PRESENT STATUS OF FUEL ELEMENT TECHNOLOGY AT THE INSTITUTO DE ENERGIA ATÔMICA, SÃO PAULO, BRAZIL

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Abstract–Résumé–Аннотация–Resumen

PRESENT STATUS OF FUEL ELEMENT TECHNOLOGY AT THE INSTITUTO DE ENERGIA ATÔMICA, SÃO PAULO, BRASIL.

The main activities of the Instituto de Energia Atômica's Metallurgical Division are currently concentrated on the development of fuel element technology for high-flux reactors and for future power reactors with UO_2 pellets as fuel. As the properties of the ceramic powders to be used are important for fabrication and reactor performance, they have been carefully studied with regard to the fabrication of dense U_3O_8 or UO_2 with aluminium cored, aluminium clad fuel plates and to dense UO_2 pellets for future reactor development. The plastic behaviour of fuel assemblies during rolling was studied with the conventional picture frame technique and also with cast clad ingots of special design. The cast cladding process affords excellent bonding, as evaluated by the resistance of the finished plates in a reverse bending test. In a test done in a locally built machine, the microstructures of cut samples from thermally cycled plates showed no evidence of reaction between the core constituents or of defects which would impair performance in reactor service. The results on the sinterability of non-stoichiometric UO_2 powders produced for utilization in UO_2 pellet fabrication are also discussed. Further developments on special materials and on the extension of the present testing facilities are reviewed.

TECHNOLOGIE DES ELEMENTS COMBUSTIBLES A L'INSTITUT BRESILIEN D'ENERGIE ATOMIQUE DE SÃO PAULO.

Les activités actuelles de la Division de la métallurgie de l'Institut brésilien d'énergie atomique portent surtout sur la mise au point d'une technologie des éléments combustibles pour les réacteurs à haut flux et pour des réacteurs de puissance actuellement à l'étude dont le combustible sera constitué par des pastilles d'UO_2. Etant donné que les propriétés des poudres céramiques qui seront utilisées sont importantes pour la fabrication et pour les performances du réacteur, elles ont été étudiées avec soin en vue de la fabrication de plaques combustibles comportant des noyaux denses d'U_3O_8 ou d'UO_2 à âme et gaine d'aluminium et de pastilles d'UO_2 denses, pour les réacteurs de l'avenir. Le comportement plastique des assemblages combustibles pendant le laminage a été étudié par une méthode classique et aussi sur des lingots à gaine coulée de conception particulière. Le processus du gainage par coulée donne une excellente liaison, comme le montre la résistance des plaques finies au cours d'un essai de flexion inverse. Au cours d'un essai effectué dans une machine construite au Brésil, il n'est apparu dans les microstructures d'échantillons coupés provenant de plaques qui avaient été soumises à des cycles thermiques aucune trace de réaction entre les constituants du cœur ni de défauts de nature à contrarier les performances du réacteur. Les auteurs étudient également les résultats sur la frittabilité de poudres d'UO_2 non stœchiométrique destinées à la fabrication de pastilles d'UO_2. Ils passent également en revue les faits nouveaux concernant les matériaux spéciaux et décrivent les travaux d'agrandissement des installations actuelles d'essai.

ПОЛОЖЕНИЕ ДЕЛ В ОБЛАСТИ ТЕХНОЛОГИИ ТОПЛИВНЫХ ЭЛЕМЕНТОВ В ИНСТИТУТЕ АТОМНОЙ ЭНЕРГИИ, САН ПАУЛО, БРАЗИЛИЯ.

