenance. For developing countries, the maintenance requirements of such systems should be carefully considered. In countries where the necessary skills for the repair and maintenance of electronics were available, no difficulties were expected. Where those skills were not available, automation could be a source of serious trouble.

90. The issue of environmental control is dealt with separately in section D.

New technologies for the production of aluminium

91. Experimental processes intended to replace the Hall-Heroult process may be divided into two categories. In the first, an entirely different process from the electrolysis of a cryolite-alumina melt is used, while in the second, an attempt has been made to change an important feature of the customary electrolysis.

New processes

92. The Toth process. Aluminium chloride is reduced by manganese metal; it is claimed that the manganese and the chloride are recycled. The process was announced in 1973. Several difficulties can arise, possibly including manganese contamination of the aluminium produced. There is no report of any commercial installations.

93. The Alcoa aluminium chloride electrolysis process. This was developed over a fifteen-year period, at a cost of approximately $25 million. Aluminium chloride produced in the reaction between aluminium oxide and chlorine is dissolved in molten alkali and alkali earth chloride, and the melt is electrolysed at about 700°C with bipolar electrodes. The chlorine is recycled. The energy consumption has been reported to be 8.9 kWh/kg Al, and the metal produced is claimed to have high purity. This process was

considered so promising that the company built a plant with an annual capacity of 15,000 tons of aluminium (in Anderson county, Texas) which went on stream on 18 May 1976. An expansion to 30,000 tons/year is under construction. The ultimate design capacity will be 300,000 tons/year.

94. The process is carried out in a complicated chemical plant in a highly developed country. According to a representative of the company present at the Workshop, the company has confidence in the process, but it may be another five years or more before it can be offered as an economic commercial process. Even then it will not make present installations obsolete.

95. Research is being done along similar lines in Japan, where a mixture of $AlCl_3$ - NACl - KCl is electrolized at 120-150°C to yield aluminium sponge. There is no report of any industrial installation.

<u>Fundamental modifications of the Hall-Heroult process</u>

96. Several companies conduct experiments with other than consumable carbon anodes. The dimensionally stable, non-consumable anode needs no petroleum coke. It is made up of a metal oxide blend and has an expected life of three years. It is still in its experimental stage. There are also experiments with titanium anode and wettable cathode. Where such anodes are used, 5-10 per cent more electricity is needed, since there is no depolarization due to the oxidation of the carbon anode as in the traditional Hall-Heroult process.

<u>Assessment</u>

97. One of the participants said that developing countries are no fields for new experiments. Since for several years to come none of the new processes can be considered a viable alternative to the traditional Hall-Heroult process, they need not be considered for the time being when a technology is selected for new smelters in developing countries.

98. There was a short discussion about alternatives to the Bayer process for the production of alumina, and the use of other raw materials (alunite in Iran, for example). One of the participants pointed out, however, that there is a lot of good tropical bauxite available, enough for at least 150 years even if a 5 per cent growth rate is assumed. In addition, much low-grade bauxite is also available that can be processed with minor changes in the Bayer technology. Consequently, the use of other raw materials and technologies is a problem for the more distant future only.

Problems of the cast-house

99. Product mix. Cast-house design was stated to be a complex problem. It depends on the product mix, and this must be determined with caution. If there is only one smelter in a country, it is expected to satisfy all needs. Some flexibility is needed, but too much flexibility results in unnecessarily costly design. It was therefore considered essential to carry out a well-based market study in good time. The electrification programme of the country may require the production of cables. For feeding an extrusion mill, extrusion-billet capacities have to be added. For export to the world market, ignots are needed. Different products are needed on the European and on the American markets, and they require different equipment. Because of uncertainties and risks in product-mix determination, the cast-house layout should be flexible and should provide for expansion.

100. Basic commodities. The three basic commodities are: 22 kg ingot (pig), sheet ingot, and extrusion billets of different sizes. If there is a large amount of metal to cast 450 kg (1,000 lb) sows are also produced. The Bahrain smelter, for example, produces 22 kg ingot, T-bars and extrusion billets for export to Japan. The T-bar is expected to replace the 22 kg ingot as it is easier to manipulate and cheaper to produce. The smelter has two homogenizing furnaces.

101. In one United States smelter, there is only one DC machine; in another marginally larger one under study, two DC casting machines, one straight-line casting machine for 22 kg ingots and a Properzi machine. The smelter in Argentina has five DC casters. It produces 20 kg and 500 kg ingot and very little rolling slab or extrusion billet.

102. As to cast-house equipment, it was mentioned that the tendency is not to build big (100,000-200,000 tons/year) hot rolling mills like those in the Federal Republic of Germany or the United States, as they are too expensive and cannot be loaded for several years by even two shifts. It is more reasonable to enter a new market with extrusion presses of 2,000-5,000 tons/year production capacity and strip-casting machines. The family of strip-casting equipment consists of the following proven and working members:

(a) Roll casters. Various types are made; about 80 units are in operation. Their product mix is restricted. They are good for foil, strips, and roofing sheets, but not for aircraft sheet and high-alloyed sheet (8,000-10,000 tons/year capacity units);

(b) Hazelett caster. The Hazelett caster is rational if the capacity is more than 60,000 tons/year. Its limitations are similar to those of big hot mills. It is a high-speed machine;

(c) Hunter-Douglas caster for widths of maximum 60 cm. It can be considered for a limited use for venetian blinds and similar materials; used mostly for scrap alloys, with a wide range of copper, magnesium and iron contents;

(d) Caterpillar caster. It has a 20,000-60,000 tons/year capacity depending on the length. It is perhaps the only one which can cast any alloy, even one containing 5 per cent magnesium.

103. It is most likely that, in the future, more strip casting machines will be put into smelters for scrap recycling.

104. Horizontal and vertical casting. Advantages and disadvantages of horizontal and vertical casting were compared. It was established that for certain purposes, the cheaper horizontal casting machine, which does not need any special foundation, may be entirely suitable, especially if a large series of the same product - "a lot of small shapes" - is needed. The surface properties of the two products are not identical and it is difficult to cast horizontally higher-strength alloys. In case of variable production programmes, vertical DC is advisable.

105. Metal purification. Opinions differed concerning the best method for metal purification. It was stated that more and more smelters are provided with molten metal filtering and degassing equipment. Chlorination seemed to be replaceable (the maintenance of chlorination equipment is difficult). In-line fluxing is used instead, or large holding-furnace capacities are applied. It was mentioned that in one developing country, the chlorinating equipment purchased was never used. In-line fluxing was claimed to be within the trend of modern development. One participant remarked, however, that his company had no in-line fluxing equipment but had little, if any, complaint about the quality of the billets exported to Japan.

106. Production of alloys. In the production of alloys, the proper sequence of alloys should be taken into consideration because of contamination factors. The production of master alloys was generally not advised for smelters. Some alloys may be made in pots depending on actual economy (e.g. iron, silicon).

The human factor

[illegible] considerations

[illegible] of an aluminium smelter, or any new industrial [illegible] the training of a new staff. If the smelter is [illegible] the nationality, mother tongue, [illegible] background, and attitude towards work of the staff [illegible] the trainers, who are usually expatriates) and of the [illegible] staff are different, sometimes very different.

[illegible] differences require [illegible] and accommodation by both sides [illegible] together with other human aspects, such as individual or national [illegible] give rise to difficulties and special problems.

[illegible] human contact, [illegible] of fundamental importance that each [illegible] the other, has a realistic estimate of the other's problems [illegible] and avoids under- and overestimation. An underestimation [illegible] should be especially avoided. Newly-trained people can do [illegible] States delegate reported that the local welders [illegible] better than welders the company could [illegible] delegate from a developing country said that [illegible]

[illegible] transfer of knowledge, both sides should [illegible] the expatriate should be [illegible] staff member eager to learn. Properly [illegible] while without motivation [illegible] interest of a quick transfer of [illegible] participants mentioned [illegible] affairs and that the expatriate instructors [illegible] of the desired [illegible] contract.

[illegible] a separate ghetto but should [illegible] This results in a better understanding [illegible] which in turn has favourable [illegible]

[illegible] expatriates and local staff

[illegible] the expatriate experts is of vital importance. [illegible] trainers and teachers should [illegible] that excellent technicians or engineers [illegible] adequate [illegible] of the expatriates [illegible] concerning local social, [illegible]

113. Even a capable and dedicated expatriate expert can, however, achieve little if his counterpart is not interested in the transfer of knowledge or skills. Proper measures for the selection of counterparts are therefore necessary.

