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04876

Distr.
LIMITED

ID/WG.146/60
21 May 1973

ORIGINAL: ENGLISH

United Nations Industrial Development Organization

Third Interregional Symposium
on the Iron and Steel Industry

Brasilia, Brazil, 14 - 21 October 1973

Agenda item 8

THE ORGANIZATION OF INDUSTRIAL RESEARCH IN A DEVELOPING COUNTRY : THE METALLURGICAL INSTITUTE "HASAN BRKIC", ZENICA, YUGOSLAVIA[1/]

by

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id.73-3764

SUMMARY

The present steel production in Yugoslavia amounts 2,5 million and an increase is expected in the next few years to 5,0 million t. The biggest steel mill is Zenica, located in the central region of the country having a very old tradition in iron & steel making. It was in Zenica that it was decided to organize a metallurgical industrial research institute, having in mind the good possibilities of cooperation with the industry. In setting up the research programme one selected the basic orientation to the beneficiation of raw materials and product research, those problems, the solution of which can hardly be expected from abroad. Starting with this activity in 1961, the Institute developed very successfuly, being today one of the biggest research organizations in the country. It has a total of 270 employees, 75 of them having a University degree, and beyond that it engages more then 120 specialists as part-time collaborators. The Institute is situated in 6 buildings having a total area of more then 14.000 m^2. These buildings house the chemical, metallurgical, and instrumental laboratories, computer and documentation services, as well as pilot-plant installations for ore beneficiation, melting of steel and alloys, hot and cold rolling mills, hammers and presses, drawing machines as well as heat treating furnaces and maintenance shop. Functioning exclusively on contract basis with the country's steel producing and steel processing industries, the Institute's yearly turnover reached the figure of 1,5 millions $ in 1972. In the past decade considerable suc-

cess was achieved in the field of beneficiation of domestic low grade iron ores, in blast furnace productivity through the improvement of technology, in improving the cleanness and quality of steel ingots and products as well as in introduction of the use of computer in solving metallurgical problems. Particular results have been achieved in feasibility studies for the creation of a considerable number of metallurgical and metal processing industries in the country as well as in improving the organization and coordination of metallurgical production in the country. In addition the Institute's staff is capable of using sophisticated up-to-date techniques in the field of investigation and testing of materials as well as in industrial experimentation.

Zenica is also the site of Metallurgical Faculty for graduate and post-graduate studies in metallurgy, having a total of approximately 500 students in this special fields. The Institute's facilities are also used for teaching purposes.

1. Historical background

Steel production in Yugoslavia amounts today to about 2,5 million tons and is planned in next few years to be increased to about 6 million tons. This production is not located within a limited region, but it is spread all over the country in many plants. Yugoslavia has a population of about 20 million inhabitants and a total area of approximately 260,000 square km. The territory is divided into six republics which have considerable autonomy. The skill of iron and steel production is very old, especially in two republics: Bosnia and Herzegovina (central region) and Slovenia (northwest region). In these regions rich archaeological finds indicate intensive production even during Roman Empire, i.e. several centuries B.C. The reasons why this production has not reached today's technological level of developed countries come from the tempestuous history of this part of the world, i.e. west part of Balkan peninsula which was for thousand years a battlefield between East and West. Over this territory marched Crusaders, Mongol warriors clashed there with Europian armies, there were long wars between Turks and Western countries. The frontier of schism between East and West Christian churches passes also through this country. Last but not least, there began the First World War, and in the Second World War it was the scene of particularly destructive battles. Just in these difficult conditions in different historical periods in Yugoslavia existed generations of men skilled in iron production and weapon forging which often was strategic target of enemies.

A special role in the development of Yugoslav iron and steel was played by the territory of present Republic of Bosnia and Herzegovina, where the greatest iron ore deposits are located. There are Ljubija and Vareš mines whose present proved reserves amount to over 600 million tons of iron ore, while the percentage of potential explorations amounts only to about 20 %. The production of these two mines today amounts to 80 % of the total country's iron-ore production. For this reason a great number of mines, coke oven plants, iron and steel works, foundries and other steel processing factories were built in this republic. Center of this activity is Zenica where the largest Yugoslav iron and steel works was built. Production of this iron and steel works today amounts to 1 million tons of steel. At present an intensive programme of expansion is to increase its production up to 2,6 million tons. Besides, this region has also rich brown-coal deposits and great water-power potential so that there are good conditions for industrial development. Since the end the of Second World War, Yugoslavia has concentrated its endeavours to overcome under-development, utilizing as much as possible its existing natural resources. During the 27-year period, steel production has increased from 0,2 to 2,5 million tons, i.e. more than twelve times. Having in mind that Yugoslavia started its contemporary development as an under-developed country, as illustrated in particular by its lack of capital and skilled workers and experts, the achieved progress represents in fact an imposing degree of development which has today very sound conditions to be in future increased and stabilized.

Actual steel production in Zenica has started in 1892 when industrialists of Austrian-Hungarian Monarchy contructed the first plant to produce steel for concrete reinforcement. The research and development activity was initiated between the two world wars, when at the end of the thirties a very modern laboratory was built in Zenica. Beside the activity connected with control of materials and finished products, there were performed various research activities in order to reduce rejected material scrap, to find out reasons of quality failure in particular phases of technological processes, etc. Very interesting are reports on desulphurization in open-hearth furnaces, experiences with open-hearth furnace basic roof, influence of copper, arsenic,and antimony contents on steel ingot and rolled products surface, etc. Modern techniques of chemical, metallographic,and mechanical testing of material were applied and the activity was promoted by production requirements. This activity was continued after the Second World War, but in the circumstance of rapid expansion of the Iron and Steel Works Zenica, including new facilities such as coke oven plant, blast furnaces, large open-hearth tilting furnaces, new rolling mills, shop for production of heavy open-die forgings, etc.

Due to the lack of appropriate experience, the selection of these processes and equipment, as well as project elaboration, were made using the help of foreign experts. It is obvious that it impeded the realization of corresponding production. Some of these difficulties are specific for existing conditions and in short, they were the following:

Low-quality blast-furnace burden due to the use of crude iron ore with high fluctuations in iron content and impurities including a gangue containing quartz and barite. No beneficiation process was applied and only one part of iron ore was agglomerated. Besides, blast-furnace process control was not efficient and it caused great oscillations in blast furnace performance, frequent breakdowns as well as low production and high coke consumption (over 1000 kg/t of iron).

Mn content in this ore was high (Fe:Mn ratio 10:1) so that its smelting gave a high Mn pig iron. Remelting of such pig iron in open-hearth furnaces caused further difficulties due to slag foaming. It was particularly complicated to produce rimming steel, because ingots contained a great number of blowholes located very near to the surface. A special procedure had to be introduced in open-hearth practice (the modified Talbot process), since the existing conditions required very high percentage of molten iron in charge, due to the shortage of scrap on domestic market.

The presence of various residual elements, especially Cu, Sb, and As, in iron ore, decreased steel hot workability and caused rough surface, especially cracked edges of rolled sections. Corresponding roll pass design to avoid high deformations by hot rolling had to be developed. All these difficulties were specific for the given raw material basis. However, there were other difficulties due to slow transfer of technology from developed countries as a consequence of shortage of experienced technologists. The lack of experience in deoxidation, ingot pouring and casting pit practice as well as in achieving of the prescribed quality of finished products according to the corresponding standards should also be mentioned. At the same time the organization and planning of production was poor, particularly quality control, economy of energy consumption, lack of information and data processing service, etc. Due to all these facts, a much longer time was necessary to achieve economically and technologically acceptable efficiency of new industrial facilities. However, at the same time, it was a chance to get experience necessary for a developing country. It became obvious that for a successful development of a country it is not sufficient to have only capital and new factories, but also to have experienced technicians and skilled labour as well as knowledge of technology as a prerequisite for better utilisation of existing facilities and efficient contribution to national economy. Such were the reasons that the endeavours for further steel industry development and organization led to a decision to establish an industrial research institute. So the iron and steel industry of Bosnia and Herzegovina with the agreement of Government of Bosnia and Herzegovina established the Metallurgical Institute in Zenica on the 1st October 1961, as an independent professional research organization.

2. The concept of research philosophy and the Institute's development

Institute's staff nucleus consisted of 8 engineers with a long experience in quality control and laboratory work in the Iron and Steel Works Zenica. At its disposal were given about 50 skilled workers, technicians and administrative personnel, together with a laboratory of 2000 square meters, equipped for basic metallographic and mechanical testing, as well as for analytical services. This was only a temporary solution until the new working premises and corresponding equipment were obtained. However, the Institute immediately organized its business on a contract basis with the industry, giving research services according to its capabilities. In the case when it was not able to realize contracted services with own staff, it engaged experts from other firms specialized for the given matter. This collaboration proved to be useful not only for work intensification in the Institute itself, but also stimulating an interest of wide range of experts for research and development and giving thus another contribution to Institute's popularization. Every service was defined by a contract including both parties' obligations, terms, costs, etc. Such a course forced Institute to form a department for research administration at the very beginning of its activity. However, the main task of the new institution was to elaborate projects for future development, since availabe conditions, as was mentioned earlier,

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were temporary and inadequate.

Determination of development concept and elaboration of future institute projects were the subject of serious considerations. Many similar institutions in developed countries, especially in USA, USSR, F.R. Germany, England, France, etc. have been visited in order to get an idea about organization system and necessary equipment. However, it is necessary to bear in mind that it is not possible to copy such organizations. This could lead to some difficulties, if the Institute was not able to meet actual requirements of the existing and future users. It is understandable that the human factor and country's economic potential, particularly that of the country's steel industry tradition, habits and other factors connected with the given environment, have to be taken into account. Therefore, the first efforts were directed towards definition of research philosophy and research programme establishment. Since an industrial institute is in question, it is understandable that the priority is given to applied research and development. However, within these global frames there were necessary special efforts to elaborate a research programme more precisely. It should always be kept in mind that there are possibilities to use the knowledge and information which are already available in the world, instead of losing time and money on already known results, which could be much more easily obtained by an appropriate transfer of technology. As the first step, library and documentation service should be organized more efficiently in order to obtain and disseminate as much information as possible on development relevant to steel industry.

Having in mind the fact that research in metallurgy could be classified into three basic activities - process research, product research and management research - each of these branches was the subject of detailed considerations. The aim was, by defining the research policy, to make a concept of working premises and to select the equipment for future institute.

Process research covers technological problems starting with beneficiation and agglomeration of ore, then ore smelting and steel melting processes, ending with steel ingots production. A smaller part of such research work could be performed using industrial facilities, but important problems require semi-industrial pilot plants which are usually very expensive.

It seemed unrealistic to include this type of equipment in the basic programme of the Institute. Two facts were decisive: financial and staff potential of the country. Furthermore, the insufficient economic power of the domestic industry hardly could secure the realization of such new technology because of high investment cost. Besides, the results of such research work covering improvement of smelting and melting processes are easily available from developed countries, because they can be obtained together with the equipment which is usually imported on credit. Therefore, a decision was taken to organize process research only for the problems the solution of which could not be expected in foreign countries. Such is the case of problems concerned with domestic raw-material basis, i.e. beneficiation and all processes relevant for domestic iron ores in order to improve blast furnace burden. Thus was born a concept to install a pilot plant only for preparation of mineral raw materials in process research, and all other problems to be solved using other countries' experiences through a well organized information service. Other process research work was to be carried out directly on industrial facilities by analysis of their performance and corresponding data processing.

Product research covers all endeavours to improve the present production quality, as well as to introduce new high-quality products into production. Such research is typical case where a non-developed country can considerably improve the efficiency of its own industry. Namely, although there is lack of economic potential and capital to build big facilities and use size-degression of costs, there is still a possibility to produce, using existing facilities, higher-quality material saleable at a higher price, which makes possible an acceptable efficiency even at lower production rate. This relates to new steel grades and alloys development, as well as to improvement of their working by rolling, forging, surface treatment, heat treatment, etc. It was decided to give priority to this kind of research.

