HISTORY OF THE EVALUATION AND EXPLOITATION OF A GROUP OF SMALL URANIUM MINES IN PORTUGAL

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Abstract

HISTORY OF THE EVALUATION AND EXPLOITATION OF A GROUP OF SMALL URANIUM MINES IN PORTUGAL.

In the period 1945–1962 a multiple small-scale uranium mining project was successfully operated in Portugal by the Companhia Portuguesa de Radium Lda, the Urgeiriça Mine and some 28 smaller mines produced ore between 1951 and 1962 and provided uranium concentrates for export under an agreement between the Portugal, the United Kingdom and the United States Governments. The uranium deposits occur in near-vertical fractures in the granites of the Beiras mostly having a NE-SW strike trend. The veins are the siliceous-pyrite-galena type with red jasper and black and white quartz gangue and much wall rock alternation and shearing. The primary uranium mineral is pitchblende and the secondary minerals tobernite and autunite occur in the near-surface zones. Of the 63 concessions controlled in 1945, the Urgeiriça Mine, dating from the radium period, was by far the biggest, but by mid-1946, after a very rapid preliminary evaluation, it was concluded that a total "possible" ore reserve of 1080 tons U_3O_8 might exist in the concessions. On this basis an agreement was reached with the Portuguese Government for the production and export of between 120 and 150 t U_3O_8 per year for a twelve-year period up to the end of 1962, and for a maximum of 1325 t U_3O_8. Production commenced on a regular basis at the beginning of 1952 and the total production quota of 1325 t U_3O_8 was produced by 31 March 1962. Since Urgeiriça provided 50–80% of the total ore throughout the period the main services were therefore located at Urgeiriça while all housing, power units, mechanical equipment etc., for the smaller mines had to be mobile. The Company innovated several techniques which are now widely used in uranium mining, e.g. radiometric borehole logging, tunnel-type radiometric selector systems for mine cars, heap leaching of uranium and in-situ leaching of uranium. Success in the whole project was due to reliable ore reserve estimates based on classical methods, tight management control, standardization of equipment and methods and also the flexibility and willingness of management to take full advantage of what were then innovations such as heap leaching, radiometric sorting etc. Good organization was the key to the success of the whole project.

INTRODUCTION

This paper is based on work done in Portugal by the Companhia Portuguesa de Radium Lda, Minas da Urgeiriça, Canas de Senhorium, between 1945 and 1962.

The Company owned or controlled a group of uranium-radium mining concessions and claims in the north-central part of Portugal, and from among these concessions the Urgeiriça mine and a group of smaller mines were brought into production between 1951 and 1962 and provided uranium concentrates for export. The basis of operations was an agreement and contract between the Portuguese Government and the Company, signed in 1949, renewed in 1955 and finally expiring in 1962.

Location

Although the work described took place between 1945 and 1962 the paper is presented here in the belief that many of the evaluation and mining techniques and problems are relevant to similar occurrences which may be exploited in the future.

The uranium concessions are located in an area of about 10 000 km^2 in the provinces of the Beira Alta and the Beira Baixa. The principal mine, Urgeiriça, is about 230 km north-north-east of Lisbon and 20 km from the district capital town of Viseu. It is located on the main railway line and on one of the highways to Spain and France. (Fig.1.)

Urgeiriça lies to the west of the dominant topographic feature of the region, the Serra da Estrela mountain range which reaches an altitude of 1991 m and has the uranium deposits located to the west, north and east of it.

Geology [Ref.1]

The uranium deposits occur in near-vertical fractures in the granites of the Beiras, which are part of the granites of the Iberian Meseta. Most of the uranium-bearing fractures have a NE-SW strike trend, parallel to the axis of the Serra da Estrela mountain range. Four districts of greater concentration of uranium-bearing fractures exist: (1) the Urgeiriça district to the west, (2) Trancoso district to the north, (3) the Guarda district and (4) the Belmonte-Sabugal district to the east of the mountains (Fig.1). The fracture pattern of each district is complex and both shear fractures and tension fractures are found and may be uranium bearing.

The veins vary in extent from some tens of metres up to several kilometres in length. They are of the siliceous-pyrite-galena type of uranium vein and have red jasper, ferruginous white quartz and black and white banded quartz as the

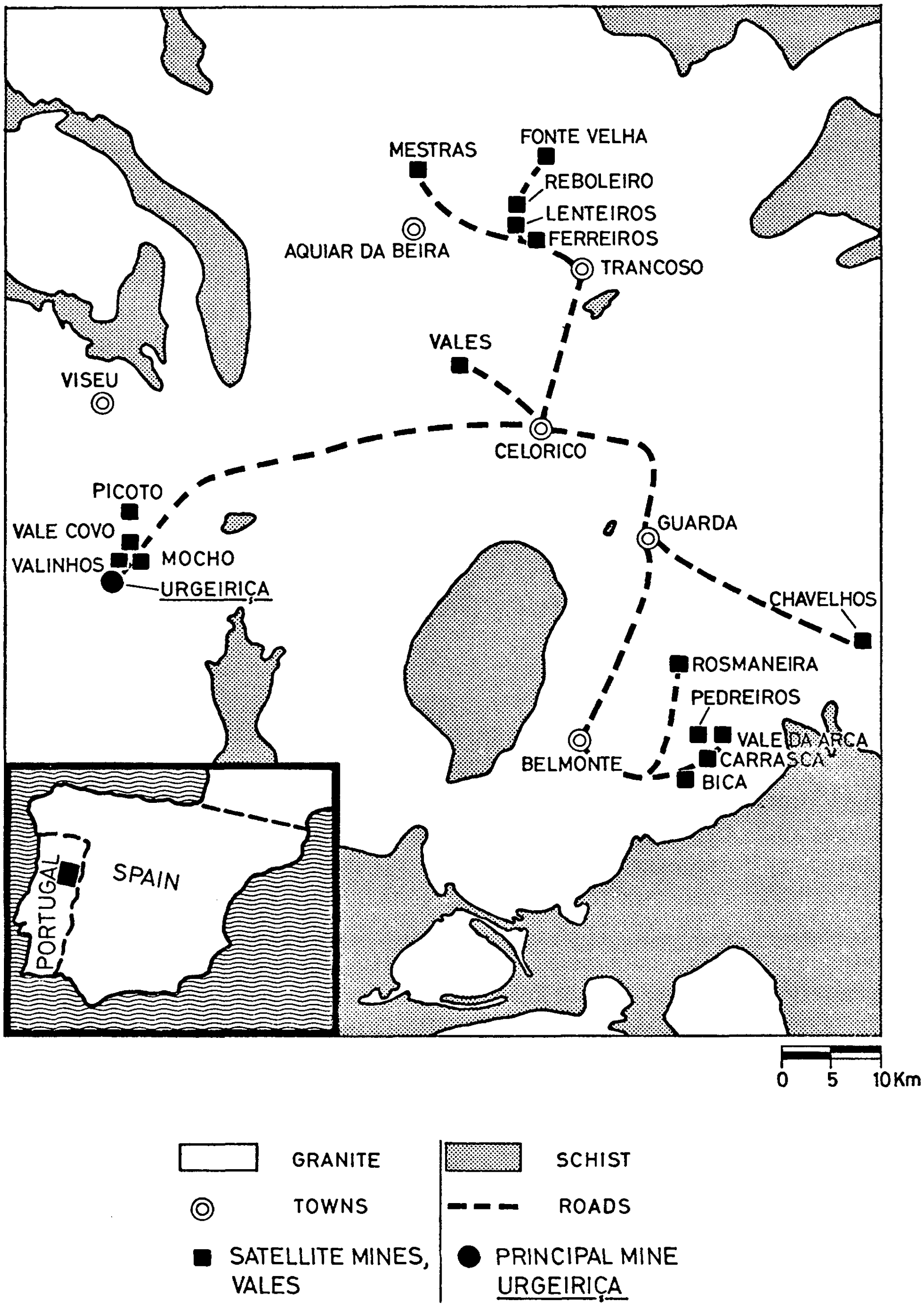

FIG.1. Uranium mining district in Portugal, 1951–1962.