114. Recruitment in developing countries requires specific criteria. Physical stature and experience in hard work may have priority above educational background. Trained technicians and engineers locally available might prefer to have a "clean job" and, as soon as they get one, leave the plant without notice, as was pointed out by a delegate from a developing country. The criteria will also vary according to the availability of trained staff, depending on, for example, whether there are 2 or 100 applicants per job.

115. Capable and dedicated local staff members may also have problems due to their specific cultural background or a lack of special education and practice in learning. This may explain the comparatively short retention span sometimes found, and the consequent need for occasional retraining. This is to be taken into consideration and should be understood by the expatriates.

116. The expatriates do a difficult job. They are away from home, family and friends, in a different culture and climate. If, however, this is met by understanding attitudes and they are integrated into the local community, they will have a better chance of liking their work, as was shown in the case of Scandinavians working in Bahrain.

The problems of training

General problems of training

117. The first difficulty to be tackled at all levels is the language, as the expatriates and the local population do not usually speak the same language. Difficulties always arise, and suitable provisions for proper communication should be made well in advance. It is an attractive proposition to train people during the construction work but it may result in a conflict. The construction work is on a strict schedule, while the trainee's progress owing to possible repetition or a more elaborate explanation of certain matters, can be delayed and no firm schedule is possible.

118. The assessment of man-months needed for training is sometimes not easy. The educational background and experience of the trainees must be considered carefully. Sometimes assessments differ greatly. One of the delegates from a developing country reported that in four offers from international companies, all of which were familiar with the country, the times foreseen for training ranged from 26 to 166 man-months.

119. The more complicated a job is, the more time is needed to train people for it. It was noted by the participants that it is comparatively easy to train anode operators, for example, but it takes more time to hand over the maintenance of the hydraulic system, some top management posts, or the research and development positions.

120. The time needed to train the local staff varies from country to country, depending mainly on educational background; in smelters built in Argentina and India, the last expatriate left the country after two years. In other cases, like in Bahrain, Ghana and Surinam, a decreasing number of expatriates is employed for long periods.

121. Staff should be planned and trained with some reserves. There will inevitably be some drop-outs, and the likelihood should also be taken into consideration that in a developing country, people with industrial experience will get higher and better jobs (engineers moving up into government posts, for example).

122. It should be considered that training pays. A smelter represents a high investment and a high product value. Damages caused by ignorance may be very costly.

Fields of training

123. One of the delegates pointed out that in a smelter there are hundreds of different jobs, ranging from pot operators through craftsmen, technicians, and engineers to top executives. Training should be provided for all jobs that are either specific in the process or, although not specific, not available in the developing country. In some cases, especially if a long period of training (e.g. for metallurgical engineers) is required, the training requirements must be foreseen in the framework of long-term planning.

124. It is sometimes requested that the local specialists be involved in the design work. This may be required by a developing country even if it involves additional expenditure. One of the delegates mentioned that a "contractual mess" might result from an early involvement and that a limit should be set on local involvement. Another delegate expressed the opinion that no contractual mess would follow if both parties had the same professional knowledge.

125. It was recommended that the training curriculum should include environmental training. The United Nations Environment Programme (UNEP) is ready to co-operate in this respect. Training in administration and decision making is also required.

The place for training

126. There may be several ways to get the necessary knowledge and skill to run an aluminium smelter, depending on local and regional conditions. In one extreme case (as happened in India), because there was already a smelter using similar technology in the country, people were trained there. In another case, a core of about 30 per cent "expatriates" from other smelters trained the 70 per cent coming from the local population.

127. It may happen that, there is a possibility of training all or some of the specialists needed not in the country itself but in that region. It was mentioned that if a smelter with pre-baked anodes is to be built, a smelter in another developing country using Söderberg anodes may be a good training ground for all jobs except the anode operators. The mixing of practices may, however, cause confusion and troubles. It was stressed that training first in another developing country and then in a developed country may have several advantages.

128. At least part of the equipment supplied for a new smelter is of a specific design and it is customary to train part of the future staff for such posts in a smelter of the supplier. Staff who do jobs that are not specific for the aluminium smelter (transport workers, electrical or mechanical engineers, accountants etc.) may be trained at any plant that uses similar equipment or where similar work is done.

129. Some of the engineering, managerial, and research and development jobs need long training. Talented young people should be sent to universities abroad if courses are not available at home. One of the participants remarked that it had proved better not to send students to countries with the highest standards of research, because, after writing excellent thesis, they either failed to return or set up requirements that could not be met.

Methods of training

130. In the discussions, several important aspects of how to train were mentioned:

(a) Training should be by doing the work rather than speaking about it. (In this way, the language barrier is at least partially overcome.);

(b) The training of counterparts is, in general, a good method for the transfer of knowledge and skills, provided both parties are selected properly. This type of training should be included in agreements on the establishing of smelters;

(c) In training programmes, the system of split simplified jobs proved successful. "Job enlargement", even in developed countries, can begin only after a period during which a proper practice has been acquired in all parts of the enlarged job;

(d) In several cases (Egypt, United Republic of Cameroon etc.), it was found useful to set up a training centre to train local personnel;

(e) Group in-plant training, irrespective of the type of contract, proved successful in other fields. It might also be tried in connection with aluminium smelters;

(f) Individual fellowship training and visits to a series of plants are common forms of training in other fields. This approach might also be extended to the aluminium industry.

The time of training

131. The time of training will depend on the character of the job. Long-term training (e.g. the training of engineers and decision makers) should be started several years before the planned start-up of the smelter. After start-up, a similar long-range plan may provide the staff for research and development.

132. Short-term training should start several months before start up and should continue during the first period of work. Refresher and further training should be provided as needed.

D. The aluminium smelter and the environment

Some general aspects of pollution

133. It is now generally agreed that industrialization creates some unfavourable side-effects if no special measures are taken to prevent them. One of these side-effects is the pollution of the environment, the recognition of which aroused public concern all over the world and prompted the drafting of pollution-control legislation and standards in various countries. As a consequence, there has been a change in the philosophy of approach: previously, the only question asked was what could be taken from the environment; now a second question has been added - what impact will the new industrial plant have on the environment.

134. The attitude to pollution control varies from country to country and, in the case of federal States (like Brazil) even from state to state. Factors of 100 in permissible pollution levels are no rarities. One of the European participants reported that on visiting an industrial area of another European country he found a degree of air pollution for which in his own country the directors of the factories producing it would have been imprisoned long ago.

135. One of the participants drew attention to the change of attitude of the developing countries. About five years ago, some developing countries claimed the right to pollute their own territory and regarded the installation of pollution-control equipment - which increased investment costs - as an effort by the industrialized nations directed against the industrial development of developing countries. Now the trend seems to have changed: developing countries are becoming more and more anxious to avoid pollution of their territory and to eliminate health hazards to their workers and the populations living near industrial plants.

136. Unless proper pollution-control measures are taken, aluminium smelters present pollution hazards for the environment. In-plant pollution may also be an important factor and certainly should not be underestimated, especially in Söderberg plants, where a considerably increased death rate from lung cancer has been observed. Nevertheless, although pollution will perhaps never be eliminated, it should not be overestimated either. The variety of standards and pollution-control legislation, ranging from no control to very strict controls, would require international action to recommend guidelines for reducing the adverse effects of pollution.

Pollution in smelters

137. The main source of pollution in the smelting process is the molten electrolyte, which produces partly gaseous and partly solid fluorides, and the anode, which is the source of carcinogenic tar fumes originating from the cracking and distillation of the pitch binder of the anode paste, carbon monoxide and dioxide, and sulphur dioxide. This latter is generated by the oxidation of the sulphur in the anod carbon.

138. A serious health hazard for the workers of Söderberg plants derives from the benzopyrene and possibly other carcinogenic compounds released during the coking of the binder. Several studies have been published recently indicating that there is a marked increase in lung cancer cases among workers in such potrooms. The factor is between two and three, a signal that something should be done immediately. In the United Kingdom and United States mortality ratios of 250 per cent were recorded, and in the Soviet Union 280 per cent. For pre-bake plants the figures were below the standard 100 per cent. In the Soviet Union, as a consequence, a standard was established allowing 0.15 μg benzopyrene/m^3. In the United States there is a proposed standard allowing 0.2 mg of particulate polycyclic organic matter (ppom). This seems to be 1,000 times more than the Soviet standards, but it includes all the vapours and droplets as well. One government investigation in a European smelter has shown, however, that both the ppom and the benzopyrene concentrations were very much higher than any of these standards.

