The incorporation of individual cooling in a compressed-oxygen closed-circuit breathing apparatus

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SYNOPSIS

A conventional compressed-oxygen breathing apparatus, which did not include provisions for dehumidification of the inspired air at high environmental temperatures, was tested at these temperatures with and without conductive cooling in the form of 2 kg of pre-frozen ice placed inside the breathing bag of the apparatus. The pre-frozen ice provided conductive cooling of the soda lime and of the chest and abdomen of the subject, who performed moderate work at 50,1 °C. Without cooling, the subject was exhausted after 35 minutes because of a wet-bulb temperature of the inspired air of 46 °C. With cooling, the subject finished 2 hours of work. This was possible by keeping the soda lime at a relatively low temperature, which resulted in a wet-bulb temperature of the inspired air of only 42 °C after 2 hours, and by conductive cooling of the chest, which resulted in the maintenance of a relatively low heart rate and rectal temperature.

SAMEVATTING

'n Konvensionele saamgepersde-suurstof asemhalings-apparaat, waarin geen voorsiening vir ontvogtiging van die ingeasemde lug by hoë omgewingtemperature gemaak is nie, was getoets by sulke temperature met en sonder geleidingsverkoeling deur 2 kg bevrore ys binne in die asemhalingsak van die apparaat te plaas. Die ys het geleidingsverkoeling aan die natronkalk, die borskas en buik van die proefpersoon voorsien terwyl hy werk by 51 °C gedoen het. Sonder verkoeling was die persoon binne 35 minute uitgeput vanweë die natbol-temperatuur van die ingeasemde lug wat 46 °C was. Met verkoeling kon die persoon vir twee ure werk. Dit is moontlik gemaak deurdat die natronkalk by 'n relatiewe lae temperatuur gehou is wat veroorsaak het dat die natbol-temperatuur van die ingeasemde lug na 2 ure slegs 42 °C was, en deur geleidingsverkoeling van die borskas wat 'n lae polsslag en rektaaltemperatuur tot gevolg gehad het.

INTRODUCTION

The kind of self-contained breathing apparatus suitable for mine rescue personnel has been arousing interest for some time. After a fire or explosion in deep mines, the ambient temperatures may exceed 50 °C. This presents a serious problem in that sufficient cooling has to be incorporated in the self-contained breathing apparatus to cool and dehumidify the inspired air. Several studies have shown that in hot ambient conditions, when sbreathing cool, dehumidified air, ub ects have better responses to heat than when breathing hot, humid air[1, 2]. If the inspired air has a wet-bulb temperature above body temperature (about 35 °C), the body gains heat through the respiratory tract instead of losing it, and, if body temperature exceeds 42 °C, tissue damage occurs.

The self-contained breathing apparatus, which has been used extensively in the gold mines of South Africa, uses compressed oxygen supplied to the wearer from a cylinder carried on the back. From there, the oxygen flows to one compartment of a breathing bag carried on the chest, and then flows through a cooling device to the mouthpiece. The exhaled air flows to the other compartment of the breathing bag. The two compartments join at the bottom of the bag, where soda lime is placed to remove the carbon dioxide from the expired air. A nose clip keeps the circuit closed.

As shown by Morrison *et al.*[1], this apparatus cannot be used safely for more than one hour at high environmental temperatures. The reason for this is that the cooling device, consisting of sodium phosphate, liquifies at 35 °C so that there is no cooling effect above 35 °C. The soda lime (Protosorb) produces humid heat when the carbon dioxide is absorbed, and, in addition to the normal load to which the wearer is already exposed when operating at high ambient temperatures, the body gains heat through the respiratory tract. The purpose of the present study was to explore the possibility of incorporating pre-frozen ice in this apparatus to improve the performance of men at high ambient temperatures.

METHODS

A healthy, acclimatized White male acted as the subject. His age, height, and weight were 23 years, 173 cm, and 70 kg respectively.

