ORNL/TM-13070

ornl

OAK RIDGE
NATIONAL
LABORATORY

MARTIN MARIETTA

Fabrication Development for the Advanced Neutron Source Reactor

B. W. Pace
Babcock and Wilcox

G. L. Copeland
Oak Ridge National Laboratory

August 1995

Advanced Neutron Source

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-13070

FABRICATION DEVELOPMENT FOR THE ADVANCED NEUTRON SOURCE REACTOR

B. W. Pace*
G. L. Copeland

*Babcock and Wilcox
Lynchburg, Virginia

August 1995

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

CONTENTS

CONTENTS (continued)

LIST OF FIGURES

ACRONYMS

ANS	Advanced Neutron Source
ANL	Argonne National Laboratory
B&W	Babcock and Wilcox
HFIR	High Flux Isotope Reactor
ORNL	Oak Ridge National Laboratory
RERTR	Reduced Enrichment Research and Test Reactor

ABSTRACT

This report presents the fuel fabrication development for the Advanced Neutron Source (ANS) reactor. The fuel element is similar to that successfully fabricated and used in the High Flux Isotope Reactor (HFIR) for many years, but there are two significant differences that require some development. The fuel compound is U_3Si_2 rather than U_3O_8, and the fuel is graded in the axial as well as the radial direction. Both of these changes can be accomplished with a straightforward extension of the HFIR technology. The ANS also requires some improvements in inspection technology and somewhat more stringent acceptance criteria. Early indications were that the fuel fabrication and inspection technology would produce a reactor core meeting the requirements of the ANS for the low volume fraction loadings needed for the highly enriched uranium design (up to 1.7 Mg U/m^3). Near the end of the development work, higher volume fractions were fabricated that would be required for a lower-enrichment uranium core. Again, results look encouraging for loadings up to ~3.5 Mg U/m^3; however, much less evaluation was done for the higher loadings.

1. INTRODUCTION

The Advanced Neutron Source (ANS) is being designed as a user-oriented neutron research laboratory around the most-intense continuous beams of thermal and subthermal neutrons in the world. The ANS is centered around a new research reactor of 330 MW fission power with an unprecedented peak thermal flux of more than $7 \times 10^{19}\ m^{-2} \cdot s^{-1}$. There also will be extensive facilities for materials irradiation, isotope production, and neutron activation analysis.

The core for the ANS reactor consists of cylindrical shell fuel elements. The entire core is replaced for refueling after each cycle (~ 17 d). Each element consists of involute fuel plates welded into nonfueled cylindrical side plates. The fuel plates and the coolant channels are 1.27 mm thick. The ANS elements are very similar to the elements fabricated by Babcock and Wilcox (B&W) for the High Flux Isotope Reactor (HFIR) located at Oak Ridge National Laboratory (ORNL) and fabrication of the ANS elements appears to be a very straightforward extension of this technology. The fuel plates consist of a "meat" of U_3Si_2 fuel particles dispersed in aluminum, a "filler" section of aluminum, and a burnable poison insert on both ends consisting of B_4C particles dispersed in aluminum. The fuel meat varies in thickness in both the radial and axial directions. The plates are clad completely with 6061 aluminum alloy, and the sideplates are 6061 alloy. The use of U_3Si_2 instead of U_3O_8 and the dual gradients of the fuel distribution rather than a single radial gradient are major deviations from the HFIR technology requiring a fuel fabrication development program. The fuel fabrication is considered to be a realistic extension of the existing technology with a high probability of success and not a major feasibility issue.

The early core design for the ANS was a compact core with very high specific uranium density.[1] The core volume was 35 L with a highly enriched uranium loading of ~ 19 kg, necessitating a uranium loading in the meat of ~3.5 Mg/m^3. The only promising fuel for this high density is U_3Si_2, which was developed by the Reduced Enrichment Research and Test Reactor (RERTR) program at Argonne National Laboratory (ANL). The data upon which the U. S. Nuclear Regulatory Commission based its approval of the use of the U_3Si_2 fuel for conversion (to low-enriched uranium) of licensed nonpower reactors is in the report *Safety Evaluation Report Related to the Evaluation of Low-Enriched Uranium Silicide-Aluminum Dispersion Fuel for Use in Non-Power Reactors*, NUREG-1313.[2] The fuel has been shown to perform well at loadings and fission densities beyond those required for the ANS core, although only at conditions of fission rate and temperature well below those anticipated for the ANS. Therefore, an irradiation testing program is in place to verify the performance at conditions as near as possible to those of the ANS. A fuel performance model is being developed to consolidate the data from the various types of tests and to predict the performance of the fuel under various conditions. At the beginning of the fabrication development for ANS, low-enriched uranium U_3Si_2-Al dispersion fuel for conversion of low- and medium-powered research and test reactors was being fabricated by three commercial companies (including B&W) at loadings up to 4.8 Mg U/m^3. However, the dual fuel gradients and the much more restrictive requirements on fuel loading and homogeneity for the high power density ANS increase the fabrication difficulty.

During 1993 the design evolved into a larger core with lower loading than the preliminary compact core design. The loading of the conceptual core design was originally 1.05 Mg U/m^3, but later it increased to ~ 1.7 Mg U/m^3, which was expected to provide sufficient excess reactivity to account for the effect of the experimental facilities in the reflector. This change lowers the uranium density to the level where both U_3O_8 and UAl_x* can be fabricated as dispersions in aluminum. Much irradiation data and experience exist for these fuels in research and test reactors. However, U_3Si_2 was retained as the reference fuel for the ANS because the higher particle density yields a lower volume fraction of fuel and thus facilitates

*A mixture of the intermetallic compounds UAl_2, UAl_3, and UAl_4, with $x \approx 3$. Typical compositions are 7 to 9 wt % UAl_2, 79 to 84 wt % UAl_3, and 9 to 13 wt % UAl_4.

fabrication and greatly improves the thermal conductivity and stability of the dispersion. The negative aspects of switching from U_3O_8 to U_3Si_2 are that (1) the higher particle density and different surface characteristics may make the desired homogeneity more difficult to achieve, (2) the fact that the fuel is pyrophoric may mandate compacting in a glovebox (the manual die sweeping operation to achieve the fuel gradient will be more difficult), and (3) oxidation sometimes occurs during (and complicates) the hot-roll-bonding process. However, the option of these backup fuels disappeared when an even larger core consisting of three elements was baselined in December 1994. This core uses uranium enriched to only 50% ^{235}U and may require a uranium density of 3.5 Mg U/m^3, eliminating U_3O_8 and UAl_x from consideration as alternative fuels and increasing the difficulty of fabrication.