139. According to available forecasts, the sulphur content of petroleum coke (used in the anodes) is likely to rise in the future because of the corresponding increase of the sulphur content in the petroleum crude. At present, 2 to 3 per cent is generally accepted, and values up to 5 per cent are not uncommon. The dry scrubber does not eliminate the SO_2; so in some cases it might be necessary to introduce more expensive equipment.

Emission control measures in smelters

140. There are now several smelters in operation that have no special equipment for the prevention or decrease of pollution. The simplest way of decreasing in-plant pollution is to hood the cells. This is easiest with pre-bake cells and rather difficult with Söderberg cells. This is one of the reasons why the new potlines are perhaps almost exclusively of the pre-bake design.

141. In some special cases it might prove sufficient to conduct the effluents collected in the hoods to a cyclone for particle removal and then to a tall stack, but in most cases dry scrubbers must be used. Alumina is then used to remove and recover the fluorides.

142. At the same time, however, some of the metallic impurities - unwanted in the metal - are also recycled, thus contributing to some deterioration of the metal quality. This effect can be overcome by selective feeding of cells producing high-purity or electric-conductor grade metal only with fresh alumina from the store.

143. The SO_2 is not eliminated from the gases in the dry scrubber. In some cases, however, it was found that there were no problems resulting from the SO_2 content of the gases when smelters were equipped with dry scrubbers only. In cases of increasingly strict pollution-control requirements the dry scrubber is followed by a wet scrubber to remove the SO_2; in some cases wet scrubbers also had to be installed on the roof of the potroom.

144. The adoption of pollution-control standards will necessarily lead to the introduction of automation.

The cost of pollution control

145. The well known maxim that "prevention is better than cure" is true for pollution-control equipment. It is usually much cheaper, and also often more effective, to incorporate pollution-control equipment in a new construction than fitting it later when compliance with local or international standards make it imperative.

146. Hooding the cells and recycling the fluorides by using dry scrubbers adds about 5 per cent (according to other estimates a maximum of 7 to 8 per cent) to investment costs. The extra cost of operation is, however, only 1-3 per cent. There is therefore no point in running a "dirty plant" to save about 2 per cent in operating costs, especially if later standards will not permit operations under such conditions and more costly retrofitting will be necessary.

Typical sites for aluminium smelters

147. The site of an aluminium smelter is always determined by a combination of factors related to overall economy and development policy. However, environmental criteria should also be considered and, to enable cost-efective pollution-control measures to be incorporated, the capacity of the air, water and land systems that surround the site to assimilate pollutants without ecotoxic effects should be taken into account. Baseline studies and environmental impact assessments should therefore be made when environmental criteria for the siting of an industry are being considered. One of the participants presented an easily-understandable simplified classification according to which the following typical sites and corresponding pollution-control measures can be distinguished:

(a) Desert or lonely peninsula (hooding plus cyclone plus tall stack);

(b) Remote area (a);

(c) Agricultural, well populated area (hooding plus dry scrubber);

(d) Pristine, sensitive area e.g. fish breeding etc. (as (c));

(e) Special cases where particularly strict standards are applied (dry scrubber plus wet scrubber, sometimes an additional scrubber on the roof).

UNEP's activities and recommendations

148. A committee working at the request of UNEP has drafted a recommendation on environmental factors that should be considered for the siting and operation of new primary aluminium reduction plants and new plants for refining bauxite to alumina, and environmental recommendations for bauxite mining. This should be a useful guide for selecting appropriate environmental management and control systems for the aluminium industry. UNEP will make the document available shortly.

149. UNEP is developing capabilities to provide advice and assistance on environmental management for the aluminium industry. Countries requiring such advice and assistance are invited to contact the UNEP Industry Programme, 17, rue Margueritte, F-75017, Paris, France.

150. Xerox-copies of a document entitled "Environmental Aspects of the Aluminium Industry - An overview", issued by UNEP in May 1977, were distributed among the participants. The 32-page booklet includes chapters on: the aluminium industry; current environmental problems, pollution abatement, technology and costs; the effect of new production processes on pollution abatement; fluoride legislations and standards; and conclusions. Further copies are available from UNEP on request. Some data on pollution and pollution control, taken from the background paper prepared by the UNIDO secretariat and from the UNEP document, are given in annex I.

III. CONCLUSIONS AND RECOMMENDATIONS

Recommendations

151. The participants in the Workshop put forward the following recommendations concerning UNIDO's future activities:

1. UNIDO should intensify its expert assistance to countries that are planning to build aluminium smelters but lack properly qualified personnel to make decisions.

2. The United Nations system, and UNIDO in particular, should be helping to provide project monitoring expertise.

3. UNIDO should take the initiative and co-ordinate training in existing smelters in developed and developing countries.

4. UNIDO should prepare a working document that would facilitate the training of aluminium smelter staff in developing countries. This document should contain a set of educational and experience qualifications and should describe typical training programmes. It should also include a standard set of manning and training schedules, possibly on the basis of a standard aluminium smelter of about 100,000 tons/year capacity. A compilation of experience in training personnel to operate smelters in developing countries could supplement the document. Participants from developing and developed countries offered to provide contributions for the preparation of such a document; UNEP offered to contribute to a chapter on environmental control.

5. A regional development and training centre should be set up, possibly in South America, with the help of UNIDO, which could help in the co-ordination of research and development activities.

6. UNIDO could help in creating up-to-date economical secondary aluminium plants in developing countries.

7. Aluminium consumption in developing countries and the dynamics of its development deserved a special attention. It was suggested that UNIDO, possibly through a system of questionnaires, should elaborate on this matter. A study that would also reflect current developments in more advanced developing countries might be a useful tool for a more realistic assessment of domestic demand.

Part two. Summaries of papers submitted to the Workshop

THE PUERTO MADRYN ALUMINIUM SMELTER, ARGENTINA

N. Angelucci, Alumetal Spa, Milan, Italy

152. The paper describes the establishment of the Puerto Madryn aluminium smelter (capacity 140,000 tons/year), which was built by a group of Italian firms under a turn-key contract with the Argentine company ALUAR. The Italian group comprised Alumetal; Italimpianti, Genoa; and Impresit, Turin. The agreement was signed on 1 December 1971. The smelter was formally accepted in July 1976.

153. The plant location at Puerto Madryn, Chubut District, about 1,500 km south of Buenos Aires, was chosen with a view to promoting the industrial development and population growth of the area. Before the smelter was set up, Puerto Madryn was a village of about 6,000 people. Estimates that the population would increase to 15,000 in about five years proved to be correct. The smelter employs about 1,100 people. ALUAR provided residential buildings covering an area of 53,155 m^2. Community buildings include a primary school, a post office, and sanitation facilities.

154. The project included a deep-water harbour that made Puerto Madryn one of the leading ports on the 3,000 km long south coast. Power supply was to be ensured by a 380 kV long-distance line (rated capacity 280 MW) to be provided by the hydroelectric power station of Futaleufú on the Andean Cordillera, 600 km west of Puerto Madryn. Because of a two-year delay in the construction of this power station, a second station consisting of six turbo-gas units with a total capacity of 120 MW had to be installed within the smelter. Gas was provided by a gas pipeline running through the whole of Argentina up to Buenos Aires.

155. The plant was able to start production ahead of schedule in July 1974. Start-up was completed in about 18 months. At start-up the smelter was managed by local personnel with assistance and technical supervision provided by ALUMETAL's and vendors' specialists. ALUAR's personnel (25 technicians) had been trained in ALUMETAL's Italian plants some 18 months before start-up. By June 1976 the smelter was entirely operated by ALUAR personnel. A five-year technical assistance agreement was signed with ALUMETAL to cope with operating problems during the initial period.

156. The smelter, which is the largest in South America, was designed to cover all domestic demand for aluminium and exports to other South American countries at a later stage. Since no bauxite is available in Argentina ALUAR signed a long-term alumina purchase contract with ALCOA for the transport of Australian alumina to Puerto Madryn by bulk carriers.