main gangue rock. Considerable strike fault movement is shown by included altered silicified granite, fault clays and breccias. Wall rock alteration; sericitization, haematitization and kaolinization, together with strike faulting, produce many sections of weak ground, making mining difficult and at times dangerous. The primary uranium mineral is pitchblende, occurring principally in a microbotryoidal form, either as a dissemination in the red jasper or as a "sooty" form, loosely adhering to cracks and vughs in the veins. At the surface and in the near-surface zone, secondary uranium minerals, principally the calcium or copper hydrous uranium phosphates, are found. Other metallic minerals in the veins are haematite, iron pyrites, galena, sphalerite, chalcopyrite and small quantities of arsenopyrite.

The veins containing the ore-bodies may vary in width from 0.20 m up to multiple veins of 5 to 10 m, but the average is about 1 m. The angle of dip varies from 60° to vertical.

History

Soon after the discovery of radium at the end of the nineteenth century, the Portuguese uranium-radium deposits were receiving attention and by 1907 a French mining group was working in the Sabugal area and another group was soon working in the Guarda area.

The date of the first uranium-radium concession, granted by the Portuguese Government Mines Department, was September 1909. The Urgeiriça deposit was discovered in 1912 and the mining concession was granted in 1915.

The Urgeiriça mine was active from 1912 up to 1926 and then for three years there was no activity in the uranium-radium mines of Portugal, but in August 1929, two British subjects privately bought Urgeiriça and founded the Companhia Portuguesa de Radium Lda (CPR). Initially, interest was confined to Urgeiriça but over the following years some other uranium concessions were acquired. From 1929 to 1938 the Company continued to operate Urgeiriça under extreme difficulties, both technical and financial, and remained the only company attempting to produce radium in Portugal.

In 1942, the majority shareholder of the company was bought out by the United Kingdom Commercial Corporation Ltd., the United Kingdom Government war-time purchasing agency in Portugal. Under this control, the 14 mining concessions then owned were not operated but were maintained on a care and maintenance basis, but in late 1944 a more inspired interest was taken in CPR by the United Kingdom Government agency responsible for uranium supplies. A policy of buying out the minority shareholders of CPR and of acquiring other uranium concessions was pursued during the first half of 1945. This policy was completely successful and by August 1945 the Companhia Portuguesa de Radium Lda, was wholly owned by British Government interests and a total of 63 uranium concessions had been acquired.

Basis of contract with the Portuguese Government

Of the 63 uranium mining concessions controlled by CPR in 1945, only three were then in operation and available for underground inspection. The Urgeiriça Mine, dating from the radium period, was 270 m deep with 13 levels developed and largely stoped out over a 300-m strike length. The solution of a fault problem revealed the possibility of extending the mine for a further 400 m. By 1946 it had been concluded that there might be about 800 t U_3O_8 at Urgeiriça and a few hundred more tons in the other properties. It was on this basis of a total reserve of about 1080 t U_3O_8 that negotiations were initiated with the Portuguese Government and plant construction started in 1949. The objective was to produce between 120 and 150 t U_3O_8 annually over a 12-year period. The agreement signed was mandatory that no less than 120 t U_3O_8 be produced each year and that a total of 1325 t U_3O_8 be produced before 31.12.1962.

The contract also contained some clauses covering extremely complex arrangements in regard to which concessions could be in exploration or production at any one time. For example, only 10 concessions could be in 'production', i.e. stoping, at any one time, and before a worked-out mine could be substituted the Portuguese authorities had to be satisfied that no ore remained in that property. The complications which thus resulted in the overall technical policy are not dealt with in this paper.

Construction and development policy

Because of the higher reserve tonnage and the existence of an infrastructure from the radium period there was no difficulty in deciding that Urgeiriça would be the centre of the organization. It was planned that the Urgeiriça ore reserve should be made to last throughout the contract period to 1962 and that development of the satellite mines should be as rapid as possible so that they should supply between 20 and 40% of the total ore milled in that period.

In planning mining production it was assumed that Urgeiriça would provide 80% of the total ore in the early years but that this would fall to 50% in the later years. With an assumed plant recovery of 90% and an average initial grade of 0.35% U_3O_8 the plant was originally planned to have a capacity of 100–200 t ore per day but this was later expanded to 150 t ore per day.

The policy for the outlying mines was based on the assumption that their individual lives would be shorter than the contract period and therefore all housing, power units and mechanical equipment should be mobile. Sectional housing panels were designed to give houses of different sizes as required. Power units were standardized to facilitate maintenance and stocks of spare parts. Design of shafts, raises, winzes and galleries were standard and used in all the mines. Timber sets were made in Urgeiriça carpenters' shop and transported to the other mines.

The auxiliary services were centred at Urgeiriça and included the main mechanical and electrical workshops, carpenters' shop, store, office, mining surveyor and geological sections and were built on a scale sufficient for the requirements of the whole organization.

The chemical treatment plant was built at Urgeiriça and also the social services which included housing for 500 people, a medical post, hospital school, shop, social club and recreation facilities. As far as possible the social services provided facilities for the other mines.

The controlling board decided that the cost of product should be the equivalent of US \$6.66/lb[1] U_3O_8 and the management was requested to ensure that this figure was not exceeded in the annual cost of production. The Company was also under very strong instructions to fulfil a minimum quota of production which was set at 120 t U_3O_8 per year.

Organization of the company

The local board of Directors, resident in Lisbon, comprised five members, three being British subjects and two Portuguese. The general manager of the Company from 1943 until the end of the contract in 1962 was resident at Urgeiriça mine and directly responsible to the board in Lisbon. The senior staff of the Company consisted of an assistant general manager, a chief mining engineer, the superintendent of the treatment plant, the chief geologist, the chief of the laboratory, the chief accountant and a chief mechanical and electrical engineer. The general manager was a Portuguese subject and the assistant general manager was British. The other senior posts were evenly divided between British and Portuguese subjects.

GEOLOGICAL DEPARTMENT AND THE EVALUATION OF THE DEPOSITS

General

The Geological Department planned, operated and assessed all surface exploration and diamond drilling, proposed mine exploration programmes, recorded geology and sample results in all mining work, advised on the geology of stoping mines and computed ore reserves for all properties. For convenience, the servicing of all the company's electronic equipment was also done by the geological department.