As regards management research, there is a great number of unsolved problems concerning the achievement of better plant and commercial efficiency by organization improvement. The question is, however, how many of such problems are to be undertaken within a metallurgical institute of industrial type. It is obvious that all of them could not be taken, but some important ones may be chosen, such as application of operational research technique, information service and data processing improvement in metallurgy, especially data relevant to technological process and product quality, as well as data processing from heat economy and power consumption, etc. These fields are probably the most potential ones where the institute can make a real and specific contribution.

Resuming thus the research and development problems which should be the subject of long-term studies in the future institute, it has been taken as a basis the following:

- beneficiation and concentration of iron ores and other mineral raw materials,
- development of new deoxidation processes and improvement of steel purity,
- development of new steel grades and other Fe-based alloys and studying of changes of their properties du-

ring hot and cold working,
- studying of heat and surface treatment processes,
- studying of heat economy problems, and
- operational reseach, information and data processing.

Besides, it is anticipated to develop good library and documentation service.

Organization set-up and elaboration of a Master Programme

After determination of basic directions of research, the future organization of the institute was set up. This organization included three types of organizational units. Basic cell comprises units concerned with particular phases of technology. Such are departments for iron ore beneficiation, general steel and alloy metallurgy, mechanical metallurgy and processing of steel, furnaces and fuel economy, and safety in metallurgy. These departments have to be completed by necessary laboratories,which are divided into four specialized groups: group of chemical-mineralogical laboratories, group of laboratories for physical metallurgy, then mathematical and documentation centers. Besides, it was necessary to organize the service to take care of operation of the whole institute, like administration and maintenance departments. Set-up of such a scheme is shown on fig 1. Basic feature of this structure is the functioning of the institute as an integral organisme and that all organized units are firmly interrelated and bound to collaborate. For example, analytical requirements from all departments are dealt with in chemical laboratories, information and data requirements in Center for documentation, metallographic testing in Department for physical metallurgy, etc. Also, there is an integral organization for administration services which are concentrated in administrative function. This is the same with maintenance. This type

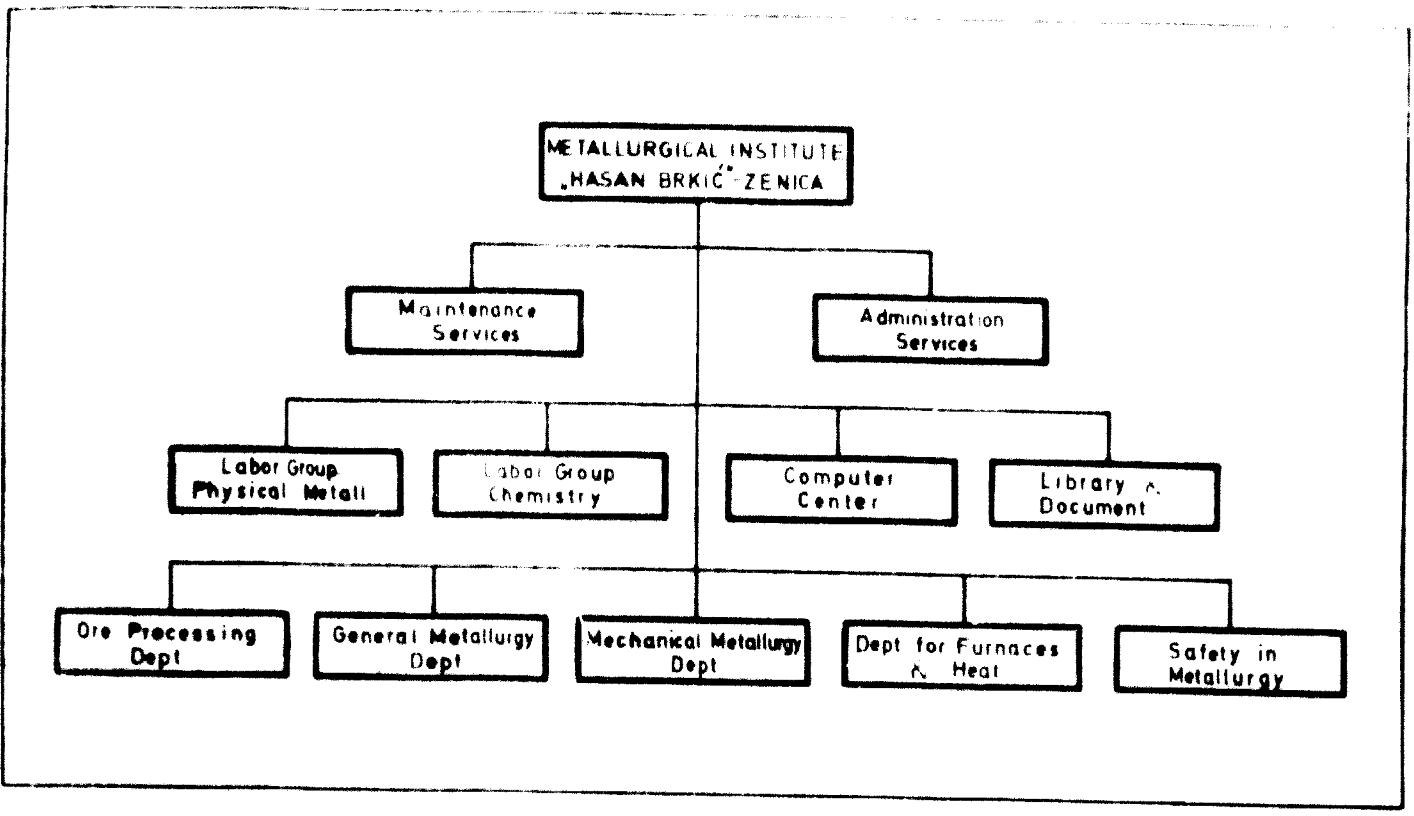

Fig 1.: Organizational structure of the Institute

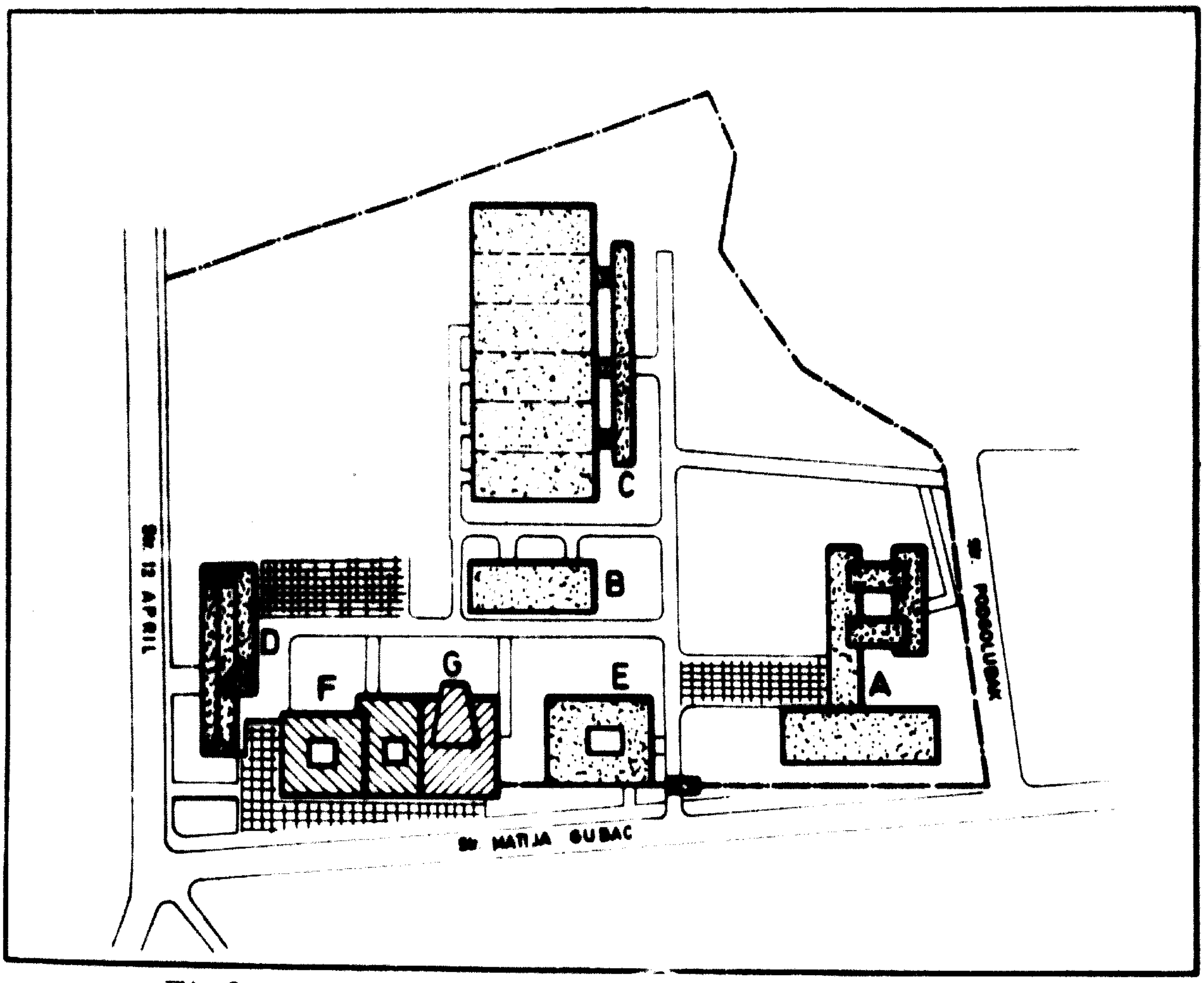

Fig 2.: The general lay-out of th · Metallurgical Institute - Zenica

of organization prevents the fragmentation of the institute, but stimulates the staff for cooperation and specialization. This organizational concept was the result of long experience and intensive considerations.

An analysis of research work gives a breakdown of the three basic types of activities :

1. Laboratory-scale research
2. Semi-industrial or pilot plant experimentation to be performed on semi-industrial facilities
3. Auxiliary intellectual activity concerned with the work in offices like drawing office, computer center, documentation services and alike.

Having such a categorization in mind appropriate objects have been designed, i.e. objects for services, laboratories, and pilot plants. Each of these objects has its own specific working conditions. By elaborating the conception of institute's project, certain circumstances, specific for given conditions, were taken into account. In the first place large objects should be avoided not only on account of technical problems such as vibration, acoustic and electromagnetic insulation, air conditioning, etc., but also because they require commitment of high financial resources, since it is impossible to build such objects step by step. Therefore, it was decided to build institute in a number of objects using an adequate free area. Such objects can be gradually constructed, technical problems can be more easily solved and financial means more easily procured, because object by object construction enables gradual accumulation of capital. So, at the very beginning it was taken into account, that the process of institute's construction will require a longer period of time and that it would take place simultaneously with regular research work. One has also to bear in mind that the engagement of research staff represents a serious limiting factor. It is not possible to get at once the whole research body, but only through gradual recruitment and training, using both domestic and international opportunities for this purpose. From this point of view, it is also more advantageous to build smaller objects. Thus one came to a concept shown on fig 2. There the blocks A and B represent laboratories for physical metallurgy and chemical investigation. The industrial-type bays for pilot equipment and semi-industrial facilities are marked by C. In a separate building is placed documentation and library service E, and in another building the administrative service D. This building D has two entrances to permit contact with clients, without disturbing research work in technical part of the institute. It is interesting to mention that in this area Metallurgical Faculty is also located. The faculty does not belong to the Institute and represents a part of the University of Sarajevo. It is equipped, however, only with laboratories for teaching purpose,whilst faculty staff uses Institute's research equipment for its scientific activity. This will be discussed later in detail.