Technology used

157. The electrolytic cells installed are the 150 kA pre-baked-anode type in operation at ALUMETAL plants. The main characteristics of these cells are given below:

Anoue current density	0.67 A/cm^2
Cathode current density	0.61 A/cm^2
Number of anode rods	16
Anode size	780 x 900 x 600 mm
Carbon block cross section	490 x 410 mm
Daily output of one cell	1,050 kg
Average life of cells	1,260 days
Raw material consumption:	
Alumina	1.93 kg/kg of aluminium
Anodes (gross)	0.55 kg/kg of aluminium
Anodes (net)	0.47 kg/kg of aluminium
Flux	0.045 kg/kg of aluminium
Power consumption	15.2 kWh/kg of aluminium

158. The smelter consists of four potrooms each equipped with 100 cells, placed end to end in two 50-cell rows. No pollution-control equipment was considered when the smelter was designed because (a) there was no local legislation on the subject and (b) the plant is located in the very windy desert territory of Patagonia. Nevertheless, static aerators ensure adequate potroom ventilation and satisfactory working conditions. Facilities are also provided for the possible installation of a fume abatement system at a later stage.

159. The degree of mechanization - though not exceedingly high, so as to avoid the use of sophisticated equipment in the initial stage - is sufficient to produce 1 ton of aluminium in 3 man-hours.

160. The main process operations are performed as follows:

Special vehicles are used for crust-breaking and alumina feeding

Every second day, bridge cranes and vacuum ladles are used to tap the metal

An electronic recording system is used to weigh the metal during tapping

Consumed anodes are replaced by means of bridge cranes every 32 days

The anode block is lifted every 25 days by means of an auxiliary beam

Special trucks are used for flux feeding.

161. The project allowed for the installation of a process computer at a later stage. The installation also included the following main units:

(a) The cast shop, where the metal from the potrooms is cast to obtain 20 kg ingots, 500 kg saws, extrusion billets, and rolling slabs;

(b) The anode plant, which provides the pre-baked anodes required for cell operation. The green-anode plant consists of a moulder for 600 kg anodes. The moulder capacity is 40 anodes an hour. The green anodes are then calcined in two 36-chamber kilns with a total capacity of about 150,000 anodes a year;

(c) The rodding plant, where spent anodes are also processed: butts are recycled for carbon recovery;

(d) All the utilities (storehouse, electrical and mechanical workshop etc.).

THE DEVELOPMENT OF THE ALUMINIUM INDUSTRY IN BRAZIL

R.C. Machado, Companhia Vale do Rio Doce (CVRD), Rio de Janeiro

162. In Brazil the domestic production of aluminium started in 1945, but cannot yet meet the local needs (235,000 tons in 1975 when 93,000 tons were imported). There are today four small smelters with sev 1 potlines in operation on the 8,000 to 40,000 tons/year scale, all of Söderberg type. Of these only two potlines have equipment for the protection of the environment.

163. By 1985 the Brazilian market will consume about 670,000 tons, according to a conservative forecast. To meet this demand, new projects will be needed in addition to the planned expansions of existing production facilities.

164. The 1973 oil crisis gave a new value to the practically unknown hydroelectric power potential of the Amazon area, just where large bauxite deposits were discovered. No alternative use has yet been found for the power. The Tocantins/Araguaia, one of the tributaries of the Amazon, alone has an estimated potential of 18,000 MW.

165. The installation of the first large hydroelectric power station in Amazônia (Tucurui) began in 1976 and the station is scheduled to be in operat by 1982. A large project to mine bauxite for export (3,35 million tons/year) began at Trombetas in 1976 to start operation in 1979. The first unit of ALUNORTE's 800,000 tons/year alumina plant should start production in 1982 (investment of about $400 million), and the construction of a 320,000 tons/year smelter of ALBRAS (investment of about $950 million; 4 potlines) is to begin at Barcarena, with Japanese participation, in 1977. Fifty per cent of the equipment will be of Brazilian origin. VALESUL Alumínio SA is to build an 80,000 tons/year reduction plant (1 potline) in Santa Cruz using imported alumina in the first years. Start-up is scheduled for late 1979. The Santa Cruz plant was planned to expedite Brazil's self-sufficiency and to facilitate the training of personnel to operate the State of Pará smelters in the Amazon area.

166. For the VALESUL Project tripartite control is foreseen: CVRD (State owned iron mining company), private Brazilian enterprise, and Reynolds will each have a one-third holding. (This should be compared with ALBRAS: CVRD 51 per cent, LMSA 49 per cent.)

167. Current capacities and those forseen for 1985 (in brackets) are: Alcan (BA) 28,000 (76,000); Alcan (MG) 32,000 (60,000); CBA 50,000 (120,000); ALCOMINAS 45,000 (100,000); ALBRAS (135,000) and VALESUL (80,000). Secondary aluminium production 27,000 (67,000).

[illegible]

[illegible] oil [illegible] tons, and [illegible] approximately 1,[illegible] million [illegible]. The construction of a 100,000 long [illegible] and the plant was commissioned in [illegible]. Present capacity is 150,000 [illegible] material of the upper [illegible] the latter being the latest and most [illegible]

[illegible] the responsibility [illegible] all the [illegible] the Guyana Bauxite [illegible] development of the bauxite industry in [illegible] own and operate the [illegible]

[illegible] smelter in Guyana include: the [illegible] industries based on the [illegible] the availability [illegible] of the foreign exchange earning [illegible] was elected as the [illegible] study

[illegible] the smelter location:

[illegible] these;

[illegible] working and living [illegible]

[illegible] raw materials and [illegible]

[illegible] of the sub-station [illegible]

[illegible] the aluminium smelter and possible [illegible]

[illegible] equipment,

[illegible] smelter.

[illegible] are based [illegible] The system is based on [illegible] computer) [illegible] cells are [illegible] and are then vented through a tall stack. The pots are tended by multi-facility overhead cranes. Each potline would have two potrooms with an approximate capacity of 74,000 tons/year. Cathode repair facilities are provided for the repair of cathode shells in the potrooms.

174. The cast-house is equipped to produce pigs, sows and rolling ingot, but could be organized to produce a wider range of products. There is a dross recovery system.

175. The installed capacity of the smelter should be about 150,000 tons a year, since the calculations indicate that this is the minimum economic size for a modern greenfield export-oriented aluminium smelter. The site layout allows for an ultimate capacity of four potlines (approximately 295,000 tons/year). The final decision would depend on satisfactory financing for the project package and on suitable contractual arrangements for the marketing of products.

176. Manpower is potentially a serious constraint. According to a provisional analysis, 88-109 men should be sent for training overseas. The estimated need in the operations phase will be 1,420-1,860 men; in the construction phase estimated peak need is 1,250 men.

THE ALUMINIUM BAHRAIN (ALBA) PROJECT

P.U. Fischer, M and F Engineering AG, Zürich

177. There are large natural gas reserves under the island of Bahrain. In 1968 a syndicate, consisting of the Government, cable manufacturers and trading companies, and a primary producer, decided to build a smelter at Bahrain and sell the metal at cost to shareholders. The Governemnt of Bahrain is the major shareholder. There are no taxes payable. The first metal was poured in May 1971. Energy exported in the form of metal generates between two and two-and-a-half times as much foreign currency as energy exported in the form of oil. Alumina was purchased from Alcoa, Australia.

178. The smelter uses 100 kA Montecatini pre-baked anode pots in two potlines of 228 pots each in two potrooms. The pots are in an end-to-end arrangement with fresh air supplied in the centre aisle. This arrangement was considered to be the most appropriate one for the climate. The 26 anodes in each pot are 1,010 mm long, 520 mm wide and 500 mm high. Anode current density is 0.76 A/cm^2; line voltage at the rectifier terminals is 1,050 V. The power station comprises nineteen 13 MW gas turbines.

179. Two gas turbine burnouts were caused by liquid entrainment in the gas supply system. The rating of the carbon plant is 15 tons/hour (continuous mixing). Raw material stocks are sufficient for a four months' supply; the main bulk store is at the harbour, 11 km from the plant site. Because of long lead times, stocks are much larger than those usually held in developed countries.

180. Recruitment and training were virtually important because the turnover of personnel was very high. The number of expatriate staff had to be increased. It takes three to four years to train a good group of potroom operators, and refresher courses at regular intervals are necessary.

181. The company has adopted a policy of health monitoring from recruitment onwards. The medical service set up includes a comprehensive industrial health programme and was extended to outside patients. It employs 40 people, including three doctors. The support services were also of importance to the whole community.