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[1] 1 lb = 0.453 kg. The lb unit is used frequently throughout this paper.

On all matters concerning ore reserves the chief geologist was directly responsible to the general manager and helped to formulate policy arising therefrom and related to the government contract.

On matters of mining geology and grade control the department provided information direct to the chief mining engineer.

Surface prospecting

The early mapping (1945–1948) of the Company's concessions had been concerned with the more significant radioactive surface zones on each concession. After 1951 the whole surface area of all concessions was re-mapped in detail. Each concession, amounting to half a square kilometre in area, was surveyed by a geologist and surveyor and accompanied by a trenching team. Topography, geology and radiometric readings were recorded on a final 1:1000 scale plan and a written report on the geology and ore potentialities was prepared. Areas of greater interest were mapped on 1:500 or 1:200 scales. No work was allowed beyond the Company's concession or claim boundaries.

Diamond drilling

Seven Craelius diamond drills were owned by the Company and directly operated by the Geological Department. Two of these were specifically for underground drilling and the other five for surface drilling. The geologists were responsible for hole planning, logging and assessments and under their supervision two junior engineers were responsible for the mechanical operation of the drills.

Over the period of eleven years, 1950 to 1960 (incl.), 62 055 m were drilled on 33 different properties. The annual meterage drilled reached a maximum in 1955 and thereafter decreased to the end of drilling in 1960. This pattern conformed to the policy needs of the company and allowed for mine development and stoping to be planned and completed before the contract terminal date in 1962.

Following surface mapping and trenching prospection, drilling was done on concessions where there was little or no earlier mining work. The ore-bodies at Valinhos, Vale da Arca, Môcho, Mestras and Pedreiros were principally discovered and defined by diamond drilling. On several other concessions, such as Bica, Carrasca and Reboleiro, surface drilling in conjunction with mining revealed the extent of the ore-bodies.

Development drilling was done on or below the extensions of many known ore-bodies, helping to define them and to estimate ore reserves so that the mining department could plan technical policy.

As the Company took over many old mines from the radium period for which no plans existed, the re-opening was fraught with risks and the drills were used on several of these small mines to locate old galleries, shafts and stopes before planning how to re-open the workings.

In hole assessment, sludge and core samples were taken, but the most important tool was the calibrated borehole Geiger counter for recording radioactivity. The 19-mm borehole probe used inside the Craelius drill rods was first developed in 1951 by AERE Harwell, England, at the suggestion of the CPR geologists. The calibrated Geiger counter results were checked on many later occasions as assessed ore shoots were mined out.

Geological mine plans

The permanent mine plans for all properties were based on a block system with a unit of 200 X 120 m. Co-ordinates were normally a local system arranged near parallel to the average vein strike in each deposit. Nomenclature of the blocks was arranged with an alphabetical designation, generally NW–SE and a numerical designation NE–SW. Identification was completed by the level number. Three scales were in general use – 1:200 for the geological and assay plans which were separate but superimposable; 1:500 for the mine level plans used in planning work; and 1:1000 for general plans and ore reserve reports. Where necessary, groupings of blocks were made for the smaller-scale plans. Transverse sections along each 20-m interval main co-ordinates were also standard practice on the 1:500 scale.

Sampling and ore reserve estimation

Sampling of mine development was done by teams of samplers, technically under the control of the chief geologist. All samples were channel samples, 20 cm wide, 3 cm deep and taken across the full width of the vein structure at 1-m intervals in all galleries, raises and winzes. Each sample was normally between 10 and 25 kg in weight and was prepared in the normal way by crushing, quartering, grinding and splitting. Assaying was done by a beta counter installation in the laboratory and a selection of samples were check-assayed by chemical methods for control purposes and to note any disequilibrium in the ores.

The normal ore reserve calculation methods were used. The ore cut-off was 0.15% U_3O_8, but in practice only zones with a minimum of five consecutive metres giving an average of over this grade were considered. Random high samples were cut to twice the average of the whole zone and the average recalculated. A sampling factor reduction of calculated grade was determined and used for each individual mine. A dilution factor of 15% was used for all mines.

Ore reserve classification system

Proven or measured ore

This is ore exposed and sampled on four sides. The maximum vertical distance between levels, acceptable for this class, was 40 m and the horizontal distance between raises was 30 m.

Probable or indicated ore

This is ore exposed and sampled on one, two or three sides, where there was reason to assume continuity from consideration of the nature of neighbouring ore blocks of similar type and comparable grade; and also ore defined by diamond drill holes and evaluated by samples of sands or cores or from calibrated Geiger counter borehole readings.

Possible or inferred ore

This is ore for which quantitative estimates were based largely on a general knowledge of the geological character of the deposit in circumstances where no systematic sampling had been done and measurements might be approximate. Estimates in this category were regarded as no more than informed guesses indicating the degree to which the deposit merited exploration and development.

Ore reserves

Ore reserve estimates were made at the end of each year for each property from 1946 onwards. At the end of 1946 the total ore reserves were stated as 1980 t U_3O_8, but only 80 t of this was in the proven/probable classes. It was on this basis that negotiations were started for the government contract, and when the agreement was signed in mid-1949, the total reserves were still at about the same figure although the proven/probable class had been increased to 375 t, mainly due to development work at Urgeiriça.

In late 1951 when production started, the total reserves were stated as 1700 t U_3O_8 of which 580 t were then in the proven/probable class. The start of diamond drilling in 1950 and the increased mining exploration saw further increases to a maximum total figure of 2070 t U_3O_8 in 1954. In the later 1950s, some re-assessment was necessary when drilled properties were opened up and mined, and as the poorer concessions were abandoned.

The ore reserves left in the mines at the end of the contract were estimated to be 540 t U_3O_8, 225 in the proven/probable class and 315 in the possible class. The total U_3O_8 sent to the plant in direct ore mined amounted to 1360 t which,

TABLE I. PRODUCTION FROM ALL MINES, 1951–1962

Name of mine	Period of production	Distance from Urgeiriça (km)	Ore milled (t)	Av.grade (% U_3O_8)	Total U_3O_8 produced (t)	Av.cost U_3O_8 (US $/lb)
Urgeiriça	1951–62	–	241 060	0.305	766.9	4.65
Bica	1951–61	130	74 050	0.271	206.0	5.63
Vale da Arca	1956–61	136	32 130	0.265	80.1	5.04
Carrasca	1952–60	132	21 730	0.444	90.5	4.19
Valinhos	1955–60	2	13 000	0.243	41.8	8.64
Reboleiro	1951–55	80	12 920	0.257	26.6	13.65
Rosmaneira	1951–56	115	6 640	0.208		
Ferreiros	1954–62	80	6 120	0.273		
Fonte Velha	1951–56	90	2 750	0.238		
Mestras	1955–58	75	2 650	0.294		
Picoto	1951–52	6	1 750	0.500		
Lenteiros	1951–55	80	1 520	0.380		
Mocho	1951–54	3	1 450	0.221	112.8	15.45
Pedreiros	1958–60	130	1 270	0.281		
Vales	1957–60	40	810	0.185		
Vale Covo	1958–60	3	980	0.175		
Chavelos	1952–53	150	260	0.144		
Others[a]	1954–62	–	45 910	0.164		
Totals:			467 000	0.306	1324.7	5.70
Averages:			(44 475)	(0.306)	(126.2)	(5.70)

[a] Includes ore purchases, heap leaching, neutralization slimes, waters, sands, etc.

together with the 540 t left in situ, amounts to 1900 t. These figures do not, however, include the low-grade natural leaching ore nor the U_3O_8 recovered from mine water, and other sources.