The fabrication development program progressed as the core design evolved. No development was started before the original compact core was abandoned, so the first experimental plates fabricated for ANS were just over 1.0 Mg U/m^3. Later plates were fabricated at higher loadings, and only near the end of the program were plates of over 3 Mg U/m^3 produced. Evaluation of these plates was limited because of the termination of the program at the end of FY 1995.

Recognizing that the core design would be an evolutionary process, no attempt was made to produce the exact fuel gradings for any particular core configuration. Rather, a generic fuel grading was used in the developmental plates. This generic grading embodied the principles that would inevitably be in the final design, i.e., less fuel near the edges (the outer edge even less than the inner) and the ends of the plates. The ends were kept symmetrical (even though this feature would probably not be desired in the final design) as compacted to discover the effects of roll bonding on the distribution. A region of constant fuel density was maintained in the center of the plates. The fuel gradients were linear as compacted to ease tracking of changes during the fabrication process. The goal was to produce fuel plates meeting the ANS requirements with modest changes to the existing HFIR process rather than relying on a totally new technology. Thus, general guidelines were agreed upon with the designers to make this goal more realistic. The fuel grading would be achieved by varying the thickness of the fuel meat (the fuel-aluminum dispersion) in the plate while keeping the volume fraction of fuel in the matrix constant (as in HFIR). The maximum meat thickness would be 0.71 mm (0.028 in.), and the minimum meat thickness would be 0.18 mm (0.007 in.). It was assumed that inspection techniques would be similar to those used for HFIR but that slight improvements could be made. Cladding-to-meat bonding inspection sensitivity would be improved to detect and reject a nonbond of 1 mm diam (compared to 1.6 mm for HFIR). The fuel distribution would be inspected by scanning X-ray transmission with a 2-mm-diam spot size similar to HFIR. The acceptance criteria would be tightened so that individual spots with 20% fuel overloads and 12-mm-long tracks with 10% overloads would be rejected (corresponding criteria for HFIR are 27% and 12% respectively).

Based on the thirty years of successful HFIR production, the fabrication development program for the ANS has the following major goals:

- Show that successful production can be accomplished with U_3Si_2 substituted for U_3O_8 in the fuel meat.
- Show that plates can be produced successfully with acceptable bonding when inspected to the 1-mm criterion (ultrasonic testing equipment exists with this sensitivity; however, no work was done on this activity).
- Show that plates can be produced successfully to meet the ultimate ANS fuel gradient design and the fuel homogeneity requirements.
- Implement processes and procedures in the fabrication plant to produce plates and elements meeting the design requirements.

2. EARLY DEVELOPMENT HISTORY

Babcock & Wilcox started development in conjunction with ORNL and ANL to evaluate the feasibility of manufacturing fuel for the ANS reactor in 1987. No baseline core or plate design had been decided upon at that time, but some potential designs had begun to emerge. A major aspect of one design in particular required biasing the fuel within the plates towards the center of the plate and decreasing the fuel near the edges and ends as shown in Fig. 2.1. This type of core could be manufactured in several different ways, including zoning the fuel core by making the center of the core a higher loading density than towards the edges. The chosen method, however, was to vary the fuel core thickness to obtain the loading gradients. The ANS concept was to be designed and manufactured using current technology instead of relying on new inventions to manufacture a fuel plate that had a fuel gradient both longitudinally and laterally. Numerous core designs were evaluated.

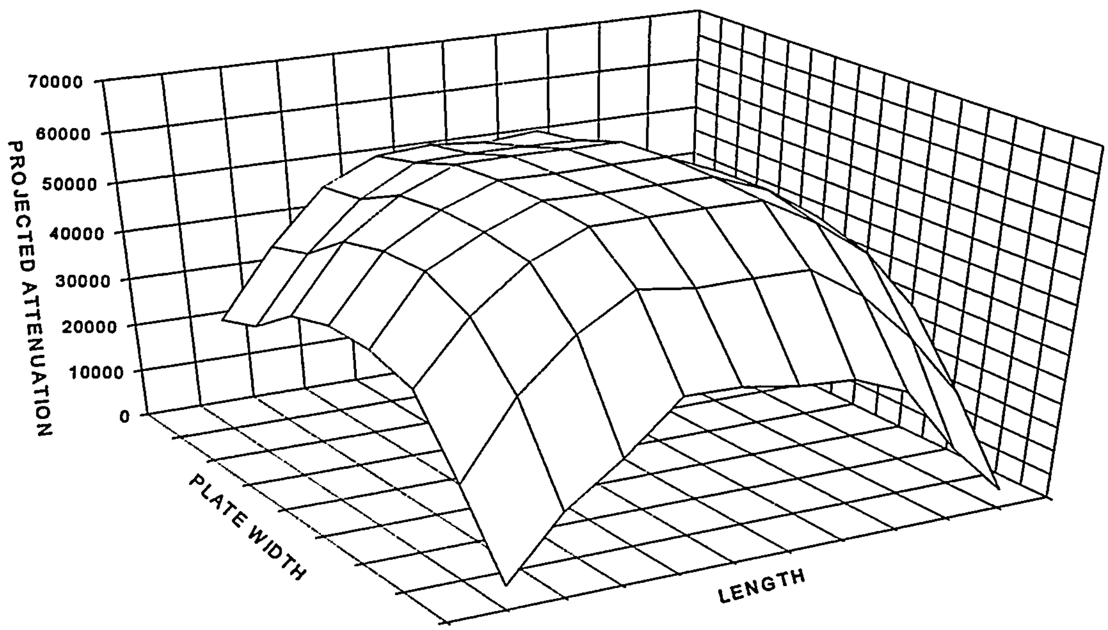


Fig. 2.1. Potential dual-gradient fuel design.