Conclusions

1. Unlike smelters in developed countries, smelters in developing countries will have to provide a large number of direct social services to employees and their families. These services run from schooling and training through medical care and industrial health schemes to sports and leisure activities.

The staffing requirements of various plants should therefore not be compared without taking due account of these extra services.

2. Investment will hardly ever yield fast returns in conventional economic terms and generally benefits the economy rather than the owners. Aluminium smelting is therefore particularly suitable for government partnership in the form of a joint-venture company. (ALBA was developed from an aluminium smelting company into a comprehensive industrial corporation that provides a wide range of services to the local community.)

3. The highest echelon of the corporate management should be employed under a special company scheme and not seconded by a management contractor.

4. Special attention must be given to creating corporate identity and a corporate spirit within the joint-venture company.

THE VOLTA ALUMINIUM COMPANY, GHANA

A.F. Garcia, Reduction Division, Kaiser Aluminum and Chemical Corporation

182. Ghana's Akosombo hydroelectric dam provides low-cost electricity, and VALCO's Tema reduction plant has now a rated annual capacity of 204,000 tons of aluminium. To the original three potlines (110,000 tons capacity) a fourth was added in June 1972 and a fifth followed in March 1977. VALCO today serves markets in Europe, Japan and the United States with rolling ingot, billet, 566 kg sows and 23 kg ingot.

183. During construction (which took seven years and two months) 5,200 Ghanaians were employed on the first phase, 1,500 on the second, and 2,300 on the third. They worked an estimated 164,000 man-months.

184. There was a unique engineering requirement during construction for extensive off-site pre-arrival and pinpoint scheduling of ships, since the time from identification of a need to delivery was often as long as six months.

185. Since it was anticipated that the abundance of labour would not last for long, VALCO was not designed to be labour intensive. The decision ensured greater uniformity in production, better operating results, and higher purity.

186. A new 150,000 A pre-baked anode cell was designed for the installation and has proven to be a sound one. The potroom environmental system begins with hooded cells that evacuate particulate matter and gases at a rate of 113 m^3/min. The emissions are passed through multicyclone dust collectors and then dispersed through a stack 152 m high.

187. An early decision was that the company would build and operate its own hospital, school, commissary, and recreation facility. A government agency (TDC) was responsible for constructing housing and building and maintaining residential sewage, lighting, and water services. The living quarters for expatriates are owned by TDC.

188. Favourable long-term financing was available. It was agreed that the dam would be financed by the Governments of the United States and the United Kingdom, the World Bank, and the Government of Ghana. Financing, ownership, and operation of the smelter is the sole responsibility of its owner. The 30-year master agreement was signed at Accra in January 1962.

189. The construction of the dam at Akosombo began in late 1961, and the first power was available in September 1965. Construction of the reduction plant at Tema began in May 1964, the first ingot was poured 30 months later.

190. Initial cost of the VALCO project was $120 million. Expansion required an additional expenditure of $22 million in 1972 and $63 million in 1977. The cost of the Akosombo dam and powerhouse, the transmission network and support facilities has been estimated at $175 million. The power contract setting the rates up to the end of 1997 has since been renegotiated and the rate to VALCO increased three times.

191. Pursuant to an initial decision, Ghanaians were recruited, trained and developed to assume supervisory control in key management functions as soon as possible. The policy was successful and has brought carefully selected Ghanaians very rapidly into the higher levels of plant management. Below this level - for first-line Ghanaian supervisors, and hourly maintenance and operations personnel - an in-house training plan and schedule was developed in 1964. A key in the maintenance training programme was retention by Kaiser Aluminum of an international industrial training consultant. In addition, Kaiser Aluminum developed in-house tests to establish the level and capabilities of those applying for employment. Throughout the training a ratio of approximately one instructor to 20 Ghanaians was maintained. On the job, the ratio was approximately one supervisor to 10 or 15 Ghanaians.

192. In the training for the first-line supervisors several important lessons were learned:

(a) Potential supervisors can perhaps be best identified by their on-the-job performance, rather than by testing or background or educational analyses;

(b) The development of tests to determine skill levels in a different culture can be very difficult and test results should be viewed judiciously;

(c) Training should emphasize the development of trouble-shooting skills;

(d) Guidelines should be developed and made known to each employee outlining specific job requirements and qualifications required for advancement;

(e) Training should be continuous and should prepare trainees to take over the highest management positions.

193. In connection with the expatriate staff the most important lessons learned were:

(a) In selecting expatriate staff members as much attention should be given to the family as to the individual;

(b) An "enclave" approach to expatriate housing, schooling, recreation etc. should be avoided; host-country supervisors and their families should be given every opportunity to share these facilities;

(c) The appointment of a top executive in a resident manager's position in the host country with specific responsibility for government and community relations is highly recommended.

194. The VALCO hospital has a staff of about 50. It serves all expatriates and Ghanaian supervisors and their families and all hourly employees. The families of hourly employees have a free service contracted for by VALCO at a clinic in Tema.

195. A main factor of the success of VALCO has been the mutual trust and co-operation shown by the owners (Kaiser Aluminum 90 per cent, Reynolds Metals 10 per cent) and the Government of Ghana.

PLANNING AN ALUMINIUM SMELTER

Y. Ismail, The Aluminium Company of Egypt, Cairo

196. The capacity of the smelter will be determined by the optimum economic size, and the funds and electric power available. Nowadays, a 60,000-75,000 ton aluminium smelter is the smallest economical size, a 120,000-150,000 ton smelter can be considered to be the optimum, and a 300,000-400,000 ton aluminium smelter the maximum economical size.

197. In Egypt, Nag-Hammadi in the desert area was chosen from seven possible sites for the construction of an aluminium smelter. The reasons for this choice were the following.

198. The site is nearest to the source of electric power of the Aswan high dam. It is also accessible to the Red Sea at Safaga and the Mediterranean at Alexandria, and all local consumers by road, rail and the Nile and other navigation canals. Nag-Hammadi also offers the best conditions in view of the strategic and social requirements established in Egypt.

199. The general layout of an aluminium smelter should assume a logical location of the various production, stores and services buildings relative to each other so as to ensure the shortest transportation routes for raw materials and products and to minimise their crossing: administration and service buildings should be located upwind while units generating gases and heat, and stores of inflammable materials, should be located downwind.

CONSIDERATIONS FOR A MAJOR ALUMINIUM SMELTER PROJECT

J.A. Lang and E.P. White, Aluminum Company of America (ALCOA), Pittsburgh

Comparison of cell types

200. There are fewer environmental problems associated with the vertical stud Söderberg cell than with the horizontal stud Söderberg cell, although the vertical cell sacrifices some operating performance.

201. For the moderate production range of 10,000 to 75,000 tons/year, the Söderberg technology requires lower investment cost and less highly-skilled workers than pre-baked-anode smelter systems. From the 1960s onwards, however, economies of scale, the increased demands of the market, and environmental considerations increased the popularity of the pre-bake system. For capacities of 100,000 tons/year and over, pre-bake potlines offer the following advantages:

(a) Lower total investment cost;
(b) Lower total manpower requirements;
(c) Lower power consumption;
(d) Lower carbon consumption;
(e) Easier protection of the environment for the worker and the community.

202. Söderberg potlines have been the popular choice for many smelters with an initial or ultimate capacity of 75,000 tons a year, but in recent years industry has shown a preference for the pre-bake potlines for ultimate capacities of 100,000 tons/year or more. For Söderberg smelters, the initial savings from not building a carbon-baking furnace and rodding room are significant. It is often overlooked, however, that investment costs for the Söderberg pot itself can be slightly higher, and the cost of molten metal produced may be higher in a Söderberg potline, if depreciation costs are not counted. With increasing energy costs, Söderberg operating costs become still higher in proportion. A choice has to be made between investing more in a pot designed for lower current density - and consequently lower power costs - and accepting a higher incremental power cost. Normally, more workers are required in a Söderberg potline than in a pre-bake potline. This fact has become more meaningful as workers resist the demanding working conditions in a Söderberg potline. The costs of environmental equipment are rising fast - and even faster in a Söderberg design.

203. Söderberg smelters may require up to 30 per cent more employees per ton of installed capacity than pre-bake smelters in the 60,000-80,000 tons/year range.