The present institute has a total working area of about 12,000 square meters and its total area is 6 hectares.

Its objects,shown on fig 2, consist of the following:
The block A (Physical metallurgy) comprises three laboratories: metallographic, metal physical,and mechanical testing laboratory. Metallographic laboratory is equipped with up-to-date optical microscopes as well as with high-temperature microscopes and microscopes for quantitative metallography. A photographic laboratory is added to the microscope room. A special department with dilatometers, laboratory furnaces,and salt baths for heat treatment is also provided.

Laboratory for physical investigation of metals includes department for metal physics equipped with electron microscope and electron microanalyser and X-ray diffraction unit. There is also a department for defectoscopy covering ultrasonic, magnetic, X-ray, γ-ray as well as other penetrant investigations.

Laboratory for mechanical testing including static and fatigue testing, as well as creep testing, although belonging to the same laboratory group, is located in a separated building in order to prevent vibration transfer to sensitive instruments.

On the upper floor of this building, which is air-conditioned and equipped with other installations necessary for the operation of precise instruments, the computer room and laboratory for calibration of furnace instrumentation is located.

The block B has a ground floor and two storeys and is intended for laboratories for chemical analyses. On the second floor there is a laboratory for regular chemical analyses, as well as for instrumental analyses including spectral, X-ray fluorescence analyses, and atomic absorption. The first floor is for ore microscopy with corresponding photographic laboratory, as well as laboratory for ore reducibility and mineral constitution investigation including differential thermal (DTA) and thermo-gravimetric (TGA) analyses, ceramic dilatometry, etc. On the ground floor there is a laboratory for refractory materials and slag investigation. This laboratory is anticipated to give services to metallurgical industry which uses big quantities of such materials and is interested in possibilities of slag processing, especially processing of blast-furnace slag.

The block C consists of 6 bays of a size 40x15x6 meters each and it is intended for pilot-plant facilities. Two of these bays are used for ore beneficiation and agglomeration experiments including crushing and grinding facilities, beneficiation batch-type pilot plants consisting of jigs, shaking tables, heavy-media separation unit, semi-industrial flotation, etc. There is also an ore-roasting rotary kiln 12 m. long with a possibility to change the angle of slope as well as the total length; there is also pelletizing and sintering facility. The third bay, assigned to general metallurgy of steel melting, consists of an electric arc furnace of a capacity of 800 kg, two induction furnaces of 60 kg capacity each, a medium-frequency furnace for vacuum melting and pouring of the same capacity, a medium-frequency furnace of capacity of 25 kg for high-vacuum melting, an electron-beam furnace for high-vacuum melting of capacity of 85 kW. Two other bays are provided for metal deformation process study. There are facilities for hot deformation consisting of a 200 t press, a 150 kg pneumatic hammer, a three-high hot rolling mill having 350 mm roll diameter which are equipped with all necessary measuring devices. An additional experimental rolling mill with roll diameter 150 mm for small-scale experiments is also provided. There is also a four-high cold-rolling mill for cold-rolled strip up to 120 mm width with possibility to roll very low thickness. The equipment includes also two wire-drawing machines starting with 6 mm rod which can be reduced down to wire of 0,1 mm. Besides, this bay is equipped with corresponding conventional heating and special vacuum heat-treatment furnaces.

The last bay is intended for mechanical workshop where machine tools for machining test pieces and parts needed for maintenance of the Institute are provided.

Center for documentation and library services is located in building F and consists of documentation department and library with book and technical magazines store-room as well as of reading room with corresponding copying machines for xerox-copies. Library subscribes to about 400 journals, including the best known metallurgical publications. Data from these journals are regularly processed by Institute's engineers.

In building D there is central storage, as well as administration and planning services, research administration and printing office for research papers and other Institute documents. Some of the Institute's installations are shown on the attached set of pictures (Fig. 3-25).

The organization of management

The Institute's total staff numbers today 270 employees, 75 of them having a university degree. Besides, the Institute employs 120 part-time collaborators which may be engaged for special problems in some of research projects. The total turnover amounts 1,5 mil $/year, 80 % of it being realised by R&D contracts with the corresponding industries, and the remaining 20 % by various services like: analytical services, verification of industrial installations in respect to safety, sale of microquantities of special alloys, defectoscopy services, certification of engineering parts, etc. The contracts for R&D projects, however, being the main subject of activity, are characterized with some particular features which are to be emphasized. The institute has a very close relation to the country's steel industry as well as to associated enterprises, like iron-ore mines, steel processing industries, steel users etc. The mutual contacts result in various initiatives: either the industry may require a solution of some particular problems of their existing or future technology or, on the other hand, the Institute may submit some proposals for research projects based on the recent international development in a particular field. The documentation service is the basis for such a research work. The institute's documentation center gives every month a survey including about 1000 bibliographical informations which are distributed not only to the own research staff, but also to all potential business partners in the industry. It proved very stimulating to keep the production engineers and technicians informed about trends of development in relevant fields because they get interested to make use of some of the achievements. So one comes to the idea to engage the institute to apply a par-

Fig 3.: The panorama showing the Institute's premises and Steel industry installations in the back