The initial work performed was a manufacturing feasibility study to address potential problems that might arise given a variety of fuel configurations. The report evaluated different configurations of cores by comparing the production capabilities among plates for a split-core single-gradient concept, a split-core dual-gradient concept, and the arcuate element design, all of which were considered as possibilities in the early stages of ANS conceptual development.

2.1 FEASIBILITY STUDY AND INITIAL DEVELOPMENT

Following the initial study, B&W performed a number of manufacturing development studies to produce dual gradients using depleted uranium silicide (U_3Si_2). The proposed plates resembled the current HFIR core plates in length and thickness. The likeness enhanced comparison of the new silicide plates to the HFIR type plates because of similarities between the proposed dual-gradient plates and the single, lateral gradient of the HFIR plate. All of the development lots fabricated by B&W are outlined in Appendix B. The first six lots manufactured were produced from compacts using a die that was approximately 15.2 × 6.1 cm (6 × 2.4 in.). This phase consisted of six lots containing two plates each, for a total of twelve plates. The first development plates were made using loadings of 1.31, 1.05, and 1.54 g U/cc in lots 1, 2, and 3, respectively. The fuel was swept using a sweep platen to bias the uranium silicide towards the center of the plate shown in Fig. 2.2. This method produced a compact with a gradient across the width on the top of the compact. The platen concept, as well as all of the other core design details, is discussed in Appendix A of this report, which should be referenced for more detailed information on the manufacturing techniques. Prior to compaction, aluminum powder was swept flat across the top of the contoured charge such that the width gradient was covered and held in place by the aluminum powder. The longitudinal gradient was controlled by a graded bottom die punch that was contoured to achieve the desired fuel distribution. The charge and filler were then compacted to approximately 95% density.

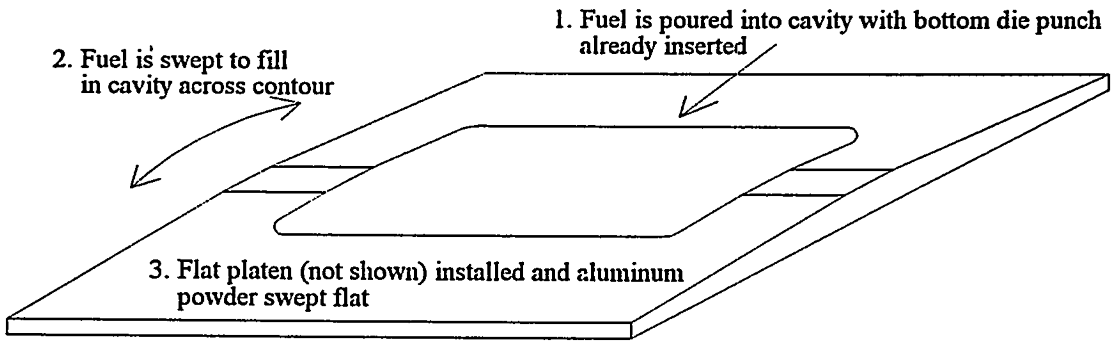


Fig. 2.2. Fuel matrix sweep platen. Source: B&W drawing T-2832 rev 0.

The first batch of compacts in lots 1, 2, and 3 bowed when removed from the die block because of the uneven expansion of the two principle components of the compacts: aluminum filler powder and aluminum/U_3Si_2 matrix. This effect is to be expected in a thin, compacted matrix with different densities from top to bottom. The compacts were, however, successfully packed in the frames and rolled. The second batch of plates consisted of three more lots of two plates each. Slight changes were made in the processing of the compacts. Breaker bars were added to the blender in an effort to improve the homogeneity of the fuel. During fuel powder matrix transfer from the blender jar to the die, a funnel was employed to allow fuel to be evenly spread across the die cavity.

It has been theorized that an oxide layer protects the U_3Si_2 fuel from extreme and rapid oxidation during hot roll. The oxidation is very typical in highly loaded plates (>4.0 g U/cc) but can be found in lower-loaded plates as well. In an attempt to decrease oxidation of the fuel during rolling, the compacts were passivated after anneal by opening the anneal oven door after the temperature had dropped below 100°C. The compacts were exposed to air for a short time five times daily to obtain a protective oxidation layer coating the fuel particles closest to the surface of the compact. Note that this method has not been sufficiently investigated to determine its effectiveness and reproducibility.

This development study showed that maintaining a controllable lateral taper in a U_3Si_2 plate was possible, but the development plates did not produce the significant longitudinal taper that would be required for ANS. The reason for the lack of taper is that, because the gradient is not supported at the ends, the fuel moves from the center of the core towards the ends to fill the void region during the hot-rolling process.

2.2 SILICIDE HFIR DEVELOPMENT

In July and August of 1991, B&W undertook further development to evaluate and obtain a better understanding of the potential of creating and maintaining the dual-gradient ANS design using U_3Si_2. The work was done in two phases. The first phase of work was an attempt to fabricate HFIR plates using U_3Si_2 fuel. In doing so, the relative homogeneity would be evaluated, yielding a better understanding of the relationship between the two fuels, U_3Si_2 and U_3O_8. In addition, other conditions typical of fuel plates, such as fuel core oxidation and stray particles, could be evaluated with reference to HFIR U_3O_8 fuel. All plates for this development were manufactured using standard HFIR procedures to determine how the silicide would react in conditions typical of U_3O_8 plates.

Three lots of six fuel plates each were fabricated with loadings of approximately 1.36 g U/cc. One additional compact from each lot was produced for destructive evaluation to study the compaction characteristics for future reference in phase two of the development.

