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The status of the ISIS targets

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ABSTRACT

Operational aspects of the ISIS neutron production targets are discussed and an outline given of future developments.

1. OPERATIONS

Table 1 gives an overall performance summary for the six targets which have been used to date.

At ICANS-X the failure of targets 1 and 2 were reported [1]. Since then two more Uranium targets have failed and some experience has been gained running with the backup Tantalum target.

The construction of the target and its cooling circuits have been described in detail at previous ICANS meetings so only a brief resume is given here. A schematic diagram of the construction of the target is shown in figure 1. The condition of the target is determined by monitoring the centreline temperatures of the target plates and the flow and pressure drop characteristics of the three heavy water cooling channels. The effective width of the cooling gaps between the target plates is monitored using a quantity called the 'gap constant' which is the ratio

$$\frac{\text{flow}}{(\text{pressure drop})^{0.55}}$$

This is constant over a wide range of flows and pressure drops and reduces as the cooling gaps become narrower. Measurements of the radiation levels around the cooling plant and measurement of the spectrum of gamma rays emitted from the target coolant are also used as diagnostics.

1.1 Uranium Target Running

In operation several radiation damage mechanisms lead to swelling of the Uranium so that the width of the cooling gaps between the target plates is reduced. This leads to a reduction in the gap constant and, finally, inadequate cooling of the Uranium.

The failure of target 2 followed this scenario and was described in detail at ICANS-X. This target was dismantled and the plates examined and the swelling of the Uranium was attributed to thermal cycling growth resulting from gross thermal cycles on the target which occurred when the accelerator system tripped.

In the failure of targets 3 and 4 the changes in flow and pressure drop of the coolant followed a broadly similar pattern to that measured in the failure of targets 1 and 2. A partial blockage was detected in the cooling channel feeding the front five plates of the target with a consequent rise in Uranium temperature. The decision to change the targets was taken when the presence of fission products in the cooling water was confirmed indicating a breach in the integrity of the Zircaloy cladding of the Uranium.

During the design of the target studies of the radiation damage mechanisms lead to an estimate of about 10000 gross thermal cycles to failure. As can be seen in Table 1 the number of gross thermal cycles on target 3 was consistent with this estimated lifetime but target 4 failed after a disappointingly low number.

In operation the gap constant of target 4 changed abruptly on two occasions a long time before its failure. This behaviour has not been observed on any other target and no convincing explanation has been found. It has not been possible to dismantle either target 3 or 4 to establish detailed reason for their failures.

It is assumed that thermal cycling growth is still the dominant limitation on the lifetime of the targets. Considerable efforts have been made to reduce the frequency of accelerator trips and significant progress has been made. Figure 2 the day by day history for targets 4 and 5 and Table 2 shows the mean number of trips per day since 1987. The reliability of the accelerator systems has now improved to the point where, from the point of view of thermal cycling growth, a target lifetime of about 400 days could be expected so the fate of target 5, now in operation, is of crucial interest.

1.2 Tantalum Target Running

Some difficulties have been encountered in the manufacture, and thus availability, of Uranium targets. This has resulted in two periods, one of two months and one of seven months, where the backup Tantalum target has had to be used. This target is identical in construction to the Uranium targets with 9 cm. diameter disks of Tantalum instead of Uranium. The neutron fluxes from the moderators are 50% of that achieved with Uranium. The time independent backgrounds are lower but this was found to be of no significant advantage to the neutron scattering experiments.

There have been no operational problems with this target. Since Tantalum is not subject to the thermal cycling growth problems of Uranium there is no need for a gradual increase in current when restoring the proton beam after a trip. This results in two gross thermal cycles for each accelerator trip and is the reason for the apparently large number of gross thermal cycles for the Tantalum target in Table 1. However, a new backup is to be provided probably using Tungsten as the target material and will have a more efficient geometry. This is discussed in section 3.

1.4 Target Changes and Disposal

A great deal of work has gone into developing the remote handling of targets since ICANS-X. There have been detailed improvements to the tools including the use of air driven torque wrenches, positional readout have been added to the remotely operated crane and the position and mounting arrangements for the cameras have been refined. As a result target changes are now essentially a routine operation without the sense of adventure evident in the early remote handling work.