В настоящее время основная деятельность Отдела металлургии Института атомной энергии сконцентрирована на разработке технологии топливных элементов для ядерных реакторов с большой плотностью нейтронного потока и для будущих энергетических реакторов с гранулами UO_2 в качестве топлива. Так как свойства керамических порошков, которые будут использованы, имеют значение для изготовления и работы реактора, они тщательно изучались в процессе изготовления плотных топливных пластин из U_3O_8 или UO_2 с алюминиевым покрытием и с алюминиевым сердечником, а также плотных гранул из UO_2, проектируемых для последующей разработки реактора. Пластическая деформация топливных сборок в процессе закатки изучалась с помощью обычного метода формовки, а также путем применения литых заготовок покрытия специальной конструкции. Процесс покрытия литьем дает прекрасное сцепление, что доказано путем испытания сопротивляемости готовых пластин на обратный изгиб. При испытании на созданном на месте механизме микроструктуры взятых проб пластин, термически обработанных в круговом процессе, показали отсутствие реакций между компонентами активной зоны или каких-либо дефектов, которые помешают работе реактора. Рассматриваются также результаты способности к агломерированию нестехиометрических порошков UO_2,созданных для использования при изготовлении гранул UO_2. Рассматриваются вопросы дальнейших разработок специальных материалов и расширения существующих испытательных лабораторий.

ESTADO ACTUAL DE LA TECNOLOGIA DE LOS ELEMENTOS COMBUSTIBLES EN EL INSTITUTO DE ENERGIA ATOMICA DE SÃO PAULO, BRASIL.

Las principales actividades de la División de Metalurgia del Instituto de Energía Atómica se dedican actualmente a la promoción de la tecnología de elementos combustibles a base de pastillas de UO_2, destinados a reactores de flujo elevado y a reactores de potencia futuros. Como las propiedades de los polvos cerámicos que se emplean son importantes desde el punto de vista de la fabricación del combustible y del rendimiento de los reactores, se han estudiado a fondo con vistas a la producción de placas combustibles de U_3O_8 o de UO_2, con núcleo y revestimiento de aluminio, así como de pastillas densas de UO_2 para reactores futuros. El comportamiento plástico de los conjuntos combustibles durante el laminado se ha estudiado por el método clásico de los fotogramas y también con ayuda de piezas revestidas en caliente de tipo especial. El proceso de revestimiento en caliente permite obtener una excelente unión, como pone de manifiesto la resistencia de las placas acabadas en un ensayo de flexiones alternativas. En un ensayo realizado con una máquina de construcción nacional, la microestructura de las muestras tomadas de placas sometidas a ciclos térmicos no presenta indicios de reacción entre los componentes del núcleo, ni de defectos que perjudiquen el rendimiento en reactores. Se examinan también los resultados de las pruebas de sinterabilidad de polvos no estequiométricos de UO_2, producidos para su empleo en la fabricación de pastillas. Se exponen otras novedades relativas a materiales especiales y a la ampliación de las actuales instalaciones experimentales.

1. INTRODUCTION

The Instituto de Energia Atômica established its Division of Nuclear Metallurgy in 1962, with the object of pursuing experimental studies on fuel element fabrication technology. Much of this work is devoted to the utilization of nuclear materials produced in the country and to the adaptation of processes that would best suit the envisaged scales of fabrication.

The initial efforts were concentrated on research reactor fuel elements, mainly for the sub-critical assembly Re-Suco [1], installed at the University of Pernambuco, Recife, and for the Argonaut reactor of the Instituto de Engenharia Nuclear [2], Rio de Janeiro. The former reactor has 2146 kg of 40-mm pellets of low density, natural UO_2; the starting material was ammonium diuranate, produced in another unit of the Instituto by purification of raw sodium uranate, obtained by treating uranium-bearing monazite. The latter reactor has six assemblies, each with 17 fuel plates, U_3O_8-Al dispersion cored, with 54.36% U_3O_8, the 20% enriched oxide being supplied by the United States Atomic Energy Commission; the plates are aluminium clad and were produced by the picture frame technique.

Other activities have mainly concerned: (a) production of metallic uranium and uranium-base alloys by magnesium reduction of UF_4 [3]; (b) production of metallic thorium and thorium alloys by calcium reduction and by pyrometallurgical processes with magnesium in molten systems, followed by vacuum distillation [4]; (c) production of solid solutions of ThO_2-UO_2 [5] as pellets and UO_2 -ThO_2-Al dispersions [6]; (d) fabrication of antimony-beryllia sources [7]; (e) metallographic and thermal cycling studies of uranium and uranium-base alloys [8]; (f) studies on fabrication of fuel plates with Al-U alloy cores [9]; and (g) pyrometallurgical reprocessing of plates containing dispersions [10].