The results of the first phase show that U_3Si_2 can be manufactured by typical HFIR procedures with few exceptions. The plates from each lot were compacted, and then the first compacts from each lot were packed and processed through hot roll. The plates were then x-rayed for initial evaluation, and upon finding the homogeneity acceptable, work continued. The remainder of the plates were hot rolled, and then all plates were blister annealed. Discoloration was found over the fuel from each plate, indicating that 480°C was excessive. The results of this development study indicated that the U_3Si_2 plates were very comparable in contour and homogeneity to the typical HFIR plate and demonstrated the potential for the use of U_3Si_2 as ANS fuel. For a more detailed discussion of the homogeneity comparisons see Sect. 4.2.

Phase two of this development followed a natural progression toward creating a dual gradient by using a HFIR die set and instilling a gradient over the length of the plate. This phase consisted of one lot (number 10) containing three plates. An additional compact was pressed for destructive evaluation.

The lot 10 compacts were made using a bottom aluminum powder filler, which was contoured along the length of the compact. A sweep blade was manufactured to position the aluminum powder such that the fuel would be biased towards the middle of the compact. In addition, a pillow block was machined to tamp the aluminum in place so that the U_3Si_2 to be swept over the top would not disturb the bottom layer of aluminum powder. This procedure was tested on the first compact. After the aluminum was swept into place, the pillow block was used to tamp the aluminum in place. Upon withdrawal of the block, the aluminum was sucked upwards with the block, thus disturbing the contoured bottom. Therefore, this method was discarded, and the fuel was swept directly over the graded aluminum powder for the remainder of the compact lot.

The plates were packed and processed as in phase one with the exception that the anneal temperature of the plates was reduced to 410°C. This temperature produced no discoloration of the plates after anneal. The dual gradient was evident in each of the three plates of the lot, as determined by destructive examination.

3. FINAL DUAL GRADIENT FEASIBILITY STUDY

The final study in proving the feasibility of manufacturing dual gradients for use in the ANS reactor comprised four major parts. The first, and possibly most important, part in continuing development was to create gradients in fuel plates that would be similar to the most current ANS reactor core plate designs. Although many fuel gradients evolved in the ANS design effort, definite similarities emerged among the different core designs. Estimating a gradient that would best detail the characteristics of these designs was a matter of combining the typical characteristics into one design that may prove the feasibility of any of the core designs.

After obtaining a suitable gradient in a number of development lots, the second part of this development was to prove the repeatability of the gradient in small plate lots. The third involved proving that the gradient could be manufactured using different loadings of uranium to a maximum of 4.8 g U/cc. The fourth and final step in the development was to center the fuel meat within the aluminum cladding.

3.1 DUAL GRADIENT DEVELOPMENT, PART ONE

The development gradient determination was of utmost importance in the design phase. The principal goal was to obtain a gradient that produced a maximum core thickness of approximately 0.76 mm (0.030 in.) and tapered to the corners of the fuel core to 0.1 mm (0.003 in.) minimum thickness. (This goal gradient was slightly more extreme than the one the core designers were working to.) To accomplish this goal, the fuel must be graded across the width and length of the fuel plate. Furthermore, control of the gradient as well as repeatability during manufacturing must be demonstrated. Cladding was to be maintained at no less than 0.2 mm (0.008 in.). The design of the compact for this purpose is shown in Fig. 3.1, and a summation of design parameters is shown in Appendix A. The method of evaluating the gradient was digital homogeneity scanning, where the fuel loading in an individual spot could be analyzed by direct comparison to the attenuation of X-rays passing through the plate over the specific core region. The estimated gradient produced as depicted by the digital homogeneity scanner is shown in Fig. 2.1. The homogeneity requirements were to be within ±10% of the fuel in the surrounding area. The loading for the initial test was only 1.3 Mg U/m^3, which was the loading expected for the core at that time.

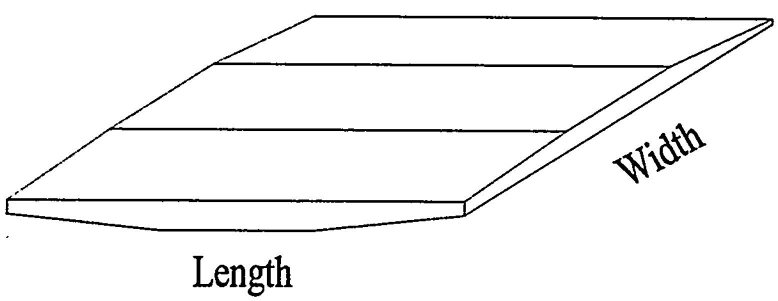


Fig. 3.1. Development compact design.

Five lots were produced consisting of four plates each for part one of the development. The lot numbers were 12 through 16. Since U_3Si_2 oxidizes rapidly, this and the remainder of the silicide development was performed in a glovebox line with inert atmosphere in lieu of the HFIR press, which is open to atmospheric conditions. This process required the selection of an alternative die. A 5.83- × 7.5-cm (2.294- × 2.98-in.) die was chosen because of the similarity in size to the HFIR die press. The design variable was the manner in which the compact was manufactured. The width gradient was produced in the same manner as for the HFIR. The fuel was swept into a given contour over a sweep platen, and an aluminum cap was then swept flat over the top of the fuel. See Appendix A for further details.

