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QUALITY EVALUATION OF CP-5 REACTOR FUEL

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DISCLAIMER

METHOD OF REPORTING RESULTS OF THE ASSAY

The U-235 content of each fuel tube was recorded on the Inspection Sheet No. 2 as shown in Figure 8. The manufacturer's listed U-235 content taken from the Manufacturer's Data Sheet was also listed. If any discrepancies existed between these two values, the U-235 content, as determined by the assay, was used.

SUMMARY AND CONCLUSION

This report described the methods used to nondestructively verify properties of the reactor fuel which were not detectable visually. All of these properties were required by contract specification and were necessary for proper operation of the reactor. The primary conclusion is that more complete accountability, as concerns the management of nuclear materials, is possible by examinations as described in this report.

QUALITY EVALUATION OF CP-5 REACTOR FUEL

INTRODUCTION

The primary purpose of this paper is to describe the manner in which verification of the quality of the fuel for the CP-5 reactor was recently accomplished. Three nondestructive inspection techniques were used for this examination. They were - radiographic, ultrasonic and gamma ray scintillation spectrometric. Visual inspection, including the measurement of visible dimensions was also carried out in conjunction with the above techniques but will not be discussed in this paper.

The three techniques each have unique features which are described together with a general description of how the methods were used to provide an evaluation of the fuel.

RADIOGRAPHIC - GENERAL

The manufacturer supplied radiographs of all the fuel tubes received by Argonne National Laboratory. A "spot check" of this radiography was accomplished by reradiographing one fuel tube set (3 tubes) selected at random from each storage drum. Each set of tubes consisted of three tubes having different diameters and which "nested" together. They were designated as inner, intermediate or outer tubes. A storage drum contained six sets or eighteen tubes total. These radiographs and the lengths of uranium cores obtained from measuring them were compared with the manufacturers radiographs and core length values. In addition, any fuel tubes having questionable core length values or poor quality radiographs were reradiographed and evaluated.

FABRICATION SPECIFICATIONS CONCERNING RADIOGRAPHY

The radiographic inspection made it possible to verify that the manufacturer had met certain contract specifications. These specifications are presented here to show the need for radiography.

The location of the core was to be such that a minimum of 1/2" length of aluminum endcap was available at each end of the inner and intermediate fuel tubes for fastening purposes. No core material was to extend into the endcap.

The outer fuel tube was to have a minimum aluminum endcap length of 1-3/8" at one (top) end and a minimum aluminum endcap length of 3-7/8" at the other (bottom) end.

The maximum core length, measured from extreme locations of core material was to be no more than 26-5/16". The mean distribution of the core material was to be no less than 23-13/16".

The minimum length of full thickness core was to be no less than 21-13/16". However, tubes having a shorter minimum length of full thickness core would be accepted if the core length measured between points where the core thickness was 90% of the core thickness at the longitudinal midpoint of the core, and was not less than 21-13/16". Measurements of the core thickness was necessary only in tubes where the minimum length of full thickness core was less than 21-13/16". Densitometer readings of the radiographs was the basis for arriving at the core thickness.

Full thickness core was defined as a uranium core thickness of $0.032^{+.004}_{-.003}$ inches for inner and intermediate fuel tubes and $0.020^{+.004}_{-.003}$ inches for outer fuel tubes.

There were further exceptions allowed as concerned minimum core thicknesses which were dependent on core position, etc. The details of these exceptions will be omitted here with only the comment that radiographs were needed for their verification.

RADIOGRAPHIC TECHNIQUE

To radiographically determine the core end structure, the fuel tubes were rotated about their longitudinal axis under a collimated x-ray beam. A sheet of film was carefully rolled and placed concentrically inside a fuel tube with a small portion allowed to extend beyond the end of the tube. Then a lead cylinder was placed inside the cylinder of film. This lead cylinder served as a radiation shield for that part of the film which was 180° from the area of x-ray incidence. This arrangement is shown in Figure 1. Appropriate rotational speeds and exposures were established for each of the three fuel tube types. The film was positioned in such a way that the film overlap is directly over an engraved identification arrow and number, which was present on each tube. A 30 second static exposure of the film overlap was made immediately preceding the rotational exposure yielding a double exposure of the x-ray collimating slit. The distance between the slit images identified the fuel tube circumference. Lead letters and numbers identical to the scribed tube identification number were placed on the tube during exposure and further identified the radiograph.

The radiographs produced by the rotational technique showed the entire circumference of the tube on one film with no superposition of images.

