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O.E.C.D. HIGH TEMPERATURE REACTOR PROJECT

DRAGON

Dragon Project Report

[redacted]

FUEL ELEMENT PRODUCTION

[redacted]

by

M. S. T. PRICE

Dragon Project Fuel Element Symposium
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Winfrith, Dorchester, Dorset, England

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*This paper should be read in conjunction with the following companion papers:- D.P. Reports 142, 150, 151 (Parts 1 & 2).

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1. INTRODUCTION

The fuel elements, originally proposed for the High Temperature Gas Cooled Reactor Experiment [1], utilised clusters of seven graphite tubes containing annular "emitting" carbide fuel inserts, made from enriched uranium, thorium and graphite powders [2]. The general features of the design have not changed greatly since that date and the latest position has recently been reported [3].

Development work was continued on the fission product emitting fuel until the end of 1961 [4]. By this time it had become necessary to order the production equipment. It will be appreciated that with this "emitting fuel" the fuel manufacturing process is comparatively simple and difficulties only arise during assembly after the heat treatment of the inserts, due to hydrolysis [5]. Thus the major part of the equipment ordered then was the Fuel Element Assembly Plant, for which a complete specification had been issued in March 1961, the contract subsequently being placed with Heraeus G.m.b.H., West Germany.

By the beginning of 1962, research work on coated particle fuels had progressed to such an extent that the main fuel development effort was switched to this field. This in turn caused a re-appraisal of the production problems.

In contrast with the "emitting" fuel element the problems in making a fuel element employing a coated particle fuel are concentrated in the fuel fabrication process. Once coated it should be capable of being handled thereafter in air and thus assembly is considerably simplified. It was this concept that originally led General Atomic to develop a coated particle fuel [6]. In the Dragon Project, on the other hand, the coated particle fuel was developed primarily as a potential method of reducing fission product release. The overall effect is to make the fuel element manufacturing process much more complex. Equipment for the manufacture of coated particle fuel could not immediately be placed on order as it was necessary to develop suitable apparatus.

A major factor which delayed the scaling up of equipment and processes was lack of staff. The signatory countries had been requested in January 1962 to nominate suitable staff for vacancies in the Fuel Element Production Group so as to be in post by September 1962. In the event no suitable candidates were put forward and other methods of recruitment have had to be exploited.

In spite of these difficulties, preparations continued through 1962 on the basis that either type of fuel would have to be made. When, at the end of 1962, major equipment began to arrive on site, it was decided to install only that concerned with the manufacture and assembly of a coated particle fuel and to keep the rest of the equipment in store.

This report describes the present position regarding the production of the First Charge of the Dragon Reactor Experiment and indicates the manufacturing

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procedures which are most likely to be used.

The next section, therefore, deals with the building in which these processes will be operated.

2. FUEL ELEMENT PRODUCTION BUILDING [7]

2.1 Building Programme

The erection of the building began early in 1962 and it was weather-tight by 1st September, 1962.

2.2 Siting

The Dragon Fuel Element Production Building is a single storey workshop type of building situated on the Dragon Reactor Site, as an annexe to the Dragon Fuel Element Storage Building as shown in Figure 1. It can normally only be entered and left through an airlock connecting it to the Storage Building. There is, however, an emergency exit at the opposite end of the building which will mainly be used during the construction period for the entry of bulky equipment. Three oil cooled transformers, suitably protected by blast walls, a liquid nitrogen storage tank and a gas bottle storage area are outside the building.

2.3 Construction of the Building

The building comprises a rectangular area 72 ft x 48 ft including a Plant Room with an extension for a degassing furnace in the north corner of 12 ft x 24 ft (see Figure 2). The framework of the building is provided by 6" x 6" stanchions based on a 12 foot module. The minimum inside height of the roof is 12 feet. Apart from the blast walls mentioned above, which are of cavity wall construction, the walls are made of $4\frac{1}{2}$" brick built into the webs of the stanchion, with high level glazing from 7 ft to roof level. Externally the brickwork is covered with stove enamel corrugated sheeting; internally it is fairfaced and painted.

The floor consists of 6" concrete with a granolithic finish of 3" with a very smooth surface. To protect it and to facilitate decontamination it is completely covered with linoleum. Holes in the floor which might act as collection points have been kept to a minimum. There is a large pit for a 400 kVA degassing furnace and two smaller pits to facilitate the maintenance of two annealing furnaces. All these are protected by 6" sills. The roof is constructed of Robertson-Thain steel Q Deck type QD3 insulated with 1" thick cone-based fibre board and weatherproofed with asbestos based roofing felt.

The airlock (see Figure 2) was provided in order to allow passage of a completed fuel element in a horizontal position into the Storage Building without upsetting the ventilation arrangements (see Section 2.4). As a result it is sufficiently large to be convenient for all other purposes.

A boot barrier will be provided in the middle of the airlock where there will be a second change of overshoes and laboratory coats. This has been instituted primarily in order to reduce contamination.

2.4 Ventilation

To avoid emission of fissile or fertile dust, a reduced pressure, relative to both the Storage Building and the outside atmosphere, will be maintained within the building. The blower and filter units are located in a separate Plant Room inside the building. Naturally there are no openable windows in the building.

Air is drawn into the building through louvres in the outside wall of the Plant Room by means of a centrifugal fan capable of delivering 2500 cfm connected in series with a preheating coil, a relatively crude inlet filter unit and a heater battery. The air is distributed along the longer walls of the building by grills just beneath the roof. The centrifugal fan has a standby motor fitted.

Also in the Plant Room a centrifugal fan, with standby motor (capable of delivering 3000 cfm), draws off air from beneath the roof by means of six extract grills situated along the centre longer axis of the building.

All extracted air is passed through three removable Vokes canister type absolute filters, each capable of handling 1000 cfm. This unit will operate at temperatures up to 540°C, and will have a leak rate not exceeding 0.05% per hour. After passing the extract fan, the air is discharged through a stack above the roof of the Plant Room.

The air temperature is controlled by room thermostats which in turn control the heater motors of two medium pressure hot water unit heaters, each with an output of 44,400 BTU/hr.

2.5 Water Supply and Drainage

Process water only is used for cooling purposes in this building with a maximum flow rate of about 7000 gallons/hr. It is supplied from a 4" dia pipe coming through the Storage Building from a cooler plant situated in the south-west area behind the Storage Building. The main line is split into two lines in the Storage Building near the entrance to the airlock and each line can be independently isolated, without entering the Fuel Element Production Building. This is of particular importance should there by any leakage or fracture of the water service. In addition each separate cooling circuit can be isolated.

A 2" dia Polyethylene active drain covered by a 6" dia M.S. sleeve leads from the middle of the south wall underneath the floor, to active delay tanks outside the building. Another polyethylene drain coming from the channel around the Degassing Furnace pit also connects to the active drainage. This will be used for pumping out any active water from the pit. Under normal conditions this will not be used.

There are two 6" dia Process Drains underneath the floor of the building. The access to one is near the middle of the south wall and to the other near the middle of the north wall. These are capable of discharging a total of approx. 600 GPM of water. This is to be compared with the worst accident condition in the building (i.e. simultaneous fractures on all water services) which could lead temporarily to a maximum water inflow to the building of 400/500 GPM. The level of the

two drain points is raised to 5½" above finished floor level. Cowls, which come down to 1" above finished floor level, are fitted over these drain points so as to prevent unauthorised discharge through the process drains.

All cooling water outlets are led to a hot sump, as shown in Fig. 2, outside the building and then pumped back to the cooling plant. This hot sump has a standby pump unit which operates automatically if the working one fails.

2.6 Nitrogen Supply and Release

Nitrogen will be used as protective gas in the different glove boxes. The gas, temporarily supplied from a liquid nitrogen storage tank and afterwards continuously from the main reactor nitrogen supply, enters the south-west corner of the building at low pressure (10" WG), passes through a silica gel drying unit and is distributed in three 3" i.d. pipes strapped to the underside of the roof. Flexible tubes will be led from this pipe supply to each glove box, and the exit gas from the glove boxes filtered in standard glove box filters and returned by flexible tubes to 3" i.d. pipes strung parallel to the input lines but connected to a Heraeus exhaust unit, placed in the Plant Room, and capable of extracting 3000 cfh. After passing Vokes canister type absolute filters, the gas is released to the atmosphere through the ventilation stack with continuous monitoring.

2.7 Hazards to the Building and Protective Devices

2.7.1 Fire and Explosion

The building itself is constructed of non-inflammable materials. However, to maintain fire protection for the electrical equipment and other combustible material, (not including material being processed within glove boxes and furnaces,) several CO_2 extinguishers are foreseen both for the main experimental area and for the Plant Room. All the equipment will be made of non-inflammable material or material with low inflammability. Except for the doors wood is not permitted. To deal with the unlikely event of metal power fires outside glove boxes additional sachet containers will be put up along the walls. Pyrene combined rate of rise and fixed temperature detector heads will be fitted to the ceiling over the whole area including the Plant Room. A smoke detector will be provided in the air duct between the first extract grille and the extract fan. There will be heat detectors within the process glove boxes all of which will be connected to a single audible alarm. Lights on top of each glove box will indicate the exact position of a fire. Manually operated fire alarm push buttons will be provided at both exits.

In order to minimise the possibility of fire due to the use of inflammable gases, (e.g. methane, propane and hydrogen) and liquids (e.g. benzene), the gas supply and store is outside the building as described earlier and the quantities of inflammable liquids allowed to be brought into the building at any one time will be severely limited. The high ventilation rate in the building ensures generally that inflammable or explosive concentrations never occur. In

addition special precautions will be taken at hydrogen connection points to sweep any leaking hydrogen away either to the nitrogen exhaust system of the glove boxes or the building ventilation, as appropriate.

Naturally, smoking is not allowed in the building.

2.7.2 Electrical Hazards

For the processes in this building it is not necessary to have a reserve electrical power unit because during a breakdown of the current, all machinery, furnaces, air fans etc, are allowed to be and are switched off automatically, and must be switched on by hand again even when the current returns.

During a total breakdown of the electrical power supply or of the mains, the building is lit at five points by emergency lighting.

2.7.3 Hazards to the Process Water System

For the initial criticality assessment it was considered necessary to guarantee that the maximum depth of water in the building would be 8 inches. The maximum inflow of water to the building during a simultaneous fracture on all water services, would be about 400/500 GPM. Other hazardous water inflows, in large quantities, are considered impossible because the level of the surroundings is more than 6 inches lower than the building and also since when finally levelled the ground adjacent to the building will slope away from the building.

In the event of emergency flooding, the 6" high sills around the furnace pits and at the exits from the building will allow a reservoir of 10,000/12,000 gallons of water to build up on the floor of the building. Thus, with a maximum inflow of 500 GPM, up to 20/24 minutes is allowed for operating the shut off valves outside the building. While this inflow was taking place about 50 GPM would be led off by the 2" dia active drain. When the water level has risen above $5\frac{1}{2}$" it will discharge through the two process water drains at a rate of 600 GPM. Because there will be a permanent shift in the building whenever cooling water is flowing, there will be ample time to isolate a fractured water pipe. Even if the inflow of water to the building were to continue the eventual outflow through the process drains effectively guarantees the maximum water level in the building.

The system of sills was instituted in order to prevent the spread of water and possible radioactive contamination into the Storage Building, the furnace pits and onto adjacent land.

It is evident that such an emergency use of the process drain is a very remote possibility. Even so this system seems to be safe in protecting the process drain against contamination from accidentally spread material on the floor, because the materials handled within this area are not soluble in water and of high density. A further security is given by an alarm system operating when a water level on the floor of approx. $\frac{1}{4}$" is reached.

2.7.4 Hazards to the Ventilation System

The fire risk in the Plant Room is very low, coming only from a possible electrical fire. The ventilation fans are supplied with a standby motor, and a changeover is possible within a few minutes. To avoid pressure being built up in the building, leading to a possible escape of fissile dust, the inlet fan is automatically switched off if the extract fan stops. The gradual build-up of contamination of the filters under normal working conditions, will be checked at intervals by portable monitors. If the permissible level of radiation is reached or the filters are blocked, the whole production process will be stopped and the filters changed by workers in pressurised suits.

Airborne monitoring equipment (in accordance with Dragon Project Specification 44) will be fitted in the air extract system in such a way that one of two sampling positions will be continuously monitored. There will be an automatic changeover to the other sampling position every 15 minutes. The sampling heads will be sited:-

(a) in the air extract system before the Vokes filters

(b) in the stack immediately prior to discharge

This equipment will be connected to the central monitoring system on Site and an audible alarm will be given when the approved maximum working levels of radiation are exceeded, so that operating staff and other staff on Site are immediately informed. In addition to this, this system will, on account of the low residence time in the building, also indicate a penetration of contaminated air into the air inlet system.