The experiments were conducted at ambient conditions of 50,1 °C dry-bulb and 30,2 °C wet-bulb temperature. The subject wore overalls under the apparatus and attempted to perform block stepping, at a work load of 35 W, for 2 hours. Oxygen flow was 1,5 *l*/min. Four experiments were conducted, three with cooling and one without cooling. In the experiment without cooling, the subject wore the apparatus without any changes being made, whereas, in the other set of experiments, the cooler was removed and the breathing tubes (inhale and exhale) were connected direct to the breathing bag. This presented no problem since the cooler and the breathing bag had the same fittings for the connecting tubes. The cooler, weighing 1,75 kg, was replaced with 12 pockets of pre-frozen ice, weighing 2,10 kg, placed in one-half of a cooling jacket used for microclimate cooling in the gold mines. The portion of cooling jacket had the same dimensions as the breathing bag (37 cm wide and 45 cm long) and was placed in the back of the bag, facing the subject,

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between the rubber bag (filled with soda lime) and the outside canvas bag. Since the soda lime is situated at the bottom of the bag, only about 4,5 ice pockets affected it, while the subject was cooled over the lower chest and the abdomen by the entire opposite side of the 12 ice pockets. The ice pockets thus cooled the soda lime and the subject simultaneously.

In the first cooling experiment, only the temperatures of the inspired air were measured. This was done by means of thermocouples inserted near the mouthpiece and the breathing bag. In the other experiments, the following measurements were recorded every 15 minutes: heart rate recorded by the palpation method, rectal temperature, inspired air temperature, temperature of the soda lime, and ice temperature. The last four measurements were recorded with thermocouples. Sweat rate was determined by weighing the subject before and after exposure and correcting for water intake. Several air samples were drawn from the breathing tube for analysis of the moisture content of the inspired air.

RESULTS

Fig. 1 shows very little difference between the temperature of the inspired air measured next to the mouthpiece and that measured next to the breathing bag when pre-frozen ice was used.

Fig. 2 gives a comparison of cooling versus no cooling. The cooling data are based on two experiments that gave identical results. Without cooling, the subject had to be stopped after 35 minutes because he was subjectively exhausted. The wet-bulb temperature of the inspired air was 46 °C after 35 minutes. This corresponded to the very high temperature of the soda lime (57 °C). After 35 minutes, heart rate and rectal temperature were 136 beats per minute and 38,5 °C, and sweat rate was 0,951 l/h.

In the experiments with cooling, the subject stood 2 hours of exposure easily, although he reported that he was aware of the hot, humid inspired air during the last 20 minutes of exposure. Cooling resulted in much lower temperatures of the soda lime and inspired air than without cooling. The temperature of the soda lime reached 50 °C after 60 minutes of exposure, and remained at about that level for the remaining 60 minutes. The relatively low temperature of the soda lime affected the inspired air, which had a temperature of 38 °C after 60 minutes and reached 43 °C after 2 hours. As in the experiment without cooling, the inspired air in the cooling experiments was saturated. Heart rate was 107 beats per minute after 35 minutes and reached 144 beats per minute after 2 hours. Rectal temperature after 35 minutes was 38,5 °C, the same as in the uncooled experiment, and reached 38,9 °C after 2 hours. Sweat rate was 1,057 l/h. In all the three cooling experiments there was still some ice left in two to four pockets by the end of exposure, and most of the pockets felt cold to the touch.