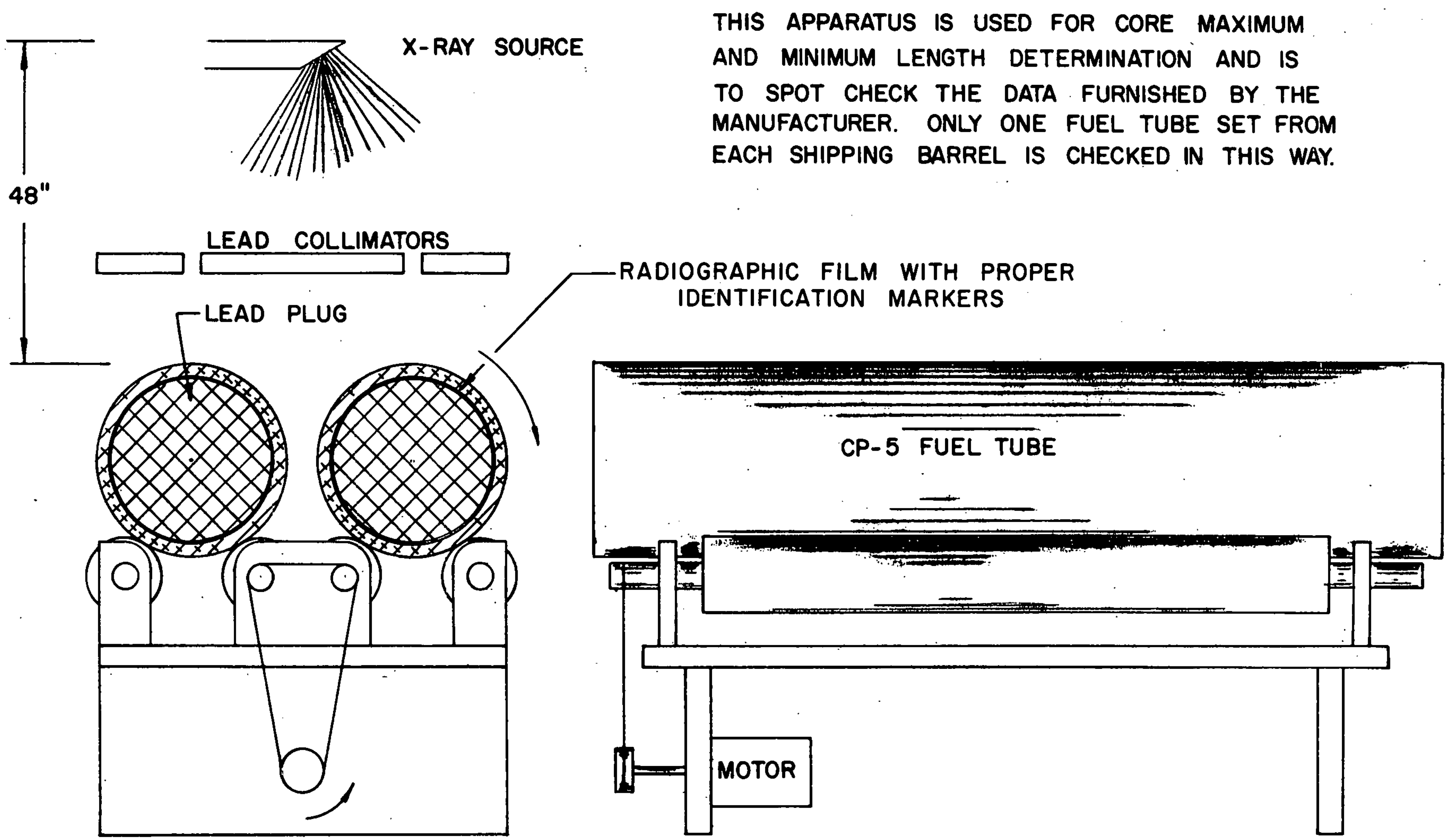

THIS APPARATUS IS USED FOR CORE MAXIMUM AND MINIMUM LENGTH DETERMINATION AND IS TO SPOT CHECK THE DATA FURNISHED BY THE MANUFACTURER. ONLY ONE FUEL TUBE SET FROM EACH SHIPPING BARREL IS CHECKED IN THIS WAY.
X-RAY SOURCE
48"
LEAD COLLIMATORS
LEAD PLUG
RADIOGRAPHIC FILM WITH PROPER IDENTIFICATION MARKERS
CP-5 FUEL TUBE
MOTOR

FIGURE 1.

Measurements of distances from core to the end of tube could be made since images of both the end of core and end of tube appeared on the radiographs. Distances around the circumference of the tube could be measured from the dark lines produced by the slit image projected onto the overlapped film during the static exposure. The radiograph was similar to that which would result from a static exposure of a fuel tube that had been cut longitudinally, flattened, and radiographed as a flat plate. Rotational techniques of this type have been used by others and it is not intended that the reader assume it was our original development. It avoided the technique of multiple, overlapped exposures which is a more conventional way of handling such a problem.

In addition, all of the tubes designated as "outer" tubes were radiographed to determine the tube top and bottom. The fuel core was not centered in these tubes (i.e., there was a longer aluminum end section at one end than the other.) This identification did not require radiographs having the best sensitivity and resolution since the difference in end lengths was a matter of inches. It was, therefore, possible to do this radiography by a single static exposure with core end images superimposed upon each other. It was also possible to obtain satisfactory images on Polaroid film and thus save the time needed for processing conventional film. Figure 2 shows the arrangement for producing these identification radiographs. The outer tube end containing the least amount of aluminum was designated the tube top end. To insure that the outer tube was not inverted during fabrication, the radiographer marked the tube top end. This marking was performed by scribing a letter "T" approximately 1/4" high with a Vibra-tool on each outer tube top end. The placement of this mark on the tube was very important since accidental inversion of the