The length contour, considered to be on the compact bottom, was produced in several different ways, as shown in Fig. 3.2. Lot 12 compacts were manufactured using a contoured bottom die punch that pressed the length gradient into place. The sketch of the bottom die punch is shown in Fig. 3.3. The width gradient platen

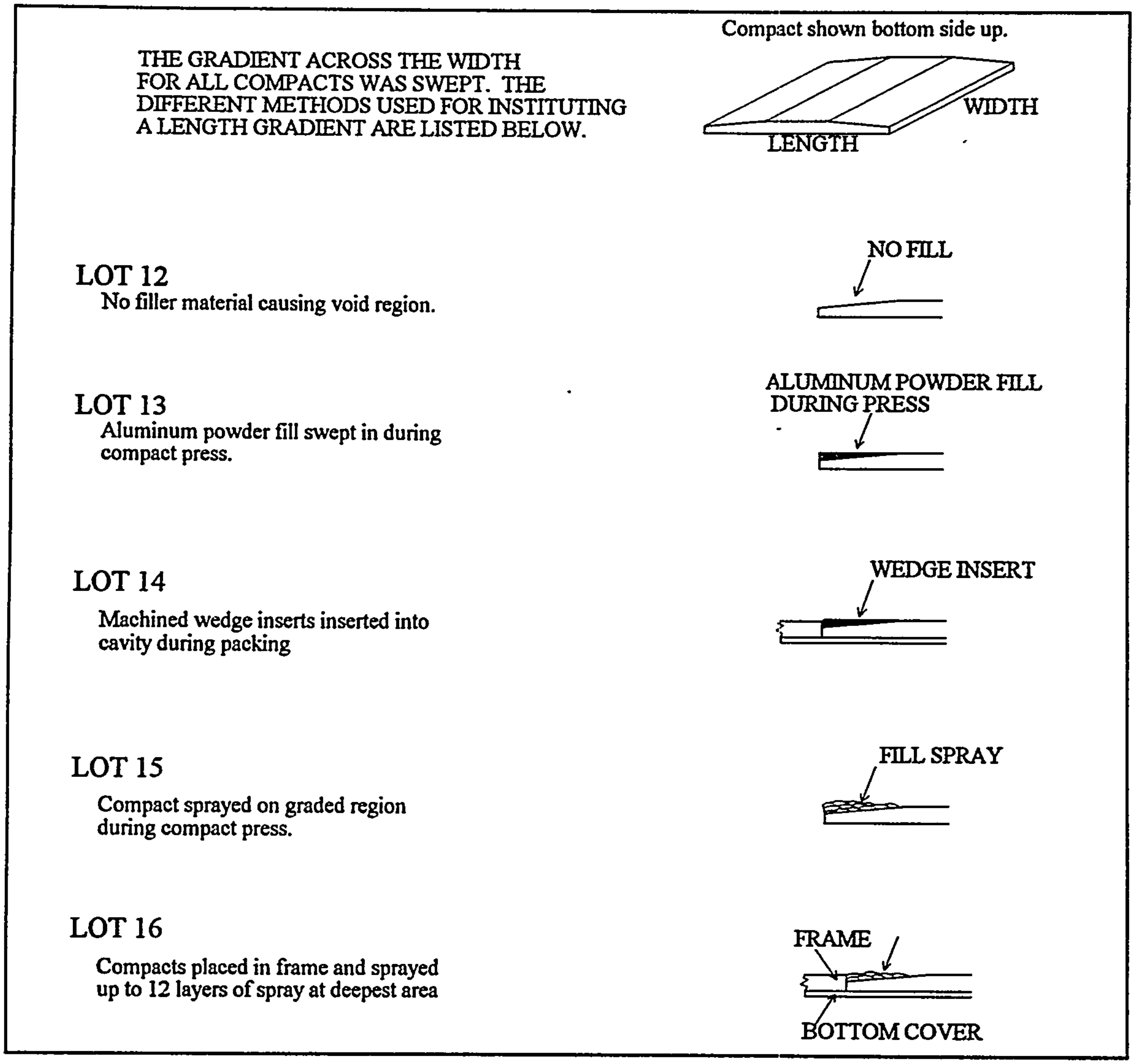


Fig. 3.2. Methods for supporting the length gradient.

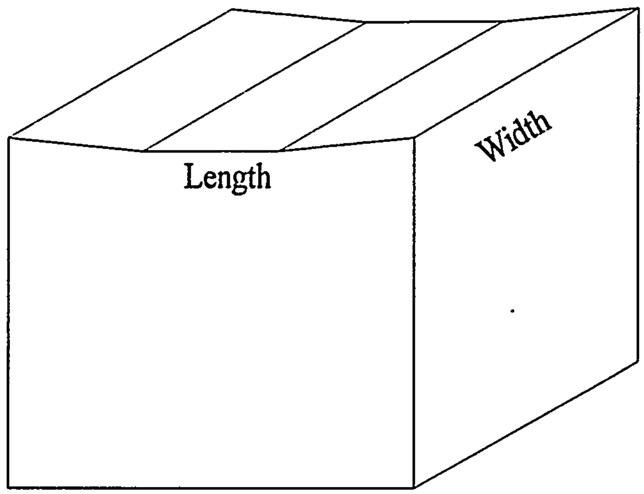


Fig. 3.3. Bottom punch design for lots 12, 14, 15, and 16.

was installed, and the fuel was swept in a gradient across the platen into the die directly onto the contoured bottom punch. Next, the aluminum filler was swept over the fuel using a flat platen. Afterwards the die was lowered and the compact was pressed, producing a compact with a visible gradient across the bottom and a flat aluminum cap on top. The lot 12 compacts were placed into a frame without any support for the length gradient and were processed through the plate stage.

Lot 13 compacts were made using a flat bottom die. A special length gradient platen was installed, and a bottom aluminum cap was swept into the die across this platen. The fuel and top aluminum filler were then swept into the die the same as in lot 12. The final compact was a rectangular solid.

The compacts for lots 14, 15, and 16 were manufactured in the same manner as lot 12 compacts except that an alternative method of filling the cavity below the length gradient was used. For lot 14, two aluminum wedges were manufactured and inserted across the end void areas to fill the gap where the length gradient is located. The wedge design is shown in Fig. 3.4. To fill this void created by the length in gradient in the compacts in lots 15 and 16, aluminum was sprayed on the compact to build up the area. The compacts were sprayed individually in lot 15 prior to being packed in the frames. The compacts for lot 16 were sprayed after being placed in the frames. The aluminum was sprayed using an arc spray system that feeds aluminum wire through two electrically charged copper conduits. When the aluminum wires connect, an arc is produced that melts the aluminum. At the same time, a blast of argon atomizes the aluminum and it is blown in a spray plume. The gun is housed in a glovebox and kept under inert atmosphere. This precaution is required because of the explosive nature of small, unoxidized aluminum particles.