The initial developments were described in two papers presented at the Third UN International Conference on the Peaceful Uses of Atomic Energy [11, 12].

Most of the activities are concentrated on two areas: (1) improvements in the technology used for dispersion cored plates, aluminium clad, for eventual use in high flux reactors [13], and (2) production of UO_2 or solid-solution pellets [14] and their assembly into fuel elements, according to the programs of the Comissão Nacional de Energia Atômica.

Efforts are also directed towards training and specializing personnel, not only technicians but also metallurgical engineers who have graduated from the universities and engineering schools of the country. For this purpose, close co-operation is maintained with the Escola Politécnica of São Paulo University, where the graduate courses lead to M.Sc. and Ph.D. degrees. The staff members already have M.Sc. degrees in metallurgical or ceramic engineering or are finishing their theses for advanced degrees.

This paper reviews the improvements accomplished in fuel element technology, presenting the solutions adopted and the results obtained, and describing in general the expansion programs that are currently under way.

2. PROPERTIES AND TESTING OF CERAMIC POWDERS

The characteristics of the ceramic powders utilized in dispersion cored plate-type fuels, or for the fabrication of sintered bodies, play an important role during the fabrication processes.

The ceramic powders required, UO_2, U_3O_8 and ThO_2, were produced in the Division's laboratories, starting from purified salts, ammonium diuranate or thorium sulphate or oxalate. Their properties can be varied over a range of values by changing the conditions under which they are prepared.

Initially, the ammonium diuranate was produced by a uranyl sulphate solution resin-exchange purifying process. This salt retained some concentration of the sulphate ion, which, to a certain extent, determined the properties of the resulting oxides. More recently, the process was changed to uranyl nitrate solvent extraction.

The calcining variables for U_3O_8 production, and further reduction to non-stoichiometric UO_2 under hydrogen, have been varied over a rather extended range of values to modify accordingly the properties of the powders.

The following tests are used:

(1) Particle density: A procedure similar to that developed at Oak Ridge National Laboratory [15] is used for the determination of UO_2 particle density. A system comprising a 20-ml pycnometer bottle, thermometer, filler tube and bell jar is evacuated and mercury admitted. This method was slightly modified for toluene density determination of U_3O_8 powder.

(2) Average particle size: The Fisher Sub Sieve Sizer is used. The apparatus has a device for compacting the powder at certain porosity levels and the air, supplied by a small compressor, is forced through the sample,

the corresponding loss of pressure being measured in a water pressure gauge. It provides measurements of average particle sizes in the 0.2- to 50-μm range.

(3) Surface area: A BET modified process of gaseous adsorption in nitrogen is used, with helium as the carrier. The equipment was built by a local manufacturer and consists essentially of a gaseous chromatography unit, with an electric furnace for degassing and a recording and integrating unit. The adsorption is done at liquid nitrogen temperature.

(4) O/U ratio: This is determined by the wet analytical procedure, and total and hexavalent U contents are measured.

(5) Optical microscopy: The examinations of alcohol dispersed powders over a glass plate are done in the Leitz MM-5 metallographic microscope; the dispersion is provided by a five-minute treatment under ultrasonic apparatus.

(6) Electron microscopy: Electron microscopical examination of the powders is currently being developed at the Electron Microscopy Centre of the Escola Politécnica, University of São Paulo, by carbon shadowed replica, in a Siemens Elmishop I microscope.

3. PLATE-TYPE FUEL ELEMENTS

3.1. Testing of fuel plates

The fuel plates are tested at present by the following procedures: (1) (1) radiography and gammagraphy; (2) gamma scintillometry, for distribution of uranium; (3) blister test, carried out by heating the finished plate for two hours at 450°C; (4) metallographic examinations of cut sections, transversal and longitudinal; (5) thermal cycling test; and (6) reverse bending test. Ultrasonic testing has so far been used in a limited way.

As tests (1) to (4) are well known, only the last two are described.