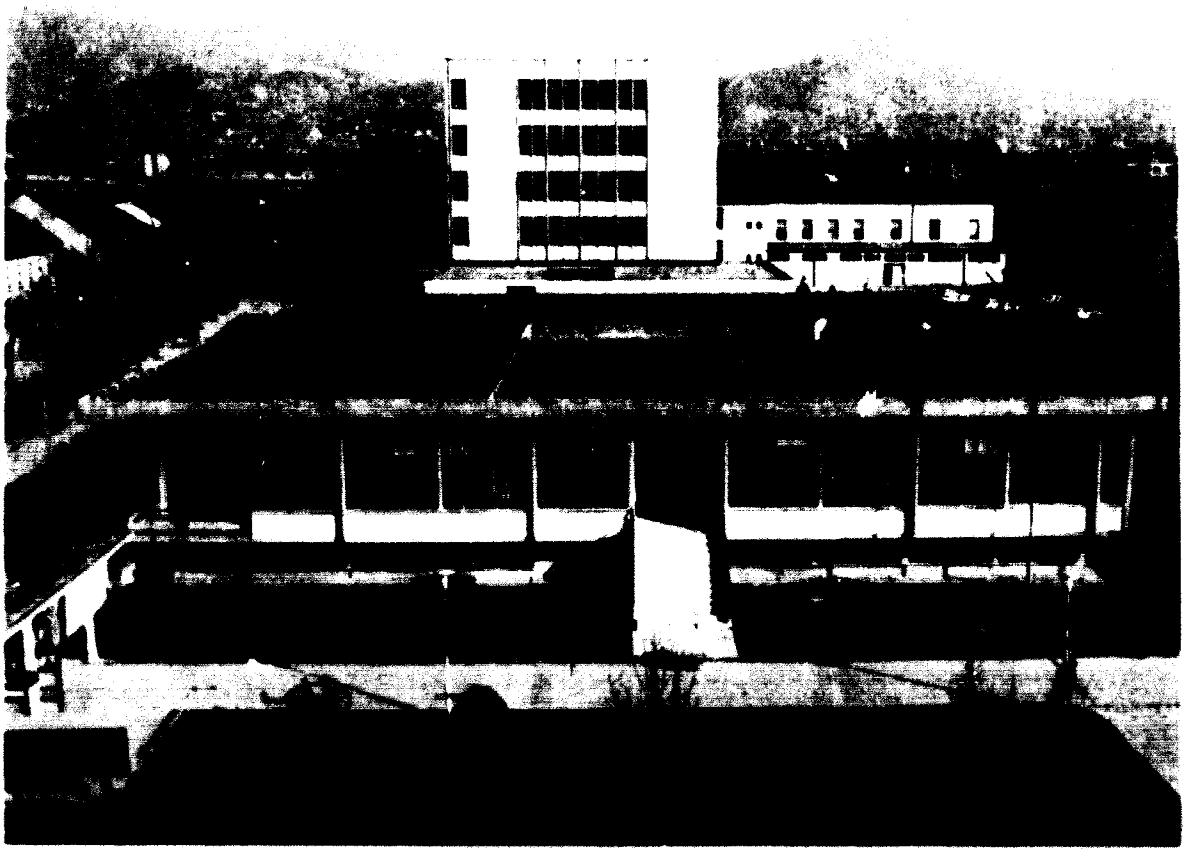

Fig 4.: Library & documentation building

Fig 5.: Reading room

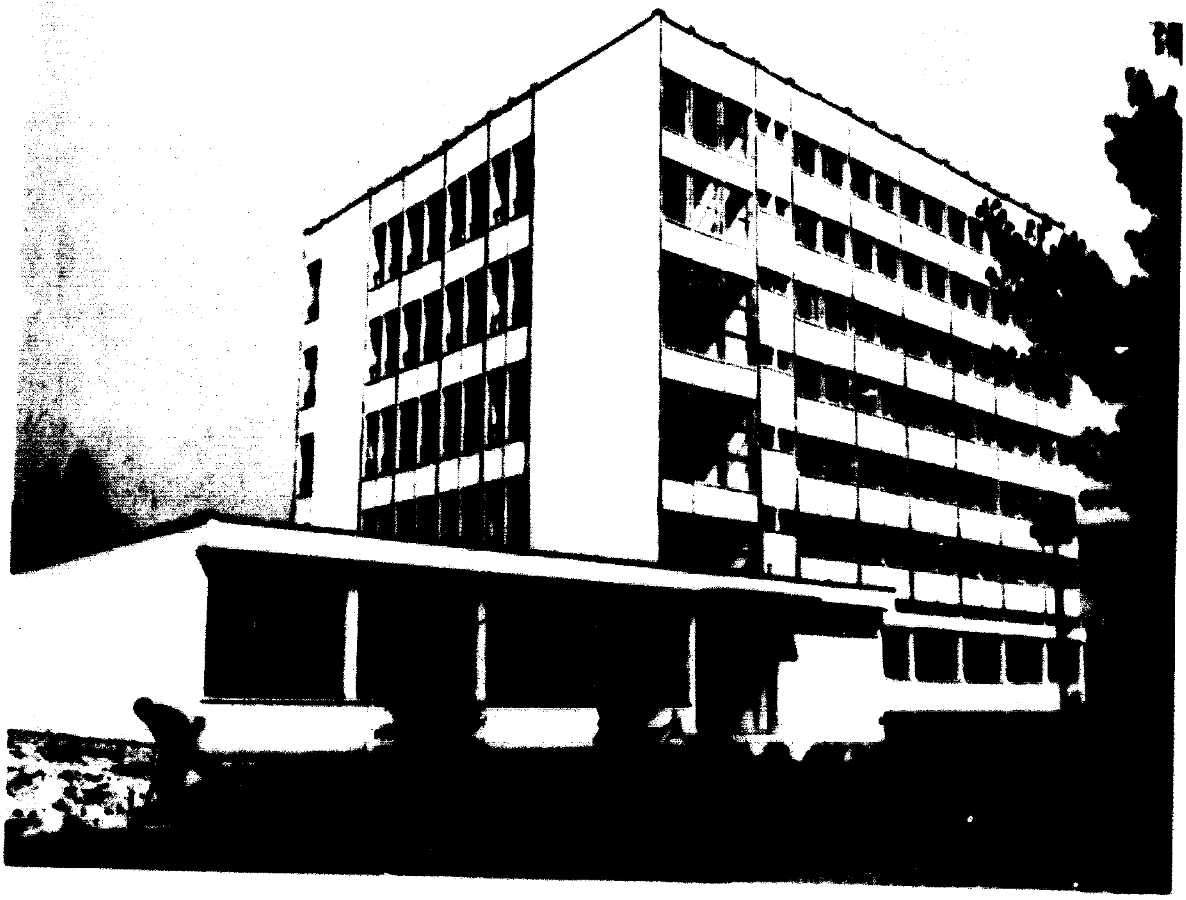

Fig 6.: Metallurgical faculty Zenica

Fig 7.: Pilot plant for flotation of minerals 300 kg/h

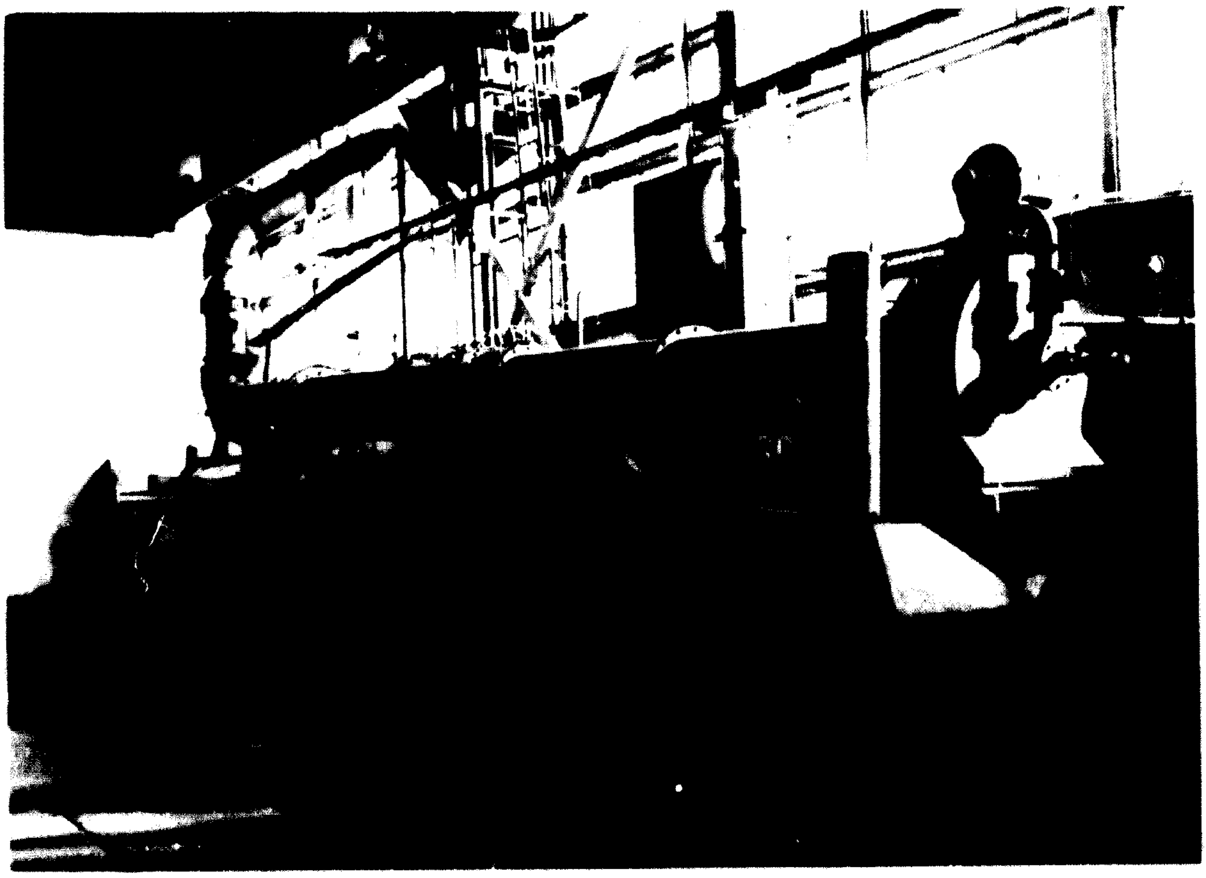

Fig 8.: Rotary kiln

Fig 9.: Electric ARC furnace 800 kg

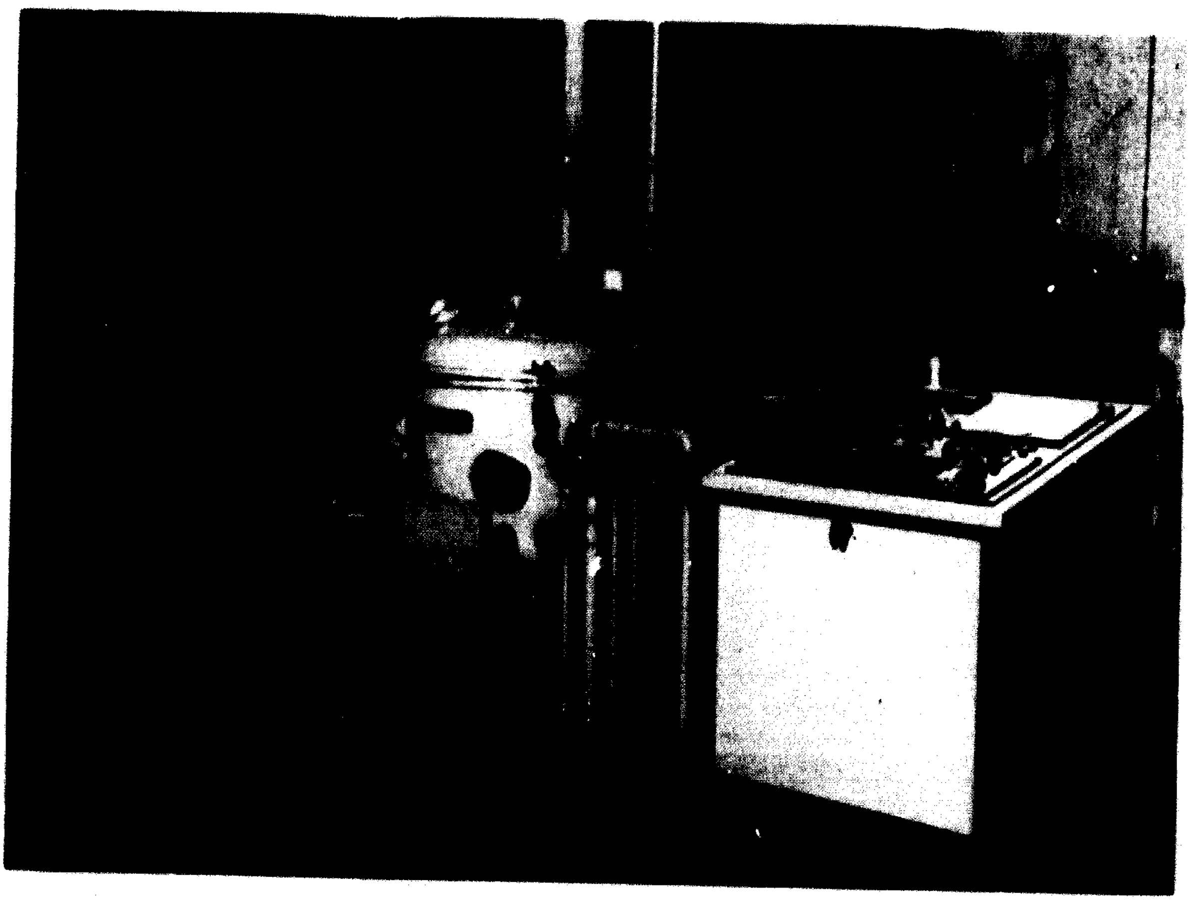

Fig 10 . : Medium frequency vacuum furnace 25 kg

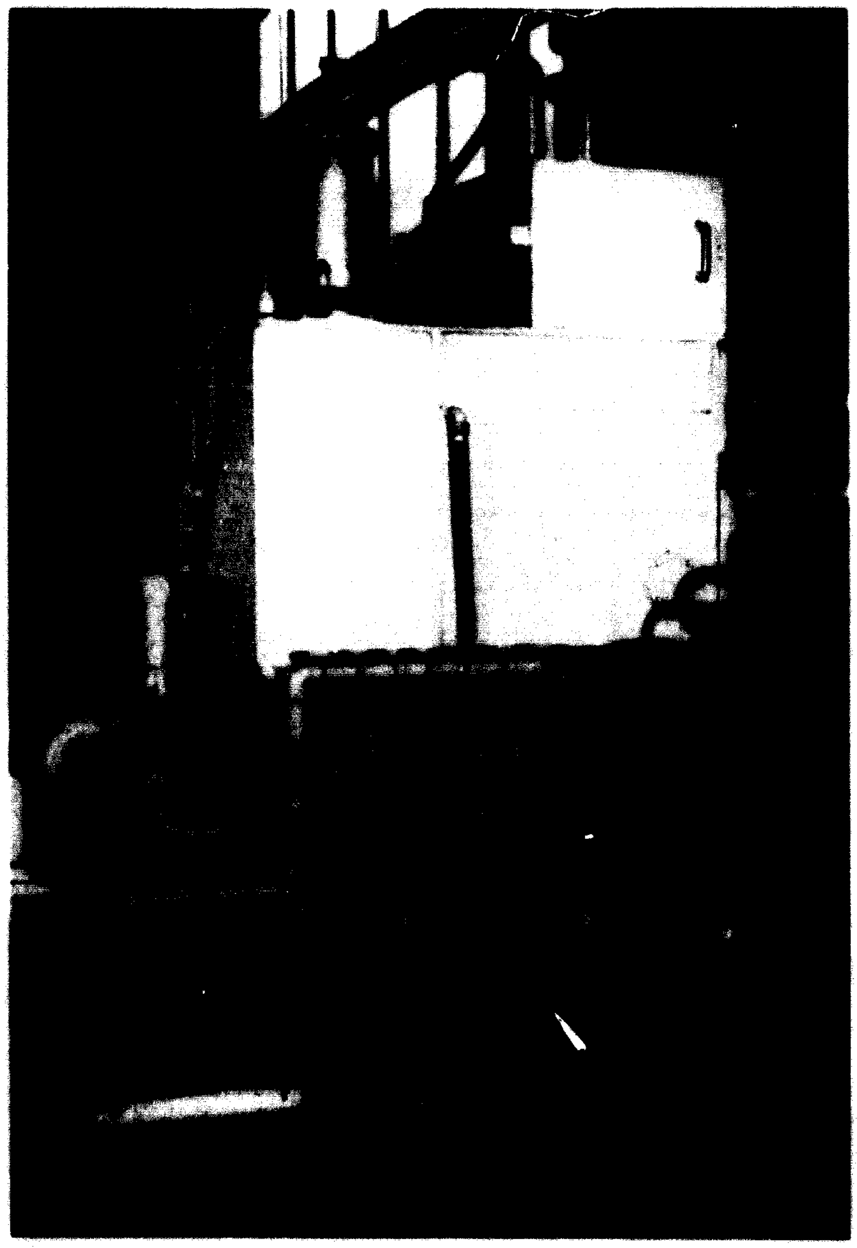

Fig 11 .: Electron beam melting furnace 80 kW

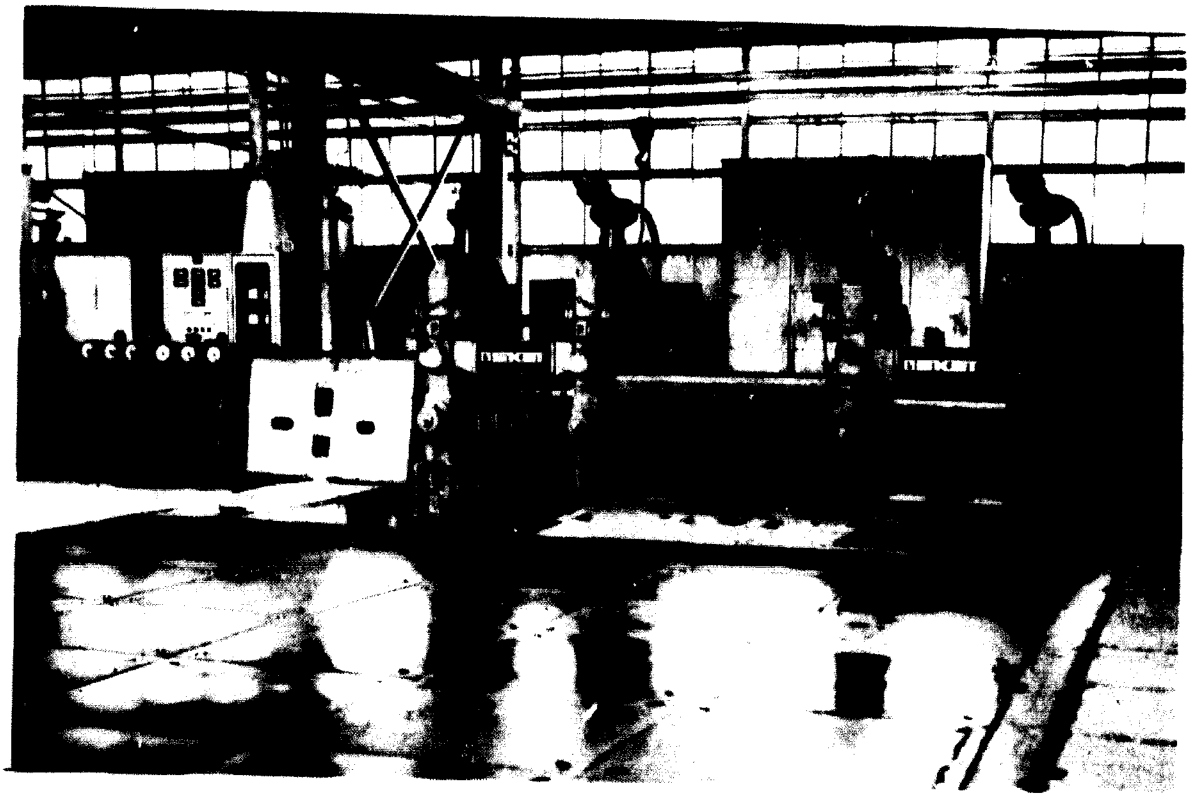

Fig 12.: Experimental rolling mill

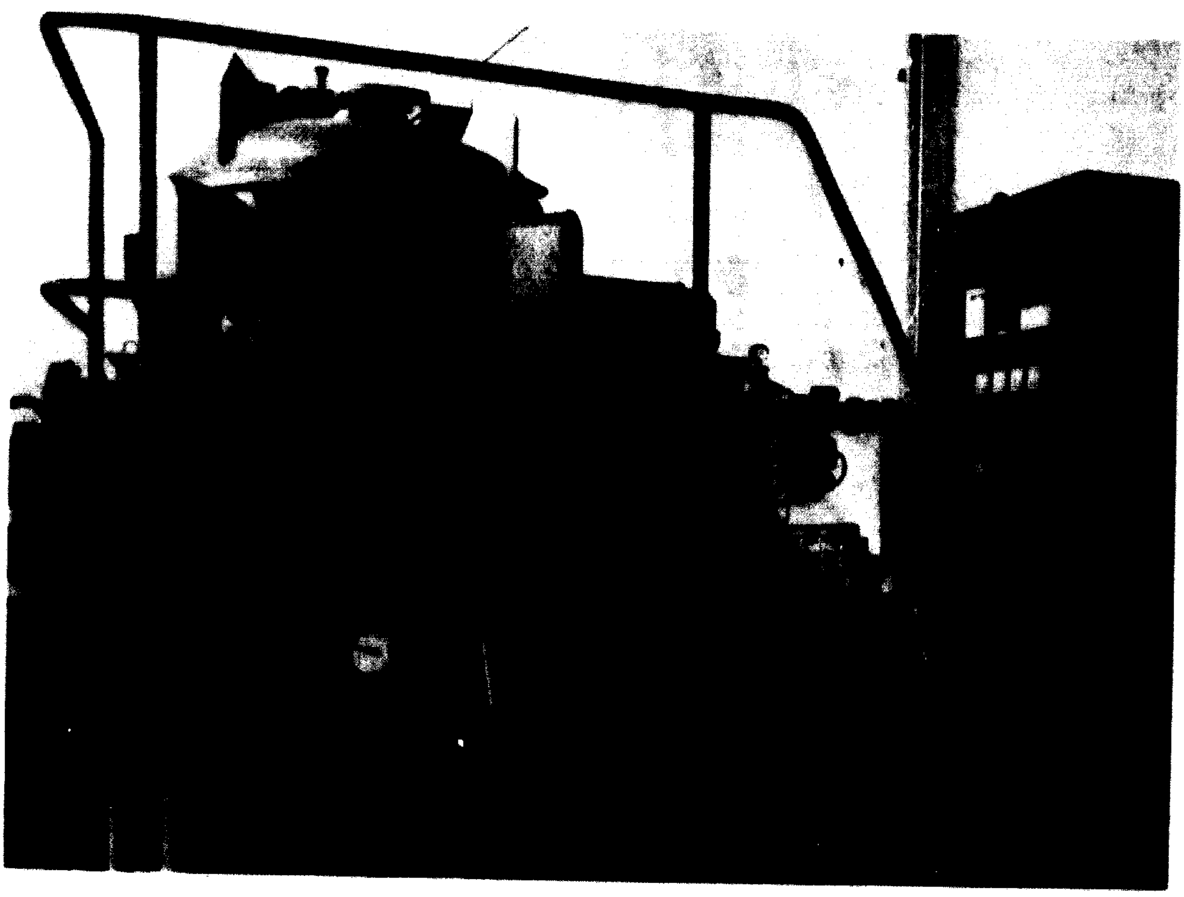

Fig 13.: Heat treating vacuum furnace

Fig 14 : Heat treating laboratory furnaces

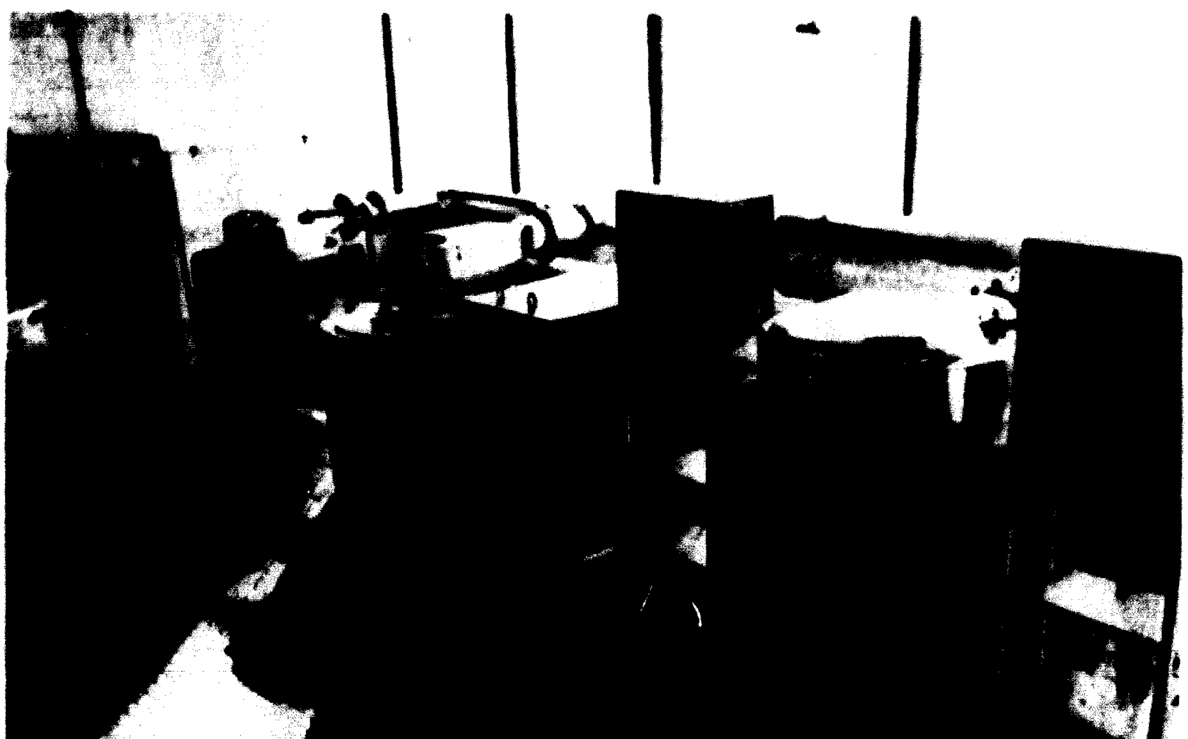

Fig 15 .: Laboratory salt baths

Fig 16 .: Metallographic microscopes

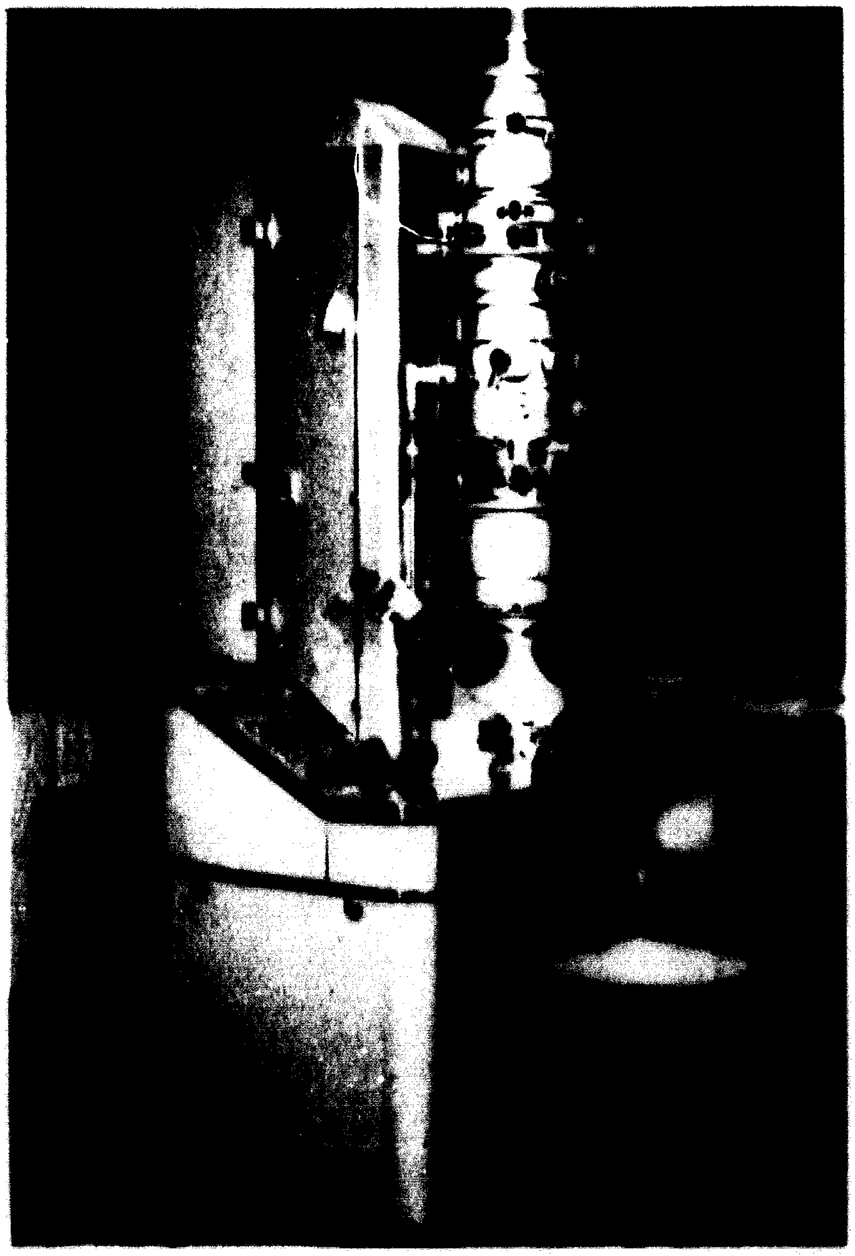

Fig 17 . : Electron microscope

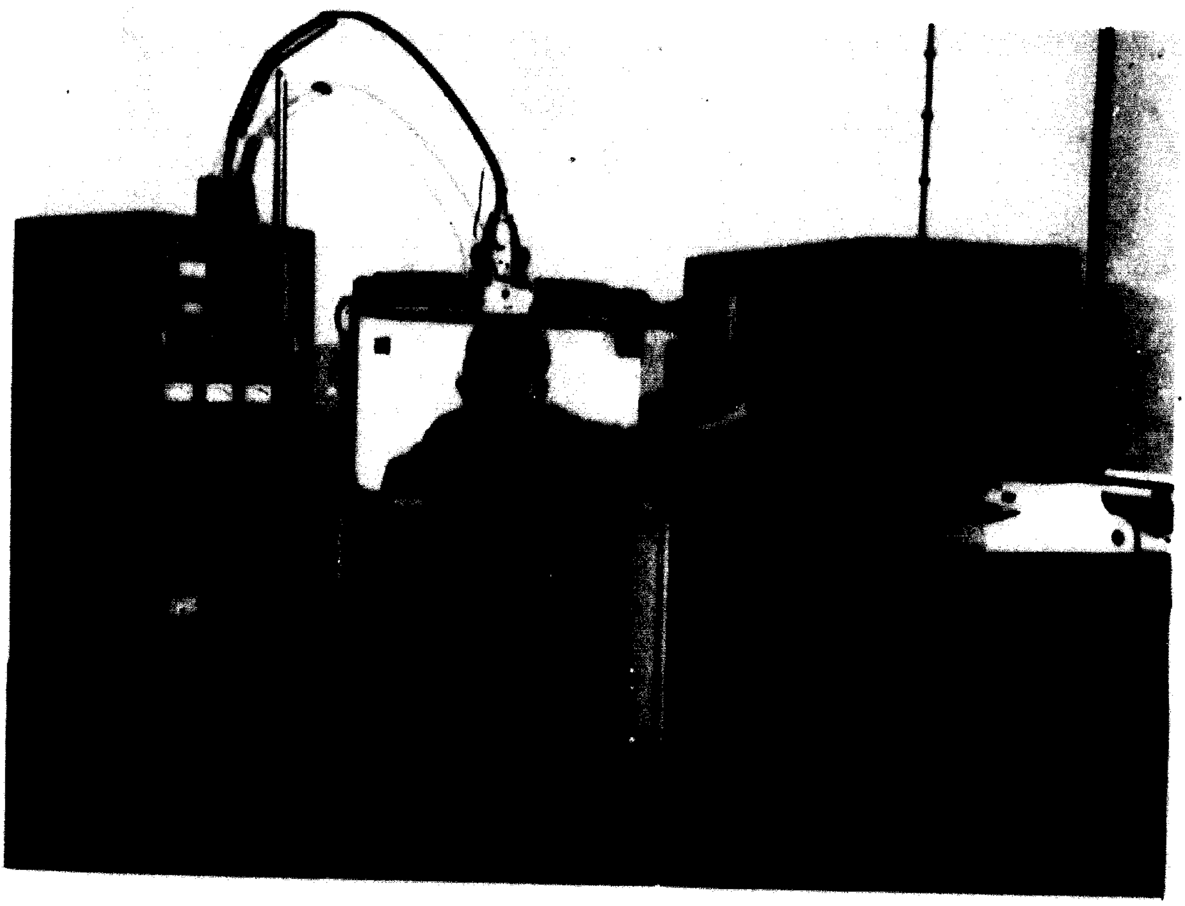

Fig 19 . : Electron probe microanalyser

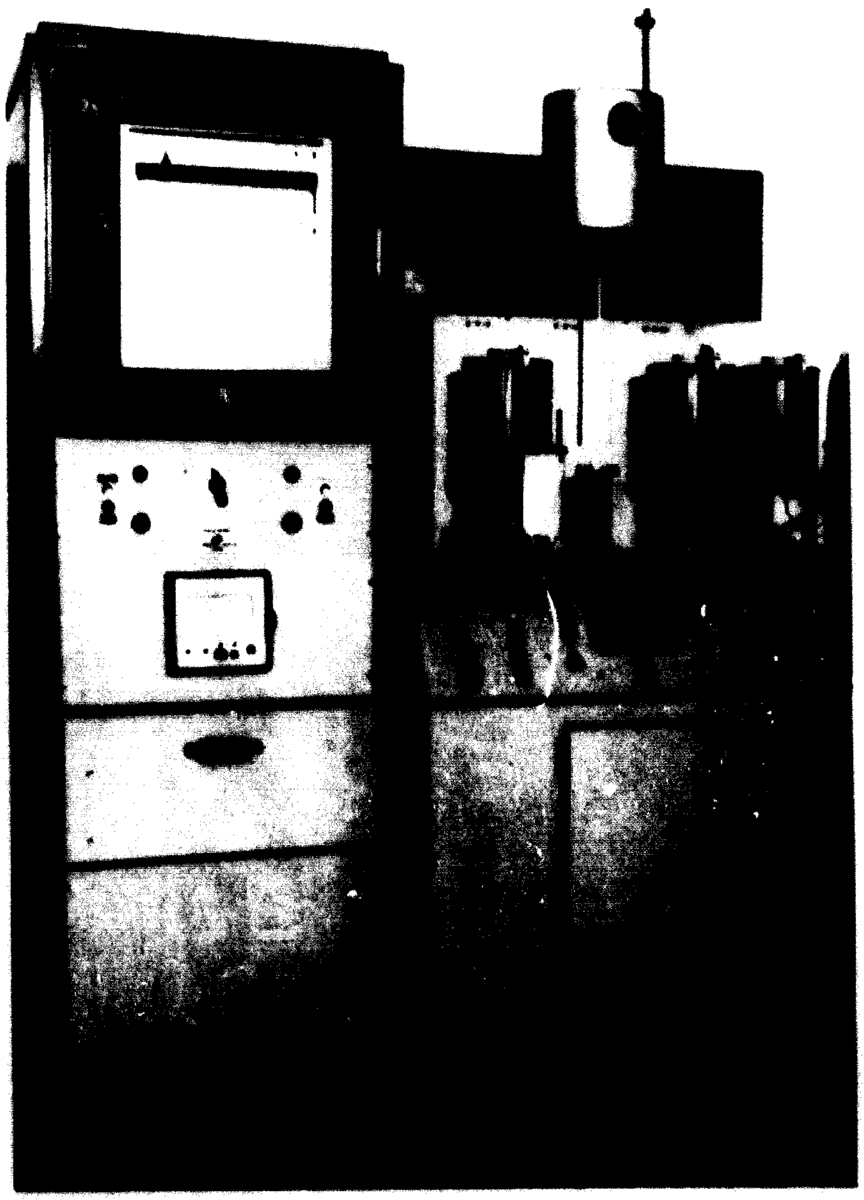

Fig 18 .: Dilatometer

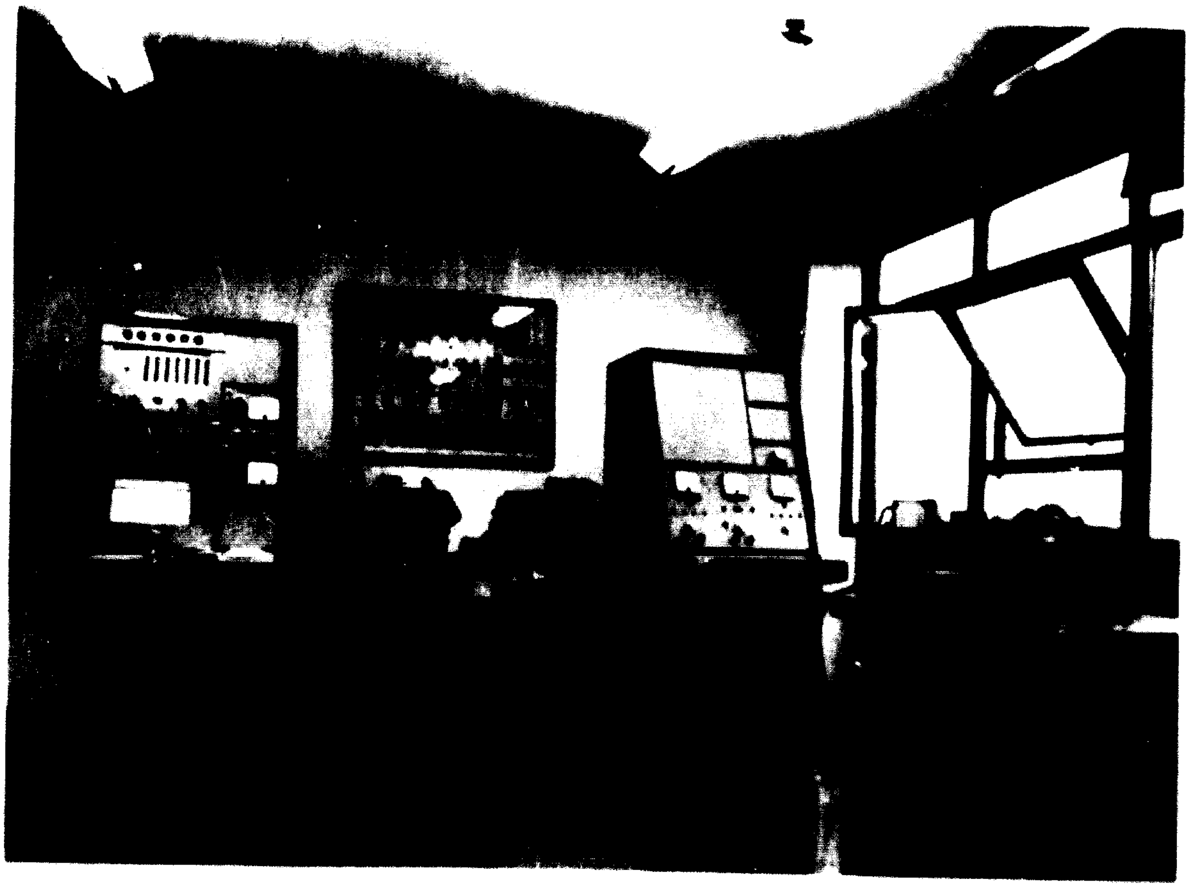

Fig 20.: X-ray difraction

Fig 21 .: DTA, TGA

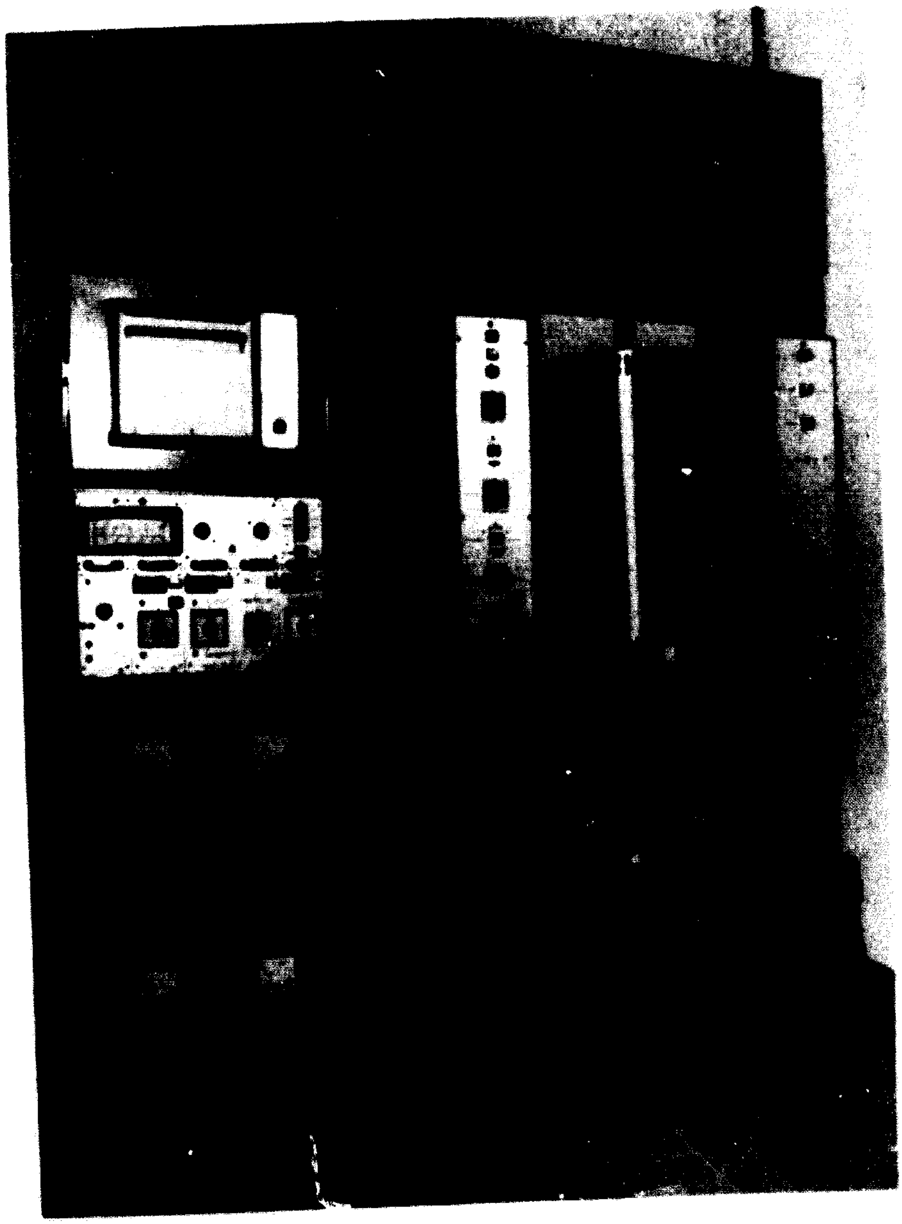

Fig 22.: Testing of refractories

Fig 23.: Testing of refractories

Fig 24.: Routine chemical laboratory

Fig 25.: Computer

ticular technology through its R&D services. The experience has shown that such information services are useful as publicity. When such a request for R&D service comes from an industry, the institute's specialists prepare a suitable research programme including a techno-economic feasibility and the strategy of solution. Such programme is subsequently treated in the research administration department estimating the cost of research and is submitted to the user in the form of a suitable contract proposal.

In the case of acceptance and after clearing up the amount and mode of financing, the contract becomes a document of mutual obligations. The institute is obliged to guarantee full confidence in connection with such a contract and all results, being subject to potential patenting or licencing rules, are a full property of the user with a full respect of the author's rights. The acceptance of the final report is to be made by the authorized experts engaged by the user, who have to check the degree of fulfilment of the contracted R&D obligations. The user, i.e. the industrial enterprise, is obliged to give to the institute access to all the relevant data as well as to all necessary industrial installations whenever it is required during the execution of the contract.

After the contract is established, the director of the institute appoints the project manager, who is authorized to develop a research strategy and timing schedule within the framework of contracted rules. The project manager is also authorized to select the research collaborators among the whole staff of the institute. So one comes to the formation of research teams, the members of which do not come from a particular department, but are chosen according to their specialization. If the project manager is, for instance, an ore beneficiation specialist, he can engage for the project not unly specialists from the ore-beneficiation department, but also specialists from other institute's departments like chemists, mathematicians, physicists, mining, electrical and other engineers. In the case that an engagement is needed outside of the institute's staff,a proposal to institute's director is to be submitted and the director may give an approval after setting up mutual duties and obligations.