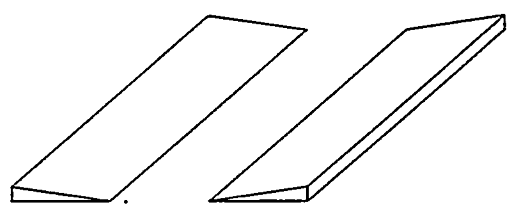


Fig. 3.4. Wedge design for supporting length gradient.

During this development, the maximum particle size in the U_3Si_2 fuel lot was reduced to 74 μm (200 mesh) in an effort to maximize homogeneity. The proportion of particles below 44 μm (325 mesh fines) was set at approximately 35% total fuel weight. These changes were made because particles above 100 μm potentially could have caused problems in the thin regions of the fuel core, which were designated at 0.1 mm (100 μm). The overall homogeneity also improved as a result of this change.

As discussed in the section on homogeneity, in general, the plates in this part of the development displayed homogeneity matching the needs of the ANS Project. Since the object was to evaluate the potential of each individual method for producing the longitudinal gradient, a review of each method led to the determination that, for use in development, wedges produced the most control over this gradient. Further refinement of the wedge method would yield an acceptable, production-quality longitudinal gradient, provided the remaining development tests were successful. To analyze the different methods, the overall gradient as well as the individual tracks (which extended down the length of the plate) were evaluated by the homogeneity scanner. Track 21, positioned in the center of the plate, was used to compare each plate and lot to evaluate each method. Other tracks were also analyzed, but track 21 is used here to illustrate the results. The gradient across the width was found to be acceptable in all cases; therefore, less consideration was given to that gradient.

Although the gradient across the width of lot 12 plates was maintained, virtually no longitudinal gradient existed down the length of the core as shown by track 21 in Fig. 3.5. The results of lot 12 compacts indicated that if a longitudinal gradient were to be employed down the length of the plate, some means of filling in the void area on the bottom of the compact would be required. Note that this was also a finding of an earlier development study, but the test was repeated during this development because of the die change. Lot 13 plates did display a gradient down the length of the plate, as shown in the plot of track 21 in Fig. 3.6. The void region in the area of the length gradient was filled with aluminum powder. However, because the aluminum powder is so light compared to the U_3Si_2, the fuel matrix swept over the bottom aluminum powder fill was not supported properly, and a constant gradient was not maintained. A firmer filler material would be required.

Lots 14, 15, and 16 all displayed the desired gradient to some extent. All lot 14 plates, which used a wedge as longitudinal gradient support, had an evenly distributed gradient both laterally and longitudinally, and all proved the feasibility of the dual-gradient design. The longitudinal gradient is clearly evident in Fig. 3.7. The spray method used in lots 15 and 16 for filling the void did not attain the same success as the lot 14 plates. Fig. 3.8 shows that the void region was well supported in each lot; however, the lack of precision in filling this region did not allow for an evenly graded distribution of the fuel.

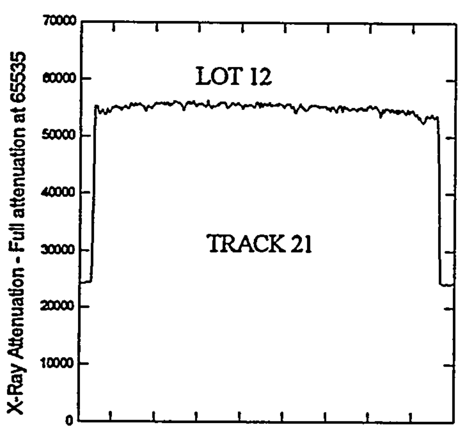


Fig. 3.5. Track 21 from a lot 12 plate.

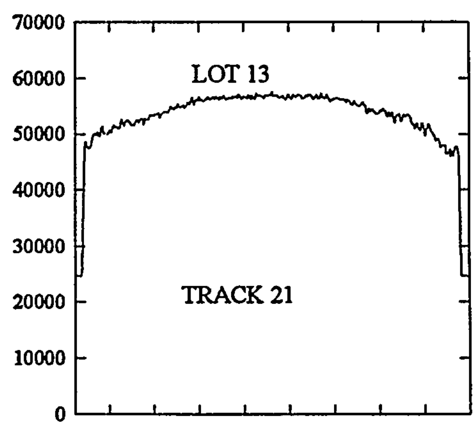


Fig. 3.6. Track 21 from a lot 13 plate.

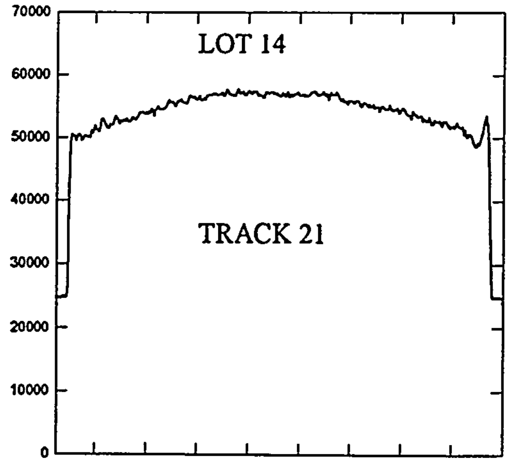


Fig. 3.7. Track 21 from a lot 14 plate.