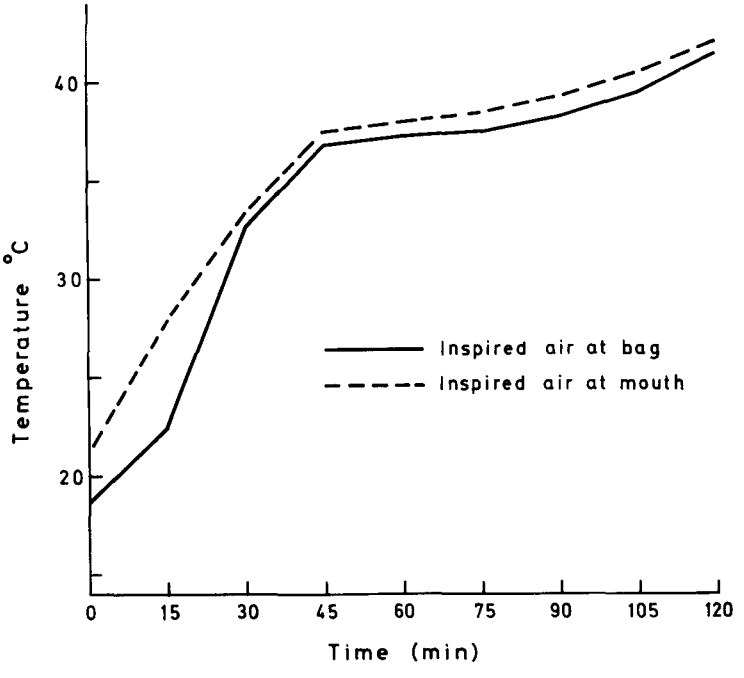

Fig. 1—Comparison of temperatures of inspired air

DISCUSSION

The results of this study show that 2 kg of pre-frozen ice placed inside the breathing bag of a closed-circuit breathing apparatus that does not make provision for dehumidification of the inspired air permits a subject to perform moderate work in heat for 2 hours. Without cooling, the same apparatus cannot be used safely for more than 30 minutes at high ambient temperatures of 50 °C.

The very marked improvement in heat tolerance was a result of conductive cooling of the soda lime and the subject, which resulted in relatively low temperatures in the inspired air and low rectal temperatures and heart rate. This allowed the subject to complete 2 hours of work. Since there was still ice left in some of the pockets at the end of all three cooling experiments, and since the temperature of the soda lime showed little increase in the last hour of exposure, it is possible that cooling could have been effective for more than 2 hours. However, the wet-bulb temperature of the inspired air reached 42 °C after 2 hours.

In the present study, cooling of the chest and abdomen and the maintenance of high sweat rates presented enough conductive and evaporative cooling for the rectal temperature and heart rate to be only 38,9 °C and 144 beats per minute after 2 hours of exposure. Fig. 2 shows that the average temperature of the inspired air over the 2-hour period was approximately 37 °C. This means that, on the average, there was no heat gain or heat loss through the respiratory tract. In the uncooled experiment, the average temperature of the inspired air over the 35-minute