204. It will be seen from the foregoing that in the capacity range of 75,000-100,000 tons/year, either the Söderberg technology or the pre-bake system might logically be specified. A decision will be influenced by:

(a) Plans for future expansion;

(b) The availability of suitable manpower;

(c) Specific environmental requirements for the community and the worker - including the need for heat protection in hot climates;

(d) The costs of financing and technology.

205. An examination of existing installations and those announced or contemplated indicates that most future smelters will be of pre-bake design and that economies will dictate a capacity of 100,000 tons/year or more.

206. The break-even point for Söderberg and pre-bake smelters may be put at 80,000 to 90,000 tons/year.

Site and environmental considerations

207. Climate and manpower availability must be considered. Infrastructure may be a large expense. Investment cost must include facilities for proper control of air, water, noise, and solid waste.

Size of potline

208. Most new potlines have a capacity of 60,000 to 100,000 tons/year and use the pre-bake system. Potlines of 240 pots are reported and some of 250 to 260 pots have been proposed. However, potline taking 135 MW (corresponding to a capacity of 75,000 tons/year) can make a disproportionate demand on a power grid. In case of a 120,000 tons/year smelter it is suggested that two potlines are preferable to one. A 100,000 tons/year potline will take 900 to 1,000 volts, and this requires dedicated maintenance and well-trained technical personnel to maintain equipment and insure the safety of the potroom employees. (One possibility is to increase total capacity to 120,000 tons/year, using two potlines of 625 V each.)

209. A larger number of pots in a smelter line places a greater responsibility on the foreman and the workman, and this affects the training required. It is easier to train men and reach optimum efficiency on a potline of 100 pots than on a potline of 200 pots.

Training

210. In-plant excercises should be coupled with classroom lectures. It is recommended that personnel for the following job responsibilities should first be trained at an existing smelter:

Works manager
Production manager

Technical manager (or chief process engineer)

Potroom superintendent

Potroom foreman - potroom technicians - potmen

Electrode foreman - electrode technicians - process operators

211. For smelter start-up and on-site training the supplier should provide the following personnel:

Production manager (one person)

Production superintendents (available for several months)

Process engineers to assist with start-up, plant operations and training

Technical foreman (who assist with the commissioning and start-up of the smelter. They might also be available for several months to assure constant coverage of the smelter. They work with the customer's foreman to assure that the latter have learned as much as possible. The total time required for training would depend on needs - from three months to one or two years.)

Products

212. Product mix for future smelters will depend on probable customer demand. Modern ingot-casting equipment is expensive; so it is important to determine the product mix as accurately as possible. If too many ingot products are specified, facility costs are disproportionately high. Sales revenue can often be increased if high quality (chemically and physically) produce are offered to customers rather than lower grade remelt ingot or 500 kg sows.

THE DUBAL ALUMINIUM SMELTER AT DUBAI

H.E. Niehaus, Dubai Aluminium Company (DUBAL), United Arab Emirates

213. DUBAL is 80 per cent owned by the Government of Dubai and 20 per cent by Alusmelters Holdings, Inc., which also includes a local Dubai interest. The total capital price of the project of building a 135,000 ton/year aluminium smelter in the vicinity of Jebel Ali (34 km south-west of Dubai) is $612 million. This sum also includes the cost of a 25 million gallon/day desalination plant. (The smelter will absorb only 500,000 gallons.) The development includes a 74-berth port (alumina will be delivered by bulk carriers of 20,000-60,000 tons dead weight), a new city, an international airport and several industrial plants.

214. The construction of the plant was started on 14 February 1977. The first metal production should start in mid-1979, and full capacity should be reached by early 1981.

215. The electricity supply of nearly 300 MW is to be provided by 13 gas turbines, waste heat will provide steam for the desalination plant. The gas will be associated gas from off-shore wells. (If the gas supply is interrupted, distillate oil sufficient for 15 days running is available in storage tanks.)

216. The smelter. The smelter will consist of 3 potlines, each comprising one hundred and twenty 150 KA centre-feed pre-bake cells in two separate potrooms. The cells will be complete with individual alumina hoppers, crust-breakers and fume shields. Dry scrubbers will be situated between each pair of potline buildings. Each potline will have a complete computer input/output terminal.

217. A mini-computer in the rectifier power area will provide the load control on each individual potline and prevent excessive peak demands on the power system; it will also provide a continuous control over critical operation parameters of transformers and rectifiers. The computer control of the potline electrolytic cells will continuously scan and regulate the resistance of each cell, and rapidly detect and suppress anode effects. (There will be no need to break the crust and feed alumina to a prescribed schedule.)

218. Cast-house. The hot metal could be cast directly into 540 kg sows, and there will be facilities for casting extrusion billets, rolling ingots and T-ingots up to 29,500 kg in a single drop, for a maximum length of 760 cm.

219. The homogenizing furnace will accept billets up to 7.6 m in length and process them at a rate of 7,300 kg/hour. The single straight-line foundry ingot-casting system will produce 5-12 ingots (22.5 kg each) per minute. The SCR 3 aluminium rod mill system will produce EC and electrical aluminium alloy rod continuously directly from molten metal.

220. Anode manufacturing. Cathode-ramming paste and anode blocks will be produced from calcined petroleum-coke, pitch and reclaimed green and baked carbon scrap, including spent anode butt scrap. Dust collection and recycling equipment will be included throughout rodding to meet environmental standards.

Manning table

	Salaried staff	Hourly-paid	Total
Works management	2	2	4
Industrial relations	12	76	88
Administration	24	44	68
Technical	25	44	69
Engineering-design	28	12	40
	91	178	269
Operations	82	849	931
Maintenance	40	398	438
Labour		40	40
TOTAL	213	1,465	1,678

221. The facility is designed to permit the addition of another potline, or a total capacity of 180,000 tons/year.

222. Gulf Extrusions Company is building an extrusion plant near the smelter. Southwire Company and Alcan will each take 40 per cent of the metal produced; 20 per cent will go to the Government of Dubai for sale in the United Arab Emirates.

THE BROKOPONDO PROJECT (SURINAM)

H.F. Robey, Jr., Aluminum Company of America (ALCOA), Pittsburgh

223. Negoti tions between the Surin m Government and the Aluminum Company of America (ALCOA) started in 1956. An agreement on the Brokopondo project for a hydroelectric power station, an alumina plant and an aluminium smelter, was signed in January 1958.

224. The project included:

(a) A 75 km road from Paranam to the Afobaka power station (opened on 26 August 1960);

(b) A hydroelectric installation at Afobaka, consisting of a dam 6,400 feet long and 218 feet high with a reservoir of 600 square miles surface area, and a 210 MW power station with 30 MW turbines (last generation unit installed 1 December 1965);

(c) An alumina plant at Paranam, of 800,000 tons/year capacity (construction started 17 July 1963 and ended 1 September 1965);

(d) A 60,000 short ton aluminium smelter at Paranam, comprising two potlines, each of 76 vertical stud Söderberg design pots housed in two buildings of 38 pots each. Because of power limitations, expansion is improbable (start-up of first potline 1 September 1965);

(e) A simple carbon plant. (Briquetted paste is shipped to Paranam from Texas.);

(f) An ingot plant to produce remelt ingot, extrusion billet and sheet ingot for shipment to America and Europe;

(g) A port, and a heavy duty bridge across the Surinam river.

225. The Surinam Government bore the costs of preliminary surveys; provided all the necessary land, water and public roads; maintained sanitation in the reservoir area; and relocated the population from the reservoir area.

226. ALCOA assumed responsibility for the financing, construction, operation, and maintainance of a hydroelectric installation, an aluminium smelter, the connecting transmission lines and the alumina plant. It undertook to conduct a $5 million 20-year exploration programme covering an area of about 2,000,000 ha. In return, ALCOA received a 75-year extension of existing bauxite concessions and new concessions and reserves. An arrangement was made for ALCOA to utilize the Western Hemisphere Trade Corporation tax advantages, and Surinam became associated with the European Common Market.

227. Because of the ties between Surinam and the Netherlands, studies were made of contractors, material and equipment suppliers from the Netherlands. Conditions leading to a departure from normal competitive bidding for the project were:

(a) All design would be done in the Pittsburgh office of ALCOA;

(b) Design would go on while construction was under way;

[illegible]

[illegible]

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training of good mechanics and first-level mechanic supervisors was slow and required more time than the training of operators. A special school was set up to train welders and give periodic retraining. Training in safety was an important part of all on-the-job instruction and remarkable results were achieved.

