DECONTAMINATION OF CAGR GAS CIRCULATOR COMPONENTS

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Abstract

This paper describes the development and full-scale trial of two methods for removal of radioactive contamination on the surfaces of CAGR gas circulator components. The two methods described are a particle impact cleaning (PIC) decontamination technique and an electrochemical technique, "electro-swabbing", which is based on the principle of decontamination by electro-polishing. In developing these techniques it was necessary to take account of the physical and chemical nature of the surface deposits on the gas circulator components; these were shown to consist of magnetite-type oxide and carbonaceous material. In order to follow the progress of the decontamination it was also necessary to develop a surface sampling technique which was effective and precise under these conditions; an electrochemical technique, employing similar principles to the electro-swabbing process, was developed for this purpose.

The full-scale trial of the PIC decontamination technique was carried out on an inlet guide vane (IGV) assembly, this having been identified as the component from the gas circulator which contributes most to the radiation dose accumulated during routine circulator maintenance. The technique was shown to be practically viable and some 99% of the radioactive contamination was readily removed from the treated surfaces with only negligible surface damage being caused.

The full-scale trial of the electro-swabbing decontamination technique was carried out on a gas circulator impeller. High decontamination factors were again achieved with > 99% of the radioactive contamination being removed from the treated surfaces. The technique has practical limitations in terms of handling and treatment of waste-arisings. However, the use of specially-designed swabbing electrodes may allow the treatment of constricted geometries inaccessible to techniques such as PIC. The technique is also highly suitable for the treatment of soft-finish materials and of components fabricated from a variety of alloys, where a general surface treatment would be inappropriate.

1. INTRODUCTION

In common with various other components the coolant gas circulators of Civil Advanced Gas-Cooled Reactors are withdrawn from service on a regular basis so that inspection and maintenance work can be undertaken. At Hinkley Point 'B' Power Station, for example, each reactor has eight gas circulators and the design intent is that two of the eight be withdrawn for overhaul at each biennial shutdown of the reactor. A withdrawn unit may either be overhauled during the shutdown period and then reinstated or it may be replaced by a spare unit and be maintained later. In either case the time spent on maintenance is closely controlled so as to limit the period during which the unit is not available for use. (This is necessary when a replacement unit has been installed so as to provide a spare to cover against an in-service failure of those circulators in use.)

Those parts of the circulator which are exposed to the reactor coolant gas while in service are subject to contamination due to the deposition of fission and activation products circulating in the coolant. To date the levels of contamination experienced at Hinkley Point 'B' have not been such as to significantly delay the maintenance activities. However, it is possible that contamination levels could rise in the future to an extent such that, in the absence of any corrective action, the need to take precautions to reduce the dose accumulated by personnel could lead to considerable extension of the time required. In view of this a programme of work was undertaken to determine methods of decontaminating circulator components should this prove necessary.

Two techniques were studied in some depth; these were Particle Impact Cleaning (PIC) and an electrochemical swabbing technique. The relevant studies are described here. Additionally, as a necessary adjunct to the decontamination studies a technique for sampling the surface contamination was developed. This is also described here.

2. THE SURFACE SAMPLING METHOD

Those steel surfaces of the Hinkley Point 'B' gas circulators which are exposed to the coolant gas while in service are generally observed, when withdrawn from service, to be coated with a tenacious, black film of varying thickness. Careful swabbing of components to remove both loose contamination and contamination associated with oil and grease films showed that the majority of the contamination was firmly bound to the component surfaces. It was, therefore, necessary to sample the surfaces for this contamination so as to obtain necessary data for the selection of suitable decontamination procedures.

The surface sampling procedure was an electrolytic one based on "The Electroleach Technique" devised by Rowland (1969) for the surface sampling of stainless steel surfaces. This technique relies on the anodic dissolution of the sampled surface by means of a current passed through an electrolyte absorbed on polyurethane foam. The sampled surface acts as the anode while a copper block, which supports the foam, acts as the cathode. Radionuclides removed from the surface are absorbed into the foam which is then analysed by an appropriate means, in this case a Ge(Li) gamma spectrometer. In the present work a circular sampling area of 27.5 mm diameter was used throughout; the general procedure followed was to take a sequential series of samples at any given location so that the profile of the contamination through the surface could be determined.

The first measurements were made on an impeller (Fig. 1) which had been permanently withdrawn from service at Hinkley Point 'B'. In this case the electrolyte used was 50 v/o phosphoric acid, as used by Rowland, and individual samples were taken over a period of 1 minute while a current of 2A was passed through the electrolyte. This technique was found to remove surface activity but it soon became apparent that it was not very successful at removing the black film from the impeller surfaces and that an excessive amount of time would be required to sample fully at any given location on the surface.

At this time a small sample of the black surface film was successfully removed from a circulator labyrinth seal (Fig. 1) by means of stripping with adhesive tape. (This sample was atypical in that the film was not strongly adherent to the surface.) Analysis showed the film to be composed of an M_3O_4 type of oxide together with a carbonaceous material. Laboratory studies, at this time, suggested that phosphoric acid is an unsuitable electrolyte for mild and ferritic steels, the impeller is $2^1/_4$ Cr/Mo ferritic steel, as oxidation to insoluble magnetite occurs. It was, therefore, considered that an electrolyte which did not suffer from this drawback, and which could dissolve the M_3O_4 in the surface film, might give better results. After extensive trials a "citrox-type" electrolyte (5 w/o oxalic acid; 10 w/o citric acid) was selected.