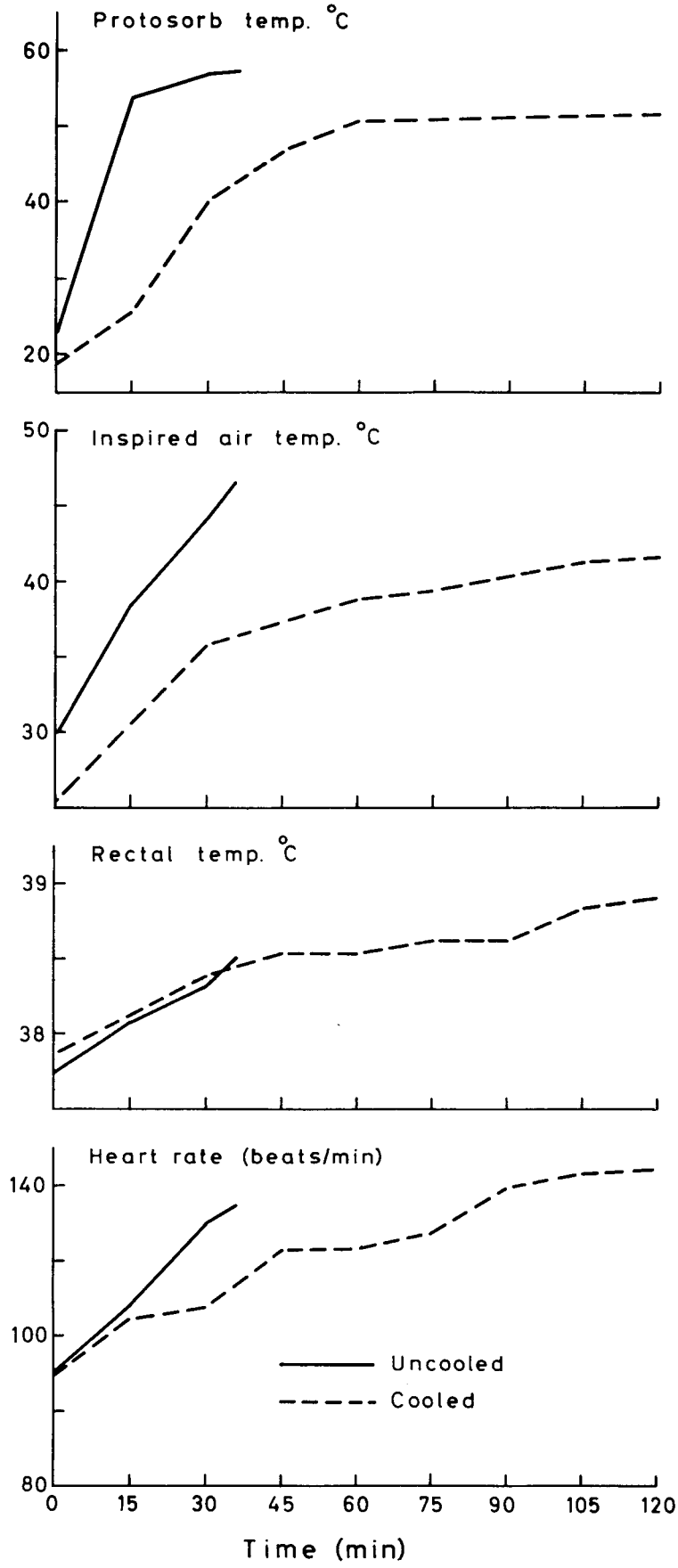

Fig. 2—Effect of cooling compared with no cooling.

period was approximately 40°C, which must have resulted in some heat gain through the respiratory tract.

This study has presented a simple and effective method of cooling for rescue-team personnel who operate at high environmental temperatures. The present method allows safe operation for 2 hours in such conditions. If the same compressed-oxygen apparatus is to be used for more than 2 hours in severe heat, it would have to be combined with other forms of conductive cooling.

REFERENCES

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2. Leyh, P., Hausman, A., and Patigay, J. Comparison d'appareils respiratoires en circuit fermé, refroidis et non refroidis, au ours d'une série spéciale d'exercices a température élevée. *Revue de l'Institut d'Hygiene des Uines*, vol. 17, no. 3. 1962. pp. 201-221.

NIM Reports

The following reports are available free of charge from the National Institute for Metallurgy, Private Bag 7, Auckland Park 2006.

Report no. 1580

The determination of silver in ores, concentrates, and mattes. (First issued in November 1973, now declassified.)

A method, based on the work of Fritz *et al.*, has been developed for the determination of microgram amounts of silver. In the proposed method, the samples are dissolved by digestion with nitric acid or by fusion with sodium peroxide, or by both procedures. The silver is separated from significant amounts of most interfering elements by its extraction into iso-octyl thioglycolate and toluene. After back-extraction into hydrochloric acid, the silver is measured by atomic-absorption spectrophotometry.

Values obtained for a standard ore and a matte are compared with those obtained by direct procedures, appropriate account being taken of viscosity and interference effects. The agreement is good, and the coefficient of variation for the extraction procedure (1,0 per cent) is much lower than that obtained by the direct procedures.

Report no. 1693

Research at the National Institute for Metallurgy on the engineering aspects of copper electrowinning. (First issued February 1975, now declassified.)

A number of hydrometallurgical processes for copper have been tested at the National Institute for Metallurgy, and the testwork on the electrowinning component is summarized here. In addition, the use of air sparging and fixed-bed cathodes was investigated as a means of improved mass transfer that would permit the recovery of high-quality copper at higher densities or lower concentrations than are usually employed. The electrowinning of copper from a chloride medium was also investigated.

Report no. 1698

Measurement of the electrical resistance of ferrochromium furnace charges.

Burden resistance, which makes a significant contribution to the overall resistance in an electric submerged-arc furnace, was determined for a number of mixtures and a number of reducing agents. The investigation was made in the temperature range 20°C to 1500°C, during which the effects of the particle size of the components of the mix and of the type and amount of reducing agent were examined.

It is concluded that the main factors controlling the resistance of the burden are the kind and the amount of reducing agent.

Report no. 1706

Concentration of magnesite from Apiesbomen, Burgersfort district.