The total U_3O_8 contained in the CPR concessions is therefore estimated to have been approximately 2000 t and thus the estimates at the beginning of the production period proved to have been sufficiently accurate to justify all the technical policies which were adopted by the management.

PRODUCTION PERIOD 1951–1962

Summary

The production period is best summarized by a tabulation of the final results as shown in Table I. Production commenced on a regular basis at the beginning of 1962 after a running-in period of several months in late 1951. The whole production operation was closed down on 31 March 1962 and thus the production period was effectively just under 10.5 years.

From Table I it can be seen that an average of 44.475 t of ore were milled each year with an average grade of 0.306% U_3O_8 and an average of 126.2 t U_3O_8/a were produced. The average cost within the working period was US $5.70/lb U_3O_8. The tonnage came from one small- to medium-sized mine (Urgeiriça) and 21 small mines – mainly very small. Favourable cost figures were held on only four of the mines, but these were all the larger tonnage mines and resulted in a satisfactory overall cost substantially below the company's target figure of US $6.66/lb U_3O_8. It could have been argued that the smaller more costly mines should never have been developed, but this was a necessity as the annual production quota of not less than 120 t U_3O_8/a was an equally firm contract commitment. Grade appeared to be a much more important factor than distance from the treatment plant in reaching good cost figures, e.g. the Carrasca Mine, although 132 km from Urgeiriça, had the best cost per lb figure (US $4.19) of the whole group because its average grade was 0.44% U_3O_8 as compared with the overall average of 0.306% U_3O_8.

The contract figure of 1325 t U_3O_8 was produced nine months before the limiting date of 31.12.1962.

A brief description of some of the more important of the mines follows:

(1) Urgeiriça Mine (Urgeiriça and Ucha mining concessions) 1945–1962

The Urgeiriça mineralized fissure zone consists of various strike faults and breccia zones with interconnecting tension fractures and branch veins. The strike is N 62° E and the dip is at a very steep angle to the south-east. The vein width was normally about one metre but widths of up to 10 m were reached locally and small stockwork zones existed. Except in the near-surface weathered zone, where secondary uranium mineralization was found, the ore consisted of finely disseminated pitchblende in red-black jasper veins or in veinlets in altered wall granite [2]. The high degree of brecciation, strong strike faulting and extensive kaolinization and sericitization of the wall-rock granite made this difficult ground to work and required close timbering in both development and stoping work. Three transverse faults divided the ore-body and several separate, near-vertical ore shoots were defined and worked.

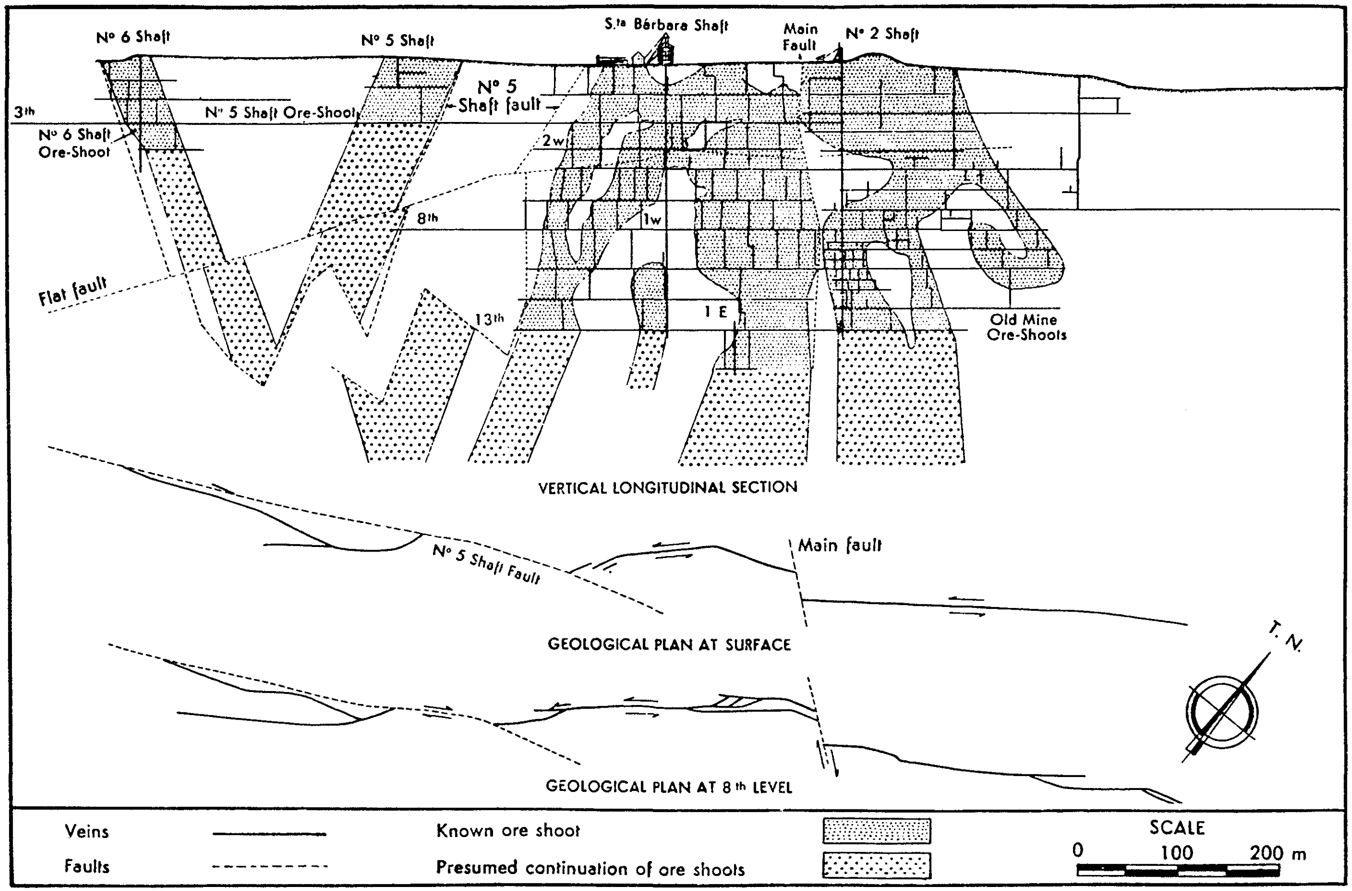

FIG.2. Urgeiriça mine. Longitudinal section and plans showing distribution of ore shoots and principal structural features.