Initial measurements with the citrox-type electrolyte were undertaken on the same impeller as had been used for the work with the phosphoric acid electrolyte. The citrox-type electrolyte was found to remove successfully the black film although at a slow rate; over thirty sequential samples of 1 minute duration with a current of 1A being necessary to expose the bright

metal finish below the black surface film. Despite its slowness in use this technique was successfully applied not only to sampling of the impeller but also to sampling of an Inlet Guide Vane (IGV) assembly (Fig. 1). A finding of great significance for the later decontamination work was that the contamination, both fission products and activation products, was incorporated in the surface film and that removal of this to the underlying white metal effected complete decontamination.

During the trials of decontamination of the impeller by electrochemical swabbing, described below, it was realised that a possible cause of the slowness of action of the sampling technique was that the coherent nature of the surface film was preventing ready access of the electrolyte to the underlying metal. Accordingly, a wetting agent* was added to the electrolyte. This was found to improve greatly the rate of action. Further trials were then undertaken with both the phosphoric acid and the citrox-type electrolytes. As a result of these trials the protocol adopted for use during the decontamination trials was that prior to decontamination the surfaces were sampled with a 50 v/o phosphoric acid 0.15 v/o Photo-flo 600 electrolyte, which was found to obtain a bright metal finish after 6 x 1 minute samples at 2A, while after decontamination the surfaces, now generally bright metal, were sampled with the citrox-type electrolyte as above.

3. DECONTAMINATION BY PARTICLE IMPACT CLEANING

3.1 The Blast Machine

The working environment at Hinkley Point 'B' ruled out the study of aqueous PIC techniques in the present work because of the lack of a suitable containment and consequent difficulties with waste disposal. The PIC development and trials were, then, centred solely around the use of a dry PIC process.

The machine used throughout was a Vacu-Blast Model PHV05+ (Fig. 2). This machine has facility for the reclamation and re-use of the cleaning medium thus reducing waste arisings significantly relative to a single-use machine. Additionally, as can be seen from Fig. 3, the point of application of the blast stream is sealed by an annular brush. This has the advantage that use of the machine does not result in significant quantities of free cleaning medium and that components of any size can be treated.

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* Photo-flo 600, Kodak plc, Hemel Hempstead, Herts.

\+ Vacu-Blast Ltd., Slough, Bucks.

Additionally, the area of the surface which is treated can be closely controlled which is of importance when treating surfaces of varying composition or finish. Against these advantages the use of this localised sealing system does mean that some surfaces of complex geometry cannot be readily accessed.

3.2 The Selection of the Cleaning Medium

As the various circulator components are reinstated in service after maintenance has been carried out it is a requirement that any decontamination process should not damage the surface in any way that could adversely affect the future use of the component. This effectively requires that a minimum of metal loss be caused as this can affect the balance of rotating components; any precision components should remain within tolerance after treatment; and surface roughening should not lead to loss of strength or to subsequent enhanced contamination.

Rogers (1980) pointed out that, when used on ductile surfaces, PIC cleaning media can be classified as being "soft" if they are intrinsically incapable of damaging the surface treated, or as being "hard" if they do cause surface damage. (A medium may be soft to one surface material but hard to another.) He also noted the possibility that soft media could be used to remove oxide layers without damaging the underlying substrate. The first trials, on the impeller used for surface sampling trials and on assorted small components, were, therefore, carried out with a soft medium, namely a mixture of crushed peach and apricot pits*. These trials confirmed that this medium was able to successfully remove loose and lightly adherent contamination. However, it did not remove the black surface film and nor was the overall level of contamination on the impeller noticeably reduced by its use. Lack of time prevented further investigation of this approach and so a hard medium was used for the remainder of the work reported.

The hard medium chosen was glass beads. This medium has an acceptably low breakdown rate to allow it to be recycled and thus to reduce waste arisings. It was chosen in preference to an angular medium, e.g. alumina, for a number of reasons, namely:

(i) their spherical shape renders the beads much less likely to become impacted in the treated surface than is the case with angular particles. This is of importance in reducing the adventitious transfer of cleaning medium into the reactor and also in reducing potential wear difficulties on surfaces in sliding contact,

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*Obtained from Dasic International Ltd. Romsey, Hants. under the trade name Paintblast.

(ii) the beads have a peening effect upon the treated surface. This, rather than being detrimental to the treated surface, can be advantageous in improving fatigue life,

(iii) at normal and near-normal angles of impact metal loss due to impacting beads occurs by a deformation-fatigue process as compared with the cutting mode of removal associated with the impact of angular particles. This is of importance because while the impacting glass beads lead to deformation of the surface impacted there is no removal of metal until a critical level of deformation energy is deposited in the surface. Because of this there is an incubation period following the start of treatment during which there is no metal loss from the surface. The length of this incubation period increases with decreasing size of the impacting particle.