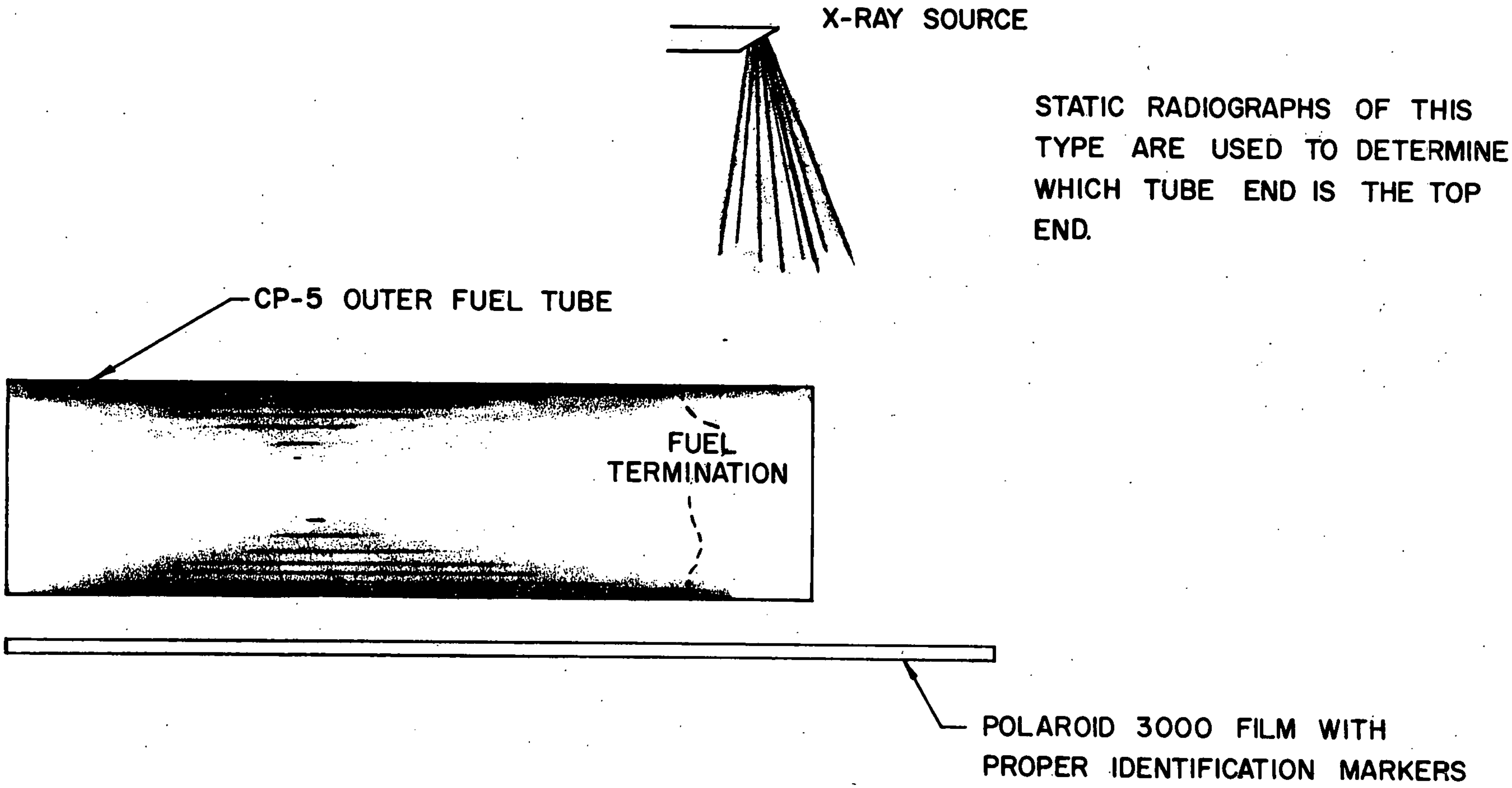

X-RAY SOURCE
STATIC RADIOGRAPHS OF THIS TYPE ARE USED TO DETERMINE WHICH TUBE END IS THE TOP END.
CP-5 OUTER FUEL TUBE
FUEL TERMINATION
POLAROID 3000 FILM WITH PROPER IDENTIFICATION MARKERS

FIGURE 2.

tube during fabrication would have caused the tube to be spot-welded through the uranium and, thus, ruined.

After completing the radiographic inspection as described above, the radiographer took measurements from the films and completed an inspection sheet. A copy of this inspection sheet is shown in Figure 3.

ULTRASONIC INSPECTION - GENERAL

All of the fuel tubes were examined ultrasonically to determine if the manufacturer had met the contract specifications concerning clad to core bond integrity.

FABRICATION SPECIFICATIONS COVERING ULTRASONIC INSPECTION

The manufacturer was required to blister test all the extruded fuel tubes at 500°C in air without flux for one hour. Tubes exhibiting blisters were to be rejected. The remaining tubes were to be ultrasonically inspected to establish the presence of a metallurgical bond over the fuel length of the tubes.

ULTRASONIC INSPECTION TECHNIQUE USED BY ARGONNE

An immersion technique was chosen for this inspection. A fuel tube was submerged in water and a straight, longitudinal sound beam was sent into the wall of the tube as shown in Figure 4. A portion of the sound energy was reflected at each of the water-aluminum interfaces. By observing the attenuation of the reflection from the inner (I.D.) surface of the tube, internal non-bonds were detected. This was due to the fact that internal non-bonds will not transmit sound waves. Thus, a non-bond revealed itself by causing a decrease in the sound waves transmitted to

CP-5 ELEMENT INSPECTION SHEET NO. 2

Tube Number__________ Tube Type __________

1. RADIOGRAPHY

	SPM Value (If Applicable)	MFG. Given Value
Aluminum Endcap Length, Numbered End		
Aluminum Endcap Length, Opposite End		
Fuel Length, Maximum		
Fuel Length, Minimum		

Fuel Acceptable _______ (Yes or No)

Remarks ____

____

For Outer Tubes Only

Top of tube (end with shortest aluminum endcap length) has been

marked as specified __________________

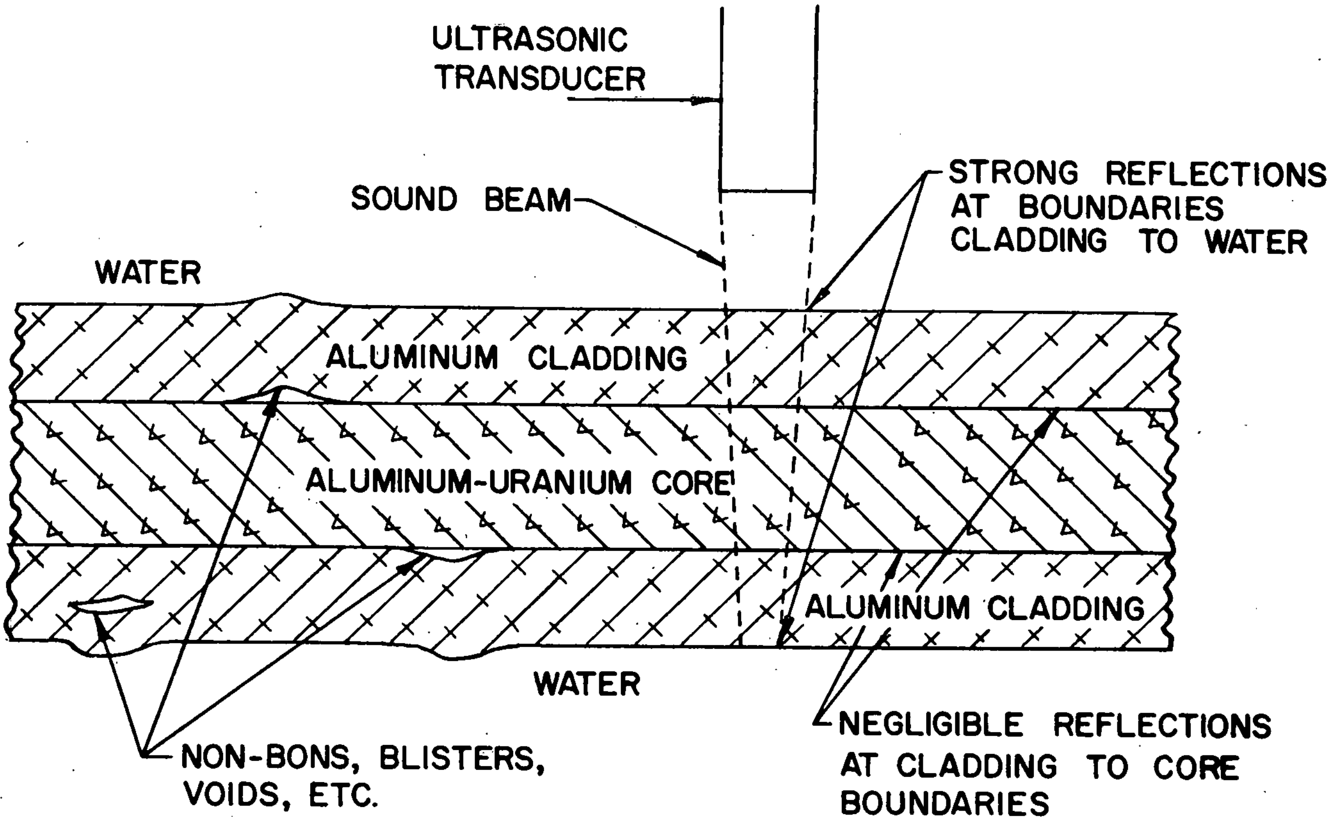
Date ______________ Signature ________________

2. ULTRASONIC

Defects and/or Questionable Areas

No.	Defect Description
1	
2	
3	
4	
5	

FIGURE 3.