A longitudinal section and plan of the mine in 1956 is given in Fig.2. The final explored length was 1200 m and the maximum depth was 380 m. The main fault divided the pre-1945 workings from the later workings.

Three vertical shafts served the main mine. The Sta. Barbara shaft, which was started in 1949 and sunk as required for development work, reached 380 m depth in 1959 and was the main haulage and personnel shaft.

In the Sta. Barbara shaft area, mineralization was more or less continuous over a distance of 270 m from the surface to the 4th level. Below the 4th level the ore-body split into a south-west and a north-east ore shoot about equidistant from the shaft (Fig.2). From development work and drilling it became evident that these ore shoots were narrowing and becoming impoverished below the 14th level.

Other areas which produced ore were the No. 6 shaft area, the No. 5 shaft, 3rd to 10th level zone, and the old mine. Drilling in the old mine showed that several richly mineralized veins, parallel to the main structure had been missed in the radium mining days and also that areas which were then uneconomic were now exploitable. Development of the old mine areas was slow because of the danger of re-forming the old levels and also because of the naturally weak ground.

Development of the 16th level was completed by mid-1961, after which no further development work was done because of the approaching end of the contract. Stoping by horizontal cut and fill started in 1951 and ceased in March 1962 at which time all the developed ore had been stoped. During the life of the mine from 1945 to March 1962, a total of 23 500 m of development works were done, 189 750 m^3 were stoped and 241 060 t ore were produced.

(2) Bica Mine: 1950–61

The second biggest mine in the group, Bica, is situated east of the Serra da Estrela mountains about 130 km by road from Urgeiriça. For most of the period this mine served as the company's headquarters in the Belmonte-Sabugal area, supervised by a resident engineer.

The mine is located on a north-east trending red jasper vein, 0.75 to 2.00 m in width and dipping north-west at 70°. The mineralization was fine-grained pitchblende in the deeper zones and secondary uranium minerals near the surface.

Bica was one of the old radium mines and a shallow adit, shaft and old mined stopes had to be by-passed when mining exploration work started in 1950. In 1952 a vertical main haulage shaft was started after initial exploration and drilling had shown the probable continuation in depth of the ore-body. In mid-1955, horizontal cut and fill stoping was started above the second and third levels.

In March 1960 all development work was stopped because of the approaching end of the contract and at that time both shafts were 240 m deep and the 7th level had been developed over a strike length of 230 m. Stoping between the 7th and 6th levels had been completed when the mine was closed down in November 1961.

During its working life for the Company, 5150 linear metres of mine development and 63 340 m^3 of stoping were done, and 74 050 t of ore were produced at Bica. A large tonnage of low-grade natural leaching ore was also produced.

(3) Vale da Arca Mine: 1952–1953; 1956–1961

Vale da Arca mine is situated six kilometres north-east of Bica and is located on the northeast continuation of the Bica vein. The vein zone, dipping at 60° to the north-west, consisted of three parallel veins with interconnecting veinlets giving a total mineralized width of ten metres.

A small amount of work had been done in the radium period, and the early mining exploration work by the Company in 1952–53 in opening up the old adit was not encouraging. It was only as a result of the diamond drilling programme started in early 1956 that the full extent of the ore-body was discovered. Mining development was re-started and three levels were developed over a strike length of 150 m to a depth of 80 m. Stoping started in late 1958 and the ore-body was finally worked out in June 1961. Stopes of 10–12 m width in very weak ground were worked.

(4) Carrasca Mine: 1952–1960

Carrasca is also located near Bica, being two kilometres north-west of it, but is not on the same vein system. A series of small ore-shoots were located on a group of narrow jasper and quartz veins. The mine was worked in the radium period and some old mined stopes had to be by-passed when mining exploration started in 1952. Stoping started in 1954 and continued until the mine was closed down in 1960. Although narrow, the veins contained sections with very rich values and routine samples of up to 13.0% U_3O_8 were recorded. A maximum depth of 170 m and a strike length of 220 m on four different veins was developed. Drilling and mine exploration showed that no further ore-bodies could be expected and the mine was closed down in April 1960 and all equipment and installations removed.

(5) Valinhos Mine: 1955–1960

The Valinhos mining concession adjoins and lies north-east of the Urgeiriça concession. Although the mine is located on the Urgeiriça vein structure, the workings remained separate. The ore-body was unknown in the radium period and was discovered in 1952 when systematic drilling along the north-east continuation of the Urgeiriça vein found ore under an alluvial filled valley. The ore-body was completely outlined by drilling before mining development started in 1955. Two vertical shafts at the extremities of the ore-body were sunk to reach a depth of 130 m and four levels were developed over a strike length of 210 m. Stoping started in the spring of 1957 and continued until the end of 1960.

(6) Reboleiro Mine: 1946–1955

Reboleiro is located in the Trancoso area about 52 km north-east of Urgeiriça and 80 km distant by road. The ore shoots were contained in a group of narrow, steeply dipping, black and white quartz veins forming part of a complex tension fracture pattern. Near-surface mineralization was secondary, but in depth the primary mineralization consisted of a loosely adhering sooty pitchblende in cracks and vughs in the quartz.

This was one of the two properties purchased by the company in 1944–45 and small-scale active mining exploration work was taken over in December 1945. Mining exploration and development were done on eight different veins in four separate groups of workings. The most extensive workings were at South Shaft where a depth of 110 m was reached and five veins were worked. Stoping started in late 1951 and continued until the exhaustion of all ore-bodies in mid-1955. Drilling had shown that no further ore could be expected and thus all equipment and installations were removed in late 1955 and the mine abandoned.

General

The six mines which have been briefly described produced 84.5% of the ore tonnage and 91.5% of the U_3O_8 during the whole protection period. In addition, smaller mines at Rosmaneira, Ferreiros, Fonte Velha, Mestras Picoto, Lenteiros, Mocho, Pedreiros, Vales, and Vale Covo produced ore from stoping and development operations (see Fig.1 and Table I).

Exploration and development work was also done on 13 other properties and a few of them, such as Chavelos, provided a certain amount of ore from development work but no mine stoping was done. The annual variations in the total work done are shown in Table II.

Development work on the 29 properties amounted to 52 190 m and stoping on 16 concessions totalled 364 860 m³. Stoping and development work on 20 concessions produced 421 100 t of ore.