In view of the nature of the black surface film on the circulator component surfaces it was considered likely that deformation of the substrate would lead to spallation of the film because of an inability to take up the geometry of the deformed substrate. Both the extent of the roughening produced by impacting beads and the mass of cleaning material required to treat a given area of surface decrease with decreasing size of the impacting beads. Taken together with incubation period effects these factors argue strongly in favour of using the smallest possible size of bead. Against this, however, is the necessity for the impacting beads to have sufficient individual energy to lead to fracture of the surface film; this is best assured by using a large size of bead. Obviously, then, an optimum size for the beads has to be determined.

The impeller used for the tests of the surface sampling procedure was used in the trials to find an optimum size of glass bead for use in the PIC technique. The first tests on the impeller were undertaken with glass beads having a size range of 45 to 85 μm. (Note that in all of the work reported here the impact velocity of the particles of cleaning medium was of order 50 m s^{-1}. The process is less sensitive to this parameter than it is to the particle size. The feed rate of the beads was of order 1 kg min^{-1}.) With this medium an apparently bright metal finish was achieved at treatment rates of about 110 to 160 minutes per square metre. However, surface sampling showed that the majority of the contamination was still present and close visual examination showed that the black surface film was still present over much of the treated surface; the apparent bright metal finish was an artefact due to numerous small areas where the film had been removed. A repeat treatment removed more of the contamination but it was concluded that the treatment rate was too slow for practical purposes.

The next trials were carried out with beads having a size range of 55 to 100 μm. In this case an apparent white metal finish was achieved at a treatment rate of order 110 minutes per square metre. Visual examination of the surface showed that the black film had apparently been removed and surface sampling confirmed that over 99% of the contamination had been cleaned from the surface. Machining marks produced in the original manufacture of the impeller were still clearly visible after treatment suggesting that any surface damage would be acceptable. Thus this size range of the glass bead medium would be acceptable for use. However, the treatment rate was considered to be somewhat on the slow side for practical application. Further tests were, therefore, carried out with beads having a size range of 75 to 125 μm. With this medium a white metal finish, together with over 99% removal of the contamination, was achieved at a treatment rate of order 20 to 30 minutes per square metre. This was considered adequate for practical purposes as other factors restrict the treatment rate attainable in most practical situations.

Visual inspection of the impeller surface after treatment with the 75-125 μm beads suggested that damage to the surface was quite acceptable but this could not be quantitatively confirmed because of the size of the impeller. Tests to determine damage effects were, therefore, undertaken on smaller components of a similar steel. These tests showed the weight loss to be effectively zero and roughening effects to lead to an alteration in dimensions of order 3 μm or less. The 75-125 μm beads were therefore considered as suitable for application to other circulator components.

3.3 Decontamination of an IGV Assembly

After completion of the optimisation tests described above, a full scale trial of the decontamination of an IGV assembly was undertaken. (The IGV is presently the component which gives rise to the largest accumulated dose during circulator maintenance.) The general construction of an IGV is shown in Fig. 4. The drive linkage for the vanes is not directly exposed to the reactor coolant gas in operation and so is not contaminated to any great extent. In view of this and its geometric and mechanical complexity it was decided not to undertake decontamination of this area. Additionally, the central bore of the IGV has a region of high precision finish and this area was also excluded from being subjected to the decontamination process as was the main seal face.

Decontamination of the IGV was performed in the circulator maintenance facility at Hinkley Point 'B'. In order to prevent the

possible spread of contamination around the facility the decontamination was undertaken in a temporary, ventilated containment within the facility. While the blast machine can be operated by one man it was decided that two men should work in the containment at any given time as a safety precaution. In the event this proved useful as the second operator was able to give assistance with the cleaning up of any spilled beads, repositioning of the IGV, etc. Both operators were provided with respiratory and auditory protection (blasting being a noisy process) and health physics supervision and assistance were available throughout.

For treatment purposes the IGV was stood on edge with its bore horizontal. This allowed relatively easy access to all of the areas to be cleaned and obviated the need for the operator to stand within the bore to work as would have been necessary if the IGV was positioned with its bore vertical. (This latter position is the usual one for maintenance purposes.) The geometry of the IGV is such that it may be considered as a number of separate surfaces. The procedure followed was to clean one of these surfaces as completely as possible before moving onto the next surface. As the geometry required careful positioning of the operator so as to manipulate the blast head properly this approach was found preferable to that of cleaning all surfaces within an arc and then moving to a different arc. At all times the treatment was aimed at producing a white metal finish and then moving to a new area; subsequent surface sampling confirmed that this procedure removed over 99% of the contamination from the treated surfaces.

The bore surfaces of the IGV, including the inner blade faces, were found to be relatively easy to treat although care was needed to ensure that the local sealing was maintained so as to prevent spillage of the glass beads. Some difficulty was experienced in treating the swivel points of the vanes as local gas passages allowed the beads access to the thrust bearing assemblies; these assemblies are not accessible for cleaning until after withdrawal from the IGV assembly. Similar considerations limited the cleaning of the thrust bearing cover plates. The geometry of the gas inlet passage and the rear faces of the vanes severely limited access with the blast head used and so little work was done in this region.