The used Uranium targets have been transferred to the Harwell Laboratory for storage. This is an interim measure awaiting the procurement of a transport flask which will enable these, and all future targets, to be transferred to the Sellafield plant of British Nuclear Fuels Plc. for disposal. The contract for the flask has been placed and it is expected to be available, with full certification for use on public roads, by the middle of 1992.

2. URANIUM TARGET DEVELOPMENT

The aim of the development program is to achieve longer lifetimes for the targets. This will involve detailed changes to the design of the target plates, changes in the manufacturing procedures and possibly the use of a Uranium Molybdenum alloy for the target material. A brief description of the techniques used to produce the Uranium plates is given below together with the plans for improvements.

2.1 Uranium target module manufacturing processes

A schematic diagram of a target plate is shown in figure 3.

Depleted Uranium is melted with additions of iron and aluminium to produce the required "Springfield adjusted" Uranium alloy. This material is cast into billets which are topped, tailed and skimmed to remove most of the casting surface defects. The machined billets are then hot isostatically pressed (HIPped) to close any internal porosity, thus densifying the material. This process involves heating the material to a high temperature (typically 850C) in a pressure vessel which contains an inert gas and simultaneously increasing the gas pressure to a high level (typically 2040 bar). Any sealed void defect or casting porosity that is within the material is closed as the material yields under heating and pressure. Discs of the required thickness are sliced from the HIPped billet, heat treated to refine the structure, and surface prepared. These discs are fitted into Zircaloy-2 cups and covers which are hermetically sealed under vacuum by electron beam welding. The HIPping process is used again, but this time the high temperature and pressure are held for a set time to enable a diffusion bond to form between the Uranium disc and the Zircaloy-2 cladding. This bond is necessary in order to form a continuous thermal path from the Uranium to the water cooling. Ultrasonic inspection methods are used to check the bond and satisfactory discs are shrink-fitted into stainless steel frames to form the target plates. The target plates are then machined to reduce the cladding to the finished thickness, stacked with the window and rear closure plate, and electron beam welded together to form the target module ready for final machining.

The development programme will be staged in four parts.

2.2 Stage 1

The initial work will involve the optimisation of the HIPping cycle to produce the best diffusion bond between the Uranium and the Zircaloy-2 cladding. It will cover the possibility of eliminating the evacuation slots in the Zircaloy cups to prevent the problems encountered on modules 5 & 6, where Uranium extruded into these slots and was found to be exposed on subsequent machining. Also the production of a more even penetration of the diffusion bond that is compatible with the automatic NDT scanning equipment, and finally to investigate the possibility of quenching the HIPped discs to further refine the grain size of the Uranium to reduce the effects of the irradiation induced growth.

2.3 Stage 2

At present the clad discs are shrink fitted into stainless steel frames and leaks have occurred through the interface to the thermocouple holes. These have to date been successfully cured on assembly by the use of custom made screw clamps and silver seals. However, internal leaks have developed subsequently during the operation of the targets and are probably due to the relaxation of the silver seals around the thermocouples caused by the normal operational temperature cycles of the targets.

This problem can be completely eradicated by replacing the stainless steel frame with an integral cup and frame manufactured from Zircaloy-2. This would utilise a square plate with a circular cavity to contain the Uranium. A solution using this method will need the development of two other items in parallel, namely longer thermowells, and a method of joining stainless steel to Zircaloy-2.

The current thermowells are manufactured in one piece and have a 1.7mm diameter hole 50mm long drilled down the centre. Experience has shown that this is the limit beyond which eccentricity occurs due to drill deflection. A programme of work is proposed which utilises electron beam welding to fabricate tubular segments to make up the longer length of thermowell required to penetrate into the centre of the larger square frames.

The final assembly stage to complete the pressure containment vessel of the target assembly involves EB welding the beam entry window to the main pressure vessel. The beam entry window forms an integral part of the target module and is EB welded to the front of the stack of 23 target plates. There will be a need to join the proposed square Zircaloy-2 frames to the stainless steel beam entry window. This is not possible by any process which involves the fusion of the two alloys because there is a tendency for brittle intermetallics to form which limit the strength of the joint. Also due to the thermal expansion mismatch between the two alloys cracks are often formed upon solidification of the weld pool.