It is particularly to be emphasized the need of a very strong system of incentives for the research personnel. When a project manager or collaborators are appointed for some particular project they are authorized to obtain an addition in the amount of up to 30 % of their salary for the duration of the project. The determination of this additional amount is ruled by a special group of experts and approved by the executive council of the institute. The research workers are obliged to perform the research work according to the stipulations of the contract. If they perform the job earlier they obtain the full amount. In the case of being late, they are obliged to pay back the part of this additional amount equivalent to the period of delay. In the case the delay is as long as the time for the research work, the research people should give back the full amount. Such a system of incentives has considerably increased the research productivity, so that 70-90 contracts are being realized per year. It is to be pointed out that the basic salaries, without the additional part mentioned above, are kept low; this makes a particular interest for everybody to be engaged in a research project. Individual research workers having a high research productivity are very pleased to work in the institute, but those who are not able to compete leave the institute looking for some less intensive engagement. The whole system had a high stabilizing effect on research staff, its fluctuation being less than 25 % through the 12 years of institute's activity, which is a very favourable figure under existing circumstances in the country.

A particular attention is to be paid to the recruitment of research workers and their specialization and training. A system of scholarship is provided for talented young men finishing secondary education with an excellent success. The institute pays for their studies at the Universities under the condition they satisfy a fixed minimum of success at their examinations. If the average drops below this value, or if the study lasts more than expected, they forfeit their scholarship. After being engaged in the institute, these young men with University degree are sent to spend some time working in the industry in order to acquire some practical experience. They can also be sent to foreign countries to gain the additional knowledge in reputable organizations. The institute supports also financially the studies for M. Sc and Ph. D. degrees. All this made the institute an attractive place for young people which get their chance in the case they have a good success during their studies as well as during their research work.

Some results of R & D efforts

In its activity through the 12 years of its existence the Institute accomplished more than 500 contract based R&D projects, about 80 % of them being devoted to the improvements of the techno-economic efficiency of the country's steel industry and the remaining 20 % to some fundamental problems. This last part of the institute's activity is concerned with the improvements of the research workers' experience in order to enable them to acquire more sophisticated skills for their future use. A short survey of some achievements will be given with the aim to get some idea about the type of activity.