Because of the manner in which maintenance of the IGV is performed the exposure rate in the bore is of prime interest as regards the accumulated dose. Measurement showed that this had been reduced by a factor of 2 to 3, dependent on position, by the decontamination process. Later

studies showed the remnant exposure rate to arise from bulk activation of the IGV unit. Taken together with the surface sampling measurements the exposure rate measurements thus lead to the conclusion that all contamination had effectively been removed from the treated surfaces of the bore.

3.4 Discussion

In considering the benefits accruing from application of the PIC decontamination it is obviously necessary to balance the dose accumulated during decontamination against the dose saved in maintenance. The experimental nature of the work together with some operational difficulties due to the poor quality of the air supply to the blast machine prevented a meaningful measurement of the dose accumulated in the decontamination process. However, it may be estimated that the total dose accumulated, from both decontamination and maintenance work, from contamination sources would be reduced by a factor of 4 or 5 if a similar exercise were to be repeated. This factor could be further improved by the use of relatively simple jigs to hold the blast nozzle so that the PIC operator was not working in close proximity to the IGV. It must be borne in mind, however, that the dose due to bulk activation is irreduceable, although unlikely to increase in the future, and so the overall dose saving from decontamination will be dependent upon the relative contributions from activation and contamination at any time.

4. DECONTAMINATION BY ELECTRO-CHEMICAL SWABBING

4.1 General

Electropolishing processes, of which the surface sampling technique described above is one, have long been recognised as of use for the decontamination of surfaces. They offer rapid decontamination to background levels with minimal metal removal and have the further advantage of producing smooth, polished surfaces which can show increased resistance to recontamination in subsequent service. They are also capable of application to a wide variety of materials, geometries and forms of contamination (e.g. Allen and Arrowsmith, 1979). However, when used in the conventional manner in which the component to be treated is immersed in a bath of electrolyte they suffer, when the component has any but the simplest geometry, from the need for complex electrode shapes if preferential metal removal at corners is to be avoided. For one-off applications such electrodes can be extremely costly. In addition to their complex geometries the nature of the circulator components gives rise to two further difficulties with

conventional bath techniques; first, their size leads to a requirement for large volumes of electrolyte which gives rise to handling and waste disposal problems; second, some components are made from a number of alloys and so preferential attack would be experienced in a bath immersion approach. In view of these factors an electro-swabing technique was developed for application to the circulator components.

The electro-swabbing technique is basically similar to the surface sampling technique described above. It differs primarily in that a larger area is treated, i.e. the cathode is larger, and that the swab is continuously moved over the surface until cleaning is effected. Because of the requirement to move the cathode over the surface a Dacron felt was used for the electrolyte absorber rather than the polyurethane foam used with the surface sampling cathode. The felt was found to be chemically and mechanically robust and not to transfer fibres to the treated surface.

4.2 Impeller Decontamination

Initial trials were carried out on the same impeller as above. Because of the relatively large area of this component it was necessary to refresh the electrolyte on the felt pad. This was achieved by having a hollow cathode, with holes to the surface supporting the felt, and pumping electrolyte to the cathode at a rate of about 50 $m\ell\ min^{-1}$ from a reservoir held at 50^0C. Surplus electrolyte was allowed to drain down the impeller into a catch tray.

Measurements with 50 v/o phosphoric acid at a current density of order $10^3 A\ m^{-2}$ (at 12 volts) showed a slow removal of the black surface film at a rate, generally, of about 100 min m^{-2}; however, in some areas the film was more tenacious and rates were a factor of 2 to 3 slower. Similar results were obtained with the citrox-type electrolyte described earlier. It was concluded that the compact nature of the film was restricting access of electrolyte to the substrate metal. In order to overcome this difficulty Photo-flo 600 wetting agent was added to the phosphoric acid electrolyte at a concentration of 0.15 v/o. (Higher concentrations were found to lead to foaming associated with hydrogen evolution from the electropolishing process.) This resulted in an improvement of the treatment rate to about 25 min m^{-2} and a lowering to 8 volt of the necessary potential. Surface sampling confirmed that > 99% of the surface contamination was removed.

4.3 Oil Seal Decontamination

The swabbing process was next applied to a wind-back oil seal (Fig. 1). This seal had a precision finish white metal bearing surface in

a mild steel carrier ring. A bath immersion technique would have led to excessive attack of the mild steel if the white metal were also to be successfully decontaminated and so the swabbing process was appropriate. In this case a graphite cathode was manufactured with a curvature matching that of the white metal surface. In view of the small surface area involved the felt pad was charged with electrolyte, 8 w/o oxalic acid at 60 C, by dipping in a bath. For treatment the seal was rotated while the cathode was held fixed. A current density of 500A m^{-} at 10 volts was used. This process successfully decontaminated the white metal surface to background levels while metal removal was even at < 25 m.

4.4 Discussion

The electro-swabbing technique has thus been shown to be an effective means of decontaminating circulator components.