Thermal cycling: This test is carried out in a locally designed and built apparatus [16], which consists essentially of two parallel tanks filled with de-ionized water, one at 30°C and the other at 85°C, the plates being periodically and cyclically dipped first in one tank and then in the other with variably adjusted residence and transfer periods (see Fig. 1). The usual cycle is 1 min in cold water, 3 min transfer to hot water, 6 min residence time, and transfer to cold water for 1 min, the cycle being repeated again. A digital recorder allows an easy check to be made of the number of cycles.

Reverse bending test: This test consists in bending the fuel plate, which has been annealed for two hours at 450°C around 90° over a mandrel with a radius that keeps a fixed ratio to the core thickness. After this, the plate is straightened under constant weight in a rotary device, and then bent 90° again, but in the opposite direction. Such cyclical reverse bending is repeated until the cladding peels off. The number of cycles that the plate withstands before peeling off occurs is an indication of the bonding quality.

3.2. Picture frame technique

The fabrication of aluminium-clad fuel plates with ceramic phase aluminium core dispersion was developed systematically by the IEA. The studies

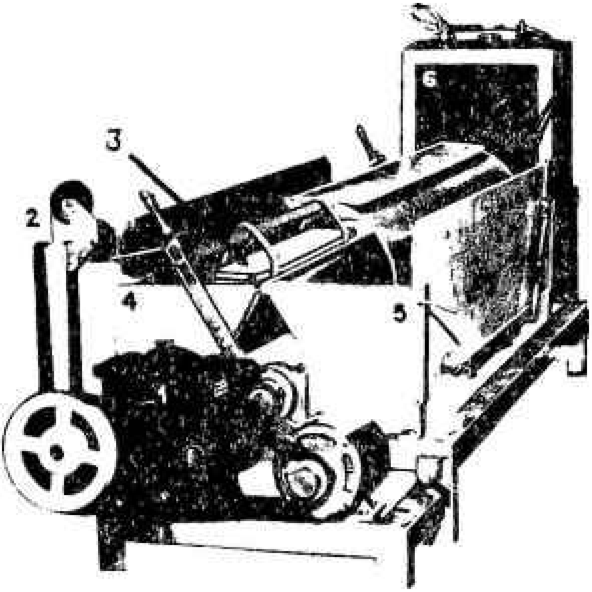

FIG. 1. Apparatus built for thermal cycling tests: (1) motor and speed reducer; (2) counter-weight acting on the plate fixture connected to the cam; (3) set of fuel plates being tested, passing from one tank to the other; (4) cold water tank; (5) hot water tank; and (6) de-ionized water reservoir, connected to the hot water tank.

were based mainly on the picture frame technique, which consists essentially of the production of roll bonded fuel plates, starting from a welded assembly made of a punched frame in which an insert of compacted dispersed mixture is placed, covered on both faces with aluminium plates.

The experimental work comprised: dispersions of U_3O_8 with aluminium, from 20 to 75% U_3O_8; of ThO_2 - UO_2-Al and ThO_2 U_3O_8-Al mixtures, from 20 to 50% of the ceramic phase; multiple cores, up to four per plate, aimed at confining the fission products in certain regions of the plate; and thicknesses varying from 2.5 to 0.7 mm.

For core production, a powder technique is used. Ceramic and aluminium powders are thoroughly mixed by means of cylindrical rubber bodies in a rotating plastic bottle; the mixture is then compacted into a prismatic body under 1 to 5 t/cm^2 pressure in a die placed in hydraulic press, the compact generally having 32 × 64 mm with variable thickness, according to the requirements. The compacts are wrapped in thin aluminium foil to minimize material losses during handling or by erosion due to jet impingement in the case of cast cladding.

The fabrication studies showed that, when U_3O_8 is fine and with a large surface area, the resulting compact density is comparatively small, corresponding to up to 12.5% closed pores. In the subsequent rolling operation, the plate showed several parallel fissures under radiographic examination, and cyclical thickness variations of the deformed core were quite evident in microstructures of longitudinally cut samples. When submitted to the thermal cycling test, such fuel plates presented an appreciable reaction between the core constituents. Microstructural examination showed irregular distribution of U_3O_8, as a disintegrated, fine powder, spread in the spaces between the elongated aluminium grains.