All other points of the building and the process will be controlled by portable monitors at approved intervals.

3. RAW MATERIALS AND COMPONENTS FOR FUEL AND FUEL ELEMENT MANUFACTURE

3.1 Raw Materials

The principal raw materials for the manufacture of the fuel are:-

93% enriched uranium metal powder

Thorium metal powder

Zirconium monocarbide powder

Carbon Black

Graphitised Coke Powder.

3.1.1 93% Enriched Uranium Metal Powder

The Board of Management of the Dragon Project agreed in

principle in February 1961, after investigation of other possibilities, to accept as the most advantageous arrangement the offer by the U.K.A.E.A. to provide an interest-free loan of enriched uranium for the First Charge of the Dragon Reactor Experiment. This non-commercial offer leaves the Project to bear only the cost of containers, transport, fabrication and burn-up, and to contribute towards the cost of reprocessing the irradiated fuel. The U.K.A.E.A. proposals were accepted in July 1961 though final instructions were not given to the Authority until October 1962, when delivery was asked for between 1st April and 1st October, 1963.

Under the agreement the U.K.A.E.A. is to make available 30 Kg of U-235 of which the Project may include not more than 25 Kg in fuel elements which are to be irradiated.

For the coated particle fuel either uranium metal or uranium dioxide could be used as starting materials. However, the process developed for the emitting carbide fuel uses uranium metal powder as raw material [2, 4] and thus if either type of fuel has to be made then only uranium metal powder can be ordered.

The specification for the supply of 93% enriched uranium metal powder for the First Charge of the Reactor Experiment is given in Appendix 1. In this specification it was not thought necessary to define limits for the other isotopes of uranium. However, it is useful for health physics purposes to know their likely concentrations and these are given below [8]:-

Isotope	Mass Percentage
U-232	Negligible
U-234	1.2
U-235	93.0
U-236	0.25
U-238	5.55
	Total 100.00

3.1.2 Thorium Metal Powder

There are two principal sources of thorium metal powder:-

(a) from the U.K.A.E.A. having been originally manufactured at an agency factory in Sheffield, England, which is no longer in production. As a result it cannot be purchased to a specification.

(b) from Compagnie Pechiney, which has a plant at La Rochelle, France.

In view of stocks of Type (a) powder already existing within the Project, it was decided as a 'compromis anglais' to utilise equal quantities of each type. This would help to use up the existing stock as well as ensuring that material of current manufacture was also used. Material is being supplied by Compagnie Pechiney in accordance with the specification given in Appendix 2.

In the meantime analyses of the Type (a) powder are being obtained. The only likely points of difficulty with the U.K.A.E.A. powder are [9]:-

(i) the oxygen content - it is believed that some of the material in store is increasing in weight due to oxidation;

(ii) the aluminium content - the analysis quoted in DPR 29 shows the surprisingly high figure of 1000 ppm.

3.1.3 Zirconium Monocarbide Powder

This requirement has only recently arisen and it has been necessary to find suitable manufacturers. Five potential suppliers have been contacted and tender action is about to be initiated. Essentially the requirement is for as fine a powder as possible bearing in mind cost and quantity of high neutron cross-section impurities.

3.1.4 Carbon Black

A medium thermal black, grade Dixitherm M, supplied by the Anchor Chemical Company, Manchester, England, has been used for all reaction sintering within the Project. It is purely a question of history that this particular black has been used and probably other types within the same particle size range (0.3 to 0.5 micron diameter as measured by electron microscope) such as Thermax or Sterling MT could equally be used. Nevertheless there is no reason to change from Dixitherm M for production.

This material is not being supplied to a specification and it will be necessary to analyse it on receipt. Due to the choice of carbon black it is not anticipated that there will be any difficulties due to high neutron cross-section impurities.

3.1.5 Graphitised Coke Powder

It is evident that the fuelled compact should have as high a thermal conductivity as possible, at operating temperature, in order to reduce the operating temperature of the coated particle fuel. In carbons and graphites heat is conducted almost entirely by lattice vibrations. There is in consequence a strong dependence of thermal conductivity on heat treatment temperature as this controls the crystallite size and hence boundary scattering. Since the fuelled compacts cannot be heat treated to temperatures in excess of 1700°C [10], it is preferable for the filler powder to be heat treated to a temperature of about 2700°C prior to incorporation.

If the thermal conductivity of a graphite is expressed as a power density, then the exponent generally lies between two and four [11]. Thus the graphite filler powder should give as high an apparent density as possible. It was these considerations that led Bickerdike at R.A.E., Farnborough, England after considerable experimental work to choose a special fine graphitised coke powder as filler.

The particular material chosen - calcined Shell H.100 Reformer residue coke, manufactured at the Shell refinery, Pernis, Holland, and purchased from Anglo-Great Lakes Corporation Ltd., Newcastle, England - is derived from a petroleum distillate coke and therefore has the additional advantage of high purity. This coke has been further treated as follows so as to give a material ready for immediate use:-

(a) it has been ground to less than 50 microns particle size in a "microniser" by Powell Duffryn Carbon Products Ltd., Hayes, England

(b) material from (a) has then been graphitised at about 2700°C in large-scale industrial graphitising furnaces by Anglo Great Lakes Corporation Ltd., Newcastle, England

(c) material from (b) is then premixed with resin binder in a sigma bladed mixer in the Experimental Graphite Plant at A.E.R.E., Harwell, England. The resin, which is a proprietary phenol/formaldehyde type coded PR 1554, supplied by Leicester, Lovell Ltd., Southampton, England, is incorporated dispersed in Industrial Methylated Spirit, the proportion of resin to graphitised coke being 14:100. The methylated spirit is subsequently evaporated by running the mixer with the lid open.

In view of the processes being applied in the manufacture of the graphitised coke it cannot be supplied to a specification but only analysed on receipt.

3.2 Components for Fuel Element Manufacture

3.2.1 Graphite Components

The fuel tube and both short and long end plugs will be supplied impregnated with furfuryl alcohol resin and the impregnant having been heat treated to 1000°C. For further information on the extensive manufacturing programme for these components reference should be made to a recent summary report [12].

Other graphite parts, such as the top block and the charcoal trap components will be supplied fully machined and inspected.

3.2.2 Metal Components

The various metal components will be supplied fully machined, degreased and inspected and also wrapped in protective film with a desiccant.

4. PRETREATMENT OF GRAPHITE FUEL TUBES AND END PLUGS PRIOR TO ASSEMBLY

4.1 Introduction

The impregnated graphite components require degassing and inspection prior to their assembly. The degassing operation is carried out in order to reduce both the reactivity to oxidising gases and also the thermal neutron cross-section. The presence of furfuryl alcohol char in the graphite markedly increases the oxidation rate [13] and from this point of view the higher the degassing temperature the better. However, at temperatures of about 2300-2400°C there is a drastic increase in the permeability coefficient [14] and thus the degassing temperature must be limited. Work by the Central Institute for Industrial Research at Oslo has indicated that from the point of view of subsequent regassing in air, a heat treatment at 2000°C in argon is better than one at 1500°C in vacuo.

The reduction in thermal neutron cross-section as a result of degassing is directly related to the reduction in hydrogen content, and it is possible that the hydrogen content also governs the oxidation rate [15].

4.2 Degassing

This operation will be carried out in a graphite resistance furnace of size, sufficient if ever necessary, to degas a completely assembled fuel element. For normal degassing work it has a capacity of 6 fuel tubes and 6 end plugs per run the hot zone being 10 inch (254 mm) diameter, 9 feet (2744 mm) long.

After competitive tendering the contract for this furnace was let to Balzers A-G., Liechtenstein.

Their original design was for a 400 kVA delta-connected graphite resistance furnace placed within a double walled stainless steel vacuum vessel. The furnace was required to fulfill two distinct functions:

(a) degassing in vacuo at temperatures up to 2000°C

(b) heat treatment of graphite (i.e. graphitising) in argon at about atmospheric pressure at temperatures up to 2700°C.

In addition the furnace was required to be capable of a controlled rate of increase of temperature, a typical programme being as follows:-

0-1000°C	at 250°C/hour	
1000-1500°C	at 50°C/hour	(to prevent spalling of impregnated components)
1500-2000°C	at 100°C/hour	
2000-2700°C	at 200°C/hour	

Hold at maximum temperature 30 minutes

The Balzers COV 24 Special degassing furnace has been tested at works and certain problems have arisen in fulfilling the specification.

The furnace has operated satisfactorily at 2000°C in vacuum but temperatures above 2470°C were not achieved because

(i) the apparent resistance of the graphite heater element fell drastically at that temperature;

(ii) this was accompanied by the onset of severe phase out of balance;

(iii) the insulation provided was too conductive.

Arising from these tests the following modifications to the furnace were initiated:-

(A) The transformer was changed from star to delta connection. This was in order to reduce the voltage and hence alleviate the out of balance found between 2200 and 2470°C.

(B) A source of purer graphite for the furnace parts was sought. It had been concluded that the breakdown problem was probably due to alkaline earth impurities in the graphite. This hypothesis was further strengthened when, as a result of vacuum treatment overnight at 2100-2180°C the "critical breakdown temperature" was increased from 2230°C to 2470°C.

Further tests at works were impossible due to the desperate water shortage then prevailing in the Alps. The furnace has therefore been brought to Winfrith and is in course of erection. Due to limited height in the Fuel Element Production Building this furnace has been placed in a large pit approximately 12' 6" long, 8' 10" wide, 15' 3" deep, served by a mobile A-frame.

4.3 Inspection and Cleaning

Equipment is being provided to inspect various dimensional features of Dragon fuel tubes and end plugs prior to assembly. The objects of this inspection are:-

(i) to eliminate faulty tubes and end plugs

(ii) to avoid difficulties with non-mating parts during assembly

(iii) to make specific pre-irradiation measurements.

The following inspection checks are therefore intended:-

Fuel Tube (to Drawing CD 33990)

Bow, Twist } with the fuel tube horizontal

1½" BSP female thread

Squareness of 1½" BSP female thread with adjacent end face

1.75" diameter bore for clearance with fuel inserts

1.255" diameter bore for clearance with mating component

$1\frac{1}{2}$" BSP male thread

Concentricity of $1\frac{1}{2}$" BSP male thread with Datum "D"

Incremental length to ± 0.005" (for correlation with post-irradiation measurements)

Distance across flats to ± 0.001" (for correlation with post-irradiation measurements).

End Plug (to Drawing CD 33989) and End Plug (to Drawing CD 34042)

$1\frac{5}{8}$" x 12 TPI Whitworth form male thread

0.187"/0.188" diameter

Concentricity of 0.187"/0.188" diameter with Datum "F"

$1\frac{1}{2}$" BSP male thread

Squareness of $1\frac{1}{2}$" BSP male thread with adjacent shoulder.

A set of tools has been designed capable of dealing with both cleaning and carrying out remedial action on the faces of mating components. It is evident that the cleaning of components has to be carried out in conjunction with the above inspection checks.

The permeability coefficient of cleaned and degassed fuel tubes and end plugs will also be measured, using a multipoint vacuum decay apparatus. On the basis of these results, material will be classified in decades so that all fuel tubes and end plugs within the same cluster will have approximately the same value of permeability coefficient.

Since no complete impregnated Dragon Grade 9 rods were available certain of the inspection checks have been tested using the first trial rods completed by Sigri Kohlefabrikate, Meitingen, West Germany (which were in impregnated Dragon Grade 6). The results obtained which are given in Appendix 3 indicate that there are not likely to be any major problems during inspection and cleaning.

5. FUEL FABRICATION

5.1 Introduction

This section outlines the proposals for the manufacture of the fuel for the First Charge of the Reactor Experiment. These are obviously directly related to the present concept of the fuel loading, but they also bear the imprint of previously proposed fuel loadings.

The fissile material will be 93% enriched Uranium 235. This will be uniformly distributed throughout the core, so as to give a total loading of 15 Kg. It will be recalled that the core consists of 37 fuel elements. It is now proposed that the fertile material (thorium) should not be homogeneously distributed but should be concentrated in the centre 7 fuel element clusters, the U-235:Th atomic ratio in these being 1:15.

The remaining 30 elements will be loaded with a diluted fuel, because it seems unlikely that pure uranium dicarbide could withstand sufficient burn-up [16]. As a result of work by Rudy at Metallwerk Plansee, Austria on the U-Zr-C system, zirconium has been chosen as the alloying diluent.

In view of these requirements, it is intended that the first step of the manufacturing process should be to prepare uranium monocarbide powder. Subsequently either $(U,Th)C_2$ or (U,Zr)C will be prepared, depending upon which type of fuel is being manufactured.