FLAWS DO NOT INTERFERE WITH TOP AL-H_2O SURFACE REFLECTIONS, BUT CAUSE SEVERE LOSS IN BOTTOM AL-H_2O SURFACE REFLECTIONS, SINCE THE SOUND CANNOT PENETRATE THE VOID. THIS LOSS OF SIGNAL IS THE BASIS OF THE INSPECTIONS.

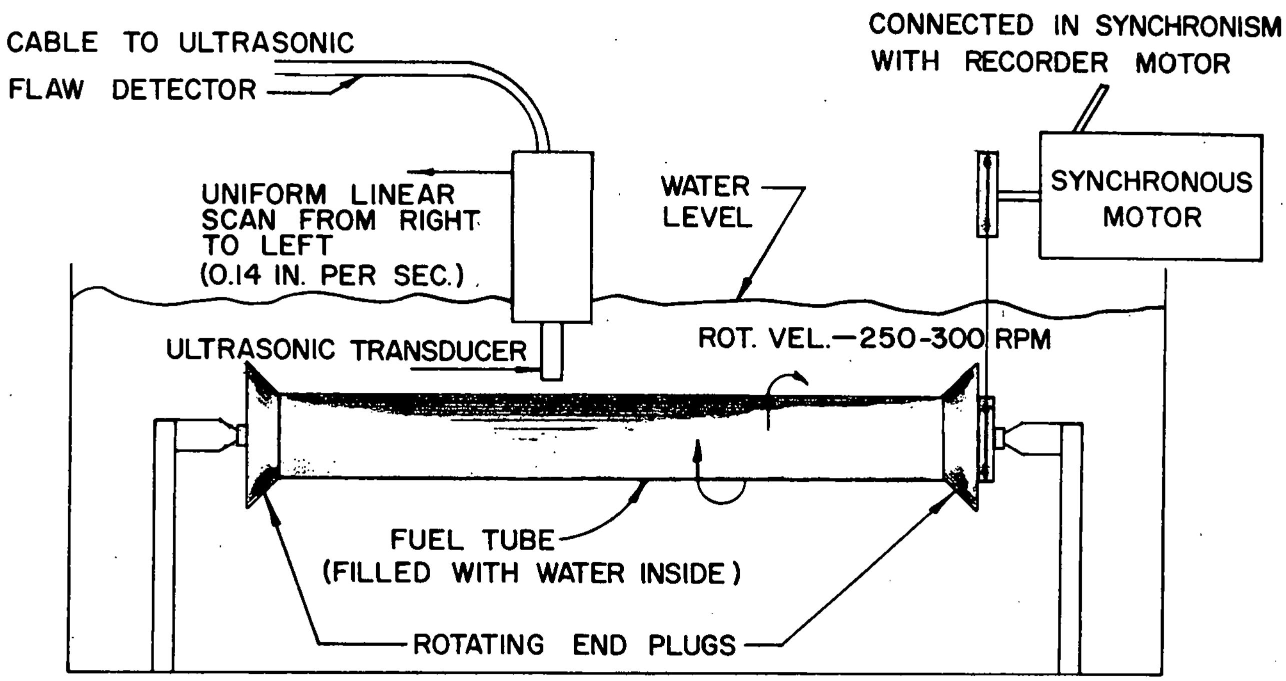
ULTRASONIC INSPECTION OF CP-5 FUEL TUBES

FIGURE 4.

(and subsequently reflected from) the I.D. surface. The ultrasonic test apparatus is shown in Figure 5.

The reference standard used to calibrate the equipment was a tube, of the same dimensions as an "inner" type CP-5 tube, containing a core of depleted uranium. One 1/16" diameter hole and 1/8" diameter hole were cut into the O.D. surface to a depth of approximately .020". Similar holes were cut into the I.D. surface. In addition, a 1/4" diameter hole, .030" deep, was cut into the I.D. surface. All of the holes had flat bottoms contoured to the curvature of the tube, so that the depth was constant everywhere in the hole. These holes caused an absence of I.D. surface reflection corresponding to their own area in the same way that an internal non-bond would cause an absence of I.D. surface reflection corresponding to its area.

Scanning was accomplished by rotating the tube while slowly moving the transducer along a line parallel to the longitudinal axis of the tube. As long as the reflection from the I.D. surface of the tube was of sufficient amplitude, the Reflectoscope printed one line across a sheet of recording paper for each revolution of the tube. A drop in the amplitude of the I.D. surface reflection triggered an alarm and simultaneously interrupted the recorder signal, thus causing a white spot to appear on the recording. Larger defects caused a series of white spots on adjacent lines so that, effectively, a plan view of the defect area was obtained. A picture of a typical recording, as described above, is shown in Figure 6. Figure 7 is a photograph showing the test apparatus and an inspector examining a recording.



A PULSE OF HIGH FREQUENCY SOUND IS SENT INTO THE WALL OF THE TUBE AND THE RESULTING REFLECTIONS ARE OBSERVED AND DISPLAYED ON A CRT SCREEN. FLAW LOCATIONS ARE INDICATED ON A RECORDING, WHICH PRESENTS THE TUBE AS THOUGH IT WERE OPENED OUT INTO A FLAT PLATE.

EQUIPMENT USED:

1. SPERRY MODEL UM-700 REFLECTOSCOPE FLAW DETECTOR
2. ALDEN MODEL 308A "FLYING SPOT" HELIX RECORDER
3. AUTOMATION INDUSTRIES 15MC, FOCUSED, LITHIUM SULFATE TRANSDUCER

MECHANICAL SETUP FOR ULTRASONIC FUEL TUBE INSPECTION

FIGURE 5.