HIP assisted diffusion bonding using a range of different thin intermediate layers to bridge the incompatibility of stainless steel and Zircaloy-2 offers a potential solution to the joining of the two alloys. This process enables bonding to take place in the solid state where it is possible to control the reaction products and therefore minimise the formation of the unwanted brittle intermetallic phases. A study will need to be carried out to optimise the nature and position of the interlayers and the HIP conditions necessary to produce metallurgically sound bonds.

2.4 Stage 3

Springfield adjusted depleted Uranium has been used so far for target production and this has well documented problems when subjected to irradiation. Some of these problems are reduced by adding molybdenum at the rate of between 2 to 5 wt.-% to depleted Uranium to form an alloy. These alloys are less dense than the present material but will have greater resistance to radiation induced growth and swelling. Thus the neutron yield may be reduced slightly but the usable lifetime of the target will be increased. It would be beneficial to introduce this material into the front plates of the module which suffer the major damage and cause target failure whilst retaining the present material in the rear plates. That way the reduction in yield would be less noticeable but the benefits of longer lifetime would be gained.

Material casting and alloying techniques will need to be evolved and diffusion bonding trials will need to be carried out to test that the material is compatible with the existing manufacturing procedures.

2.5 Stage 4

The present 9cm diameter discs could be replaced by 9cm square blocks of similar thickness within the proposed square Zircaloy-2 frames. This would increase the volume of Uranium material in the target by about 20% and improve the coupling to the moderators. Engineering and diffusion bonding implications would need to be studied as part of a development programme.

3. NON URANIUM TARGET DEVELOPMENTS

The design of a new backup target is well advanced. The aim is to achieve the best possible neutron production from a non-Uranium target which is compatible with the remote handling facilities, disposal arrangements and the existing target cooling systems and which will require no changes to the Target Moderator Reflector Assembly,

These constraints are mainly met by retaining the pressure vessel design used for Uranium targets. Two materials have been considered namely Tantalum and the Tungsten/Iron alloy used for the LANSCE target. The Tungsten alloy has been chosen for the target as the neutron yield is about 15% higher than from Tantalum. The mechanical properties of tungsten under irradiation and thermal cycling are not well known and if the detailed design results in relatively thin block of Tungsten then this decision will be reviewed.

The gains from the geometry of the target will be achieved by using square blocks rather than the cylindrical geometry of the Uranium and existing Tantalum target. (Note that this gain could be achievable with Uranium and is the subject of Stage 4 of the development programme above.) The improvement in neutron fluxes from the moderators over the existing backup target will be about 30% thus giving fluxes about 60-65% of the Uranium target fluxes.

Commercially, the Tungsten alloy is sintered from powder and supplied in the form of hot pressed block. This has been found to have variable density, as low as 17 gm/cc compared to the expected density of 18.85 gm/cc. Also it is extremely difficult to produce holes in the block which limits the penetration depth of thermocouples to a few millimetres. A development program is underway to form the material using the Hot Isostatic Pressing technology which has the prospect of achieving uniform density and deep holes for thermocouples.

4. REFERENCE

[1] The ISIS Target A. Carne, T.A. Broome, J.R.Hogston and M. Holding
Proceedings ICANS X Los Alamos 1988
IOP Conference Series 97 (79)