5.2 Preparation of Uranium Monocarbide

5.2.1 Batch Size and Production Rate

The total batch size will be between 250 and 300 g. The upper limit is restricted because of criticality (double-batching) considerations. The required input, in order to produce two fuel elements per week, with no allowance for losses, is (for stoichiometric UC and given a 15 Kg reactor loading of U-235),

871.8 g 93% enriched U-235 metal powder (see Section 3.1.1)

44.5 g Medium Thermal Black, grade Dixitherm M (see Section 3.1.4).

Thus with a total batch size of 230-300 g and only four batches manufactured per week, the throughput would be 1000-1200 g. It is evident that this part of the process will not be a bottleneck, the more so since the equipment being installed will have capacity considerably in excess of this.

5.2.2 Procedure

The procedure adopted utilises reaction sintering of the elemental powders. Experience with the Project of the manufacture of uranium monocarbide is limited since earlier proposed fuel loadings required a greater proportion of thorium containing elements and the preferred fabrication route then was by way of uranium dicarbide [17]. The much larger proportion of elements now containing uranium-zirconium monocarbide as fuel favours the uranium monocarbide route. Furthermore, a considerable amount of information has recently been published on the manufacture of UC in this way [18-20]. If this route gives difficulties in the subsequent preparation of $(U,Th)C_2$ particles then the UC line can easily be changed over to UC_2 production for the seven thorium containing elements.

An alternative procedure comprising making UC_2 throughout as the first stage and, for the zirconium containing elements, of reducing the UC_2 with zirconium metal powder has not been pursued (beyond noting that it is a possibility [21]). The greater stability of uranium monocarbide to moisture [22] would favour the chosen method.

The obtaining of the precise composition of uranium monocarbide would not appear to be important, in view of the possibility of subsequent adjustment.

The uranium monocarbide will be manufactured in a suite of interconnected low leak rate glove boxes, the atmosphere being dry nitrogen. The sintering stage will be carried out in vacuo in a furnace connected to this set of glove boxes, with argon being used for back filling to atmospheric pressure. Further details of the operations are given below, each operation indicated being carried out in a separate glove box.

Operation	Remarks
Weighing	This will be the entry point for the uranium metal powder, coming from a nearby small capacity safe and also the carbon black. Batches of material will be passed through to the next operation through a transfer tunnel which contains an externally operated valve for criticality control. There is a similar criticality control point after each subsequent weighing operation in the uranium monocarbide part of the line.
Mixing 17	Batches of weighed ingredients will be mixed in a V type mixer. The recommended mixing time is 60 minutes. Before proceeding to the reaction sintering stage it may be necessary to cold compact the mix. The eventual choice will be of the route giving the lowest losses. In view of the considerable excess capacity available in this section of the line other factors affecting this choice, such as increased density of pressings, effect of strength of pressings on grinding time and possible restrictions on evacuation time by using uncompacted powder are relatively unimportant.
Weighing	
Reaction Sintering	This operation will be carried out in a horizontal axis graphite resistance tube furnace purchased from Spembly Ltd., Chatham, England. This furnace, which has a hot zone, $1\frac{1}{2}$" diameter, 7" long (measured at 2700°C) i.e. a heated volume of approximately 200 cm^3, is capable of attaining temperatures up to 3000°C in about 30 minutes. For this application it will operate either under vacuum at an absolute pressure of about 10^{-4} Hg, as is normal practice or possibly in argon at about atmospheric pressure using tantalum foil as a getter [23].

A typical operating schedule is likely to be:-

Heating to 700°C and then 1125°C (following Regan and Hedger [18])	2 hours
Hold at 1125°C	1 hour
Cooling time	1 hour
Charge, discharge and purge	1 hour
	5 hours

(i.e. less than 1 working day)

Hot pressing is a possible alternative process [24] and a design, supplied by Metallwerk Plansee and modified to suit local conditions, has been manufactured (as well as its attendant glove box). Lack of experience within the Project - no development work of any sort on hot pressing has been carried out - resulted in the preference for reaction sintering.

Weighing

Grinding

Batches of sintered material will be ground in a ball mill running on grinding rolls purchased from Pascall Engineering Co. Ltd., Crawley, England. A grinding time of 4 hours is expected on the tungsten carbide mill with tungsten carbide balls. However, since tungsten carbide is normally bonded with cobalt, which has a very high thermal neutron cross-section, it may be preferable to use iron mills. Nickel-bonded tungsten carbide is another possibility which is likely to be ruled out as nickel has a pronounced catalytic effect on the oxidation of graphite. Some information on the impurities found in uranium monocarbide after grinding in various media has recently been reported [25].

The ground material is sieved by hand first on a coarse sieve to separate powder from the balls of the ball mill and then through a 400 mesh sieve (37 micron aperture, sieve to ASTM Standard E11-58T.) The ground powder passes on to the first stage of the manufacture of the particle.

5.3 Preparation of Fuel Particles

5.3.1 Batch Size and Production Rate

The total batch size will be between 1.0 and 1.3 Kg. The upper limit has been fixed in relation to the largest batch which it is considered may be processed in the later stages of manufacture, particularly the production fluidised bed furnaces. The required input, in order to produce two fuel elements per week, with no allowance for losses, is (for stoichiometric $(U,Th)C_2$ or (U,Zr)C and given a 15 Kg reactor loading of U-235).

For the zirconium containing elements		For the thorium containing elements	
Uranium monocarbide (prepared as described in Section 5.2)	916.3 g	Uranium monocarbide (prepared as described in Section 5.2).	916.3 g
Zirconium monocarbide	2849 g	Thorium metal powder (see Section 3.1.2)	12007.4 g
		Medium thermal black Dixitherm M (see Section 3.1.4)	1286.7 g
Total	3765.3 g	Total	14210.4 g

There is obviously a large difference in throughput required between the zirconium and the thorium-containing elements. However, since the number of thorium-containing elements is only 7, the period of high throughput will only last about 1 month.

5.3.2 Procedure

The procedure to be adopted uses powder metallurgy agglomeration techniques developed by C.E.N., Mol, Belgium for the preparation of spherical particles [26]. For a considerable time this stage of the process has been a bottleneck. The difficulty has been to prepare spherical particles at a sufficient rate. Earlier work on comminution [27] has been discarded because of the need to use a method capable of giving a high yield of particles suitable for either of the two subsequent process routes (i.e. sintering, melting and coating or merely sintering and coating).

Previous fuel particle spheroidising processes used by the Project and its contractors have utilised,

(a) a rotating cylinder, approx. 70 mm internal diameter, the inner surface of which is lined with 600 grade silicon carbide paper [17].

(b) a vibrating "sombrero" - shaped metal cup, again with its inner surface coated with silicon carbide grains.

The rotating cylinder method has been limited to a production rate of not more than 10 g/hr/cylinder. Attempts to scale-up the process to larger cylinders have not so far been successful and thus many cylinders would have been required to fulfill production requirements. Although the 'sombrero' technique has been used extensively at Harwell*, there is insufficient experience to date at Winfrith.

The spherical particles will be manufactured in a set of three inter-connected low leak rate glove boxes, the atmosphere being dry nitrogen. Further details of the operations are given below, each operation indicated being carried out in a separate glove box. For simplicity only the uranium-zirconium monocarbide process will be given. The uranium-thorium dicarbide can be assumed to be carried out in a similar manner.

Operation	Remarks
Weighing	This will be the entry point for the thorium metal powder, the zirconium monocarbide powder, the carbon black, camphor and isobutyl ketone. Uranium monocarbide will be passed through into this glove box as the finishing stage of the manufacture of UC. Batches of material will be passed through a transfer tunnel which contains an externally operated criticality control valve.

*The author is indebted to Mr. H. Lloyd and Mr. N. R. Williams (A.E.R.E. Harwell) for advance information on this technique which was not developed under a Dragon contract.

Particle Preparation

The general sequence of sub-operations in this glove box will be Mixing, Agglomeration, Spheroidisation and Sizing. Uranium monocarbide powder and zirconium monocarbide powder will be mixed in a Lodige-Morton mixer to give a damp 'cake'. Typical proportions and procedure used by C.E.N., Mol are:-

Uranium monocarbide and zirconium monocarbide	100 g
Camphor	2 g
Isobutyl ketone	5 cc.

The damp mix is put on a nominal 350 micron aperture sieve, together with three 20 mm diameter titanium carbide balls (each ball weighing 62 g). A sieve stack comprising the 350 micron aperture sieve, a 177 micron sieve and a bottom pan is placed on a rotary sieving machine* (manufactured by Siebe Techniek, Mülheim-am-Rohr, West Germany). The machine is then started up and the balls, which appear to run around all the surface of the sieve, force the mix through the 350 micron sieve and onto the 177 micron "spheroidising" sieve. In order to prevent the late dropping of granules onto the spheroidising sieve, the top sieve is removed after about 10 minutes. Spheroidising then continues for a further 50 minutes. In the work at C.E.N. Mol the yield of particles in the correct size range after 60 minutes spheroidising was about 60%. Since two separate sieve stacks can be placed on the same machine, the yield of particles of the correct size is about 120 g/hr/machine. The sieves can be used up to six times before they have to be cleaned. In production, cleaning need therefore only be carried out once daily.

An earlier, somewhat similar, though more complex, C.E.N. Mol method of preparing particles by rotary sieving only gave a yield of about 40%. The increased yield in the revised process is believed to be due to better maintenance of the plasticity of the particles by greater control over the partial pressure of the solvent. This is achieved by placing some 10 cc isobutyl ketone in a container below the 177 micron sieve such that the atmosphere of the sieve stack is maintained saturated with ketone vapour.

Photographs of unsintered particles made by the old and new methods are given in Figure 3.

The above spheroidising procedure has been successfully applied to Zr/U ratios between 6/1 and 15/1 (atomic).

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*described as a "machine pour criblage d'essai avec commande positive par eccentrique combinee pour l'emploi d'une servie de cribbes normalises"

If the particles are to be subsequently melted the spheroidising stage would be cut to the minimum. This is primarily in order to reduce processing time but also to facilitate later separation of melted and unmelted particles.

It is intended that the above rotary sieving technique will be put into production without any scale-up. To make the zirconium - containing particles only two machines are required, whilst if the 2 elements/week throughput is maintained at least four machines are required when the time comes to prepare the thorium-containing elements.

The preparation of the particle will take place in a single large glove box in order to simplify recycling. One of the glove boxes, originally ordered for the complex fuel box testing procedure in the Heraeus Fuel Element Assembly Plant, has been modified for this purpose. This box has a working area approximately 98 inches long, 39 inches wide.

Weighing — Sized spherical particles will be weighed prior to sintering. Since the sintering furnace was already existing it was not practicable to connect the sintering furnace to this line and therefore after weighing particles will be posted out.

5.4 Sintering

Whether or not particles are to be melted they will all be sintered. Particles which are not going to be melted require sintering so as to give them adequate strength in the subsequent coating operation. Those which are to be subsequently melted require sintering in order to degas them and avoid break up in the melting process due to internal gas pressure.

A relatively large Balzers IOV 16 induction furnace was already existing in the fuel development laboratories within the Project. This furnace was surplus to requirements and will therefore be utilised for production sintering. It is already fitted with a large glove box allowing the top lid of the furnace to open into the glove box. Additionally the glove box is fitted with a small pulley block and movable lifting arm.

It is anticipated therefore that the furnace will operate once daily, the batch size being either 1 kg in the case of the uranium-zirconium monocarbide particles or 4 kg in the case of the uranium-thorium dicarbide particle. A typical heating cycle taking into account the reported characteristics of the IOV 16 furnace and the technical requirements of the sintering operation will, for either type of particle, be:-

Room temperature - 1950°C in 4 hours

Hold at 1950°C for 2 hours

Cooling time 15 hours.

A sintering temperature near 2000°C has been chosen partly because it falls into line with previous practice [27], but mainly because it reduces the deposition of carbon during the coating operation within the pores of particles which have only been sintered. [10]

On completion of the sintering operation particles will be sieved into their correct size range. This may be adequate to break up doublets [27] but if not a separation process will be necessary in the case of particles which are only sintered so as to prevent such doublets being coated. [10]

Particles will be posted out of the sintering box then passing either directly to one of the three coating furnaces or alternatively to the plasma melting equipment.

5.5 Melting

A prime feature of employing a melting process in coated particle fuel manufacture is to guarantee the sphericity of the particles prior to coating so as to avoid stress concentrations occurring in the highly anisotropic pyrolytic coating. Another main objective is to reduce the surface area of the particle and hence the fission product emission by way of pores. Even though melted particles may exhibit internal porosity or surface quenching cracks the surface area is still likely to be lower than for a sintered particle. The sintered particle on the other hand may have sufficient voidage to prevent particle breakage caused by increased volume due to burn-up or by gaseous fission product pressure build-up.

Evidence which will permit a clear choice for or against melting is not at present available. In the circumstances therefore there is no choice but to proceed with melting as an optional addition to the production fuel fabrication process.