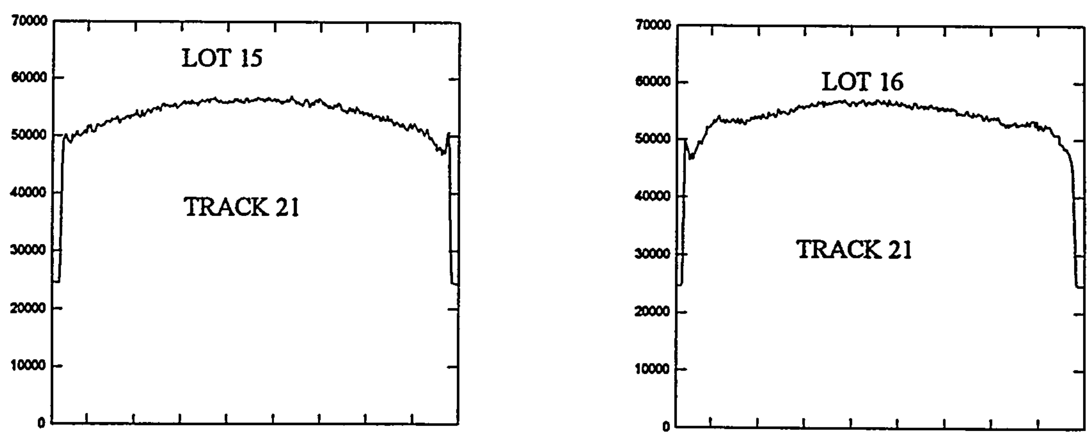


Fig. 3.8. Track 21 from lot 15 and lot 16 plates.

3.2 REPEATABILITY STUDY, PART TWO

The consistent gradient demonstrated by the lot 14 plates indicated that the support for the void area in the longitudinal profile would need to be of a homogeneous, dense material. For lots 17 and 18, the idea of wedges was further improved upon by actually machining the wedges into a pocketed frame. Figure 3.9 shows the configuration of the dished frame with the machined gradient that was used in these subsequent lots. Lots 17 and 18 were intended to demonstrate the repeatability of the dual-gradient concept, and this concept was considered a better alternative to using machined wedges inserted into frames with complete cavities.

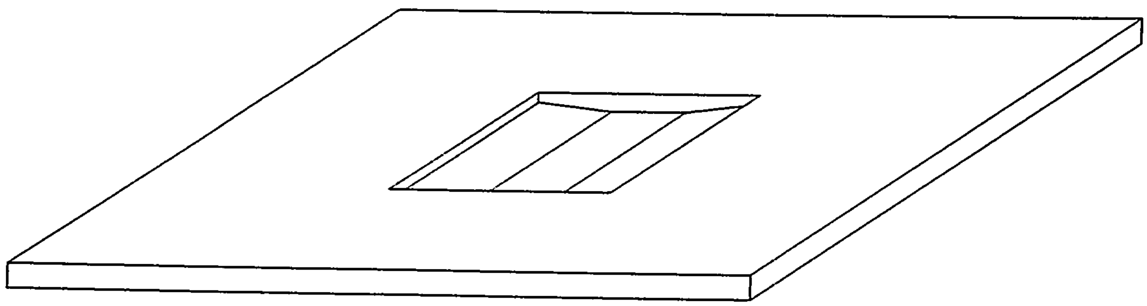


Fig. 3.9. Dished frame with built-in support for length taper.

Part two of the development demonstrated that the longitudinal gradient was repeatable. Fig. 3.10 shows the digital homogeneity scan of track 21 from one lot 17 plate. The symmetry from end to end on the core was excellent and was repeated on each plate. The same track from each plate in lot 18 is shown in Fig. 3.11. The ±10% boundaries are overlaid on the graph as well to show the consistency of each plate.

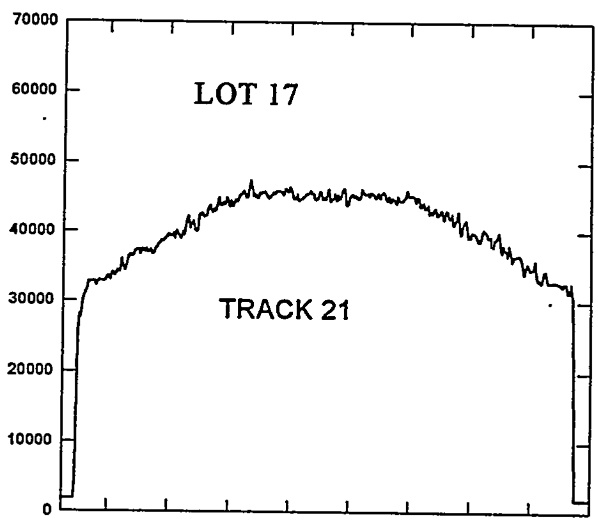


Fig. 3.10. Center track from a lot 17 plate.