The variations in annual totals (Table II) reflect both general policy and technical considerations. Mining development increased each year up to 1954,

TABLE II. ANNUAL FIGURES FOR DIAMOND DRILLING, MINE DEVELOPMENT, STOPING AND ORE PRODUCED FROM UNDERGROUND MINES

Year	Diamond drilling (m)	Mining development (m)	Stoping (m^3)	Ore produced (t)
1945–1950	2 123	8 170	–	3 955
1951	3 583	3 412	2 890	4 723
1952	5 871	3 990	21 830	31 302
1953	6 398	5 020	30 240	38 515
1954	6 592	5 225	21 300	35 075
1955	8 663	2 953	35 350	35 135
1956	7 767	4 275	32 815	39 320
1957	6 698	5 980	36 430	44 140
1958	6 063	5 850	42 840	50 645
1959	5 941	4 905	50 800	51 535
1960	2 356	1 855	47 080	42 805
1961	–	522	37 975	38 540
1962	–	33	5 310	5 410
Totals:	62 055	52 190	364 860	421 100

but uncertainties regarding the renewal of the government contract in 1955 brought about a marked decrease in mining exploration and development in that year. After renewal was assured, increased development was done to secure the ore tonnage required for the second half of the contract. The progressive decrease in average grade also meant that more ground had to be developed in the later years to meet tonnage requirements. Both the cubic metres stoped and the tonnage of ore produced reached maximum figures in 1959. The close-down operation started in April 1960, two years before the end of the contract, and this was immediately reflected in a reduction of all mining work. From then to the end of the contract the only mining work done was that which was calculated to give the exact ore tonnage requirements. During this period the estimates were very complex; it was necessary to have sufficient ore to provide an exact tonnage figure to be achieved two years ahead, but no unnecessary development work was to be done. The decision not to develop the 17th level

TABLE III. ORE PROCESSING PLANT FIGURES

Year	Milling rate (dry t/d)	Feed grade (% U_3O_8)	Recovery (%)	Cost per dry ton milled (US $)	Cost per kg U_3O_8 (US $)
1952	85.2	0.37	94.8	6.17	1.74
1953	112.0	0.35	88.5	4.78	1.48
1954	110.5	0.35	93.2	5.11	1.48
1955	104.5	0.34	92.3	4.77	1.45
1956	113.3	0.32	92.5	4.72	1.51
1957	133.8	0.27	89.2	4.31	1.68
1958	155.0	0.26	90.4	4.14	1.68
1959	154.5	0.27	90.1	4.18	1.62
1960	141.3	0.25	89.6	3.99	1.67
1961	142.1	0.23	90.6	4.51	1.99
3 months only	94.1	0.22	89.6	5.82	2.55
Averages:	125.2	0.306	91.0	4.60	1.64

at Urgeiriça was at times felt to be risky but in the end the stopes above the 16th level were exactly worked out on the last days of the tonnage requirement. At Bica the decision not to develop the 8th level was also taken nearly two years before the end and in that case the stopes above the 7th level were worked out in November 1961 so that from then onwards Urgeiriça and Ferreiros and some other sources had to be relied on for the terminal tonnage requirements.

Ore grade

In the original planning in 1949–50, when only 375 t U_3O_8 in proven and probable ore were in sight, the estimated average grade for ore to the plant was 0.35% U_3O_8, and at that time a provisional average cut-off grade of 0.20% U_3O_8 was assumed. The average grade of ore from each mine is indicated in Table I and the annual average grade of ore entering the plant is given in Table III. As shown in Table III the estimated average grade was fairly well maintained up to 1956. The sharp fall occurred between 1956 and 1957 when the averages were respectively 0.323% and 0.274% U_3O_8. The grade then progressively decreased to 0.22% U_3O_8 in the final year.

In the early years the main source of ore was Urgeiriça and Ucha but the high-grade ore from Carrasca was an important factor in keeping up the average grade. Development on the levels below the 12th in Urgeiriça had indicated that a fall in grade was to be expected from 1957 onwards and the exhaustion of the rich ore in Carrasca also contributed to the lower average grades. The average grade of all mine ore over the whole period was 0.31% U_3O_8.

The cut-off grade was changed to 0.15% U_3O_8 at an early stage in the production period. Selection at shaft head was practised at all mines and a division into ore (plus 0.15% U_3O_8), natural leaching ore (0.05% to 0.15% U_3O_8), and waste (0.05% U_3O_8) was practised. The low-grade, heap-leaching ore did not go to the plant but was treated in a separate process described below.

Organization of mine services

Mining organization

The chief mining engineer and his assistant were resident at Urgeiriça but visited each of the mines once per week making full underground inspections in each case. The category and number of staff in resident control of each mine depended on the size and complexity of the operation but the larger mines were under the control of a resident engineer.

Grade control

Final ore grade for each producer was determined on chemical assay at the point of entry to the treatment plant, but up to that point all grade control was radiometric. All mines were issued with small portable GM counters calibrated to indicate waste, heap leach ore, and ore. At four of the mines tunnel-type radiometric car analysers were installed and classified all material extracted into the three classes. On all small mines, hand-picking assisted by GM counters was done to reduce waste transport to a minimum. Within limits it was always more economic to keep the plant operating at capacity and thus if any ore shortages developed the standard cut-off of 0.15% U_3O_8 was temporarily reduced to ensure full capacity.

Ventilation, safety and accident control, etc.

As for the other services, the main control of these services was centred at Urgeiriça. A ventilation, dust control and radon inspector was responsible for the regular inspection and sampling of all mines and he reported to the chief mining engineer. An accident committee met once a month and training courses in rescue and first aid were held at all mines.

A hospital and main medical clinic operated at Urgeiriça and regular visits by medical staff were made to the other mines.

Mechanical and electrical services

The workshops at Urgeiriça were responsible for all mechanical and electrical maintenance on all mines. A foreman mechanic and electrician visited each mine once a week on maintenance inspections. The carpenters' shop was also centralized at Urgeiriça.

Transport

Transport of ore from the satellite mines was done on contract by a fleet of trucks of about 15 t capacity. Under the contract all materials from the central workshops at Urgeiriça were carried to the other mines on the return journey. The company maintained a fleet of Land Rovers and cars for staff transport.

Laboratory

The laboratory at Urgeiriça operated as a separate section to carry out routine analysis of samples from surface and mine exploration and development, stope control, ore stock control and treatment plant operation. Between 1000 and 1500 samples were analysed per month about 10% by chemical methods, mainly for checking equilibrium, and the others radiometric.

General office, stores, etc.

The chief of the general office at Urgeiriça was responsible for time-keeping, pay office, store, etc. on all mines. The chief storeman was the only purchasing agent of the Company and supplies to the other mines came through the Urgeiriça store.

Mine labour

Between 500 and 600 men were employed underground on all mines during the normal years, and, in addition, a further 300 to 400 surface workers were employed by the mining section on auxilliary mining services.

ORE PROCESSING PLANT

The plant worked on a continuous shift basis employing 80 persons of whom 60 were on shift work and the others on maintenance. Over the whole period the milling rate averaged 125.2 t/d and the cost per dry ton milled was approximately US $4.60.

The figures for daily throughput, grade of feed, recovery and product grade for the years 1952 to 1962 are given in Table III. The year 1951 is not included as it was mainly a running-in period. During the period 1952 to 1956 the daily tonnage and grade were almost exactly those which the plant had originally been designed to treat, i.e. 100 t/d at 0.35% U_3O_8. No outstanding difficulties were met and the recovery was 91.2%.

During 1956 it was foreseen that the average ore grade was likely to fall to about 0.26 U_3O_8 and, in order to maintain U_3O_8 output and overall cost per kilogram, it would be necessary to increase throughout by 40 to 50%. To meet this requirement various modifications were made to the plant in early 1957.

In 1958 the average daily thoughput reached 155 t. From January 1957 to April 1960 the recovery averaged 89.8% but the concentrate grade fell. The final period, dating from May 1960 until the end of production in March 1962, coincided with the running down of the whole operation and further reduced the average feed grade to about 0.23% U_3O_8.