These characteristics are undesirable, and it was accordingly judged necessary to modify the type of ceramic powder used, in correlation with its physical properties. For this purpose, several lots of high-density U_3O_8 were prepared by disintegrating pellets which had previously been sintered in air at 1400°C for three hours, and classifying the resulting grains between 150 and 325 mesh. The oxide thus produced had a surface area of only $0.05\ m^2/g$ and an apparent density of $8.3\ g/cm^3$. Similar studies were carried out with ThO_2-U_3O_8-Al dispersions containing dense ceramic phases.

The plate type fuel elements produced with such powders and containing 55% U_3O_8 -45% Al in the core were rolled down to a final thickness of 1.20 mm (0.52 mm core and cladding of 0.39 mm in each face) and withstood the blister test; even after they had been submitted to 500 cycles in the thermal cycling test, no evidence of reaction was noticed.

The results obtained show that the plate type fuel elements produced are fully satisfactory for research reactors, confirming the experience already acquired in the IEA. They also show the importance of close and systematic control of the dispersion constituents, especially the ceramic phase, for the characteristics of the fuel plate and its behaviour during roll bonding.

3.3. Cast cladding process

The fabrication process for cast cladding fuel plates has received relatively little attention in the technical literature [17] when the efforts applied to the development of the picture frame method are considered. This situation can be explained by the success of the picture frame method in producing sound fuel elements, which satisfy stringent specification requisites. However, when cladding fuel core bonding is considered, the possibility, and even the necessity, of enhancing plate fuel quality becomes apparent; this is particularly true when U_3O_8-Al dispersions have to be used.

The author's experience has shown that the currently adopted blister test does not always give a reliable indication of bonding quality. After application of a reverse bending test, it was noticed in many instances that U_3O_8-Al plates that had passed the blister test showed very weak dispersion adherence to cladding.

It is felt that cast cladding has the potential to improve bonding characteristics, because of the heavy initial constraint applied to the ingot dispersion core by the solidifying aluminium melt. As a consequence of this greater degree of physical involvement of components, it is now possible to roll at temperatures lower than those required for the processing of picture frame assemblies. The resulting decreased thermal effects make it possible to apply dispersions such as UO_2-Al, which would otherwise present too large a reactivity.

The cast cladding procedure, as now employed at the IEA, continues to follow the general pattern established in previous papers [11, 12].

The centering of the dispersion compact in the mold, a serious problem in previous work, has been improved by distributing the loads of the positioning screws over two small, 1-mm-thick aluminium plates at the core sides.

FIG.2. Microstructure of 25% UO_2 - 75% Al core after 1000 thermal cycles; transverse section · 80.

It was found that void formation, on solidification, could be eliminated by pouring the aluminium melt at 700°C; temperatures higher than 800°C caused funicular openings in the castings, and were capable of destroying the dispersion core through excessive thermal expansion against the supporting screws or by too large a thermal shock.

The ingots were machined before rolling to remove small surface casting defects. Before this operation, the ingots had been checked by gammagraphy for voids. The reductions on rolling varied widely, but generally remained under 20% per pass. Plates were usually rolled in the 500-520°C temperature range, but even at 400°C good results were obtained.

The influence of the dispersion ceramic phase powder component turned out to be critical when high-performance fuel plates were desired. For U_3O_8 powder of low density and large surface area, the structure of the corresponding dispersion presented heavy ceramic phase stringering, prone to develop large reactivity with the aluminium phase in thermal cycling conditions. A much better microstructure could be obtained by the utilization of high-density and small surface area U_3O_8 or UO_2 powders; although present, the fibrous stringering structures were then much less evident than in the former case (Fig.2). Beaver et al. [18] recommended characteristics for cermet grade U_3O_8 that were reached by the material prepared by the authors; the surface area was under 0.04 m^2/g with toluene impregnation picnometer densities larger than 8.25 g/cm^3.

One of the interesting results in cast cladding development work that have been obtained so far is the successful fabrication of 30 wt % UO_2-Al dispersion cored plates. The microstructures present only a minor degree of stringering and the core density, after rolling at 550°C, reached 99.6% of the theoretical value: gammagraphy showed good distribution of the rolled nuclei, and the blister test, at 450°C for two hours, indicated satisfactory bonding.