235. Peak employment was approximately 3,400, including about 140 expatriates, 25 of whom were involved in administration, accounting, engineering, and 115 expatriates were directly concerned with the supervision and training of construction crews. By 1976 the number of United States technicians had been reduced to 26. Key operating managers and engineers were assigned to the Surinam project nine months to a year before scheduled start-up.

236. As a rule, the best performers on the construction work were offered the best jobs in operations. The transition took place without major problems.

THE IRANIAN ALUMINIUM COMPANY (IRALCO)

F. Shahvarani, Iranian Aluminium Company (IRALCO), Tehran

237. IRALCO was constituted in 1967. The holders are: the Iranian Government (82.5 per cent), Reynolds International (12.5 per cent) and the Pakistani Government (5 per cent). Its aluminium smelter at Arak in Central Province has a rated capacity of 45,000 tons/year. The construction of the plant including the unloading and storage facilities at Bandar Shahpour harbour (Persian Gulf) began in October 1969 and ended in May 197[illegible].

238. The smelter is equipped with uncovered 63-68 kA pre-bake Troutdale pots. The dimensions of the pre-baked anodes are 520 x 402 x 407 mm, the anodes about 121 kg. There are two potlines (four potrooms), each of 140 pots. The fixed capital investment was $58.8 million; there are 1,250 personnel. Electric power (120 MW) is provided from the national grid.

239. In 1976, owing to an energy shortage the power supply was reduced to an average of 67 MW, and production decreased to 32,000 tons/year. Originally it was planned that 75 per cent of the output would be exported, but in the end 60 per cent was absorbed by the local market.

240. The carbon complex (carbon paste, carbon bake and rodding) produces 40,000 tons of anode blocks a year.

241. In the cast-house there are one homogenizing furnace, four holding furnaces, one pig-casting unit, and two vertical DC casting units. The current production schedule is to produce 14,400 tons/year of 10.50 and 1,000 pound pure ingots (99.5-99.7 per cent), 3,600 tons/year of foundry alloy, 18,000 tons/year of 7-inch and 8-inch 6063 billet, and 12,000 tons/year of 8-inch EC and 1,000-pound EC sow.

242. To save know-how costs, it was decided that three more potlines would be built of identical design but with hooded cells and pollution-control equipment (dry scrubbing). The cost was $120 million (including $20 million for the dry scrubbing pollution-control equipment). The work was done by a local engineering firm.

243. By the mid-1980s, production capacity will be raised to 120,000 tons/year.

244. Another smelter, with a capacity of 150,000 tons/year is planned for the Persian Gulf coast.

245. In 1975, Iran's consumption of aluminium was 61,500 tons (imports 30,000 tons), equivalent to a <u>per capita</u> consumption of 1.8 kg/year.

246. The supply of alumina is temporarily being obtained from the international market. There are long-range plans for prospecting for bauxite and other possible raw materials in Iran and also for establishing an alumina plant. It is planned to use a computer and automatic equipment in the smelter so as to minimize the number of workers.

INDONESIAN ASAHAN ALUMINIUM SMELTER PROJECT

B. Siahaan, Asahan Hydropower and Aluminium Smelter
Development Authority, Sumatra

217. The river flowing from Lake Toba in Sumatra to its estuary on the Straits of Malacca with a total fall of 900 m offers a potential power of approximately 1,050 MW. On the basis of this asset, the Indonesian Government offered favourable incentives to and concluded an agreement with twelve Japanese companies and the Governemnt of Japan to establish a joint-venture company, the Asahan Aluminium Company, in which the Indonesian Government has a 10 per cent holding that is to be raised to 25 per cent twelve years' after operations start. It has been agreed between both Governments and the Company that the Governments will facilitate the Company's access to capital and foreign exchange. The task of the Company was to develop a power plant, a smelter and the necessary infrastructure. The 600 MW Asahan hydroelectric power plant will be equipped with 78.9 MW and 87.2 MW vertical Francis turbines. The 225,000 tons/year capacity aluminium smelter will have 175 kA pre-baked anode cells in 3 potlines with 170 pots in each, with gas cleaning facilities. The size of the potrooms (with 170 cells) is 640 x 52 m. Ingots will account for 75 per cent of output and sows 25 per cent. The infrastructure to be built includes the harbour (with 3 berths), roads and bridges, and a new town of 200 ha. The estimated costs are: smelter $489 million, power plant $271 million, and infrastructure $92 million.

218. The licenses and rights of the Company are:

(a) The Government licensed the Company, for 30 years after the smelter starts to operate, to construct and operate the smelter and power-station. The Company has the right to expand the capacity of the smelter to 360,000 tons/year;

(b) The Company must put the power plant and the smelter into operation not later than eight years after the agreement is signed;

(c) During the term of the agreement the Company may import and use, in Indonesia, free of import duties, sales taxes and the like, all machinery, building materials and so forth required for construction, operation and maintenance;

(d) During the term of the agreement the Company has the exclusive right to export at its own discretion products of the smelter free of export duty and any other tax levy.

249. The Company obligations are:

(a) The Company has to train its local employees in accordance with the detailed training programme approved by the Government. The Company may not import unskilled labour and within five years after starting the operation of the smelter, not less than 75 per cent of all employees in each classification (managerial, technical, administrative, clerical and other skilled labour) shall be held by Indonesian nationals;

(b) The Company must give first priority to local services and materials and must give preference to local contractors;

(c) The Company must sell in Indonesia one-third of the aluminium produced by the smelter. (Several aluminium extruders and sheet making plants are in operation in the country.);

(d) During the first ten years following the start of operations, the corporation tax of the Company shall be 37.5 per cent of taxable income and 45 per cent thereafter.

250. To facilitate and ensure prompt and successful implementation of the project, and to achieve inter-sectoral co-ordination, a new public authority was established as sole representative of the Government and with all the powers, rights and privileges of the Government.

THE CONSTRUCTION OF THE BALCO ALUMINIUM SMELTER AT KORBA, INDIA

T.B. Singh, Bharat Aluminium Company Ltd (BALCO), India

251. India has large bauxite deposits and considerable hydro-power resources, and these constitute a basis for the development of primary aluminium production. Current capacity is 270,000 tons/year, and is expected to develop as follows:

1979	350,000 tons
1989	800,000 tons
2000	1,100,000 tons

252. The Bharat Aluminium Company (BALCO), set up in 1965, is owned by the Indian Government. The construction of an integrated aluminium complex was started in October 1969 with the technical co-operation of Chemokomplex, Hungary. The alumina plant was commissioned in April 1973. The complex has a bauxite mine and a 200,000 tons/year alumina plant. The 100,000 tons/year aluminium smelter with 100 KA cells (Söderberg VS), an anode paste plant and the corresponding facilities to produce rod, section, tube, sheet, and plate are being built with the collaboration of Tsvetmetpromexport, USSR. The first phase of the smelter (capacity 25,000 tons/year) has been in operation since May 1975. Owing to a power shortage, the second phase could not be started since 1976. Construction should be complete by the end of 1978.

253. In the smelter there will be a 408 Söderberg VS 100 kA cells placed end to end in a single row (to ensure a comfortable atmosphere with natural ventilation) in two potlines and eight potrooms. (Eight cells are in reserve.) Anode current density is 0.67 A/cm^2, power consumption is 16,020 kWh/ton. Each potline is connected to a rectifier station with six rectifier units, each of 22 kA capacity at 950 V.

254. The smelter is equipped with two-stage gas-cleaning installations (two to a potline - electrostatic precipitators followed by wet scrubbing with soda solution). The scrubbed liquor from the gas-cleaning installation and the carbon dusk skimmings from the cells are processed in a cryolite regeneration and flotation unit. The waste products are dumped in a special evaporation mud pond after treatment with lime.