In the field of preparation of iron ores, the main preoccupation was investigation of domestic ores together with the problems of production of sinter in Zenica. Wide investigations of mineralogical structure of particular Vareš ore varieties were performed and documentation made. This work made possible subsequent investigations of different technological procedures of beneficiation. Since the data about mineralogical components in the ores and gangue as well as their chemical, physical,and pyrometallurgical characteristics were previously unknown, even theoretical possibilities of beneficiation were controversial and too hypothetical. Today we are able to define more thoroughly the problems of hematite and siderite, distribution of Fe substance and gangue by individual fractions, magnetic and flotating characteristics of particular components,and to get closer to applicable solution. In all previous investigations the problem of enrichment of Vareš iron ores was so complicated, that there were doubts whether the enrichment was possible at all, especially within economic limits. But the mentioned investigations including possibilities of selective exploitation together with different improvements in the process of primary heavy-media separation, especially in relation to the treatment of fines, etc. give a considerably more optimistic picture. Complex schemes of beneficiation composed of flotation and sintering with domestic coal could give such a solution for Vareš iron ores to have a value in comparative relations with the development on the international market. Besides this, considerable improvements in actual practice of crushing and screening, sampling and quality control of ore in Zenica are achieved, as well as in the production of sinter of increased basicity and with greater participation of fines in the blends as brand, calcined pyrites, etc. Studies of replacing coke by domestic fuel in sintering process are of special interest because they give possibilities to increase the use of domestic raw material.

In investigating the process of blast-furnace smelting there were several directions,such as studying general work conditions with special regard to burden materials, then studies with the aim of improving the functioning of particular machines and facilities and finally studies to improve the metallurgy of blast furnace. In the first part special task was to explain real influence of quality of coke and iron ore on the operation of existing blast furnaces. The importance of the strength of coke was demonstrated and some mistakes and the benefits of domestic coal blends which lowered this strength were eliminated. An analysis of influential factors in connection with quantity of blast furnace dust as well as behaviour of particular elements, like Zn, Pb, S, Cu and As in the smelting process proved very useful . These activities, together with mastering of technique of mathematical programming and application of computer, formed the basis for elaboration of mathematical model for making material and heat balance of blast furnace, which is today in operation, giving an exact picture of behaviour and distribution of material in blast furnace which previously could not even be imagined. Besides, we are closer to computerization of composing a charge for blast furnace based on a more realistic valorization of particular ores and burdens, what is important not only from the standpoint of achieving more efficient work of blast furnaces, but also for clearing up mutual relations of the steel industry and ore mines.