There are several different processes potentially available for the melting of mixed uranium carbides. They may be classified as follows [27]:-

(a) Melting and resolidification of individual particles by passing the feed material through a heated zone ("shot tower", plasma or three phase arc)

(b) Formation of spherical droplets by spraying a melt or by impinging molten material against a surface

(c) Rounding of agglomerated carbides by embedding in graphite powder and heating above the melting point.

Of the various methods, plasma arc melting has been pioneered within the Project [28], whilst S.G.A.E., Seibersdorf, having no plasma equipment available, have investigated a three phase arc furnace [27]. It was also known that the melting of carbide agglomerates in a large excess of carbon is carried out in the U.S.A. thus explaining why many particles of U.S. origin have a carbon skin prior to coating. However no work on this type of melting was carried out within the Project. It appeared then that although the process was quite feasible for the melting of $(U,Th)C_2$, it would be difficult to operate a graphite resistance tube furnace for a reasonable time at temperatures in excess of 3200°C which are required for

the melting of (U,Zr)C with a Zr:U atom ratio of 8:1. A recently suggested modification to this process [29] may bring this type of process back into consideration, but for the First Charge of the Reactor Experiment only plasma arc or three-phase arc melting have been considered.

Until recently neither of these two methods was entirely satisfactory. The three-phase arc suffers from one severe drawback in that the present design will not melt 250-350 micron particles of (U,Zr)C [27]. In addition due to turbulence in the arc not all the particles pass through the hot zone. For this reason the yield of melted $(U,Th)C_2$ particles after a single pass can hardly be raised above 75% [27] though much lower yields have been reported. Furthermore the throughput of the three-phase arc at 10-100 g/hr is rather low.

Against this the plasma jet is capable of melting either type of particle with a 90% yield on a single pass [30]. It was reported [30] in December 1962 that a throughput of at least 200 g/hr could be obtained.

As a result it is now intended that plasma arc melting equipment will be installed in the production line. The development of the plasma arc furnace for fuel melting is described in a recent report [29].

It should be noted that due to spheroidisation on melting the particle size may appear to increase [29] or decrease depending upon the method of test, angularity and porosity of the feed material. The choice of starting material will therefore have to be related to the particle agglomeration process.

Since the efficiency of melting is not 100% it will be necessary to employ a separation process after melting. For this purpose, the Seibersdorf inclined belt apparatus appears to be the most suitable [27].

After separation, particles within the correct size range will be posted out and passed to the coating process.

5.6 Coating

Two types of coating process have been studied in the Dragon Project

(a) using a rotary kiln method

(b) with a fluidised bed furnace.

The rotary kiln method suffers from severe theoretical disadvantages in that the particles spend too much time in a static array for deposition to be uniform (i.e. the proportion of time spent in actually tumbling is fractional).

However, following the successful application of fluidising techniques for coating fuel particles by J. H. Oxley and his co-workers at the Battelle Memorial Institute, Columbus, Ohio, a high temperature fluidising system was developed for the Project at R.A.E., Farnborough, England.

The development of the fluidised bed apparatus up to prototype production equipment has been described elsewhere [16], though special mention should also be made of the papers from Metallwerk Plansee [31] and

R.A.E., Farnborough [32].

The factors affecting the choice of coating agent and thickness are discussed in a companion paper [10]. As a result it is at present proposed that an initial coating of pyrolytic carbon 15-20 microns thick should be laid down with the aim of accommodating fission recoils from the edge of the fuel particles. The first part of this initial coating is applied at a low temperature so as to prevent the complete sintering of the bed.

Subsequent layers of silicon carbide and then pyrolytic carbon are laid down at temperatures between 1500 and 1700°C, which are a compromise taking into account the following factors:-

(i) for neutron economy the total amount of silicon carbide allowed in the Reactor Experiment is severely limited

(ii) the fuel operating temperature is likely to be up to 1500°C, coatings should therefore be laid down above that temperature.

(iii) to minimise uranium diffusion into the coating, the coating temperature should be kept below 1700°C. This is probably more important as a means of facilitating the testing of particles.

As a result the following sequence of coating operations is now intended:

Stage	Thickness of coating (microns)	Deposition Temperature (°C)	Coating Agent	Carrier Gas
1	15-20	initially 1350 followed by 1620	Hexane	Argon
2	30	1550	Methyl-trichloro-silane	Hydrogen
3	30	1650	Hexane	Argon

The factors which may modify this procedure are also discussed in reference [10].

Coating will be carried out in approximately 1 Kg batches in one of three scaled-up fluidised bed furnaces. It was not possible to scale up the original 1" diameter reactor until August 1962. In order therefore to get the long delivery item, the furnace section, on order as rapidly as possible the production apparatus was split down into units. The main units are the furnace, the nozzle, the particle charging gear and the glove boxes. These latter are required for maintenance of the furnace parts which are liable to get contaminated with active material. The three furnace sections are on order from Efco Furnaces Ltd., Woking, England, for delivery in February 1963. The remaining parts are being fabricated locally. In view of the large number of sub-orders a pre-erection is scheduled.

The production fluidised bed apparatus follows closely the design of the prototype production apparatus [16]. Difficulties with the prototype have been small, mainly centred around the design of the nozzle section.

It should be noted that the general opinion in the United States in November 1962 was that the present type of production fluidised bed apparatus cannot be stretched to larger sizes [33].

It is anticipated (and indeed is normal development practice) that all three coating stages will be carried out in the same furnace purely as a sequence of operations. The total cycle time for coating is likely to be 4 hours unless slower rates of deposition (less than 10 microns/hour) become necessary on technical grounds of performance. It appears therefore that each furnace can produce 1 production batch during daytime working. This is a considerable excess capacity for the coating of (U,Zr)C particles but extra working may well be necessary for the $(U,Th)C_2$ particles unless time can be gained in the process of the zirconium containing elements. There is certainly no reason to contemplate the purchase of a fourth fluidised bed apparatus at a cost of nearly £10,000.

Coated particles will be discharged from the bottom of the fluidised bed nozzles and if satisfactory may then be handled in air for the initial stages of consolidation.

5.7 Consolidation

5.7.1 Introduction

Coated particles are not very strong. The load required to fracture a particle has been reported to lie between 658 g (± 40%) and 1340 g (± 8%) [6] and similar results have been indicated from Harwell [34].

It is therefore necessary to devise a consolidation process which will not break particles either during mixing or moulding. Although a departure from conventional graphite manufacture processes, the above argument would seem to favour the R.A.E. gas-cracking process [35]. Furthermore this is as yet the only developed process for fuel particle consolidation to which the Project has access.

5.7.2 Procedure

The first part of the procedure adopted is to cold mix coated particles with the resin bonded graphitised coke powder premix (see Section 3.1.5). A typical composition used in development work (near to the limit of loading of coated particles)is:-

Coated particles	100 g
Resin bonded graphitised coke powder	35 g.

At present no large-scale method of mixing exists which will guarantee an adequately homogeneous mix when subsequently divided into amounts for a single pressing. It is therefore intended that preforms will be mixed individually in a tumbler mixer, the mixing time not exceeding 15 minutes. This involves an enormous

amount of handling and if only a slightly larger capacity mixer could be developed (which would give homogeneous sub-mixes) there would be a considerable saving.

The individual mixes will be loaded into dies, pressed in an Apex hand-operated hydraulic press at 100 psi, then heated to 180°C (with the pressure maintained) for 15 minutes. On completion of pressing the heat will be switched off and the dies cooled to room temperature in 15 minutes. Thus the total cycle time for pressing will be approximately 40 minutes. Three Apex presses type M1 have been purchased for this part of the process.

Consolidation will be carried out using the R.A.E., Farnborough, England, gas-cracking process which has been further developed by them as a semi-continuous process [32]. Pressed preforms prepared as above are placed within graphite sample holders (2 preforms per sample holder). These are densified by passing through a multizone furnace manufactured to an R.A.E. Specification by the Royal Ordnance Factory, Patricroft, England. Material takes approximately 22-23 hours to pass through the hot zone so that one sample will be loaded and unloaded every 80 minutes. A diluted hydrocarbon gas is passed co-current down the centre of the preforms so as to diffuse into the pores and deposit carbon. Smoke tests with ammonium chloride have shown that there is no need for any secondary inert gas flow around the outside of the compacts to prevent soot deposition. The temperature in the furnace is deliberately skewed so as to reduce the temperature and assist penetration as deposition proceeds. Typical conditions for the existing Patricroft furnace are:-

Zone	Temperature at mid-point of zone (°C)	Zone length (inches)
1	800	18
2	885	21
3	880	21
4	860	21
5	650	18

These conditions relate to operation with a "white-spot" nitrogen carrier gas saturated at 50°C with benzene (i.e. 220 mm partial pressure), the total flow rate being 2 litres/minute (measured at atmospheric pressure). Hexane is a possible alternative gas but this would probably have to be maintained at 30°C in order to obtain a sufficient partial pressure.

The number of accepted compacts required per week is 420. With 100% utilisation one furnace can give a maximum of 252/week. Thus 3 such furnaces are necessary in order to cover breakdowns. It is intended to move the Patricroft furnace from Farnborough to Winfrith on completion of a full-scale trial lasting several days. A contract has been placed for the purchase of two similar furnaces from Royce Electric Furnaces Ltd., Woking, England, for delivery in February 1963.

The furnaces will be gloveboxed at each end and fitted with automatic pneumatic loading and unloading gear. A mock-up of the loading gear has already been constructed.

It will be seen that the maximum temperature reached by the compact during heat treatment will not exceed 900°C. In order therefore to reduce the reactivity to oxidising gases and the thermal neutron cross-section, it is necessary to degas them at as high a temperature as possible, bearing in mind limitations imposed by the coating process [10]. This operation will be carried out in the annealing furnaces belonging to the Heraeus Fuel Element Assembly Plant. These furnaces were originally required for the reaction sintering of the old type of "emitting" fuel and a maximum temperature of 1800°C was therefore specified. The original design of these furnaces called for an 81 kVA power supply. When the two furnaces were put on test at works the maximum temperature of only 1400°C was reached. Calculation indicated that an input of 150 kVA was necessary to achieve a final temperature of 1800°C. Since the nearest size of transformer available was 220 kVA, it has been necessary to re-run cable accordingly.

It is now recommended [10] that the maximum coating temperature should not exceed 1700°C. The maximum degassing temperature of the compacts is therefore also restricted to 1700°C in order to avoid particle rupture. Similar considerations are likely to restrict the heating rate. Should it be possible at a later date to admit a higher degassing temperature for the compacts, these furnaces are unlikely to be adequate.

After degassing the compacts will be subjected to a dimensional check. In this connection the worked example defining the dimensions of the compact should be noted [3].

6. ASSEMBLY

The glove boxes of the Heraeus Fuel Element Assembly Plant were specified on the basis of the old "emitting" type of fuel. Thus the assembly stage, as then envisaged, had to be carried out in an inert atmosphere. To this end the stainless steel glove boxes were specified to be of low leak rate. Since vacuum tight glove boxes proved to be no more expensive these latter were in fact ordered from Heraeus.

One of the incidental advantages of a coated particle fuel is that it can be assembled in air - otherwise the coated particles are of little use. This development was anticipated when the Heraeus plant was ordered since a further requirement was that the tops of the glove boxes could easily be removed thus converting the boxes into stainless steel tables.

Further developments affecting the use of the Heraeus Assembly Plant have been

(a) the elimination of the fuel box from the design thus freeing the annealing furnaces and associated joint glove box for use in the degassing of fuel compacts (see Section 5.7.2).

(b) the elimination of brazed joints from the design [3] thus deleting the end plug cap braze and the brazed joint between the fuel tube and end plug.

These developments have greatly simplified the assembly of fuel elements. As a consequence the number of glove boxes (or tables) required for assembly has reduced from 6 to 2. The welding of the stainless steel inner and outer cone assemblies has been discussed in a previous report [4] as also have the design of the fission product trap and the hand broaching of thermocouple grooves.

The main thermocouples being fitted are of the mineral insulated Chromel - Alumel type, conforming to the specification given in Appendix 4, the contract having been awarded to British Insulated Callenders Cables Ltd., Prescot, England. These thermocouples will only measure fuel tube temperatures. Additional special thermocouples may be fitted, particularly in the central purge hole.

The fission product trap material has now been specified [36] to be a proprietary activated carbon grade Ultrasorb SC II - 10 + 24 mesh supplied by the British Carbo Norit Union Ltd., West Thurrock, England.

It is anticipated that the inspection and cleaning of the graphite components prior to assembly (see Section 4.3) together with the inspection of the degassed fuel compacts (see Section 5.7.2) will eliminate the majority of the assembly problems.