255. Planned capacities for casting and semis are:

Aluminium pigs	40,000 tons/year
Properzi rods	10,000 tons/year
Extruded products (section and tube)	10,000 tons/year
Rolled products (sheet and plate)	40,000 tons/year

256. Some points of special interest that arose during the construction of the smelter were:

(a) Jungle clearance and site levelling was started even before the Government's formal approval was obtained;

(b) It was planned that 95 per cent of the plant and equipment would be obtained from within the country. Some firm orders for important items (e.g. rectifiers and the anode paste plant) were issued even before the Government's formal approval on the basis of rough estimates, and advance orders were made for certain construction materials (cement, steel sections, pipes);

(c) It had to be considered that during the monsoon season (1,500 mm rain in July, August and September) the water-table rises to 1 meter below ground level. A special task was to complete deep excavations and concreting in the critical areas so that subsequent work could continue even during monsoon;

(d) Because of the lack of argon, aluminium busbars had to be carbon-arc welded. The graphite electrodes were made from discarded stubs of electrodes of electric-arc furnaces;

(e) A restriction of the proposed bed drainage proved suitable and has saved considerable time and cost;

(f) The problems caused by the delay in the arrival from abroad of a steam pressure reducing device were solved by hiring an old steam locomotive from the railways;

(g) A chief project manager was directly responsible for all construction activities. He was assisted by civil, mechanical and electrical engineering chiefs and a chief of planning and co-ordination;

(h) A large public contractor was engaged for the main civil and structural construction work. Its men and material were available when crash activity was needed.

257. The cost of the integrated plant - including a township and social economic facilities (hospital, schools etc.) - was 2,750 million rupees. The cost of the smelter section with its auxiliary units (anode paste plant, gas cleaning etc.) was 800 million rupees. The social economic facilities accounted for as much as 5 per cent of the total cost of the project. A volume of 1,200,000 m^3 of earth was excavated, and 150,000 m^3 of concrete were used.

258. The enterprise meets the entire cost of medical facilities for all its employees and their families and provides housing to over 70 per cent

of its employees. The education of employees' children is also provided at a nominal fee up to high school level.

259. BALCO organized a proper training centre well in time. As a result, about 60 per cent of the smelter crew who are now running the plant successfully and efficiently, were complete beginners with no prior experience in any factory.

Annex I

SOME DATA ON POLLUTION AND POLLUTION CONTROL

Fluoride emission. The quantity of fluoride emitted from the pots, expressed in kilograms per ton of aluminium produced.

Type of pots	Fluoride Gaseous	Fluoride Solid	Total
Söderberg	19	4	23
Pre-bake (about)	7.5	7.5	15

(See references 1,2, and 3)

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

In the United States, regulations for the control of fluoride emissions are based on the "process weight rate" for dust emission. This relates emission to the total weight of materials processed. The formula used, for areas that are less than 50 per cent urban, gives the following permissable emission figures:

Aluminium production rate tons/year	Allowable emission kg/ton Al
15,600	3.0
93,600	1.7
187,200	1.0

(See reference 4)

With a few exceptions, only industrialized countries have promulgated emission standards and regulations. They include the following:

	Maximum emission (kg F/ton Al)	
	Fg	Ft
Federal Republic of Germany (proposed)	1.0	
Japan (Fukuoka) (see reference 5)	1.2	
Japan (Kagawa)	1.0	
Netherlands	0.37	1.12
Norway		1.3
United States (Federal, proposed)		1.0

Working environment. The threshold limit values (TLV) recommended by the American Conference of Governmental Industrial Hygienists for 1974, are:

	mg/m^3
Fluoride (as F)	2.5
HF	2.0
Fluorine F_2	0.2
SO_2	13
CO_2	9,000
CO	55
Coal tar pitch volatiles (benzene-soluble fraction)	0.2

Other recommendations:

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

The major pollutant of environmental concern emitted by the aluminium industry is fluoride. Benzopyrenes are also causing health concern. Severe effects such as crippling fluorosis have so far only been observed from long-term occupational exposures. It has been estimated (see reference 6) that the exposure limits for hydrogen fluoride and inorganic fluoride recommended by the United States National Institute for Occupational Safety and Health:

2.5 mg of F/m^3 of workplace air,
4.0 mg of F/1 of urine collected preshift, and
7.0 mg of F/1 post shift, are a valid protection for a worker's health.

For domestic animals, levels up to 40 ppm of fluorides (such as NaF) could be ingested without clinical interference and with normal performance. For turkeys and laying or breeding hens, tolerable levels up to 400 ppm have been reported (see reference 3).

Fluoride is the most phytotoxic pollutant and may cause injury to susceptible plant species at atmospheric concentrations less than 1 part per billion or 0.8 $\mu gF/m^3$. Fluoride has also one other important characteristic - it accumulates in the plant.

The cost of removing fluorides from effluents by various treatments has been estimated for a plant producing 250 tons of aluminium a day, with a daily flow of 20,000 m^3 of effluent containing 35 ppm of fluoride.

Process	Residual discharge fluoride kg/1,000 kg	Capital cost[a] ($/annual ton)	Total operating cost ($/ton)
Dry scrubbing	0	48.6	19.8
Wet scrubbing (once through)	5	9.0	4.5
Wet scrubbing (recycle)	1	12.2	7.5
Recycle with bleed and filtrate treatment	0.05	14.0	8.4
Once-through and alum treatment	1	22.2	16.7
Once-through and activated alumina treatment	0.25	11.3	9.4
Once-through and hydroxylapatite treatment	0.25	26.6	24.0
Once-through and reverse osmosis treatment	0.8	-	29.7
(See reference 7)			

Note: Capital costs have been adjusted to 1975 dollars.

a/ Dollars/annual ton = total capital cost divided by annual production rate rate.

Comparison of smelter gas effluent treatment systems

Effect and cost (closed pre-bake cell-case only)

System applied: Primary cleaning	Secondary cleaning	Emission kgF/ton Al (95% hooding)	Investment cost of gas cleaning equipment $/annual ton Al	Operation cost increment $/ton Al
None	None	16	-	-
Wet scrubber	None	3.8	56	23
Alumina + bag filter (dry system)	None	1.3	89	20
Alumina + bag filter (dry system)	Spray screen	0.7	141	40

The costs of alternative methods of smelter gas emission control have also been reported by the International Primary Aluminium Institute (IPAI). According to their findings, if the investment cost of one ton annual smelter capacity is assumed to be $2,000, the fluorine emission control equipment will cost an additional 2 to 11 per cent of this (average 6.6 per cent). The additonal operating cost increment, due to emission control, for pre-bake anode cells, will be between $6.17/ton aluminium (dry primary system only) or 0.8 per cent to $52.75/ton aluminium (wet primary plus wet secondary system, including multi-purpose cryolite recovery plant), or 6.6 per cent.

The later introduction of gas collection and treatment in old plants may cause technical difficulties and additonal cost. Menegoz and Sala quote these increments of investment costs:

	Investment cost increment $/ton annual capacity
Gas collection only	17.87
Roof screen only	39.00
Collecting, plus secondary system	60.75-63.60

(See references 2, 8 and 9)

The air pollution control measures applied in aluminium smelters are summarised in Singmaster and Breyer (reference 10), and data concerning considerably increased occurrence of lung cancer among workers in electrolysis halls in the USSR were reported in Konstantinov et al.(reference 11).

Annex II

LIST OF PAPERS SUBMITTED TO THE WORKSHOP

ID/WG.250/1	Indonesian Asahan Aluminium Smelter Project B. Siahaan
ID/WG.250/2	Background Paper on the Volta Aluminium Company (VALCO) A.F. Garcia
ID/WG.250/3	Planning of Aluminium Smelter Y. Ismail
ID/WG.250/4	Background Paper on the Iranian Aluminium Company (IRALCO) F. Shahvarani
ID/WG.250/5	Aluminium Smelter Construction in Developing Countries Secretariat of UNIDO
ID/WG.250/6	Background Paper on the Aluminium Bahrain (ALBA) Project P.U. Fischer
ID/WG.250/7	Construction of an Aluminium Smelter and Related Facilities in a Developing Country - The Brokopondo Project, Surinam H.F. Robey, Jr.
ID/WG.250/8	Considerations for a Major Aluminum Smelter Project J.A. Lang and E.P. White
ID/WG.250/9	Background Paper on the Planning of the Aluminium Smelter for Guyana P.A. Thompson and E.L. Carberry
ID/WG.250/10	Background Paper on the Construction of the Balco Aluminium Smelter at Korba, India T.B. Singh
ID/WG.250/13	Background Paper on the Puerto Madryn Aluminium Smelter Argentina N. Angelucci
ID/WG.250/14	Background Paper on the Dubai Aluminium Smelter in Dubai, United Arab Emirates H.E. Niehaus
ID/WG.250/15	Development of the Aluminium Industry in Brazil R. de Campos Machado
ID/WG.250/17	Status Quo and Trends in the Primary Aluminium Industry D. Altenpohl

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