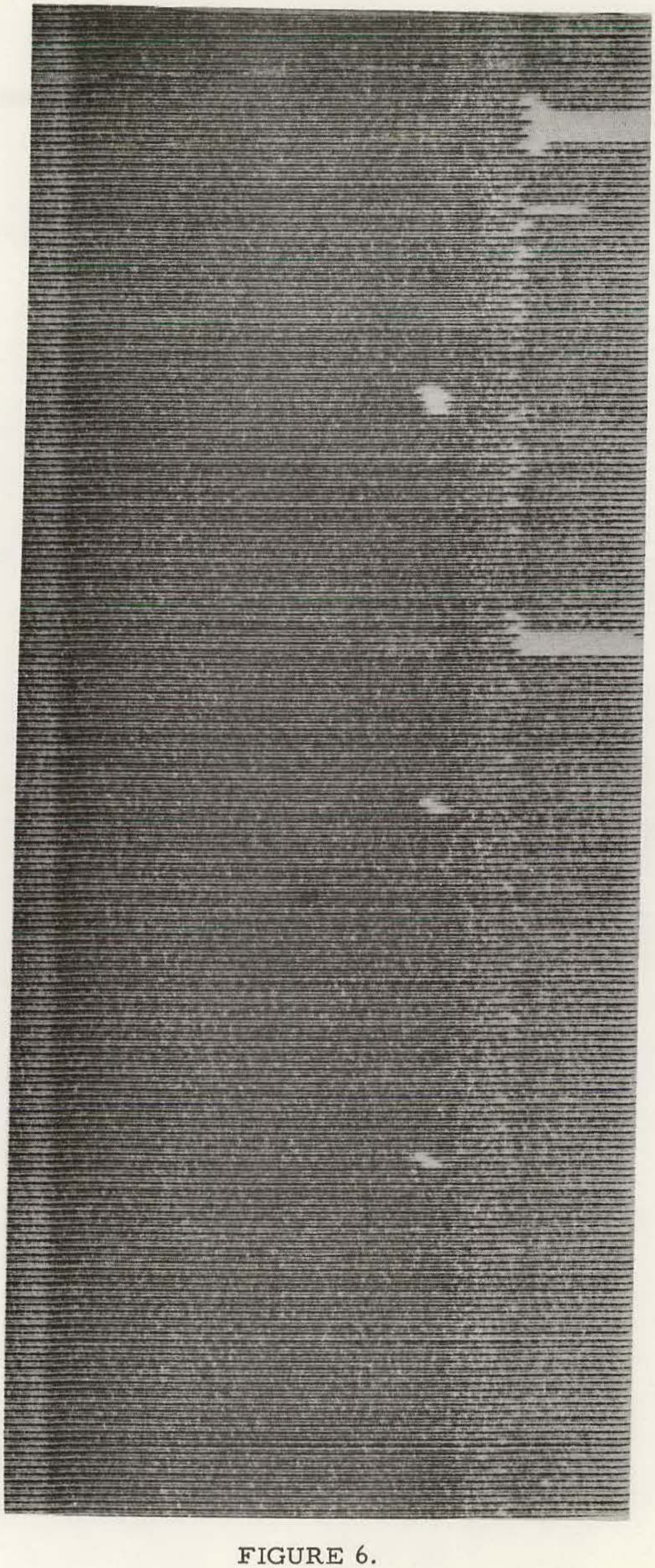


FIGURE 6.

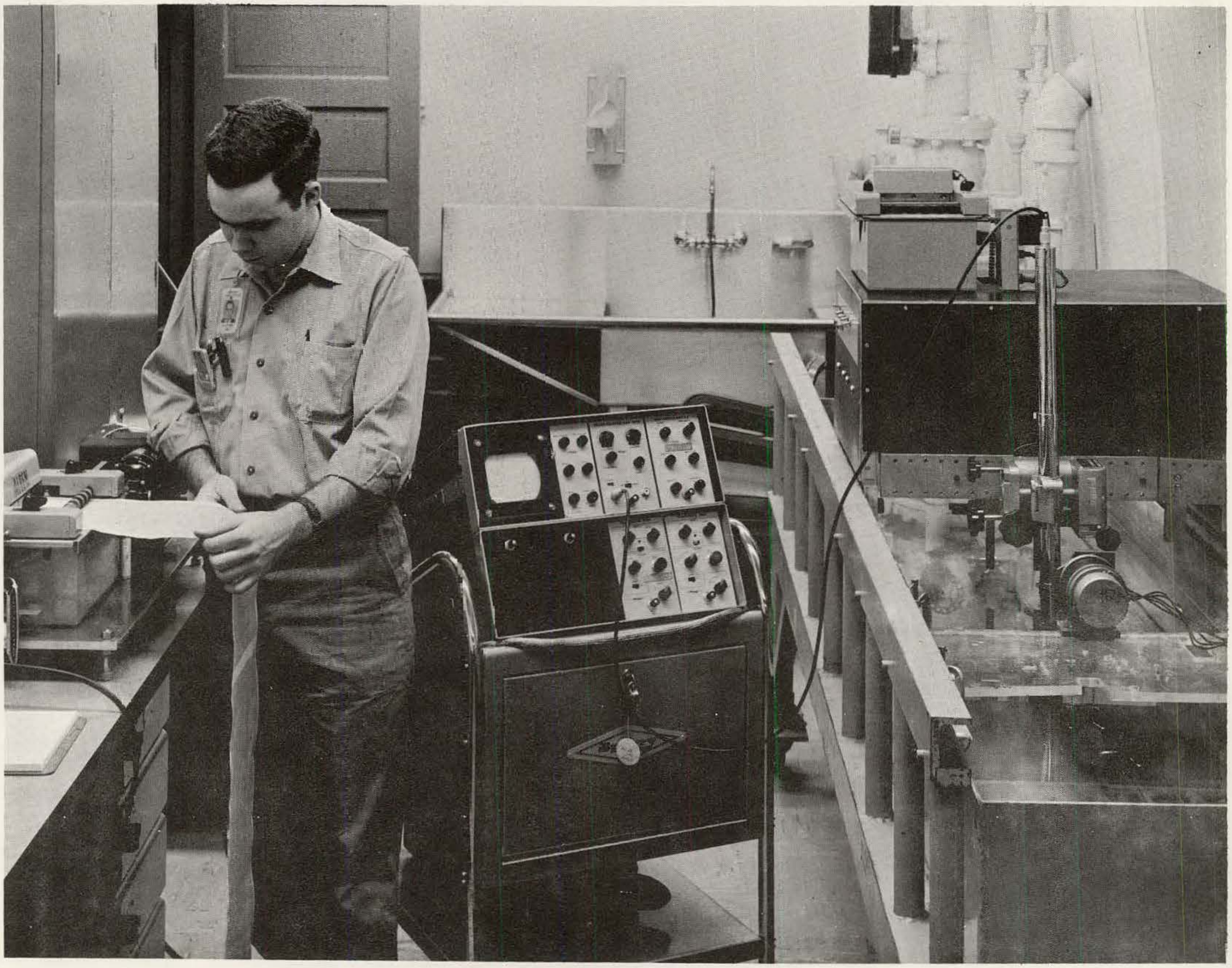


FIGURE 7.