Improvement of functioning of installations consisted of studying the rate of wearing of blast-furnace linings by radioactive isotopes, resulting in corrections of furnace profiles and better organization of blast-furnace general repairs so that in this way considerable results in improving efficiency of smelting were achieved. Besides it, the reconstruction of cowpers is completed with the aim of providing high temperatures of blast, as well as automatization of their use. Also significant progress is achieved in the field of dust extraction from blast-furnace gas, which must be clean for its use in coke-oven firing.

Studies of possible improvement of the smelting process included the analyses of possibilities of controlling furnace from the top as well as possibilities of automatic distribution of air in blast tuyeres, then application of high blast temperatures and realization of the most acceptable composition of slag from the standpoint of influence of BaO and MgO on its metallurgical function. However, the most important result is, without any doubt, introduction of liquid fuel injection in blast furnace, construction and automatization of it. That led to the turning-point in the operation of blast furnaces in Zenica and made possible savings of about $ 600000 a year.

Special subject of investigations was the modification and application of blast-furnace slag. The results of investigation of its hydraulic characteristics, together with specific chemical composition and characterization of granular and crystallized slag, served as the basis for subsequent research work. Studying characteristics of crystallized slag made possible its application in aggregates and for road construction. Production of light construction elements on the basis of slag as economic replacement for foreign licences is also elaborated.

Efforts in the production of steel were aimed to increase the productivity of OH furnaces and to improve the quality of steel ingots. Developing integral burners for combined heating by liquid fuel and coke oven gas increased the productivity of OH furnaces by 15-20 %. At the same time systematic studies of heating procedures, and influence of quality of refractory material and shape of furnace construction on duration life of the furnace, contributed to extending the campaign of OH furnaces and to increase their efficiency. Experiments in intensifying the process of injection of compressed air in liquid bath showed the possibilities to increase the productivity by more than 30 %. Contribution to improving the quality and increasing the yield is accomplished by a number of measures like application of synthetic slags and Perrin's procedure, and casting in argon. The most important result is, however, introduction of the steel degassing by means of RH process; this gave especially good results in production of heavy forgings, such as for shipbuilding, where the number of rejections due to non-metallic inclusions or flakes was radically reduced. A great number of experiments such as improving the shape of ingots, introducing exo-frames and the selection of best exothermic-masses and anti-piping compounds, etc. made possible significant improvement of yield. A special result originated from investigation of rimming steel with increased concentration of Mn in solution, where original contribution in this complex field is achieved by setting regression equation between the depths of external blow-holes and parameters of melting and teeming. It should be also mentioned the development of a method for continuous control of temperature of liquid steel during refining.