The assembly sequence is summarised in Figure 4. The fuel rod assembly will be made on an open "converted glove box" table. The complete element assembly will be carried out in a vacuum tight glove box in air. The object of using such a glove box and not a table is to enable a final room temperature degassing immediately prior to passing out of the line for canning, utilising the observations reported in Figure 12 of reference [13].

The complete fuel element (Fig. 5) will be passed out of this final glove box into a polythene bag and onto a trolley by which it is transported out of the Fuel Element Production Building into the Storage Building. There the trolley will be moved onto rails over the Storage Building pit and the fuel element will be lowered to rest on the fuel element can spike. The top part of the can will then be placed in position at the same time stripping off its polythene bag.

The object of the polythene bag is to prevent contamination of the fuel element. This will be a particular problem for the first charge fuel elements since the Storage Building will not be very clean at that stage. This question will need re-examining at a later date. A possible alternative for the first charge would be to use part of the pit for the Balzers degassing furnace.

7. CONCLUSIONS AND COMMENTS

This report has outlined the production process which it is intended shall be used for the fabrication of the first charge of the Reactor Experiment. Due to lack of experimental evidence the decisions taken for certain stages of the process are somewhat arbitrary. The next stage of the pre-production work apart from commissioning of equipment, which is a major task, will be to examine these proposed methods in greater detail on larger scale batches with

a view to optimising the process to give minimum losses and also to reduce the amount of material recycled.

The detailed safety aspects of the production line have not been covered and will be the subject of a separate report at a later date.

8. ACKNOWLEDGMENTS

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SPECIFICATION FOR THE SUPPLY OF ENRICHED URANIUM POWDER FOR THE FIRST CHARGE OF THE DRAGON REACTOR EXPERIMENT

1. ENRICHMENT

Enrichment will be 93% ± 1% on a mass basis. Isotopic analyses will be carried out on each 5 Kg delivery and will be quoted to a precision of ± 0.2%.

The results of the isotopic analyses shall be reported to the Project within 28 days of the despatch of each consignment.

2. METHOD OF PREPARATION

The powder will be produced in ½ Kg production batches by calcium reduction of enriched uranium dioxide.

3. PARTICLE SIZE

The powder will be prepared so that all particles pass through a 300 mesh B.S. Test Sieve (to B.S. 410: 1943).

4. PARTICLE SHAPE

The particles shall be "spherical" or shall be aggregates of "spherical" particles. The term "spherical" shall be understood to imply that the oxide has been properly reduced to metal powder via a liquid phase.

5. PURITY

(a) On each 5 Kg delivery

The purity shall be measured on every delivery. Each delivery shall be 5 Kg in weight and shall conform to the following specification. An analytical report for each delivery will be supplied within 28 days of the despatch of each 5 Kg consignment.

Element	Maximum content by weight (ppm)
Oxygen	3,500
Nitrogen	500
Iron	500
Aluminium	200
Silicon	200
Magnesium	200
Calcium	200
Nickel	125

Element	Maximum content by weight (ppm)
Chromium	100
Molybdenum	100
Manganese	50
Chlorine	20
Fluorine	20
Boron	1
Cadmium	1

The material will be vacuum freeze dried to a moisture content of not more than 0.02% by weight.

(b) On each ½ Kg Production Batch

The oxygen and nitrogen contents shall be measured on every ½ Kg production batch. The maximum content of these elements shall not exceed the values given in 5(a) above.

6. ANALYTICAL METHODS

The analytical methods used to ensure that material conforms to the above specification shall be defined in writing by the U.K.A.E.A. before the supply commences.

7. PACKAGING

7.1 Inner Containers

(a) These shall be 56 ml screw-top polythene bottles - U.K.A.E.A. Northern Groups Stores Coded Item 661/9751.

(b) The polythene bottles shall be individually enclosed in P.V.C. bags fabricated from stock at least 3 thousandths of an inch thick and sealed by dielectric welding.

(c) Each polythene bottle shall normally contain one half of one production batch of 500 grams of powder.

7.2 Intermediate Containers

(a) These shall be of a U.K.A.E.A. registered design as detailed on U.K.A.E.A. Risley drawing AE.167259 (larger of the two sizes shown).

(b) Each container shall bear an indelible serial number (for E.N.E.A. Security Control purposes).

(c) Normally five bagged inner containers shall be packed in one intermediate container.

7.3 Controlled Atmosphere

The powder shall be packed under argon so as to provide an argon atmosphere inside the inner container, P.V.C. bag, and intermediate container. After sealing the intermediate container shall be pressurised to 10 psig. The argon used shall be of "high purity grade" containing not less than 99.995% argon.

7.4 Outer Transport Containers

These shall be provided and packed by the supplier in conformity with U.K.A.E.A. transport and criticality regulations.

Prepared by J. R. C. Gough

B. J. Harman

M. S. T. Price

SPECIFICATION FOR THE SUPPLY OF THORIUM METAL POWDER FOR THE FIRST CHARGE OF THE DRAGON REACTOR EXPERIMENT

1. METHOD OF PREPARATION

The powder shall be produced by the calcium reduction of ThO_2.

2. PARTICLE SIZE

The powder shall be prepared so that all particles pass through a 300 mesh B.S. Test Sieve (to B.S. 410: 1943). There is no lower limit to particle size.

3. PARTICLE SHAPE

No restriction is placed on particle shape.

4. PURITY

The purity shall be measured on every production batch. An analytical report for each production batch shall be supplied within 28 days. The purity of each batch shall conform to the following specification:-

(a) The total Thorium content must not be less than 99% by weight.

(b) Total impurities other than oxygen not present as water must not exceed 0.15% (1,500 ppm) by weight.

(c) Individual impurities must not exceed the values given below, without the written agreement of the Project.

Element	Maximum Content by Weight (ppm)
Oxygen (not present as water)	8,500
Calcium	500
Nitrogen	300
Water	200
Iron	150
Silicon	150
Aluminium	50
Magnesium	50
Manganese	15
Nickel	15
Chlorine	5
Chromium	5
Copper	5

Element	Maximum Content by Weight (ppm)
Lithium	3
Uranium	1
Boron	0.5
Cadmium	0.2

When the figures (as parts per million) for the Rare Earth elements are inserted in the following expression, the value of the expression must not exceed 100 :-

$$15(Sm) + 11(Eu) + 100(Gd) + 2(Dy) + 0.025\ (ORE)$$

In this expression the term "ORE" (other rare earths) represents the total content (as parts per million) of elements of atomic numbers 57 to 71 inclusive less the samarium, europium, gadolinium and dysprosium contents.

5. ANALYTICAL METHODS

The analytical methods used to ensure that material conforms to the above specification shall be defined in writing by the supplier before manufacture commences.

6. MEASUREMENT OF THERMAL NEUTRON CROSS SECTION

The supplier shall arrange for the measurement of the thermal neutron cross section on one sample of material from each production batch.

The method of testing shall be notified to the Dragon Project before manufacture commences. The results shall be expressed in a manner which is internationally acceptable.

7. PACKING

(a) All packing must comply with the Governmental and International Regulations in force for all modes of transport used. All deliveries are required to be sufficiently identified.

(b) Unless otherwise agreed in writing with the supplier packing shall include the following features:-

(i) Inner containers in the form of strong polythene jars with sound well made seams, and good quality threaded tops. (A specimen shall be supplied to the Dragon Project for approval before use.) The tops shall be further secured with P.V.C. adhesive tape.

(ii) The polythene jars shall be individually enclosed in polythene bags, fabricated from stock 10 thousandths of an inch (250 microns) thick and sealed by dielectric welding.

(iii) Each polythene jar shall normally contain a minimum of 2.700 Kg of powder and a maximum of 2.800 Kg.

(iv) The powder shall be packed under argon so as to provide an argon atmosphere inside the jar and bag, to avoid significant oxidation of the powder.

(v) The inner bagged containers shall be enclosed in tins with roll-sealed, soldered or press-in tops.

(vi) The tins shall in turn be packed so that they remain undamaged under conditions normally incident to transport and under conditions incident to minor accidents.

Prepared by B. J. Harman

THE INSPECTION AND CLEANING OF IMPREGNATED DRAGON GRADE 6 FUEL TUBES

1. INTRODUCTION

This report covers the inspection and cleaning of impregnated Dragon Grade 6 Fuel Tubes. These tubes represented the first batch of components completed by Sigri, and were delivered to A.E.E., Winfrith in November, 1962. Although the base stock was Dragon Grade 6 (against Dragon Grade 9, the chosen material for the first charge of the Reactor Experiment), the results of this inspection and cleaning were considered to be a reliable guide as to the eventual condition of the Dragon Grade 9 tubes at present being processed by Sigri. It should be pointed out that the exudation of these particular rods was excessive and that remedial measures have already been taken.

2. INITIAL INSPECTION

Initial inspection showed that all the tubes had exudation in varying amounts, details as follows:-

(i) All 25 Rods-outside surfaces slight to medium and patchy exudation.

(ii) All 25 Rods-$1\frac{1}{2}$ inch B.S.P. Female Thread had heavy exudation necessitating retapping.

(iii) 6 Rods. No exudation in the bore. They were, therefore, measured as reported later.

(iv) 1 Rod. Bore exudation was too heavy to be cleaned by the available hand tool.

(v) 2 other tubes were unable to be cleaned completely. (As indicated in Table 2A.)

(vi) The surface finish on end faces and bores before cleaning was noted and classified as shown in Table 4.

(vii) The remaining 16 Rods had slight to heavy exudation in the bore.

3. BORE AND THREAD CLEANING

The 16 Rods mentioned under item (vii) above had the 1.750/1.755" bore cleaned with a hand tool. This tool comprised a $1\frac{3}{4}$" End-mill cutter ground to 1.752" diameter with a lead at the end of each cutting edge, attached to a 6 ft length of copper tube. In operation the copper tube was passed along the $1\frac{3}{4}$" bore and out through the small bore at the end pulling the cutter along the $1\frac{3}{4}$" bore to be cleaned, the reverse process being used for extraction.

For the $1\frac{1}{2}$" B.S.P. and 9/16 inch B.S.F. female threads, standard taps were used and applied by hand. The taps initially started by hand. It was necessary in most cases to use a wrench on the taps.

Due to the abrasive nature of the exudation, the cutting edges of the tools quickly became worn and difficult to use and would not accept the inspection thread gauges. It, therefore, seems necessary to design special tools that can be reground and adjusted, or relax the thread tolerance on the $1\frac{3}{4}$" B.S.P. female thread so that "free fit" taps could be used.

4. ROD INSPECTION

4.1 Squareness of 1.75"/1.755" dia. bore with end sealing face, adjacent to 1½" B.S.P. Female Thread

For this measurement mandrel engagement in bore extended for 12" from end sealing face. Two random measurements (disposed at approx. 90°) were made across the diameter of the end seal face. The results obtained are given in Table 1.

TABLE 1

Serial	Measurements across seal face		Finish seal face
0007	.0035"	.0040"	For Assessment see Surface Finish in amplified Table 4
0012	.0010"	.0010"	
0035	.0035"	.0010"	
0038	.0015"	.0055"	
0042	.0020"	.0010"	
0055	.0050"	.0015"	

4.2 1.750"/1.755" dia. bore dimensions prior to cleaning

Only the 6 Rods which did not have any exudation in the bore (as mentioned in para. 2 (iii) above) were able to be measured. Two circumferential measurements (disposed at approx. 90°) were made at each of six axial positions along the bore. The results obtained are given in Table 2.

4.3 1.750"/1.755" dia. bore after cleaning

After cleaning the bores, tubes Nos. 0018 and 0024 each had one prominent pit and tube No. 0052 had approximately 25 small pits (with approx. depths as indicated in Table 2A, together with the bore dimensions after cleaning.) The bores were measured with a Mercer cylinder bore gauge and the results obtained are given in Table 2A. Whilst generally the bores of the remaining tubers were found to be dimensionally satisfactory, ten tubes did vary slightly outside the prescribed limits, all at the 48 inch position, the greatest local error found being 0.0035 inches above the maximum size (tube No. 0016).