CLASSIFICATION OF TUBES ULTRASONICALLY EXAMINED

A classification system was established to provide a guide for the acceptance or rejection of fuel tubes from the viewpoint of the ultrasonic inspection. The classification system was as follows:

Grade A - Tubes suitable for reactor use, from an ultrasonic viewpoint, having no internal flaws.

A1 - 100% inspection, unobscured, indicates no internal defects.

A2 - 100% inspection impaired by the presence of surface marks, dimensional deformities, or other flaws external in nature. The flaws obscured the area immediately below them and could, therefore, possibly have concealed an internal flaw. No internal defects were indicated in any unobscured area.

Grade B - Questionable tubes which had internal flaws indicated ultrasonically but not accompanied by visible superficial evidence.

B1 - Internal flaws occurred at random points.

B2 - Internal flaws formed a definite pattern (lines, square, patch, etc.)

Grade C - Generally unsatisfactory tubes which had internal flaws with one or more flaws supported by the presence of a visible blister on the tube surface. These tubes were rejected.

C1 - Blisters occurred at random points only.

C2 - Blisters occurred in a definite pattern (line, square, patch, etc.)

METHOD OF REPORTING CONCLUSIONS FROM ULTRASONIC DATA

All ultrasonic defects which corresponded to the 1/16" reference standard or larger were recorded on the Inspection Sheet shown in Figure 3 and on report form shown as Figure 8. Description of the defect and its location was given. Surface defects and tube curvature and bowing irregularities which obscured the ultrasonic signal were listed in the "Remarks" portion of the Inspection Sheet. The fuel tube classification number was assigned according to the system described previously.

GAMMA RAY SCINTILLATION SPECTROMETRY EXAMINATION

All fuel tubes received by the Laboratory were nondestructively assayed. There were two reasons for a fuel assay:

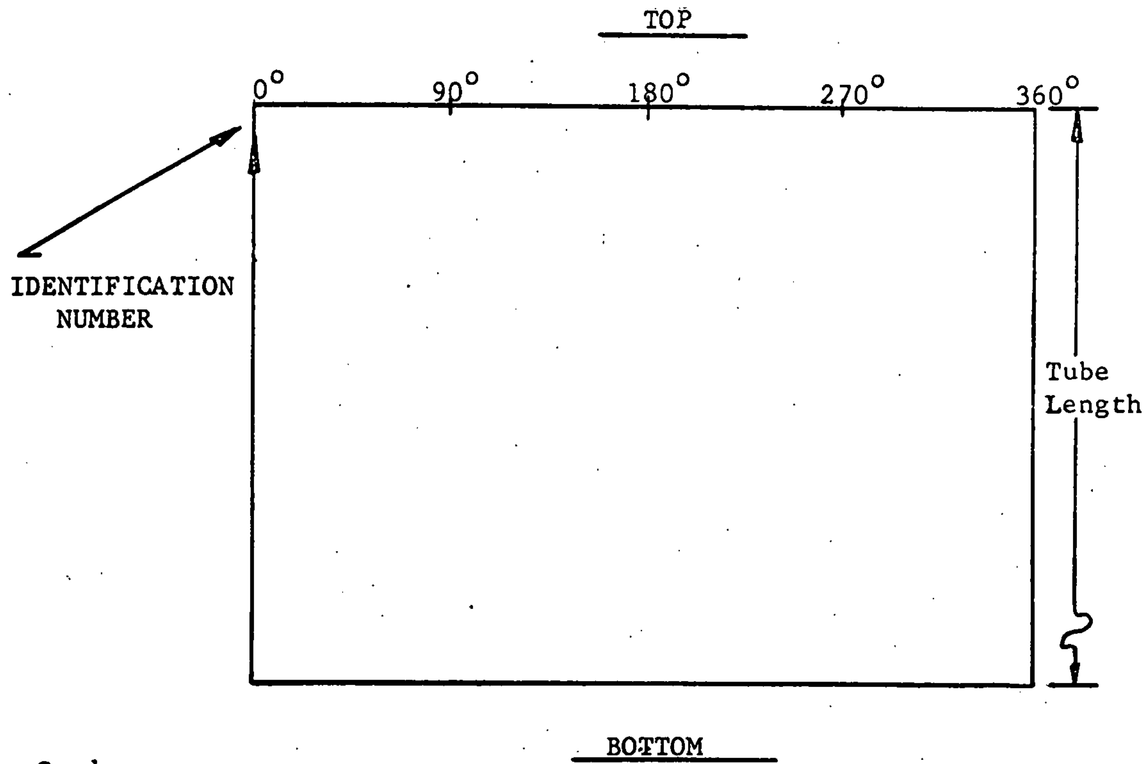
1. To insure that the fuel tubes contained the amount of uranium that the manufacturer reported they contained.
2. To insure that the fuel tube uranium content was within specifications.

SPECIFICATIONS

Fuel tubes were to contain a core of aluminum-uranium alloy formed from uranium approximately 93% enriched in U-235. The core sections were to have an alloy variation of no more than ± 1 wt% U-235 between like tubes and no more than ± 1 wt% U-235 within one tube.

The mass of U-235 in the core section of the inner fuel tubes was to be 62.0 $\pm$ 3 grams. The mass of U-235 in the core section of the intermediate fuel tubes was to be 73.0 $\pm$ 3 grams. The mass of U-235 in the core section of the outer fuel tubes was to be 35.0 $\pm$ 3 grams.