At the same time considerable results were achieved in improving the operation of rolling mills. Introduction of rectangular ingots weighing 5 to 5,5 tons instead of previous square ingots of the same weight together with the new roll-pass design for the existing blooming mill enabled an increase of this production by 100,000 to 150,000 tons per year without any additional investment. That has a particular significance for Iron and Steel Works in Zenica because the capacity of the blooming mill was a bottle neck. Furthermore, rolling of ingots weighing 6,5 tons was also introduced and made possible the production of rails 54 kg/m in lengths of 25 m. Significant success was achieved in production of rails, channels, beams, and other sections. New roll-pass design was introduced so that the productivity was increased and at the same time the percentage of first-class products was increased by 10 to 20 %. Ten years ago sections in Zenica were rolled using old methods. Today that is performed applying the most modern roll-pass design like, for example, for rails and beams a system of diagonal and for channels a system of special roll-pass design. Because of that, the percentage of first-class rails is raised up to 90 to 95 % and for other sections up to 95 to 100 %, while ten years ago it was about 70 to 80 %. Cracked edges on rails and sections practically disappeared. Recent use of the first stand of the heavy section mill with a screw-down for rolling of first initial shaped passes contributed to significant improvement of quality of heavy sections and rails from the standpoint of deformation of material and achievement of size accuracy. Economic effect of these results is also significant especially when decreased delays in rolling are taken into account. Consequently, this gave rise to a higher hourly productivity which in case of some sections was increased by more than 100 %. Thus in production of rails it was previously about 35 t/h and today it amounts to 75 to 80 t/h and more. For the same purpose of increasing the productivity, the Institute was also engaged to design and introduce special rolling-mill guides and guards together with certain mechanizations, especially in light-section and merchant rolling mills.

Besides these contributions connected directly with particular metallurgical processes, a great number of attempts was made for increasing the efficiency of individual facilities by improving machine and electrical design, by introducing mechanization and regulation, etc. Improving efficiency of various heating furnaces in rolling and forging mills by introduction of mixed gas, developing automatic regulation of coal blending for coke-ovens by the use of radioactive sources; introducing new procedure for hot repairs of refractory linings, developing rapid communications between express laboratory and steelworks, etc. all these are just some examples of those numerous solutions.

Special field of intensive activities of the Institute were the efforts on improving the quality of present production and introducing new products. That refers also to the improvement of the surface quality of blooms, billets, and final products by investigating different conditioning procedures, especially the use of electric arc and oxy--coke-oven gas torches. A special attention is being paid to the improvement of mechanical characteristics of structural-steel grades, rails, and heavy forgings. Complete defects in production of tyres, wheels, and axles are identified and classified; this is a useful contribution in diagnosing defects in this field. Also there was a considerable contribution in improving the quality of steel rod for production of bolts by cold working where entirely new technology was introduced. The contribution of the Institute in expanding production programme includes over 20 entirely new products, some of which are very important, like high-tensile ribbed concrete reinforcement steel bars, steel-base cast rolls, wear-resistant manganese rails etc. Among the products, it is worthwhile to mention heavy rails UIC54 type, bulbed flats for shipbuilding, patented high-tensile wire as well as wire for concrete reinforcement welded meshes and springs, forged steel moulds for spun casting of pipes, steel for forging dies, cast alloy-steel rolls, open-die forgings for rotor bodies as well as forgings for shipbuilding, piston rod, and crankshafts, Mn-castings and steel for crushing machines for ores, high-alloy steels for rolling-mill entry guide, etc.

Along with these activities which are directly of R&D-type, scientific potential of the Institute was constantly being developed, qualifying the staff for more complicated problems and mastering new methods and techniques of investigations which make possible more efficient research work in the next period. Tables 1 and 2 contain a review of methods of investigating metals and minerals which are mastered in the Institute and introduced in regular application, and which represent the modern achievements of laboratory technique in the field of metallurgical investigations. The Institute in its up-to-date activities developed and particularly improved application of high-temperature metallography, quantitative metallography as well as metallography in colour. X-ray diffraction analysis is also introduced for investigating characteristics of crystal lattice of iron and its alloys.

Physical metallurgy:
1. Application of replicas in metallographic technique
2. High-temperature metallography
3. Metallography in colour
4. Quantitative metallography
5. Electron microscopy
6. Point analysis by electron microprobe
7. X-ray diffraction
8. X-ray defectoscopy
9. γ-defectoscopy
10. Surface defectoscopy by applicating penetrant
11. Magnetometer investigations
12. Dilatometry at high cooling speeds
13. Precise measurements at tensile test
14. Mechanical testing at higher and lower temperatures in the interval from -180^{o} to $+1100^{o}C$
15. Microtechnique of mechanical testing
16. Torsion testing
17. Creep testing
18. Hot-deformability testing by torsion at high temperatures
19. High-frequency fatigue testing
20. Registration of oscillograms force-distance and force-time during impact-testing

TABLE 1 : New methods and techniques of testing mastered in Metallurgical Institute of Zenica

Especially is to be emphasized the mastered diffraction technique indicating the micro-stresses of second order which is used for efficient following of precipitating process in metals. Electron microscopy is introduced for some fundamental investigations of crystal structure. Furthermore, the technique of testing by electron microprobe is initiated, giving the possibility of detecting concentration of elements on distances of 1 μm, thus permitting phase analysis of metal and mineral samples. The pioneer role in our conditions the Institute played by introducing intensive use of spectral methods in analysis of iron and steel where today, by the way of emissive or absorptive spectroscopy in visible or in X-ray part of spectrum, quantitative analysis of many elements in iron and steel in very wide field of concentration is performed. Because of this, the Institute became the centre where every day specialists from other enterprises as well as institutes are coming to increase their own knowledge. Further results are achieved in phase analysis of alloy steel by application of electro-

isolation or isolation by the way of selective dissolution with the subsequent separation of isolates. The samples obtained are further investigated by very sophisticated techniques with the aim of identification of their chemical, crystal and molecular structure. In co-operation with Max-Planck-Institut für Eisenforschung in Düsseldorf, the Institute got in our country to the highest point in the field of these investigations; this gives a possibility to investigate very effectively origins of certain impurities in metals, as well as to identify particular phases responsible for some properties of iron and its alloys.

Metallurgical chemistry:
21. Emission spectral analysis of metal and non-metal substances 22. X-ray fluorescent analysis of metal and non-metal substances 23. Atomic absorption analysis of metal and non-metal substances 24. Flame spectrophotometry analysis of metal and non-metal substances 25. Conductometric determination of C and in iron & steel 26. Coulometric determination of oxygen in iron & steel 27. Chromatographic determination of diffusive hydrogen in steel 28. Gas analysis in metals by extraction in inert atmosphere

29. Isolation phase analysis of oxides, carbides, and nitrides in steel
30. Microanalytics of isolates
31. X-ray diffraction analysis of mineral and ceramic substances
32. Dilatometry of mineral and ceramic substances
33. Differential thermal analysis
34. Thermogravimetry
35. Thermovolumetry
36. Qualitative and quantitative microscopy of mineral and ceramic substances

Application of electron computer:

37. Multiple regression and correlation analysis
38. Analysis of variance for total and incomplete set of data
39. Setting up and solving of transporting matrix
40. Linear programming
41. Optimisation of burden in metallurgical prosses by use of linear programming
42. Modelling of metallurgical processes

TABLE 2 : New methods and techniques of testing mastered in Metallurgical Institute of Zenica

Metallurgical Institute "Hasan Brkić" in Zenica first in our country started to introduce mathematical methods in scientific research work in iron and steel metallurgy using the computer for more than 8 years. Starting with the elaboration of application of methods of multiple regression and correlation analysis, which it brought to a high degree of perfection in analysis of influental factors in metallurgical problems, the Institute passed to the elaboration of matrices of particular phases of technological processes to be today in full swing of making static and dynamic models of particular metallurgical processes which are starting to influence the quality of work and organization of technological process.

Besides activities on the field of improving the technology and strengthening the scientific potential, it is necessary to underline the contribution in the field of development of economic and structural policy for ferrous metallurgy of the country. That refers to the expansion programme of the Iron and Steel Works of Zenica to 2,6 million tons of steel together with programmes for construction of new plants for bolts and nuts, for production of limestone and lime, as well as for a new enterprise for manufacturing wire,the success of which in business is the best proof of the proper choice of production programme as well as of its economic and technological concept. Special studies are elaborated about development possibilities of Ironworks in Vareš and about efficiency of low-shaft electric reduction furnaces in Ilijaš. The feasibility studies of constructing new iron and steel works in Prijedor, located directly on the ore deposits, considerably influenced the long-term policy of development of iron and steel production in Bosnia and Herzegovina.

The Metallurgical Institute gave its contribution also to the integration of all enterprises of ferrous metallurgy in Bosnia and Herzegovina working out the necessary studies about technological and economic advantages of that union. Quantifying the advantages which can be achieved by co-ordination of mines and ironworks and further processing industry, one contributed to the formation of the Mining and Metallurgical Combine (RMK) in Zenica, the biggest economic concentration of this kind in the country. By its feasibility studies of development of ferrous metallurgy in Bosnia and Herzegovina,the Institute worked out the documents which represent the basis for its perspective orientation. Incorporating into these studies modern technological solutions and including them in development concepts and needs of wider regions in the Republic, as well as proposing the dislocation of particular phases of finalization on the one hand and the bringing of extractive processes near raw-material deposits on the other hand as it is anticipated in construction of the new Iron and Steel Works in Prijedor, the Institute is making a significant contribution to a more uniform and efficient economic development of the country.

The Metallurgical Faculty

The presence of the Metallurgical Institute in the proximity of the biggest steel works in the country was the reason to make use of such favourable conditions to organize a metallurgical faculty. So the Metallurgical Faculty in Zenica was founded as a part of the University of Sarajevo. Although the University of Sarajevo comprises a large number of faculties the dislocation of Metallurgical Faculty to Zenica, at a distance of 80 km from Sarajevo, proved to have many advantages. The faculty building, which is built in the immediate proximity of the Institute, has all necessary lecture rooms and basic laboratories for teaching purposes. They are equipped with some basic equipment intended for the training of students in basic techniques, like microscopy, chemical analyses, instrumentation etc. The research activity of teaching personnel, however, is performed within the framework of the Institute, where the students can also perform their practical work for final examination. The students have the opportunity to be "on the spot" both in the Institute as well as in the Iron & Steel Works and get there proper idea about the metallurgical practice and research. This proved to be very useful for education. Metallurgical faculty in Zenica has just more than 12 years of activity and gave more than 200 University degrees in metallurgical engineering. It has now approximately 500 students. Beside the professional teaching personnel as a basic faculty staff, a participation of the best institute's specialists in the teaching process is used. At the same time some experts from the industry are also engaged for the same purpose of teaching. The professional teaching staff however, being in the proximity of the institute has a very convenient source of ideas for research which eliminates their alienation from the industry's needs and avoids the sterilization of science often met in developing countries.

Conclusion

Resuming the description of the Metallurgical Institute Zenica as an example of development of an industrial institute in a developing country, the importance of a careful elaboration of research philosophy is emphasized. There are some semantic problems in using the word "research" in various circumstances, because it is obvious that this word has different meanings in developed and developing countries, which have very different human and financial potentials. It seems to be useful to point out that the research work in developing countries should be primarily concerned with the practical problems.

By solving such problems one can achieve not only useful solutions for the industry giving a contribution to the country's economy, but one can also avoid sterile research. So the "innovative performance" becomes a basis for evaluation of success and publication of papers whilst the fundamental research is to be established on a sound practical experience and verification in development.

Acknowledgments

The author feels obliged in the name of the Metallurgical Institute "Hasan Brkić" Zenica to express his deepest thanks to UNIDO for the efficient assistance and contribution to the development of this Institute. This applies also to the famous institutions like TsNIIChMet in Moscow, Max-Planck-Institut für Eisenforschung in Düsseldorf, Forschungszenter des August-Thyssen-Hütte in F.R.

Germany, IRSID in France, BISRA in England and many other companies, without the assistance of which in training the research staff the Institute could hardly achieve the today's stage of development.

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