TABLE 2

Serial No.	Diameters at distances indicated from 1½" B.S.P. Female Thread End					
	12"	24"	36"	48"	60"	68"
0007	1.7525" 1.7530"	1.7530" 1.7530"	1.7535" 1.7520"	1.7545" 1.7520"	1.7530" 1.7530"	1.7530" 1.7530"
0012	1.7525" 1.7530"	1.7525" 1.7525"	1.7520" 1.7525	1.7530" 1.7550"	1.7520" 1.7525"	1.7520" 1.7520"
0035	1.7530" 1.7530"	1.7530" 1.7530"	1.7530" 1.7530"	1.550" 1.7510"	1.7530" 1.7525"	1.7530" 1.7530"
0038	1.7535" 1.7535"	1.7540" 1.7535"	1.7535" 1.7535"	1.7540" 1.7550"	1.7530" 1.7530"	1.7530" 1.7525"
0042	1.7525" 1.7525"	1.7515" 1.7525"	1.7515" 1.7520"	1.7525" 1.7545"	1.7520" 1.7525"	1.7515" 1.7515"
0055	1.7525" 1.7525"	1.7525" 1.7530"	1.7525" 1.7525"	1.7550" 1.7515"	1.7525" 1.7530"	1.7520" 1.7520"

TABLE 2A

Tube Serial No.	Diameter at distances indicated from 1½" B.S.P. Female Thread End						Remarks
	12"	24"	36"	48"	60"	68"	
0003	1.7520" 1.7525"	1.7520" 1.7520"	1.7525" 1.7520"	1.7535" 1.7510"	1.7525" 1.7525"	1.7525" 1.7525"	
0006	-	-	-	-	-	-	Excessive exudation
0010	1.7525" 1.7520"	1.7525" 1.7525"	1.7525" 1.7520"	1.7570" 1.7510"	1.7525" 1.7520"	-	Local exudation
0014	1.7535" 1.7530"	1.7535" 1.7530"	1.7535" 1.7530"	1.7540" 1.7545"	1.7530" 1.7530"	1.7530" 1.7535"	
0015	1.7525" 1.7525"	1.7525" 1.7530"	1.7525" 1.7525"	1.7525" 1.7525"	1.7520" 1.7525"	1.7520" 1.7520	
0016	1.7530" 1.7530"	1.7535" 1.7530"	1.7535" 1.7535"	1.7520" 1.7585"	1.7530" 1.7535"	1.7530" 1.7530"	
0018	1.7535" 1.7530"	1.7530" 1.7530"	1.7535" 1.7535"	1.7545" 1.7525"	1.7535" 1.7540"	1.7525" 1.7530"	Pitting .044" deep. One prominent spot.
0021	1.7530" 1.7535	1.7535" 1.7530"	1.7530" 1.7530"	1.7555" 1.7515"	1.7535" 1.7540"	1.7530" 1.7525"	
0024	1.7530" 1.7530"	1.7530" 1.7530"	1.7540" 1.7540"	1.7555" 1.7545"	1.7535" 1.7530"	1.7520" 1.7520"	Pitting .025" deep approx. One prominent spot
0027	1.7520" 1.7520"	1.7540" 1.7545"	1.7520" 1.7515"	1.7545" 1.7570"	1.7520" 1.7525"	1.7515" 1.7520"	
0033	1.7525" 1.7520"	1.7520" 1.7525"	1.7520" 1.7520"	1.7510" 1.7570"	1.7520" 1.7520"	1.7520" 1.7520"	
0037	1.7530" 1.7530"	1.7530" 1.7525"	1.7530" 1.7530"	1.7530" 1.7510"	1.7530" 1.7540"	1.7530" 1.7520"	
0047	1.7520" 1.7525"	1.7525" 1.7520"	1.7525" 1.7520"	1.7515" 1.7555"	1.7530" 1.7520"	1.7525" 1.7525"	
0048	1.7545" 1.7530"	1.7545" 1.7535"	1.7545" 1.7535"	1.7560" 1.7550"	1.7545" 1.7550"	1.7535" 1.7540"	
0049	1.7520" 1.7525"	1.7520" 1.7520"	1.7525" 1.7520"	1.7560" 1.7525"	1.7525" 1.7525"	1.7525" 1.7515"	
0050	1.7530" 1.7530"	1.7535" 1.7530"	1.7535" 1.7530"	1.7565" 1.7515"	1.7535" 1.7530"	1.7530" 1.7535"	
0052*	1.7520" 1.7525"	1.7520" 1.7520"	1.7525" 1.7520"	1.7520" 1.7540"	1.7525" 1.7520"	-	Local exudation*
0054	1.7530" 1.7520"	1.7525" 1.7520"	1.7525" 1.7520"	1.7520" 1.7545"	1.7525" 1.7525"	1.7520" 1.7520"	
0058	1.7525" 1.7520"	1.7540" 1.7525"	1.7530" 1.7530"	1.7530" 1.7520"	1.7525" 1.7530"	1.7525" 1.7530"	

*Extensive pitting near open end - approximately 25 separate spots up to .04" deep.

4.4 Bow and Twist

For these measurements the tubes were freely supported at the extremities of the full hexagon profile. Bow was measured along centre line of hexagon feature for each of three planes. Compensation was made for natural deflection, i.e., two diametrically opposite measurements for bow were made in each plane and then resolved.

Measurements of twist we made at five axial positions on one hexagon face only.

Measurements of Bow and Twist include any variations due to exudation and/or dimensional tolerances. The results obtained are given in Table 3.

Although in two cases the bow appears rather large, the flexibility of the rods made it fairly early to straighten and should present no assembly difficulties. It may, however, be advisable to position the bow of each rod towards the centre of the element on assembly, therefore, minimising rubbing between elements during loading of the reactor.

4.5 1½" B.S.P. Male Thread

The 6 tubes with no exudation in the bore and only slight to medium on the outer surfaces were also checked for the 1½ B.S.P. Male Thread with an upper retaining bolt (mating component) giving a fairly free fit.

4.6 Surface Finish

The degree of exudation in the bores was classified as follows:-

H - Heavy,

M - Medium,

SL - Slight.

The condition of the end seal faces was also classified in the following way:-

S - Satisfactory

LD - Effective seal face reduced, due to local damage

SE - Slight radial scores and/or slight exudation build up

X - Damaged beyond salvage.

The estimates of surface condition of the bores and the condition of the end sealing face are given in Table 4.

5. CONCLUSIONS AND RECOMMENDATIONS

(a) Care should be taken during the impregnation treatment to minimise exudation as this considerably increases problems on site.

(b) The condition of the end sealing face is generally poor and permanent remedial measures seem likely to be necessary. Protection of this face during transport should be considered.

TABLE 3

Serial No.	Twist End to End Within	Twist Max. Within	Bow Plane 1	Bow Plane 2	Bow Plane 3
*0003	6'	12'	.022"	.015"	.013"
0006	6'	6'	.012"	.036"	.035"
0007	6'	6'	.019"	.018"	.035"
0010	6'	6'	.007"	.021"	.026"
0012	6'	6'	.011"	.032"	.037"
0014	6'	6'	.047"	.038"	.008"
0015	6'	6'	.019"	.025"	.041"
0016	6'	6'	.040"	.001"	.042"
0018	6'	6'	.013"	.011"	.002"
0021	6'	12'	.070"	.039"	.034"
0024	6'	6'	.023"	.027"	.004"
0027	6'	6'	.014"	.062"	.052"
0033	6'	6'	.031"	.030"	.060"
0035	6'	6'	.054"	.037"	.021"
0037	6'	6'	.030"	.037"	.005"
0038	6'	6'	.026"	.031"	.057"
0042	12'	12'	.009"	.006"	0
0047	6'	6'	.035"	.032"	.006"
0048	6'	6'	.018"	.002"	.021"
0049	6'	6'	.028"	.011"	.032"
0050	6'	6'	.020"	.004"	.028"
0052	6'	6'	.022"	.002"	.021"
0054	6'	6'	.002"	.015"	.021"
0055	6'	6'	.012"	.002"	.002"
0058	6'	6'	.019"	.001"	.018"

*Longitudinal crack noted at centre of rod in Plane 2.

TABLE 4

Tube Serial No. (Dragon Grade 6 impreg.)	1.75"/1.755" dia. bore	End Sealing Face
0003	H	LD
0006	H	SE
0007	Clean	X
0010	H	LD and SE
0012	Clean	SE
0014	H	SE
0015	SL	SE
0016	SL to M	SE
0018	H	SE
0021	H	SE
0024	H	SE
0027	M	SE
0033	M	SE
0035	Clean	SE
0037	H	SE
0038	Clean	S
0042	Clean	SE
0047	H	SE
0048	M	S
0049	H	SE
0050	M	SE
0052	H	SE
0054	H	SE
0055	Clean	S
0058	H	SE

(c) The 1.750/1.755" bores were in general satisfactory after cleaning. The slightly larger I.D. at 48" from the open end should be noted.

It should also be remembered that these results were obtained with point contact. A fuel compact with its 2" length would have an effectively tighter fit than these results.

(d) The bow of these tubes was not large enough to cause difficulties in assembly, provided that the bow is placed towards the centre of the cluster. If these rods were assembled they would touch in certain cases and a finite initial stress would be set up. In view of the current opinion that the life of the fuel tubes in the Reactor will be limited by stress build-up (due to flux and temperature gradients) a limit to the amount of permissible bow does now seem necessary.

(e) Twist measurements to date show this to be negligible.

(f) The wearing of cotton gloves by the operators for cleaning and measuring proved in one case to be insufficient guard in stopping sweat from the hands getting onto the rods. Surgical gloves will unfortunately need to be worn inside the cotton gloves.

Prepared by:- W. H. Martin

R. P. Sinden

SPECIFICATION 324/66 FOR THE SUPPLY OF NUCLEAR GRADE THERMOCOUPLES FOR THE FIRST CHARGE OF THE DRAGON REACTOR EXPERIMENT

1. SCOPE

This specification covers requirements for nuclear grade mineral insulated metal sheathed thermocouples for the first charge of the Dragon Reactor Experiment.

The provisions of this specification cover the manufacture, testing and supply of thermocouple cable and thermocouples complete with insulated hot junction and cold end seal.

2. MATERIALS

2.1 Conductors

The conductors shall be Chromel for the positive conductor and Alumel for the negative conductor. Only material made by the Hoskins Manufacturing Company of Detroit shall be used.

2.2 Mineral Insulant

The insulant shall be premium grade magnesia of 99.4% minimum purity. In addition the following impurities shall be restricted to the limits quoted:-

Boron	10 ppm maximum
Sulphur	0.001% maximum
Chlorine	0.005% maximum
SiO_2	0.2% maximum
CaO	0.05% maximum
Fe_2O_3	0.10% maximum
Other metal oxides	0.2% total maximum

The magnesium oxide shall be of the fused type with large particle size of about 1 to 2 microns measured by surface area technique. The insulant shall be calcined at 1400°C immediately before use in the cable.

2.3 Sheath Material

The sheath shall be of 18% chromium, 8% nickel austenitic stainless steel stabilised with titanium in accordance with B.S. 1508/821 or A1S1 Type 321.

All tubes used in manufacture shall be made by seamless, cold drawn processes and shall be clean, smooth and free from harmful defects, oil and grease, drawing lubricants or other contamination.

2.4 Certification of Materials

The manufacturer shall certify that the materials used in manufacture conform to the above clauses 2.1, 2.2 and 2.3.

3. DIMENSIONS

The outside diameter of the sheath shall be 1.5 mm (0.059 in). The manufacturing tolerances on this dimension shall be stated by tenderers. The minimum sheath wall thickness shall be 0.15 mm (0.006 in) and the minimum diameter of the conductor wires shall be 0.30 mm (0.012 in).

4. MANUFACTURE

4.1 Cable

The thermocouple cable shall be manufactured by a multi-pass reduction process from the materials specified in Section 2.

Metallic materials shall be maintained free from contamination during all stages of thermocouple manufacture.

Adequate precautions must be taken to prevent the absorption or adsorption of moisture by the magnesia. Cable must be provided with durable and efficient end seals during storage periods prior to the preparation and sealing of individual thermocouples. Methods proposed for temporary end sealing of cable shall be approved by Dragon Project.

The thermocouple cable shall be heat treated during manufacture to ensure that in the finished cable the conductor wires and sheath are fully annealed and that the grain size of the conductor wires does not exceed 0.13 mm.

The finished cable shall have a clean, scale-free and corrosion resistant surface. The sheath shall be substantially free from dents, grooves, die marks or other visible defects and any such defects shall not exceed 0.05 mm (0.002 in) in depth. The surface finish of the sheath shall be not worse than 48 micro-inches centre-line-average.

4.2 Thermocouples

4.2.1 Hot Junction

The hot junction shall be insulated from and encapsulated by the sheath. The magnesia insulation used for the hot junction shall be dry and must conform to Section 2.2. The conductor wires shall be welded at the hot junction and not twisted. The complete junction shall be central in the sheath.

The sheath closure weld shall be free from pinholes and must not reduce the wall below the minimum specified thickness. The outside diameter of the completed end closure shall fall within the limits specified for the sheath. The closure weld and sheath shall be in the annealed condition.

The thickness of insulation between the weld bead and the sheath shall be not less than that for the unwelded conductor and sheath. The thickness of insulation between the weld bead and the end seal shall be not less than one cable diameter and not greater than $1\frac{1}{2}$ cable diameters.

4.2.2 Cold End

The cold end shall comprise an insulating seal capable of operation up to 400°C and of being impermeable to moisture during storage and prior to commissioning. The diameter of the seal shall not exceed the diameter of the cable.