For large components such as the IGV it can achieve comparable treatment rates to the PIC treatment described above and would be amenable to remote application. However, for such components it suffers from difficulties associated with disposal of the chemically aggressive electrolytes and also from the need to ensure complete removal of the electrolyte from all crevices, etc. A higher level of operator expertise is also required than is the case with the PIC process. For the smaller, high-value components such as the oil seal these difficulties are of less significance and it is in this area that electro-swabbing has the greatest potential

5. CONCLUSIONS

Both a Particle Impact Cleaning technique and an electrochemical swabbing technique have been developed and shown to be successful in the decontamination for re-use of CAGR circulator components. Both techniques readily attain better than 99% removal of contamination with only small and acceptable surface damage. The PIC process is generally preferable for large components while the electro-swabbing technique is well suited to the treatment of high value precision items.

6. ACKNOWLEDGEMENTS

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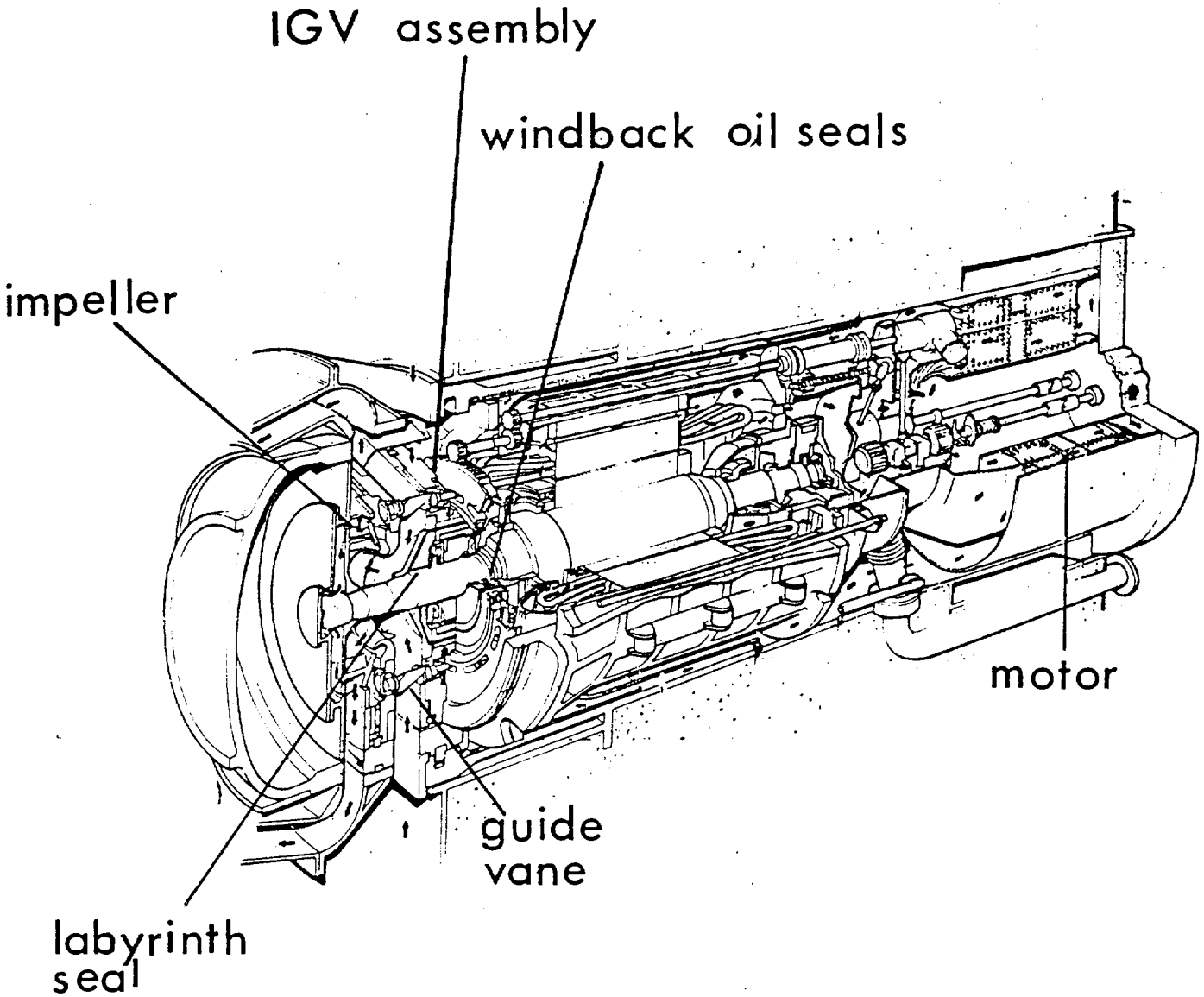

Fig1 General arrangement of the Hinkley Point 'B' gas circulator.