In the search for a source of high-grade magnesite (having an SiO_2 content of less than 1 per cent), the deposits on the farm Apiesbomen have been examined by several organizations with apparently discouraging results. An additional examination was undertaken by the National Institute for Metallurgy on 13 samples supplied by the Geological Survey. After preliminary tests on the individual samples, two of them were combined to form a first-grade composite sample having an SiO_2 content of 2,0 per cent, four were combined to form a second-grade composite sample (SiO_2 5,1 per cent), and the remaining seven samples, which had either a CaO content of more than 15 per cent or an SiO_2 content of more than 11 per cent, were retained for possible future experimentation.

For the beneficiation of the composite samples, use was made of selective crushing and screening in which lower-grade material was rejected in the finer sizes, manual colour sorting in which lower-grade material was rejected in the dark-coloured products, and high-intensity magnetic separation in which a small amount of material high in silica and iron was rejected in the magnetic fraction. (It is assumed that the manual colour sorting could be duplicated by an automatic colour sorter.)

These procedures were applied to the first-grade composite sample, and enabled 38,4 per cent of the composite to be recovered as a concentrate having an SiO_2 content of 0,5 per cent, or 68 per cent of the composite as a concentrate having an SiO_2 content of 1,0 per cent.

The same procedure was applied to the second-grade concentrate but failed to produce material having an SiO_2 content of less than 1 per cent. Instead, 42 per cent of the composite sample was recovered as magnesite having an SiO_2 content of 2,1 per cent. Although some further improvement in grade might be obtained by the use of additional methods of concentration, it is considered unlikely that magnesite having an SiO_2 content of less than 1 per cent will be obtained from the second-grade composite sample by the methods indicated.

So far, flotation has not been tested as a method of beneficiation, because mineralogical examination of the samples indicated that the siliceous impurities — mainly sepiolite and palygorskite — were finely disseminated within the magnesite. However, flotation may have to be tested in any further work that is undertaken on the Apiesbomen deposit.

Report no. 1709

The mineralogy, chemistry, and certain aspects of reactivity of chromitite from the Bushveld Igneous Complex.

This report is the third in a series that aims to define, chemically and mineralogically, the chromitite of all the major seams in the crystallization sequence of the Bushveld Igneous Complex in which chromium spinel is a major cumulus phase. Ninety new chemical analyses are presented, giving the SiO_2, Cr_2O_3, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, NiO, MnO, TiO_2, V_2O_3, CoO, and ZnO contents of the chromitite and constituent chromium spinel from all the major seams.

On the basis of these chemical data, combined with field and laboratory observation, three major groups of chromitite are distinguished, i.e., those from a serpentinite environment (originally cumulates rich in olivine), those from a cumulate environment rich in pyroxene (LG1 up to UG2, using Cousins's notation),

and those from a cumulate environment rich in plagioclase (MG3 to UG2). The chromium spinels in the series from the lower seam in the serpentinite environment through LG1 up to UG2 show a decrease in the percentage by mass of MgO and Cr_2O_3, and an increase in the percentage by mass of FeO, Al_2O_3, Fe_2O_3, TiO_2, V_2O_3, NiO and ZnO, whereas the percentage by mass of CaO, MnO, and CoO remain roughly constant. Also, in the same sequential series, the chromium-to-iron ratio in the ore decreases from *ca* 3 to 1,2, and the steelmaker's basicity ratio of the ore decreases from *ca* 1,3 to 0,7.

The crystals of chromium spinel in the chromitite are round octahedral in habit, and their size varies inversely with the percentage by volume of primary magmatic gangue present in the ore. $M_2^{2+}M^{4+}O_4$ and $M_2^{3+}O_3$ are present as solid solution in the chromium spinel. The quantity and ratio of these components of the solid solution vary depending on the cumulate rock environment. The composition of the chromium spinel from cumulate environments rich in plagioclase seems to be controlled by a mechanism that caused the concentrations of magnesium and aluminium in the chromium spinel to fluctuate sympathetically. Certain chemical features of UG2 in relation to UG1 indicate a strong possibility that a major influx of fresh magma from depth occurred between these two seams.