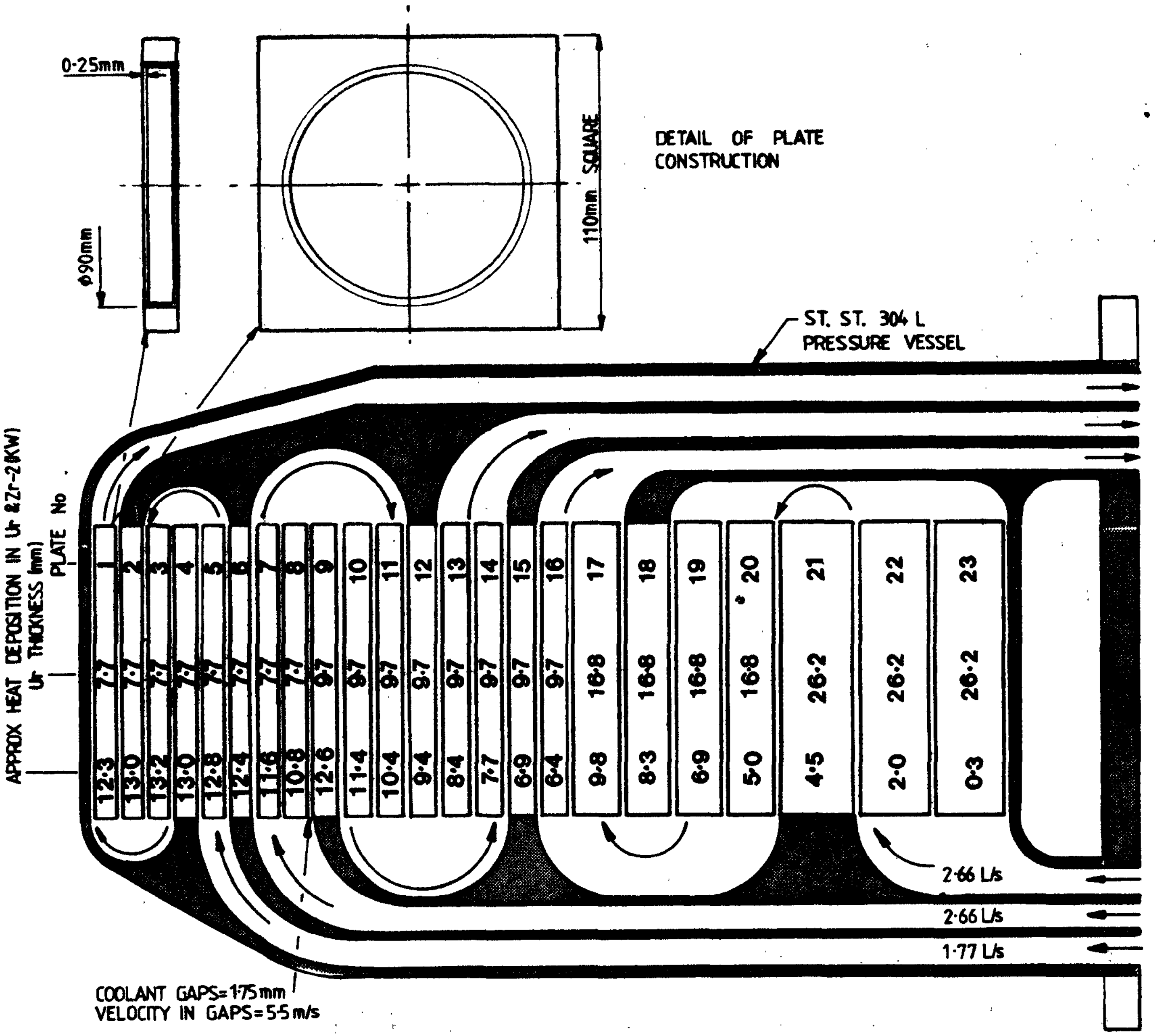
Table 1. ISIS TARGET PERFORMANCE SUMMARY

Target	Gross Thermal Cycles	Integrated Current mAhr	Neutron Production mg
U#1	Not Measured	92.4	75
U#2	40000	53.1	52
U#3	10389	174.9	163
U#4	4147	138.8	130
Ta#1	18124	327.5	153
U#5	1541	106.0	97

Table 2. MONTHLY MEAN NUMBER OF TRIPS PER DAY AND MONTHLY TOTALS OF BEAM CURRENT ON TARGET

Month	Year	Trips/day	mAh	Target
September	1987	94	12.2	Uranium #2
October		367	11.0	
November		496	19.4	
December		640	10.4	
January	1988	75	27.1	Uranium #3
February		59	13.8	
June		56	19.6	
July		83	13.3	
August		76	37.1	
September		61	20.6	
October		61	43.2	
November		57	30.5	Tantalum #1
December		45	29.9	
March	1989	45	10.1	Uranium #4
April		36	40.4	
May		33	35.3	
June		32	10.7	
July		35	10.2	
August		40	32.3	
September		56	38.5	Tantalum #1
October		45	40.3	
November		49	31.4	
December		69	40.0	
April	1990	41	43.3	
May		33	34.9	
June		27	38.7	
July		24	10.6	Uranium #5
August		25	40.6	
September		26	54.8	

The calculation of trips/day only included those days when ISIS was running.