The complete absence of reactivity between the UO_2 and Al dispersion components, during fabrication and on thermal cycling, is probably due to the UO_2 powder characteristics; the ceramic was obtained by fragmentation of pellets that had been sintered in argon at 1400°C to at least 93% of the theoretical density. A 30 wt % UO_2-Al plate went through 1098 thermal cycles in water, from 30 to 83°C, not showing the least indication of reactivity with aluminium; observations of the thermal cycled nucleus were achieved with metallographic techniques.

Difficulties in producing UO_2-Al plates are recorded in the literature. Waugh [19] showed that certain types of UO_2 react strongly with Al at 600°C. The authors believe that this problem can be circumvented by using the lower fabrication temperature feasible in the cast cladding procedure and by an appropriate specification of the UO_2 powder characteristics.

Since satisfactory irradiation behaviour of UO_2-Al has been achieved [20], the prospects of applying such dispersions in plate type fuels are excellent after a compound with U_3O_8-Al has been obtained. For the same U content, UO_2-Al dispersions have the following advantages: (1) the volume fraction of the ceramic phase is smaller, which enhances dispersion plasticity and core-cladding bonding, and the possibility of reactivity on thermal cycling is decreased because of the reduced UO_2 contact areas with Al; (2) the dispersion thermal conductivity is improved as a result of the larger value this property has with UO_2 [21] and the greater proportion of metallic matrix present.

Other advantages of a general character are: (3) once it is admitted that the limit of the uranium content in the plate, for successful rolling, is dependent on the maximum allowable volume of the ceramic phase, it is clear that more fissionable material can be put in UO_2-Al fuel, since UO_2 is 30.5% more dense than U_3O_8 (this is particularly important when low enrichment uranium dioxide is to be used for plate fabrication); (4) there is evidence that stringering occurs to a smaller degree, probably as a result of the greater UO_2 fragmentation resistance.

The dearth of information on the bonding quality of plate core-cladding obtained with the cast cladding method led to the development of the reverse bending test already discussed. This test, carried out on 41 fuel plates, indicated that the number of bending cycles corresponding to cladding integrity loss really gives an index of bonding quality. Experimental evidence strongly supports this indication. It was shown, for instance, that plates rejected on blister testing (the conditions of which correspond to the previously mentioned annealing) could not stand more than one bending cycle; good plates held up for more than ten. Furthermore, as was expected, the reverse bending index increased with increasing aluminium content in the fuel.

A series of 60 cast clad fuel plates with differing contents of U_3O_8 or UO_2 was made to evaluate the influence of powder characteristics, compacting pressure and rolling conditions on the homogeneity of the deformed dispersion and on bonding quality. Some of the principal conclusions are: (1) highly dense and chemically stable cores can be obtained; (2) nucleus homogeneity satisfying the requisites for high-flux reactors [21] was reached;

and (3) bonding quality, as indicated by the reverse bending and blister tests, was excellent in plates with 25 to 35 wt % U_3O_8 or UO_2, while plates with 45 and 55 wt % that passed the blister test showed poorer bonding after application of the reverse bending test.

4. CERAMIC PELLET FUEL ELEMENTS

Emphasis has been placed on development work for the production of high-density UO_2 and UO_2-ThO_2 bodies.

UO_2 pellets with densities as high as 97.2% of theoretical were obtained by sintering hyperstoichiometric oxide in argon atmospheres at 1400°C. The powder characteristics were studied extensively by using the testing procedures previously described. The resulting data correlate well with the sintering performance.

Active work is being performed on the behaviour in reduction atmosphere sintering of various types of UO_2 produced by hydrogen reduction of ammonium diuranate, precipitated in different conditions. Current research has shown that even the UO_2 with the poorest sintering qualities, when tested in inert atmospheres, can attain 92% of theoretical density when sintered in hydrogen for only two hours at 1600°C.