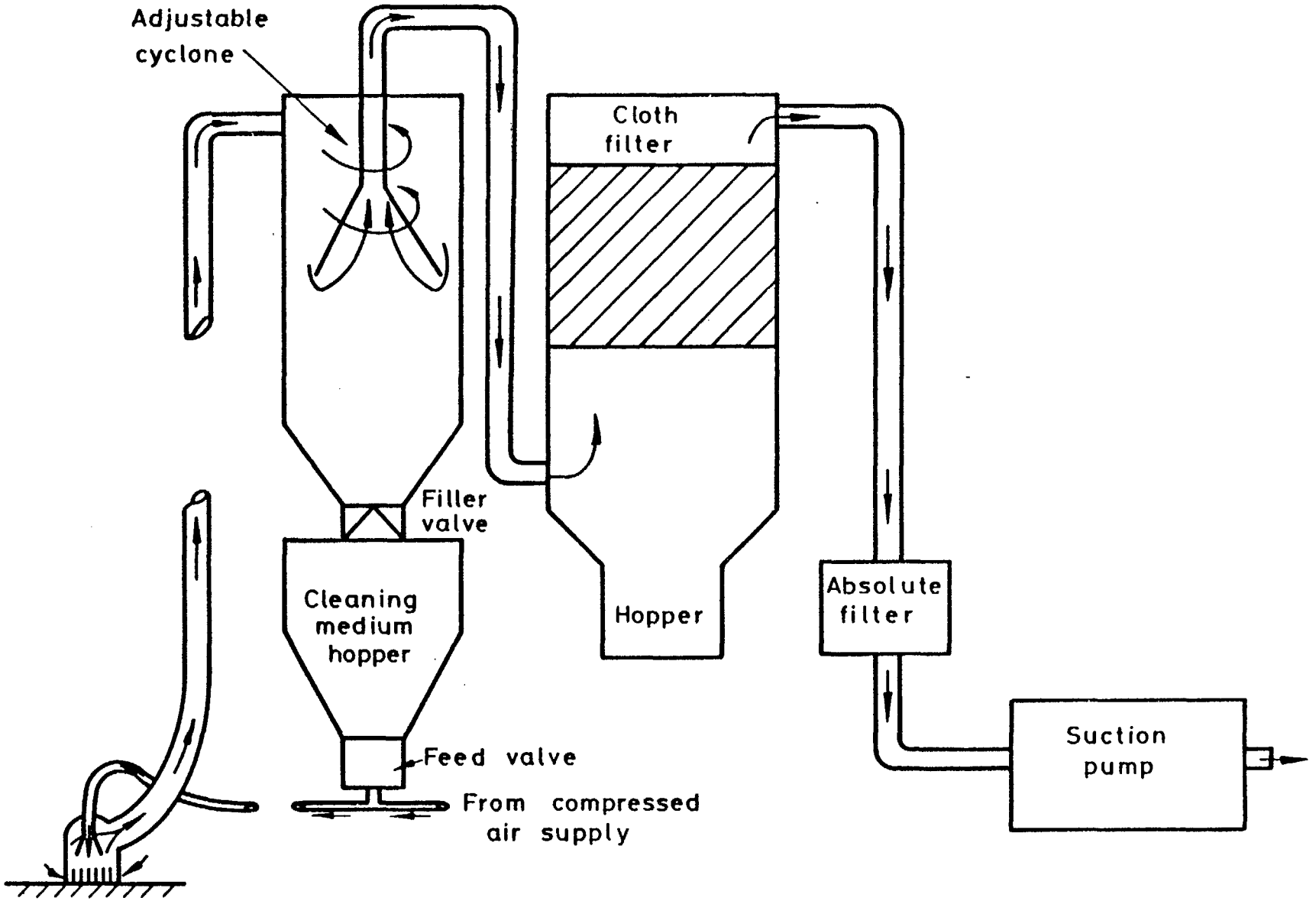

FIG. 2 Schematic Illustration of the Layout of the Vacu-Honer Machine.