Locate the above listed defects by number on the sketch given below:



Tube Grade ______________

Remarks ____

____

Date ______________ Signature ______________

3. GAMMA RAY SPECTROMETRY

Grams U^{235} in Tube (SPM) ____________ gms

Grams U^{235} in Tube (MFG) ____________ gms

Grams U^{235} per Specifications ____________ gms

Remarks ____

____

Date ______________ Signature ______________

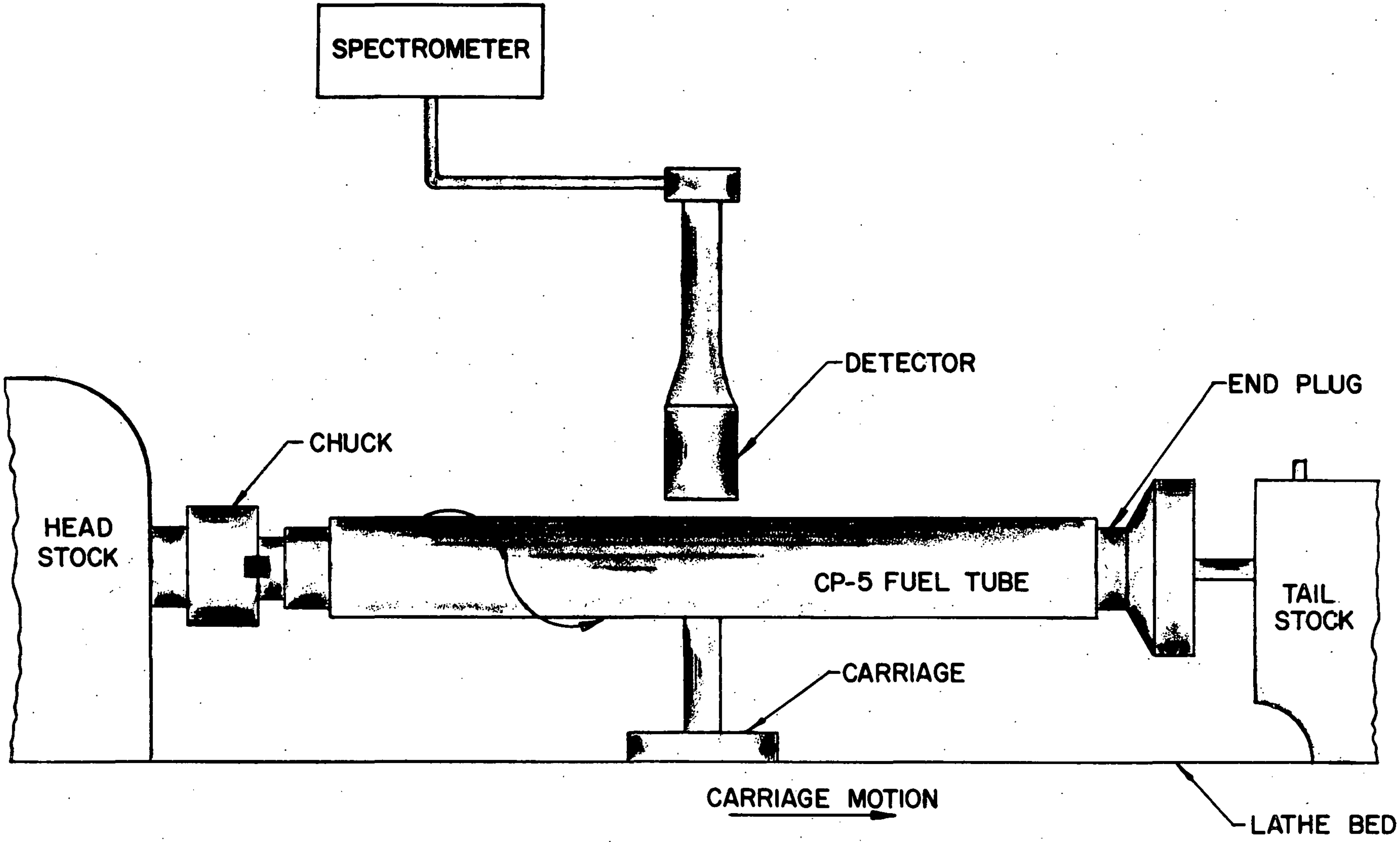
FIGURE 8.

Fuel tubes were delivered in matched sets such that the total mass of U-235 in each set of three tubes (inner, intermediate, and outer) was to be 170.0 $^{+6}_{-2}$ grams.

METHOD OF INSPECTION

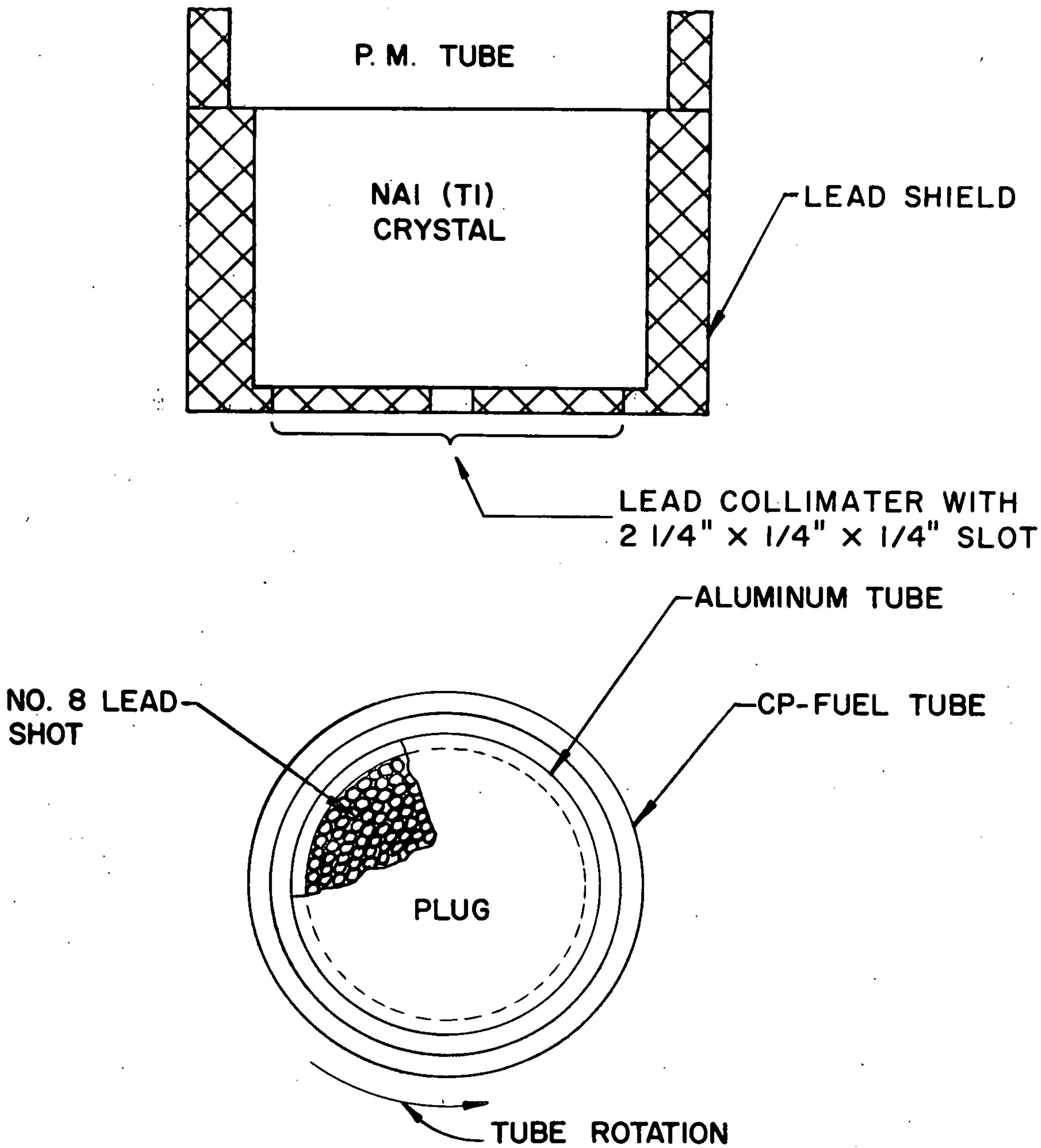
The U-235 loading was determined by measuring the intensity of the 185 Kev gamma rays, which is proportional to the number of U-235 atoms present. A gamma ray scintillation spectrometer was used for this measurement. The CP-5 fuel tubes were carefully placed over an aluminum tube which contained lead shot. This tube supported the fuel tube and the lead shot supplied shielding to insure that only the tube surface nearest the detector was counted. The aluminum tube and fuel tube were placed in a lathe specially adapted for this application as shown in Figure 9. As the lathe rotated the tube, a sodium iodide detector scanned the fuel tube length. The detector's geometry was defined by a slit in a lead collimator which was parallel to the fuel tube's longitudinal axis as shown in Figure 10. Figure 11 is a photograph of the lathe with an internal shield tube in place. Uranium foils of a known weight and enrichment were placed on the inner aluminum shield tube. These foils, fuel tubes, and the combination thereof, were counted to determine a satisfactory statistical error. By using this data, and an additional factor which corrects geometrical differences between the foils and fuel tube, the U-235 weight per tube was calculated.[1] The precision of the weights determined, based on counting statistics for two standard deviations, was approximately 1% for the three tube sizes.