Proposals for the method of cold end sealing must be submitted to Dragon Project for approval and shall be stated in the tender documents.

The conductors shall be colour coded in accordance with B.S. 1843: 1952:-

Positive conductor - Brown

Negative conductor - Blue

4.2.3 Straightness

Adequate precautions shall be taken to ensure that the thermocouples are straight and free from bowing, bending or kinking.

5. FREEDOM FROM CONTAMINATION

Cable and thermocouples shall be manufactured and tested under clean conditions and shall be free from contamination by the following:-

(1) Materials of high neutron cross-section, e.g. boron, cadmium, silver, etc.

(2) Metals of low melting point, e.g. lead, tin, zinc, etc.

(3) Lubricants and compounds containing sulphur, and lead.

(4) Chloride contamination from handling with bare hands or other sources.

Final cleaning shall normally be by immersion in trichlorethylene vapour but other methods may be submitted to Dragon Project for approval.

Cable and thermocouples shall be manufactured, inspected and tested, packed and where appropriate stored under clean conditions approved by Dragon Project.

The manufacturer shall give all necessary facilities for a representative of Dragon Project previously nominated and agreed with the manufacturer to satisfy himself that the manufacture of cables and thermocouples complies with these requirements.

6. TESTS

6.1 Cable Tests

6.1.1 Sheath Integrity Test

Each length of cable from which thermocouples will be manufactured shall be sealed at each end and completely immersed in water for a period of 12 hours and within 4 hours of removal from the water and without intermediate heating the following tests shall be carried out.

The insulation resistance measured between conductors and between each conductor and sheath at room temperature shall be not less than 1000 Megohms per 90 metres.

These tests shall be carried out with a stabilised voltage resistance and insulation test apparatus using a potential of not less than 250 volts D.C.

The test potential shall be re-applied with reversed polarity after allowing the cable to discharge and the minimum level of resistance given above shall be attained in both tests.

The water used for immersion in the initial part of the test shall contain a wetting agent and shall have a surface tension not exceeding 35 dynes/cm.

6.1.2 Dimensional Test

Each cable length shall be checked to ensure conformity with the manufacturers stated diametral tolerances.

6.1.3 Sheath Ductility Test

An 18 in (45 cm) length of cable shall be selected at random from 10% of manufactured cable lengths and subjected to a wrap test in which the length is wrapped at room temperature around a mandrel having a diameter of twice the cable outside diameter.

A minimum length of 12 in (30 cm) shall be wrapped. The cable shall be tested subsequently to verify the integrity of the sheath by a leak detection method details of which shall be submitted to Dragon Project for approval.

In the event of failure a further sample shall be taken from the end of the coil remote from that initially tested and submitted to the wrap test. Failure of this sample shall reject the coil and the manufacturer shall also submit to this test a sample from each coil manufactured since the last tested coil.

6.1.4 Hot Resistivity Test

A 12 in (30 cm) length shall be taken from each end of the finished cable prior to the cable being released for further

processing. Test leads shall be attached and the whole immersed in a furnace at 500°C. The resistance between conductors and sheath shall not be less than 20 Megohms when measured at 250 volts D.C.

6.1.5 Conductor Resistance

The resistance of each conductor shall be measured after the thermocouple cable has been completed and prior to further processing into thermocouples. The resistances so measured shall not exceed the values calculated from the minimum conductor diameter quoted in Section 3 and the specific resistivity of the conductor wire stated by the wire manufacturer.

6.2 Thermocouple Tests

6.2.1 Length

The length of the thermocouples shall be measured and the length so determined shall be within ±0.125 in of the specified dimensions.

6.2.2 Closure and Seal Test

The hot junction closure and end 3 in (7.5 cm) of cable shall be immersed in boiling water for one hour. Immediately following this immersion the whole unit including the cold end seal shall be submerged in cold water for 24 hours. Within 4 hours of removal from the cold water and without intermediate heating the insulation resistance shall be shown to be not less than 1000 Megohms using a voltage of 250 volts D.C. Water used for this test shall contain a wetting agent and shall have a surface tension not exceeding 35 dynes/cm.

6.2.3 Loop Resistance Test

The loop resistance of the finished thermocouple shall be measured at room temperature and shall not exceed the value calculated for the length of the unit from the minimum conductor diameter quoted in Section 3 and the specific resistivity of the conductor wires stated by the wire manufacturer.

6.2.4 Radiographic Test

The hot junction shall be subjected to X-ray examination in two planes at 90° to verify that the junction and closure comply with Section 4.2.1.

Dragon Project or the authorised inspectors appointed by the Project may at their discretion select random samples not exceeding 10% of the finished thermocouples and request the manufacturer to provide radiographic evidence that the selected thermocouples comply with this requirement.

6.2.5 Hot Insulation Test

The hot junction closure end and not less than 12 in (30 cm) of cable shall be heated to 500°C for not less than 15 minutes and not more than 30 minutes and the insulation resistance between conductors and sheath shall be not less than 5 Megohms when tested at temperature and at a voltage of 250 volts D.C. The cold end seal shall be tested in a similar manner but the heating temperature shall be 400°C. The insulation resistance at temperature shall be not less than 20 Megohms at a voltage of 250 volts D.C.

6.2.6 Calibration

Each thermocouple shall be calibrated at four temperatures which shall be selected in accordance with the service requirements and by agreement with Dragon Project.

The accuracy of the thermocouples shall be within ±3°C up to 400°C and ±0.75°C above 400°C.

For calibration the cold junction shall be maintained at 0°C. Boiling demineralised water shall be used for calibration at 100°C and for other higher temperature calibration points the melting points of pure metals shall be employed. Calibration temperatures shall be suitably corrected for variations in barometric pressure and, where appropriate, for deviations in freezing point of particular batches of pure metal from the standard values. The errors found during calibration shall be recorded to ±0.5°C. The error in the thermal E.M.F. compared with the relevant Table of B.S. 1827: 1952 shall be recorded.

6.3 Alternative Tests

Manufacturers may propose for approval by Dragon Project alternative tests to those listed under Sections 6.1 and 6.2 provided that it can be established that a product of equal or superior quality is guaranteed.

7. IDENTIFICATION

Each individual thermocouple shall be identified with a serial number which shall be clearly marked on a suitable identifying sleeve.

8. CERTIFICATION

The manufacturer shall provide a test certificate for each thermocouple. The certificate shall certify that the thermocouple has been manufactured in accordance with this specification and shall include the following information:-

(1) Serial number, manufacturer's name and date of manufacture.
(2) Type of conductors.
(3) Type of sheath material.
(4) Sheath outside diameter.
(5) Type of insulant.
(6) Length.

(7) Conductor diameters.
(8) Resistance between conductors.
(9) Resistance between conductors and sheath.
(10) Error in thermal E.M.F. compared with the relevant Table of B.S.1827: 1952 at various temperatures.

9. INSPECTION

All thermocouples and cable used in the manufacture of these thermocouples shall be subjected to tests as indicated in Section 6 of this specification. All testing shall be the responsibility of the manufacturer.

10. CLEANING AND PACKAGING

Following completion of manufacture and testing all thermocouples shall be cleaned by trichlorethylene vapour treatment. Alternative methods of cleaning may be submitted to Dragon Project for approval.

Cold seals may require to be protected from contact with the cleaning agent if they are susceptible to damage by this reagent.

After cleaning the thermocouples shall be freed from all traces of cleaning reagent and subsequently handled only with gloved hands.

Each individual thermocouple shall be heat sealed in a polythene bag and securely packed to ensure maintenance of straightness and freedom from damage during transport. Each package shall be clearly marked with the following information:-

(a) Contract Number.
(b) Thermocouple type and dimensions.
(c) Number of units.