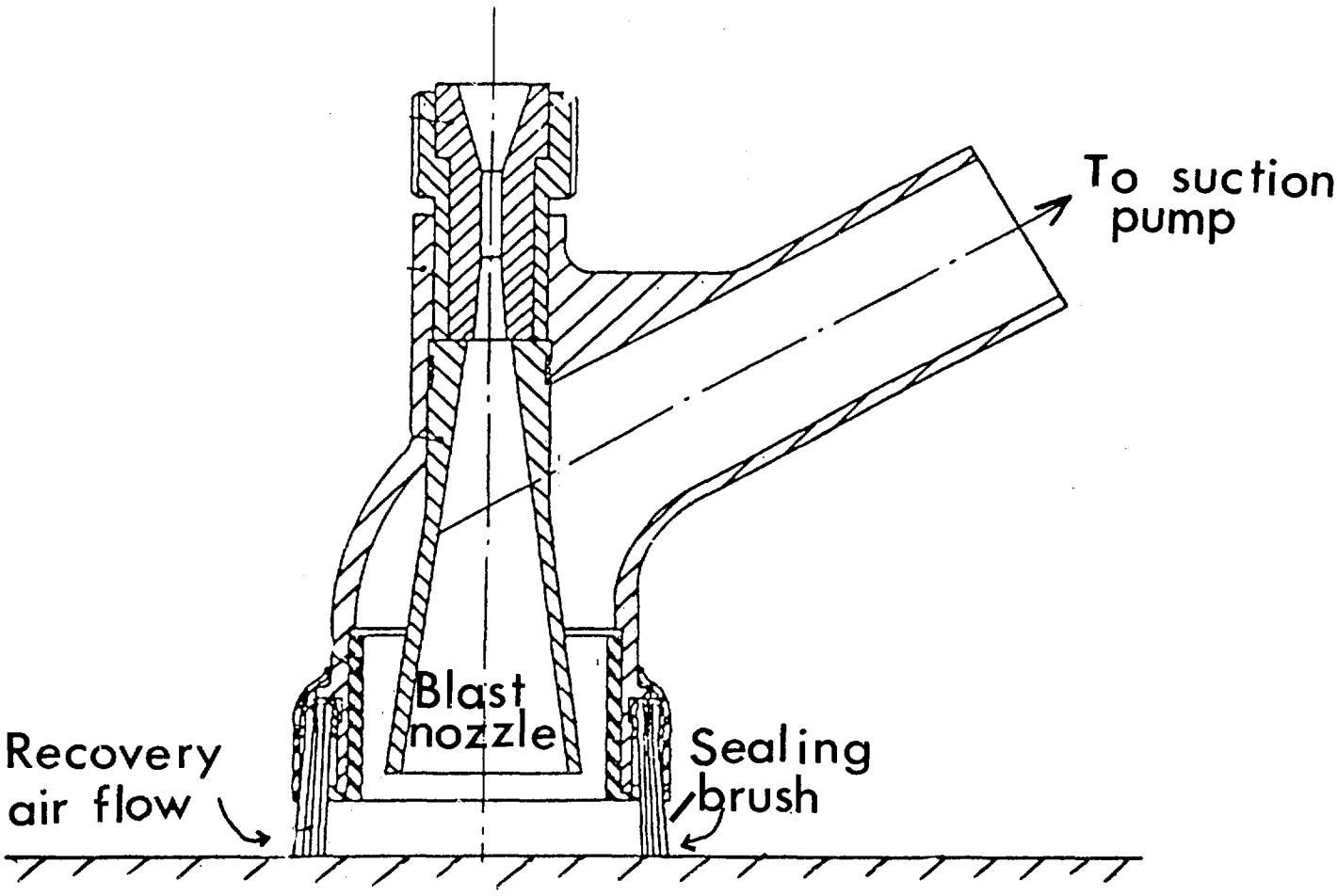

Fig 3 The blast gun with sealing arrangement.