Pellets of UO_2-ThO_2 or U_3O_8-ThO_2 mixtures were fired under various conditions to produce high-density bodies. For U_3O_8-ThO_2 compositions sintered in air for three hours at 1400°C, densities as high as 94.1% of theoretical were achieved; in this case, there is strong ceramographic evidence that UO_2-ThO_2 solid solutions were formed to a great extent.

The present status of ceramic research at the IEA is such that only minor developmental difficulties will have to be overcome to open the way to successful production of UO_2 fuel elements for a sub-critical assembly, for which 92% of theoretical density is acceptable. Previous experience [1] has demonstrated that where conditioning, pressing and pre-sintering are concerned, IEA's know-how is sufficient to produce confidence in the results that can be achieved in pilot plant scale production. The areas in which there is a need for further research effort are high-temperature hydrogen sintering and pellet surface finishing.

5. PILOT PLANT FOR CERAMIC FUELS

To achieve further development in ceramic fuel technology, a pilot plant is being built alongside the existing experimental facilities. Its design and construction are based upon previous experience gained in the existing laboratories.

The building is expected to be completed in May of 1971 and it has a total floor area of 1100 m^2, not including the external gas-storage depot.

Part of the equipment was designed and built in São Paulo by specialized Brazilian manufacturers, on the basis of previous experience acquired in the construction and operation of similar but smaller capacity units, which were also locally manufactured. Among the units that have already been received are: an oil-fired muffle furnace, for calcining the ammonium diuranate, which is equipped with a charging car for the alloy steel trays; an electric muffle, continuous stocking furnace, for UO_2 reduction under hydrogen; ball mills and mixers of various types. Other items were imported and some have already been delivered, such as one set of Stockes automatic presses for precompacting, granulating and final pellet pressing; a Harper model MM-6428 continuous high-temperature, molybdenum wound furnace for UO_2 hydrogen sintering; equipment for continuous centreless grinding of the sintered pellets; apparatus for inspection of cladding tubes and for welding the assembled fuel sets.

The pilot plant will constitute a flexible unit for development work on ceramic fuels and its capacity is expected to be about 300 kg/month of UO_2 pellets.

6. SPECIAL MATERIALS AND TESTING LABORATORY

The need for processing highly enriched fuels, irradiated elements and toxic compounds led to the design, based on previous experience of one of the authors [22], of a small facility to carry out that task on a laboratory scale.

The fundamental purpose of this unit will be to develop the technology for recycled enriched fuels to be employed in thermal reactors. Since the necessary glove-box work will require considerable experience, the preparation of technicians for such job will be included in the scope of the laboratory main activities.

The objective of the enriched ^{235}U fuel program is to make possible the development of fuel fabrication procedures in which the highest standards of materials accountability must be respected.

The irradiated materials section of the laborabory will have three hot-cells for pyrometallurgical reprocessing of fuels, for fabrication of gamma-active components and for testing. Special attention will be given to the installation of metallographic apparatus and shielded electron microprobes for the analysis of gamma-active samples. Microprobe and scanning electron microscopy will be applied extensively to evaluate fuel homogeneity and composition, as well as texture and pore morphology.

7. CONCLUSIONS

A review was presented of the contribution of the Instituto de Energia Atômica to the development of the Brazilian technical know-how on reactor fuel. The efforts to balance the creation and transfer of technology were implemented in a manner compatible with the national desire for rapid progress in nuclear science.

Fabrication of U_3O_8-Al dispersion-cored, plate type fuel by means of the picture frame technique has reached an advanced stage; it has been proven adequate to meet the specifications for production of research reactor fuels.

The cast cladding process was studied extensively. Fuel plates containing UO_2 or U_3O_8-Al dispersions and made with this technique presented excellent core-cladding bonding and good nucleus homogeneity.

The possibility of rolling at lower temperatures than those required for the picture frame technique opened the way for the use of materials such as UO_2, which otherwise could have too large a reactivity with aluminium.

Research in ceramic pellet technology has led to successful procedures for the fabrication of high-density UO_2 or UO_2-ThO_2 solid-solution fuel element components.

The completion of a UO_2 fuel element pilot plant and of a special materials laboratory will further work aiming at the production of power reactor fuel.

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