Several further alterations to the plant were made and by these measures, recovery was maintained at about 90% but product grade again fell.

The plant operating costs per dry ton milled and per kg U_3O_8 produced are shown on Table III. Except for the last two years which were abnormal, owing to the approaching close-down, the cost per dry ton milled was progressively reduced during the operating period.

OTHER SOURCES OF U_3O_8 AND SUBSIDIARY TREATMENT METHODS

Besides the ore produced by direct mining on the Company's concessions, followed by direct feed to the treatment plant, there were various other sources of U_3O_8 and also other subsidiary treatment methods which contributed to the final total of U_3O_8 produced.

Ore purchases

The only ore purchases made by the Company were from the uranium prospecting and development section of the Portuguese Government, Junta da Energie Nuclear. The total ore purchased between 1957 and 1962 amounted to 4552 t with an average grade of 0.35% U_3O_8.

Old surface dumps

Several properties contained uranium-bearing dumps dating from the radium period, either consisting of mine ore which had been below the cut-off grade of the radium period or of tailings sands or slimes rejected from the old radium plants. The total ore recovered from old dumps amounted to 7141 t with an average grade of 0.355% U_3O_8.

Urgeiriça treatment plant tailing's water neutralization slimes

The treatment plant tailing's disposal flow consisted of 600 to 650 t of water carrying 120 to 150 t of sands and slimes per day. Settlement of solids was effected in the tailings disposal dump and the clean water run-off from the top of the dump emerged in a sump at the base. About 250 t of water was returned daily for use in the plant but the remaining 350 to 400 t were sent to waste. The waste water had a pH of 3.5 and a U_3O_8 content of 10 to 15 mg/litre, and was therefore passed through a neutralization system before joining a nearby stream. Precipitation took place in a series of pits and labyrinths. The resultant slimes were allowed to settle and dry in pits and were afterwards dug out and returned to the plant feed just before the rod mill. Over a ten-year period, 3930 dry tons of slimes with an average grade of 0.47% U_3O_8 were produced from this source.

Neutralization slimes from mine water

In some mines, pyrite in the ore, on being oxidized and attacked by the natural waters, produced a dilute sulphuric acid which, under oxidizing conditions, tended to leach small quantities of U_3O_8 from ore in place or broken ore in stopes. A routine check was kept on the pH and U_3O_8 content of waste mine waters. At Urgeiriça the water was used direct by the treatment plant and on some other properties by the natural leaching system, but at Bica and Vale da Arca it was found to be worthwhile making a small neutralization system for excess waste mine waters. About 36 t of dry slimes with an average grade of 2.40% U_3O_8 were produced in this way.

Other ore sources

Small contributions were made by a few other sources, one of these was from waste mine timbers. Old timbers removed from the mine during re-forming work were found to be impregnated with uranium from mine waters. All old timbers were therefore used to fuel the furnaces of the sample preparation drying room and the resulting ash was recovered and treated. Over the period, about 14 t ash with an average grade of 2.22% U_3O_8 were recovered.

Water, liquors and concentrates

The above extraneous sources entered the treatment plant before the rod mill and were therefore subject to the recovery factor. The following sources entered after the rod mill and were considered to have 100% recovery.

Urgeiriça mine water

All the Urgeiriça-Ucha drainage mine water was used by the treatment plant and this water had a small but valuable U_3O_8 content. The origin of the dissolved uranium was the same as described above. The leaching of U_3O_8 within Urgeiriça mine was not uniform, and several studies were made of the process.

The volume of water pumped and the U_3O_8 content varied seasonably. The grade of the water pumped expressed in mg U_3O_8/litre showed higher values in the spring and low values in the autumn. The monthly rainfall graph and the monthly total volume of water pumped corresponded very closely in form but were off-set by about five months indicating that drainage through the mine took that time. The total of 41 587 t U_3O_8 from this source amounted to approximately 3.0% of the total production. This U_3O_8 was considered to have been 100% recovered by the plant.

Stope leaching at Urgeiriça

An experimental attempt to speed up leaching in place was made in 1958 and 1959 – probably the first attempt at in-situ uranium leaching anywhere in the world. Backfill to stopes, originating partially from wall rock, often carried 0.02 to 0.03% U_3O_8. In an experimental stope between the 12th and 13th levels strongly acid liquors with a pH of 2.5 and a U_3O_8 content of 2.13 g/litre were produced, and 121 kg U_3O_8 were recovered in four months. The method gave results but it seemed probable that the U_3O_8 would anyhow have been recovered by normal drainage over a longer period. This factor, combined with the inconvenience to normal mine operation, led to the discontinuation of the system.

The heap-leaching system

The Company pioneered and successfully developed a "natural" leaching or heap-leaching treatment process for low-grade ores. The range of grades treated by this process was approximately 0.05 to 0.15% U_3O_8 and covered the low-grade ore selected at the surface hand-picking or Geiger counter selection installations. No ore was mined specifically for this treatment process.

The natural leaching possibilities of Urgeiriça ore were first noted in 1950–51 when it was found that an exposed dump of development ore had been very substantially leached by rain-water over a period of six to twelve months. As it was realized that this phenomenon could be put to practical use, an early series of tests were carried out at Urgeiriça in 1951–1952, and it was found that ores from different deposits varied greatly in leaching efficiency if only water was added.

The natural leaching process is initiated by the aerial oxidation of pyrite in the presence of moisture and the subsequent attack on uranium minerals by the dilute sulphuric acid produced. The chemical reactions and many detailed experiments on Portuguese ores have since been described in a series of papers by several authors from the National Chemical Laboratory, Teddington. [3–5]

The methods employed at Urgeiriça and Valinhos gave recovery efficiencies of well over 80% and eventually reduced the turn-round period to eight or ten months. The biggest tonnage treated was from Bica mine and unfortunately this was also the most difficult ore to treat. Despite many efforts the overall leaching efficiency remained low at Bica. The principal reasons were that the pitchblende was finely disseminated and tightly locked up in the siliceous gangue and the calcite content of the gangue which consumed acid and also produced calcium sulphate which formed hard layers and inhibited drainage.

Over the ten-year period, 1952–62, a total of 83 600 t of low-grade ore was treated and 43 172 t U_3O_8 were recovered. With an initial average grade of approximately 0.077% U_3O_8 this gave an overall recovery of about 66%.

PRODUCTION TOTALS

Summary

The total production of U_3O_8 based on the CPR laboratory assays was 1324.670 tons, but the final accepted figure was 1325.683 tons based on the assays from the purchasing agency and referees.

For the present purpose, discrimination by sources is based on the CPR assays. Table IV gives a summary of the main sources of U_3O_8 making up the total.

As was to be expected, the Urgeiriça-Ucha mine was by far the largest producer, providing 49.42% of the U_3O_8 which was directly mined and 57.89% of the total U_3O_8 produced. Bica mining concession was the second largest producer and Carrasca and Vale da Arca, respectively third and fourth largest.