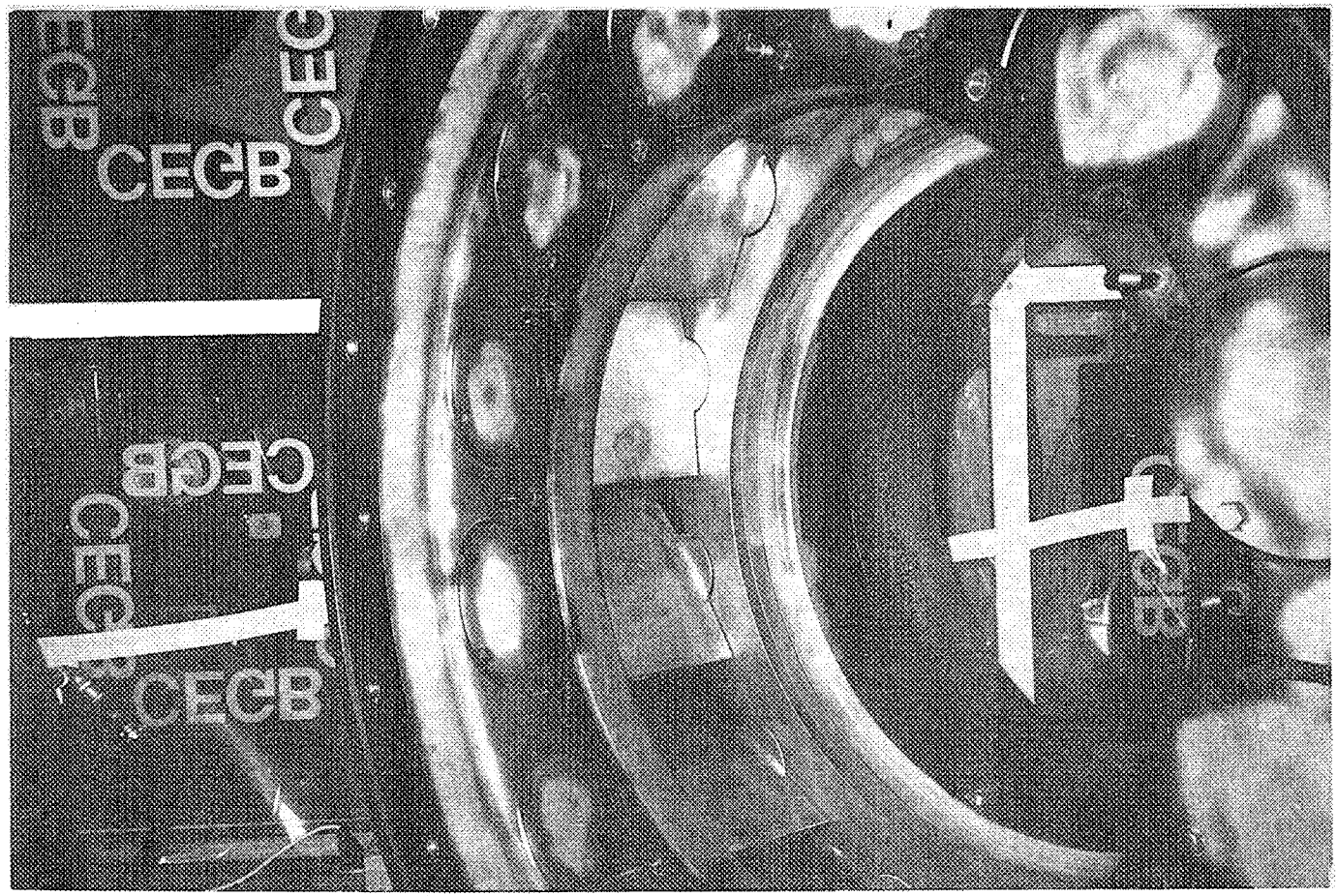

Fig 4a IGV assembly (reactor side).

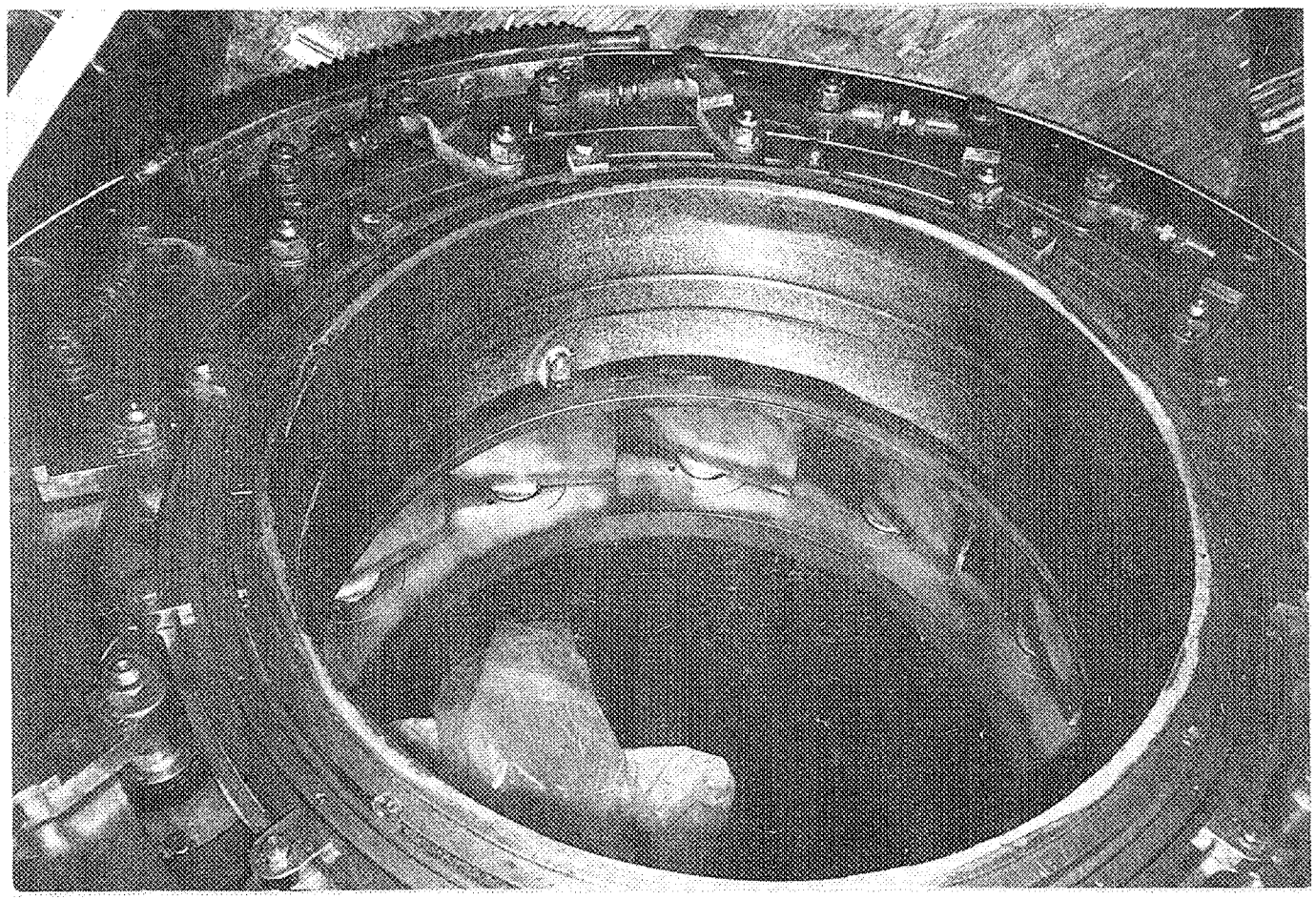

Fig 4b IGV drive mechanism (remote face from reactor)