1 - Beyer, N.S., "Assay of U-235 in Nuclear Reactor Fuel Elements by Gamma Ray Scintillation Spectrometry", Proceedings of the Fourth International Conference on Nondestructive Testing, 1964, p.331, Butterworths, London



MECHANICAL SETUP FOR THE CP-5 FUEL TUBE ASSAY
GAMMA RAY DETECTION

FIGURE 9.



CP-5 FUEL TUBE ASSAY DETAIL

GAMMA RAY DETECTION

FIGURE 10.

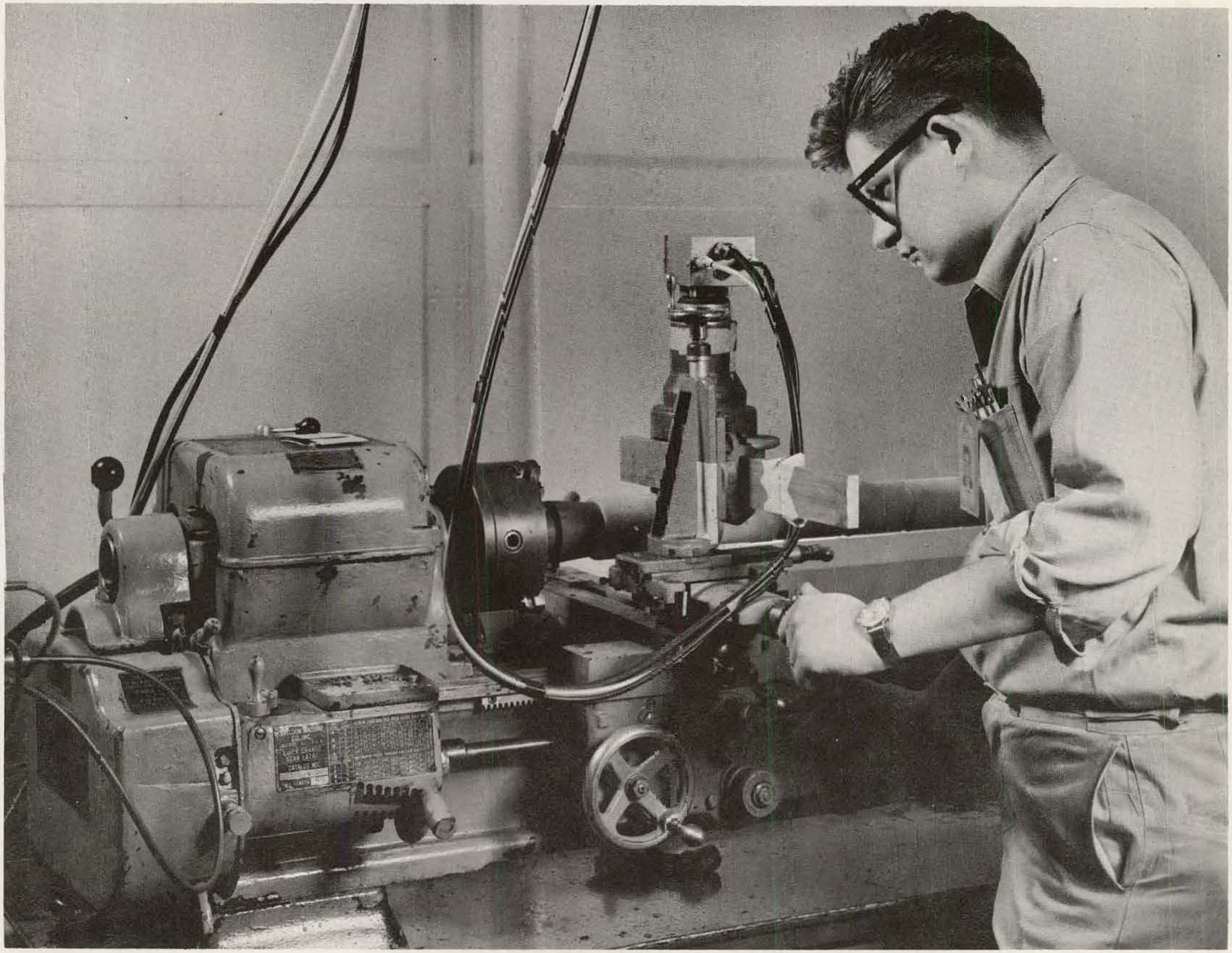


FIGURE 11.