The gangue phase in UG2 down to LG1 falls close to the pyroxene (or olivine)—plagioclase join in the triangle $(Mg + Fe^{2+} + Mn) - Ca - (Al + Fe^{3+})$. As expected, the gangue phases in the chromitite from a serpentinite environment seem to be largely serpentine and magnetite. The amount of gangue in the chromitite increases from LG1 up to UG2. As a result, the size of the spinel crystal decreases, and its surface area increases, which should enhance reactivity.

Chemical conversion tests, by Messrs Albright and Wilson, of the chromium in the chromium spinel to sodium chromate underline the importance of factors such as grain-size distribution and, possibly, the presence and character of the gangue material.

The major conclusions to be drawn from the present study are as follows:

(1) the upper chromitite seams deserve a proper evaluation of metallurgical and economic feasibility,
(2) the detailed results of Albright and Wilson Ltd are inconclusive, and
(3) more work is necessary on individual occurrences of chromitite in order to explain certain peculiar petrological trends.

Report no. 1711

The oxidation of aqueous solutions of ferrous sulphate in a bubble column.

A study was made of the variables affecting the rate of oxidation of concentrated aqueous ferrous sulphate solutions (1,0 to 1,6 M) in a bubble column at temperatures from 60 to 110 °C and at total pressures in the column from 200 to 600 kPa.

The oxidation rates, controlled, firstly, by the chemical reaction in aqueous solution and, secondly, by the mass transfer of oxygen from the gas phase into solution, were characterized in terms of various parameters for the gas, liquid, and column. The oxidation rates can be satisfactorily predicted by expressions that have been derived empirically.

Report no. 1722

The determination of small amounts of fluoride in uranium compounds by use of an ion-selective electrode.

A method is presented for the determination of fluoride in uranium metal and oxide at levels from 16 p.p.m. upwards. Uranium is separated from fluoride by extraction into a solution of di(2-ethylhexyl)-phosphoric acid (HDEHP) in carbon tetrachloride. The fluoride remaining in the aqueous phase is determined by potentiometric measurement with an ion-selective electrode. A correction is made for the fluoride lost during the dissolution or extraction step, or both, which is based on a determination of the apparent loss of fluoride on spiked samples that are taken through the whole procedure.

Control of basic oxygen steelmaking

An international symposium sponsored by the Computer Applications and Process Control Committee of The Canadian Institute of Mining and Metallurgy will be held in Toronto on 2nd to 4th September, 1975. The symposium is intended to bring together steelmakers and computer experts from around the world to appraise the state-of-the-art in this difficult control area. The symposium will stress discussion and recent work or ideas. Presentations are invited on the following:

1. Operating experience with basic oxygen melt-shop computer systems
   - — operating problems, reliability, startup
   - — man-machine problems
2. New developments in basic oxygen steelmaking control put into practice
   - — new sensors
   - — operating practices
3. Research
   - — pilot-plant or research studies on control
   - — measurement theory
   - — control algorithms
   - — modelling.

Information on presentations and attendance is available from: K. R. Barnes, Research & Development Department, The Steel Company of Canada, Limited, Hamilton, Ontario L8N 3T1, Canada.

New journal

A new journal entitled *Engineering and Process Economics* is to be published in quarterly issues, one volume per year, the first being scheduled to appear early in 1976.

This journal will take in all aspects of costs, economics, and related activities in the engineering and process industries. In addition to such industries as chemicals, pharmaceuticals, petroleum refining, and petrochemicals, the journal will include mineral and ore processing, metals production, food processing, and, indeed, the whole spectrum of process industries together with the contracting industry that serves them. The journal will thus be multi-disciplinary in the sense that all relevant types of engineering and the different technologies contributing to them will be covered by being related to the economic and business environment in which they exist. The aim of the journal will be to contribute to the advance and spread of relevant knowledge, in theory and especially in application and practice, and also to provide a forum for the exchange of information on problem solving.

All areas of process engineering will be covered from research and development through design and construction to plant operation and eventual replacement. The journal will have a character between that of the more traditional academic approach and that of the industrial trade journal. While its standards will be those of the former, it will aim to meet the needs of an extensive readership in industry for whom its contents need to be of practical value.