T_{cl} (max) = 380°C

W max = 300 W cm^{-2}

T (Zr) ~ 120°C

BULK OUTLET TEMPERATURE 50°C

OUTLET PRESSURE 3·4 BARS

HEAT DEPOSITED IN TARGET	KW
a) In ^{238}U including decay	209
b) in Zircaloy-2 cladding	6
c) in Pres. Vessel including Window	7
d) in Heavy Water Coolant	5
TOTAL	227

INLET PRESSURE 4·76 BARS

HEAVY WATER COOLANT

AT 43°C

FIGURE 1 SCHEMATIC DIAGRAM OF ISIS URANIUM TARGET

Uranium targets 4 and 5

Accelerator trips per day

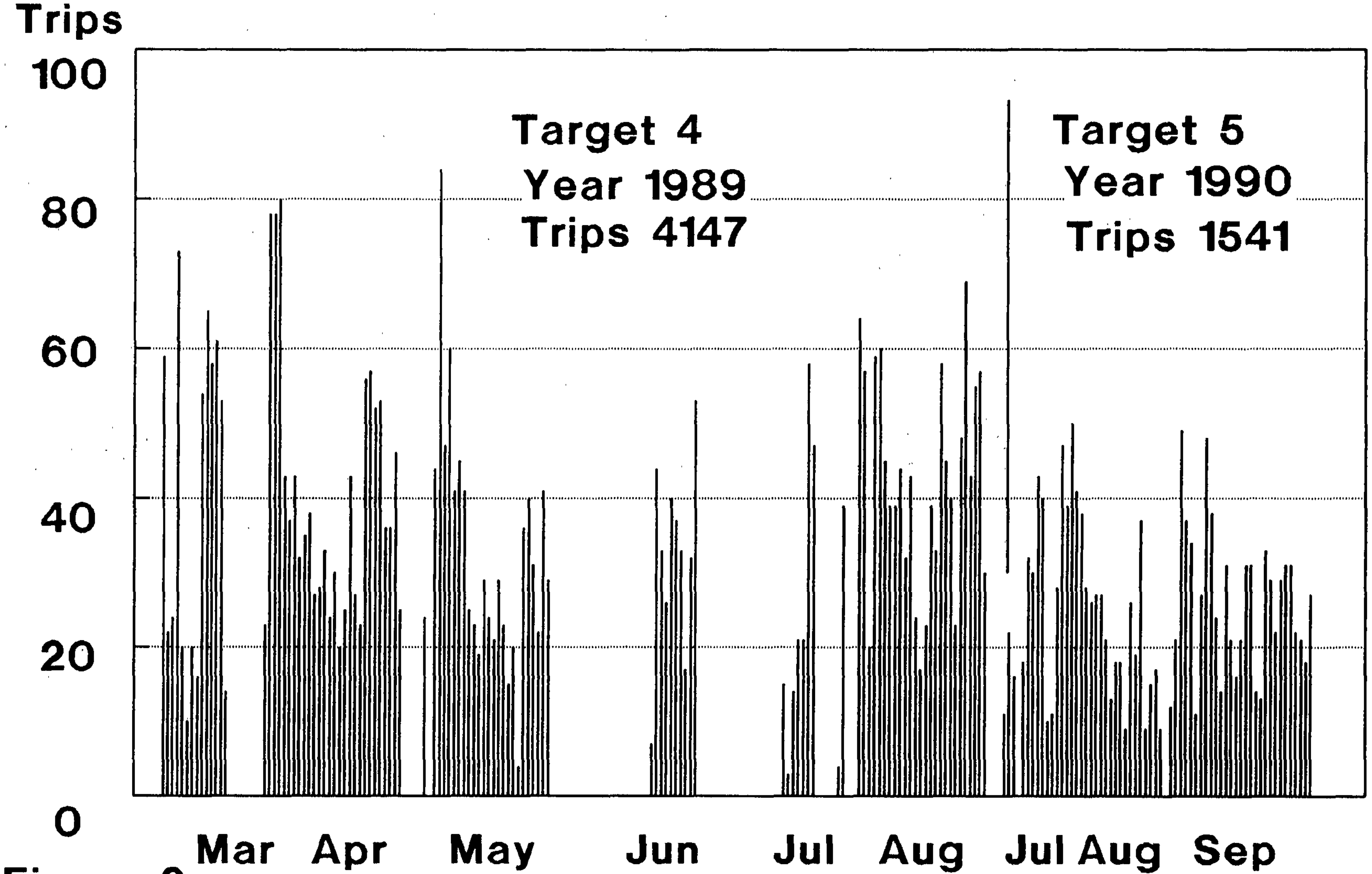


Figure 2

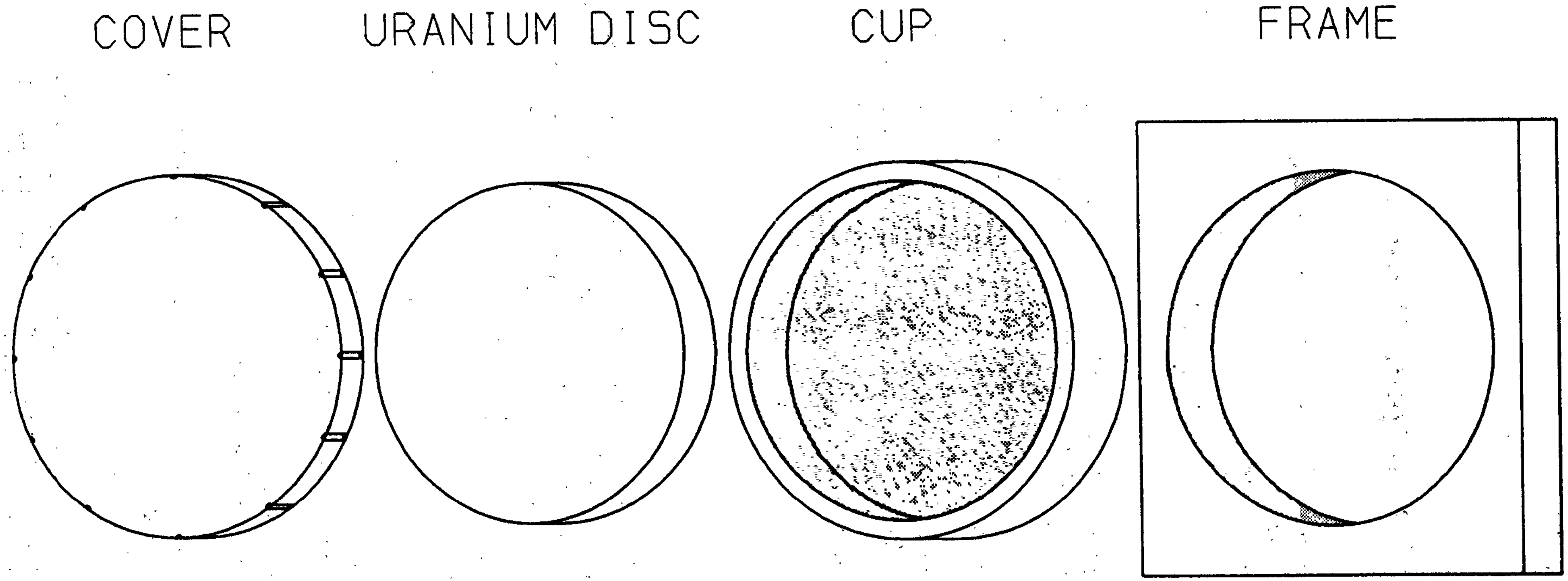


FIGURE 3 SCHEMATIC DIAGRAM OF A URANIUM TARGET PLATE