Prepared by:- J. F. G. Condé

M. S. T. Price

F. A. Reichardt

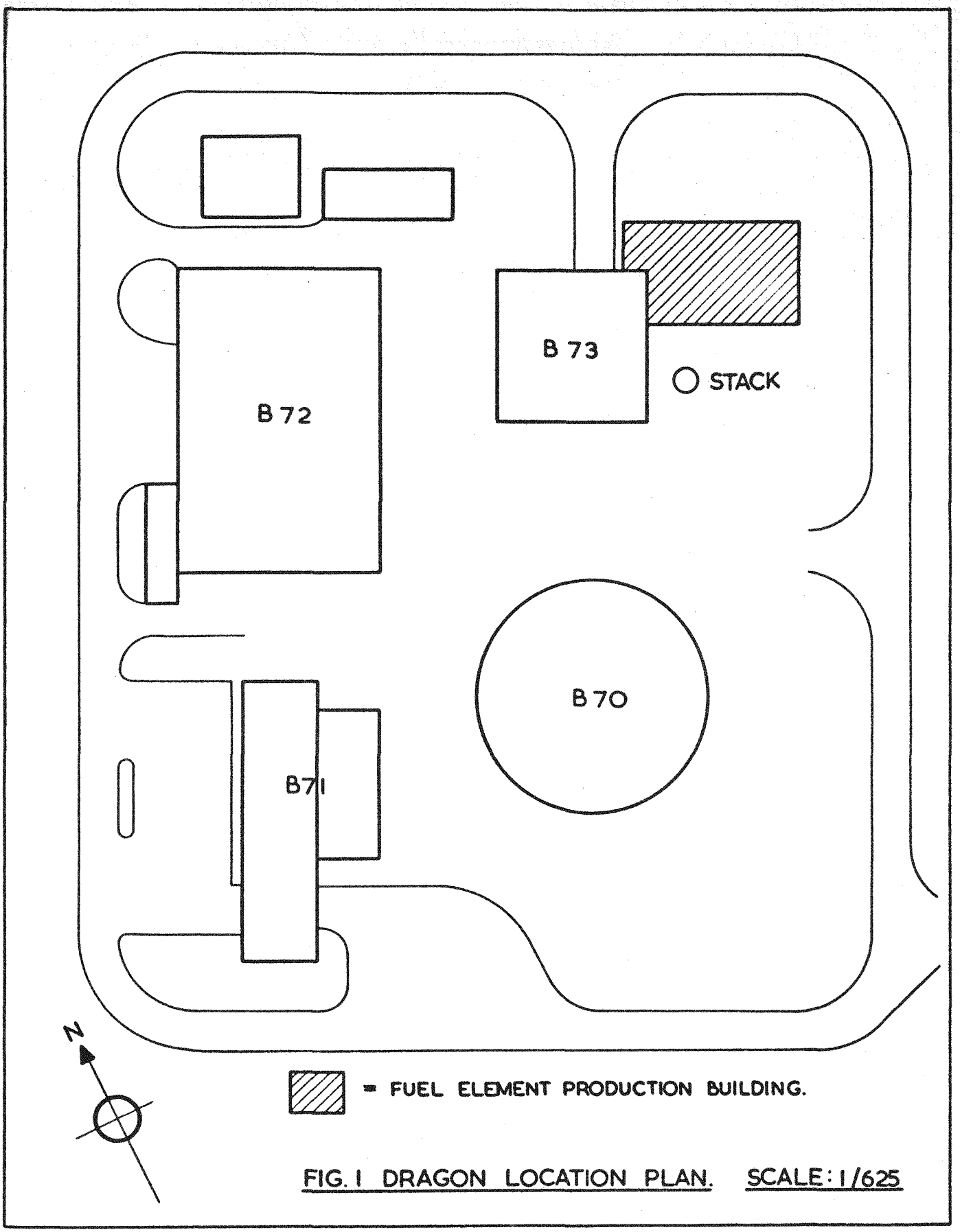


FIG. 1 DRAGON LOCATION PLAN. SCALE: 1/625

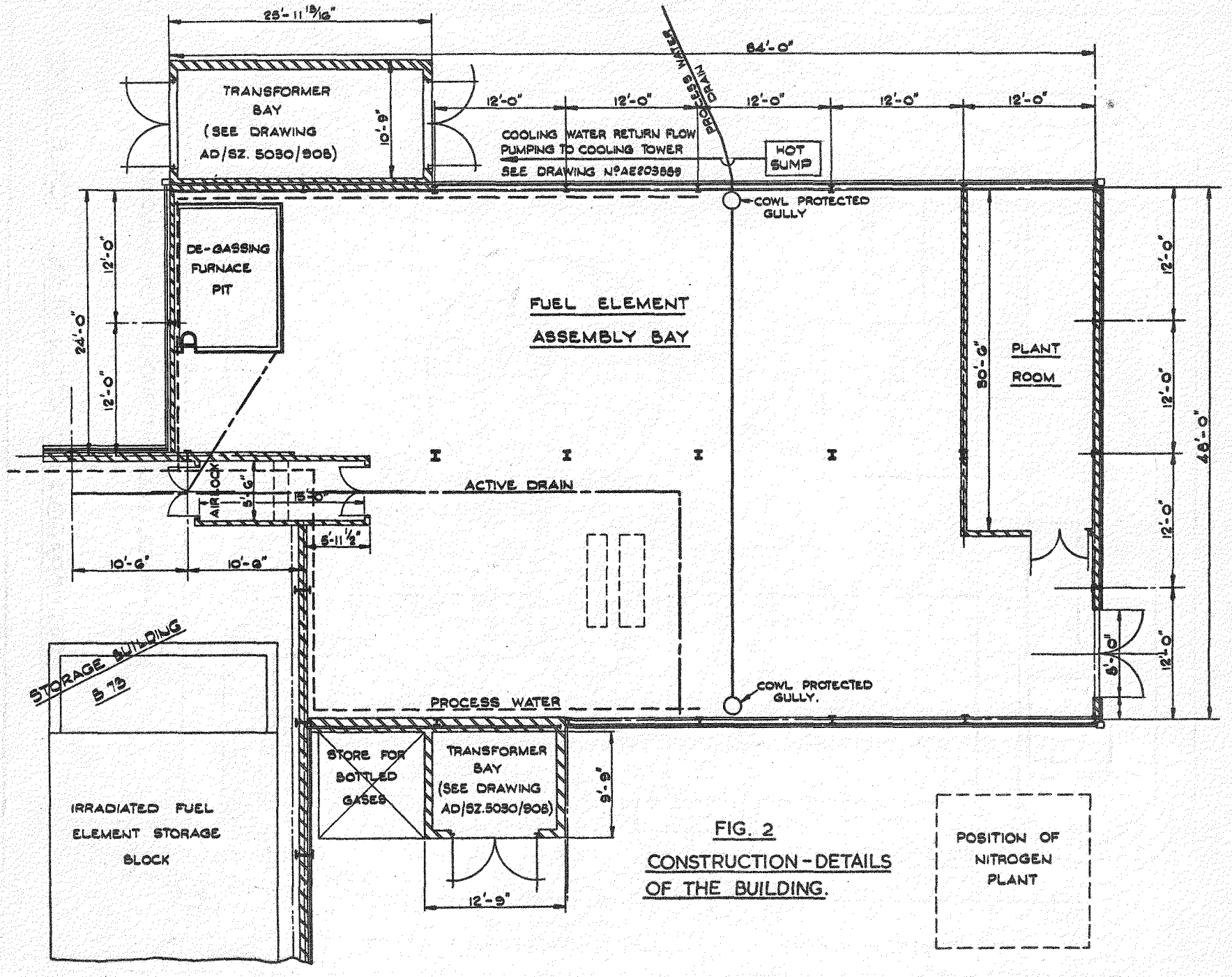


FIG. 2

CONSTRUCTION - DETAILS OF THE BUILDING.

POSITION OF NITROGEN PLANT

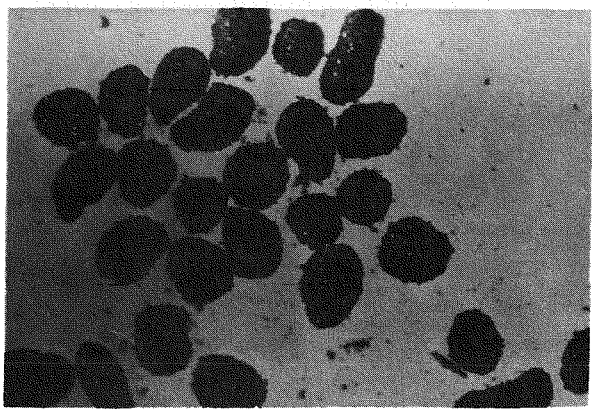


FIG. 3(a) (U,Zr)C PARTICLES MADE BY THE OLD METHOD (20X)

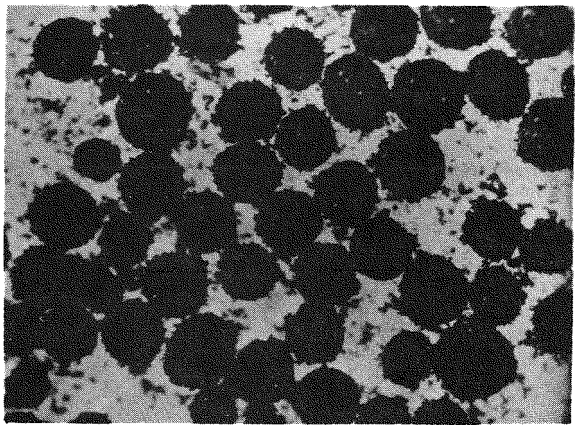
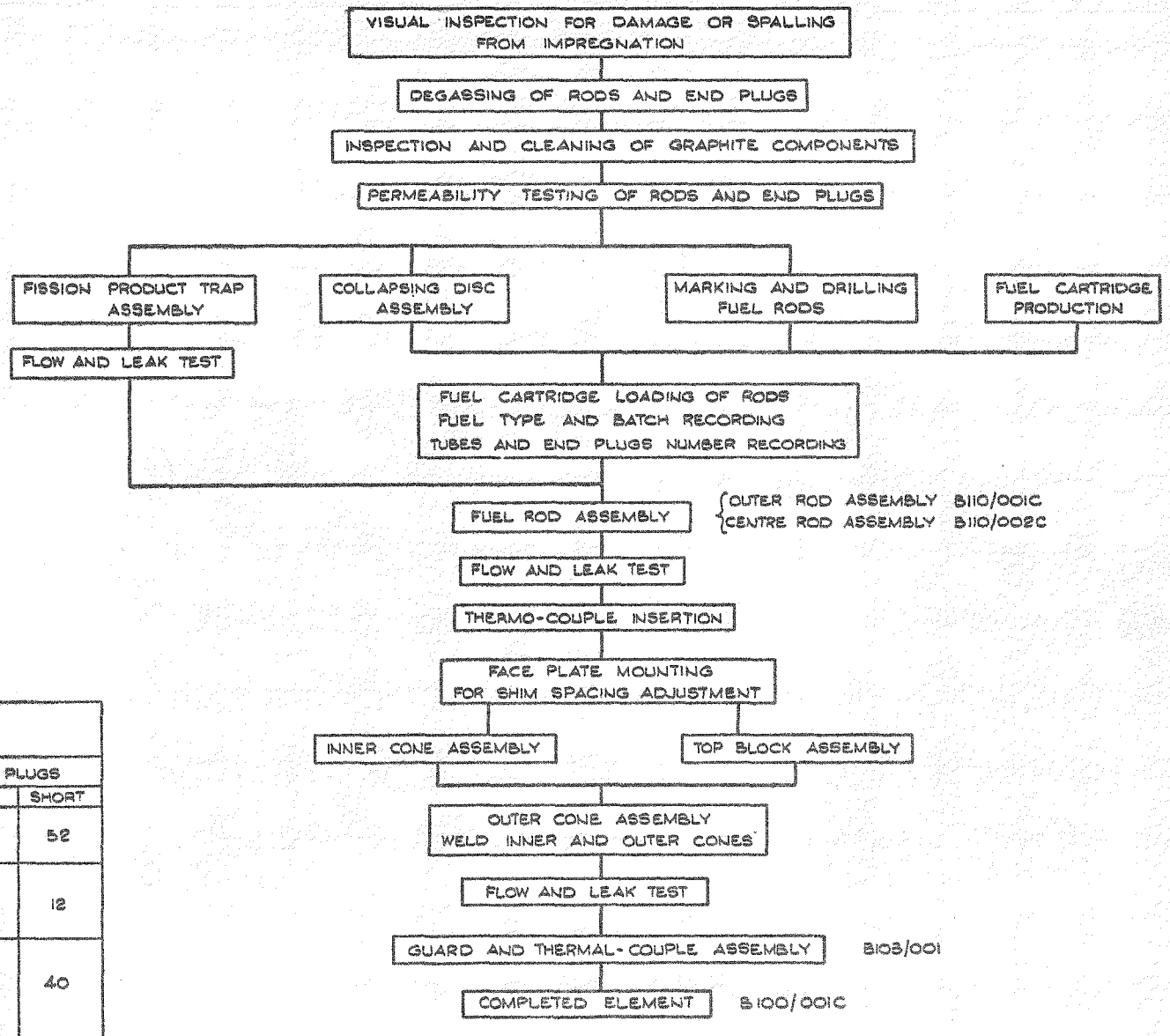


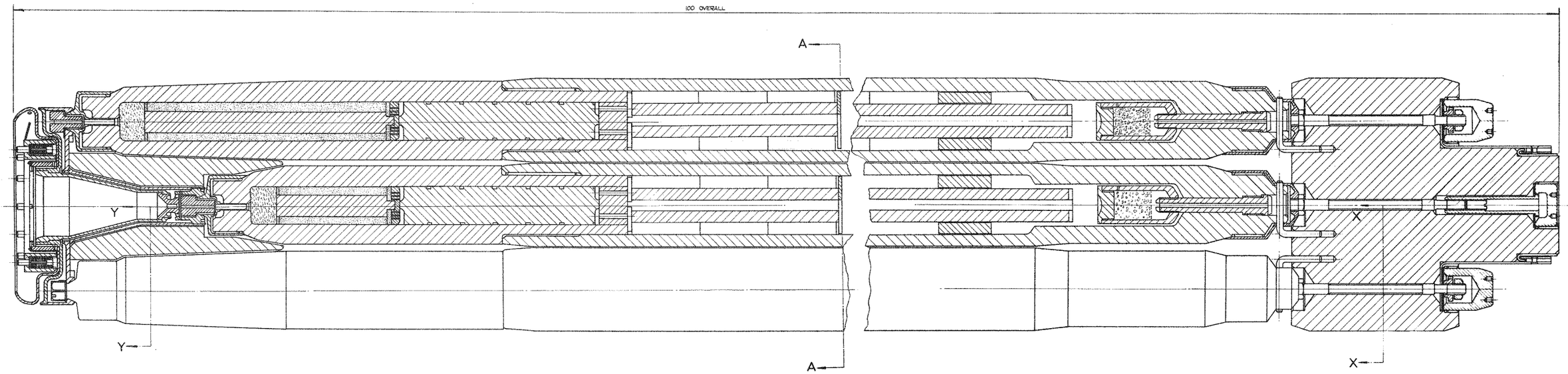
FIG. 3(b) (U,Zr)C PARTICLES MADE BY THE NEW METHOD (20X)

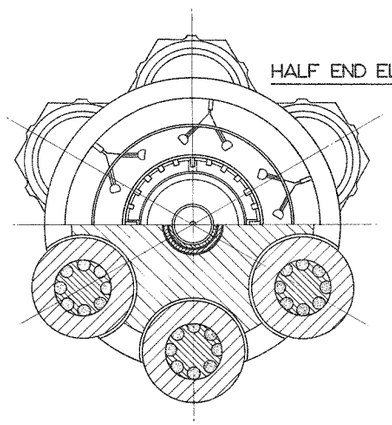


ESTIMATE OF YIELD AND LOSSES (FROM DPRDD 604)

	FUEL TUBES	END PLUGS	
		LONG	SHORT
No. SUPPLIED FOR DEGASSING AND ASSEMBLY	320	308	52
DEGASSING ASSEMBLY AND HANDLING LOSS	40	68	12
No. OF FINISHED COMPONENTS FOR REACTOR LOADING	280	240	40

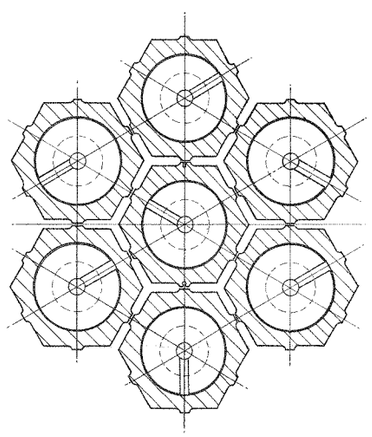
FIG. 4 FUEL ELEMENT ASSEMBLY SEQUENCE



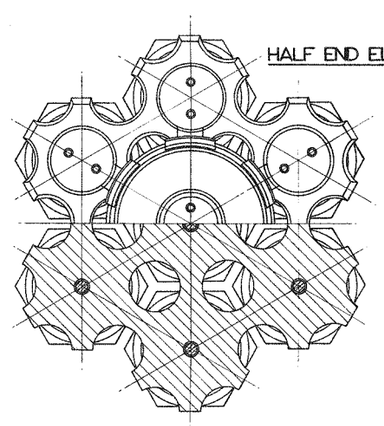


HALF END ELEVATION (BOTTOM)

HALF SECTION ON Y-Y



SECTION A-A



HALF END ELEVATION (TOP)

HALF SECTION ON X-X

FIG. 5. FIRST CHARGE FUEL ELEMENTS (SECTION)