Cost of product

An average cost of US $5.70/lb U_3O_8 was achieved, which can be broken down as shown in Table V.

TABLE IV. SUMMARY OF SOURCES OF U_3O_8 PRODUCED

	U_3O_8 (t)	% of total U_3O_8 produced
Ore from stoping mines:		
Urgeiriça and Ucha	654.580	49.42
Bica	188.109	14.20
Carrasca	90.020	6.80
Vale da Arca	77.790	5.87
Valinhos	34.509	2.61
Reboleiro	26.596	2.01
Nine other stoping mines	59.951	4.52
Sub-total	1131.555	85.43
Ore from development mines [3]	1.891	0.14
Ore from open-cast mines [6]	41.526	3.13
Ore purchases	14.180	1.07
Old surface dumps and various other ore sources	25.911	1.96
Slimes (Urgeiriça neutralization etc.)	18.830	1.42
Water (Urgeiriça & Ucha mine)	41.708	3.15
Liquors and concentrates (natural leaching, percolation leaching)	49.069	3.70
Total:	1324.670	100.00

TABLE V. COST OF PRODUCT

	Average cost (US \$/lb U_3O_8)
Mining cost	2.89
Transport cost	0.29
Diamond drilling	0.20
Treatment plant	1.64
General overheads	0.51
Taxes, etc.	0.17
Total:	5.70

Final costs

Amortization of capital expenditure had been calculated to be complete as at 31.12.1962, the limiting date of the contract, but in fact the contract tonnage figure was achieved on 31.3.1962 and therefore there remained a nine-month amortization of capital which is not included in the costs given in Table V. There was also a large item of closure expenditure incurred after 31.3.1962, which is not included in the cost of product figures given in this table. As shown, an overall figure of US \$5.70/lb U_3O_8 was achieved under these conditions.

When the remaining nine-month amortization and the closure expenditure are included the final overall figure for the whole project is approximately US \$6.66/lb U_3O_8, or almost exactly the target cost.

STAFF, LABOUR AND SOCIAL SERVICES

Staff

The total number of staff which included all salaried personnel paid on a monthly basis ranged between 110 and 120 in normal years. Senior staff amounted to between 20 and 30 persons and the rest were junior staff. The total names of staff inscribed on the books of the Company during the production period was 255 and turnover was thus about 100% in the 11-year period.

Labour

In the normal years the total labour inscribed on the books of the Company varied between 1000 and 1200. The total number of different names on the Company's books for the whole production period was 5800 and the labour turnover in the 11-year period was therefore about 500%. This high figure was caused by the many itinerant underground workers, who only worked seasonally on the bigger mines and also by the fact that on the small mines local labour was employed which did not move on to other mines when these short-term mines were closed down.

CLOSURE PERIOD: APRIL–JULY 1962

Production of uranium concentrates ceased on 31 March 1962. There then followed a four-month period in which the affairs of the Company were finalized and the assets arranged for hand-over to the Portuguese Government Agency, the Junta da Energia Nuclear (JEN), as required by the original agreement.

The total number of employees had already been gradually reduced from 1245 in early 1960 when reductions started, to 560 at the end of March 1962. In the following months staff and workers were reduced to about 150 and this number were finally taken over by the JEN at the end of July 1962.

Both staff and workers were given a final indemnity which was considerably above the minimum legal requirement for the dismissal of employees in Portugal. The planned gradual phasing of dismissals over nearly two and a half years, and the final indemnity made it possible to avoid, as far as possible, hardship and distress which might otherwise have been caused by the sudden stoppage of the activities of the Company.

In conformity with the terms of the agreement all fixed and movable assets were handed over in good condition to the JEN. Industrial buildings and housing were cleaned and made wind and weather tight, machinery and mining equipment was either taken to storage at Urgeiriça after being cleaned and serviced or, if left on the sites, was protected against the weather.

All shafts on abandoned mines were sealed with a reinforced concrete slab or were adequately protected by walls. Open pits which presented any possibility of danger were filled in or protected.

The Urgeiriça tailing's disposal dump, which was liable to give rise to dust in high winds was protected by turfing over all the walls and the top was covered with lime to neutralize acid waters. All natural leaching dumps and any others where there was any possibility of acid waters were also covered with lime which was well dug into the heaps.

Finally, at the end of July 1962, the Company's assets were handed over to the Junta da Energia Nuclear as representative of the Portuguese Government.

CONCLUSION

In the 1950s a multiple small-scale uranium mining project was successfully operated in Portugal. It was based on one principal mine at which the main services and the ore treatment plant were located. Success was mainly due to a tight management control, standardization of equipment and methods and long-term planning involving the proving of ore reserves and the activating and closing down of the satellite mine on a strict time schedule. A contribution to success was also management flexibility and willingness to take full advantage of what were then innovations such as heap leaching, radiometric sorting, etc. Good organization was essential to the success of the whole project.

Another essential ingredient to success was to have reliable and sound estimates of ore reserve tonnages and their availability for all mines and at all stages from the beginning to the end of the project. This was vitally necessary so that management could decide and control the necessarily complex technical policy. The evaluation of the ore reserves in these small deposits was based on classical ore reserve estimation methods but utilizing calibrated radiometric measuring methods appropriately checked by chemical analysis.

ACKNOWLEDGEMENTS

In such a complex project, covering a period of over seventeen years, a very great number of persons were connected with, and made considerable and valuable contributions to, the fulfilment of the work and the author has called upon elements of all these contributions in preparing this history. The author therefore wishes to thank and acknowledge everyone who was in any way concerned with the CPR project.

The author wishes, above all to acknowledge the excellent management of the late Eng°. Joaquim de Sousa Byrne who was General Manager of CPR Lda at Urgeiriça from 1943 to the end of the contract in 1962 and who was principally responsible for the successful fulfillment of the project. Among his colleagues, the author wishes to acknowledge the very considerable contribution of Dr. J.A.E. Bennett, M.I.M.M., who shared the early assessment work with the author and was eventually Chief Geologist of the Company, and Mr. W.K. Brown, M.I.M.M., Assistant General Manager and Chief Mining Engineer from 1950 to 1956.

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DISCUSSION

I. ASPELING: What is the magnitude of the sampling factor, and what is the justification (if any) for the arbitrary cutting-off of values?

M.V. HANSEN: The answers to both parts of your question are empirical. In 1946–47, prior to the production period, a trial stope some 20 metres in length known as the "Study Stope" was opened at Urgeiriça. Each one-metre vertical cut was channel-sampled at horizontal intervals of one metre extending vertically over 30 metres. All ore recovered was carefully bulk-sampled and checked against the 500–600 channel samples taken. As a result of these fairly extensive studies it was decided that the erratic high values would have to be cut. In addition, a reduction of 5% had to be made in the sample values to permit them to be equated with the bulk-sample values. Similar tests were performed at all the smaller mines. The sampling reduction factor never exceeded 10%.

M. DAVID: I would just like to point out that the excellent regression line which was shown in Fig. 1 of my paper[1] relates to one level of Urgeiriça. It indicates that radiometric measurements are appropriate in this case, which may not necessarily be true for many other deposits.

[1] IAEA-SM-239/36, these Proceedings.