To subscribe (100 Dutch guilders or 40 U.S. dollars annually) or to obtain a specimen copy of the journal, write to Elsevier Scientific Publishing Company, P.O. Box 211, Amsterdam, The Netherlands.

Competition for student members of the South African Institute of Mining and Metallurgy

Each year the Institute offers a prize (or prizes should the entries warrant it) of up to R100 for the best paper or dissertation on a topic appropriate to the interests of the Institute. The competition is open to all Student Members of the Institute.

A Student Member who is in full-time study at a university may submit the dissertation or thesis he has to write in part fulfilment of his university degree, provided that it is presented in a manner and on a topic suitable for publication in the journal.

Entries for 1975 should reach the Institute by 31st December, 1975.

Resources of Southern Africa

The Associated Scientific and Technical Societies of South Africa (AS & TS) are to hold a conference on the Resources of Southern Africa Today and Tomorrow from 22nd to 26th September, 1975, at the Rand Afrikaans University, Johannesburg.

It is the purpose of the Conference to outline the many areas of interplay among the various resources of Southern Africa and among the disciplines involved in their development and utilization. In each of the sections — Human Resources, Food and Agriculture, Flora, Fauna and Forestry, Water, Minerals, and Energy — the intention is to present realistic facts, avoiding narrow politics and emotionalism, with the object of promoting inter-regional technological and economic collaboration. By highlighting the factors that are relevant to wise planning and conservation of the resources of Southern Africa, the AS & TS hope to make a contribution to improved standards of living of the peoples of the sub-continent.

Further information is obtainable from The Secretariat, AS & TS, P.O. Box 61019, Marshalltown 2107.

Energy Survey 1975

Energy is a theme that is receiving an ever-increasing amount of interest, both among academics and industrialists. But what is the energy situation in South Africa? Are we heading for a shortage of energy and the resultant economic slow down? Up to now, very little has been done to find out how South Africa uses its energy, how efficiently it uses it, and what energy-consumption trends can be expected in the future.

The Energy Utilization Unit at the University of Cape Town hopes to rectify this situation in the near future. Work is proceeding at the moment on the preparation of a questionnaire that will be distributed later this year to the industrial, mining, and transport sectors of the economy. A separate survey of the domestic sector is also being undertaken. There is an obvious need for information of this sort, which was brought out forcibly by a number of authors at the first South African Energy Conference, held recently in Cape Town.

A number of S.A.I.M.M. members hold positions in companies that will be approached for information about their companies' use of energy, and co-operation is sought, because, without it, the energy survey cannot succeed. All information will be treated as confidential, and any results will be presented in a format that will prevent identification of individual companies.

Activation analysis

The next International Conference on Modern Trends in Activation Analysis will be held in Munich, from 13th to 17th September, 1976. This Conference continues the series of Modern Trends Conferences organized at College Station, Texas (1961, 1965), Washington (1968), and Paris (1972). The international response to the previous meetings has been extremely favourable and encouraging. It is therefore clear that Modern Trends '76 again promises to be one of the leading scientific meetings in the analytical field. The international and multidisciplinary character of the Conference will be able to provide a working forum for all those interested in the many facets of the well-acknowledged potentialities of activation analysis.

The Conference will consist of a series of invited papers as well as the presentation of appropriate contributed papers. All major aspects of activation analysis will be discussed, particular emphasis being placed on the application of the method in a wide variety of scientific and technical fields, and papers falling under this broad category from prospective delegates are welcome.

The scope of the Conference is as follows:

A. Fundamental contributions
   Recent progress in technical development
B. Applied contributions
   1. Biological and biomedical applications
   2. Environmental and ecological applications
   3. Industrial applications
   4. Applications in geo- and cosmo-sciences
   5. Applications in archaeology, art and forensic sciences
C. Inter-disciplinary contributions
   1. Accuracy and precision
   2. Sampling and homogeneity control
   3. Standard materials
   4. Comparisons with other analytical methods.

Further information is available from Prof. Dr F. Lux, Institut für Radiochemie der Technischen Universität München, D-8046 Garching, F.R. Germany.