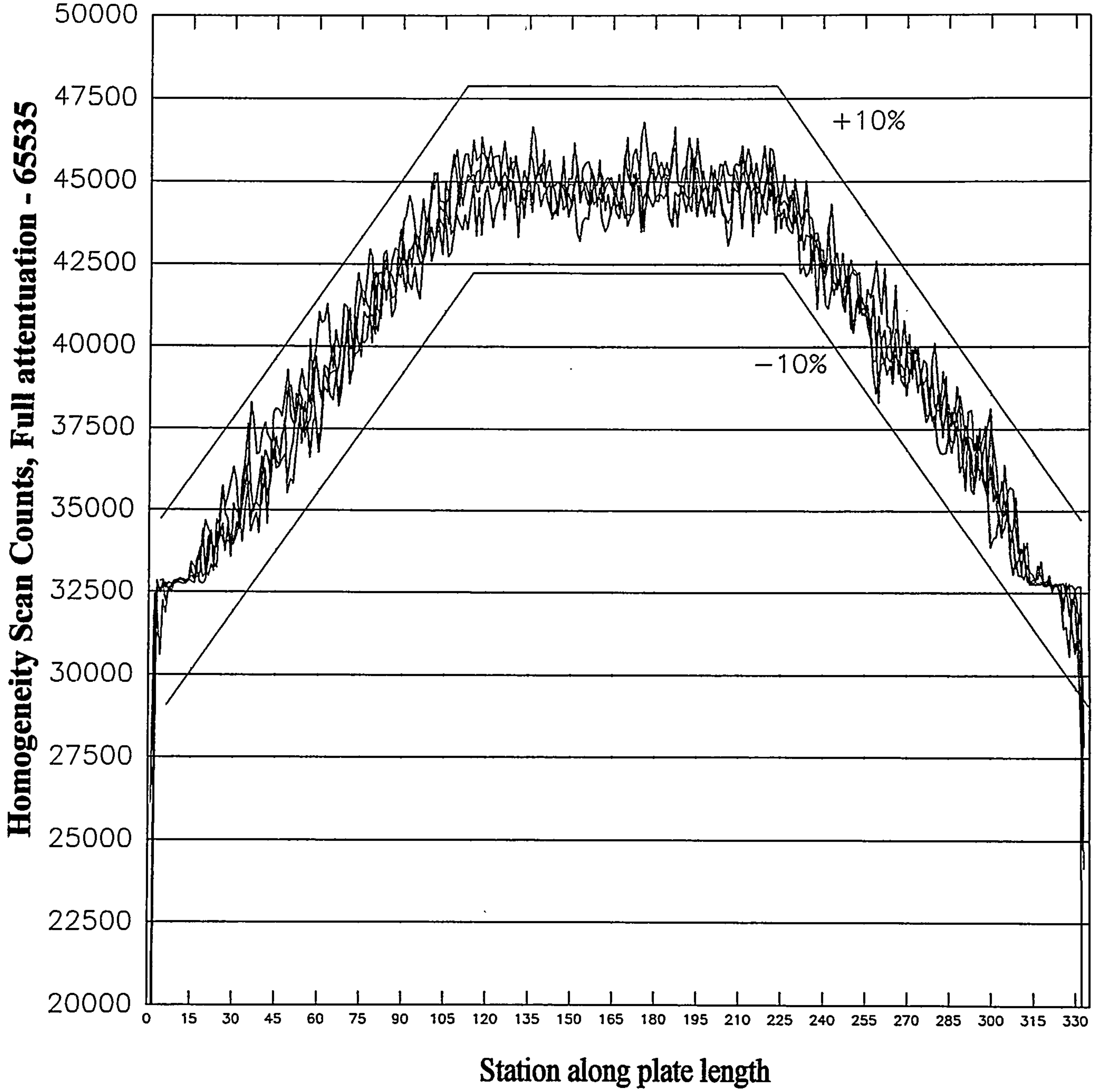


Fig. 3.11. Center track of four lot 18 plates with estimated ±10% loading curves.

After using the methods of dished frames as shown in Fig. 3.9 and inserting wedges into the frame cavities as done in lot 14, Fig. 3.2, the wedge method was chosen for further development lots because of the ease of manufacturing. The wedges did, however, have a tendency to slip and become slightly repositioned during insertion into the cavities when packing the compacts in the frame. This resulted in some fuel's lodging between the wedge and the frame, causing a slight indication on the digital homogeneity scan. This condition was considered acceptable for development purposes because the machined cavities did not exhibit the same condition, thus leaving a corrective measure that could be used in the event that the wedge/frame indication proved unacceptable.

3.3 LOADING DEVELOPMENT, PART THREE

After proving the feasibility of dual gradients, the next logical step in development was to produce similar gradient plates using different loadings. The chosen loadings were 1.7, 3.0, 3.5, and 4.8 g U/cc. Three plates of each type were manufactured in lots 19, 20, 21, and 22. One plate from each lot was to be destructively evaluated.

During compaction of each compact lot, fabrication of higher-loaded compacts became more difficult. Because of the increased density of the fuel matrix (see Appendix B for the volume and weight percent loading) in relation to the top aluminum filler, the expansion of the compacts when removed from the die cavity was not uniform, causing small hairline cracks on the surfaces of the compacts. In lots 19 and 20, the cracks were almost imperceptible, but in the higher-loaded lots, more severe cracks were found. No significant fuel losses were found in any of the compacts because of the cracks, and the compacts were considered acceptable to pack into the frames. With additional development and further adjustment of the compaction pressure, the cracks could potentially disappear altogether. Nonlinear compaction of the fuel matrix resulting from the graded fuel placement is discussed further in Sect. 3.5.

The final plate cores of each lot displayed the desired gradient, including the higher-loaded lot 22. As can be seen in Fig. 3.12, the track down the center of the fuel core displayed a nearly symmetrical gradient from end to end. The condition of fuel trapped between the wedge insert and the frame appeared to increase, as can be seen in the sharp rise of the scanner readings at the ends of some of the tracks. This accentuated condition, which resulted from to the increased loading and hence more fuel per cubic centimeter becoming trapped, was expected and did not raise concern. Low-density areas because of the cracks in the higher-loaded compacts were not evident in the final plate cores.

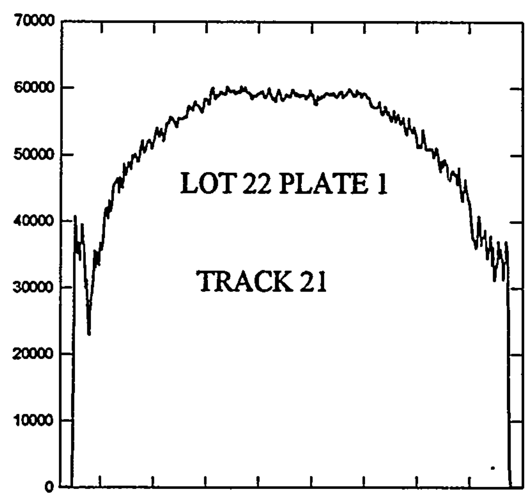


Fig. 3.12. Center track from a lot 21 plate.

3.4 CENTERED FUEL DEVELOPMENT, PART FOUR

To optimize the design of the dual-gradient concept, the fuel should be centered within the aluminum cladding. This means that the distance from the top of the plate to the upper core boundary (top clad) in any given position along the fuel core must be the same as the opposing distance from the bottom of the fuel plate to the lower core boundary (bottom clad). To accomplish this goal, B&W proposed a new clamshell design in which the top and bottom cover plates would be dished to accommodate a compact with symmetrical gradients both longitudinally and laterally on both the top and bottom as shown in Fig. 3.13.

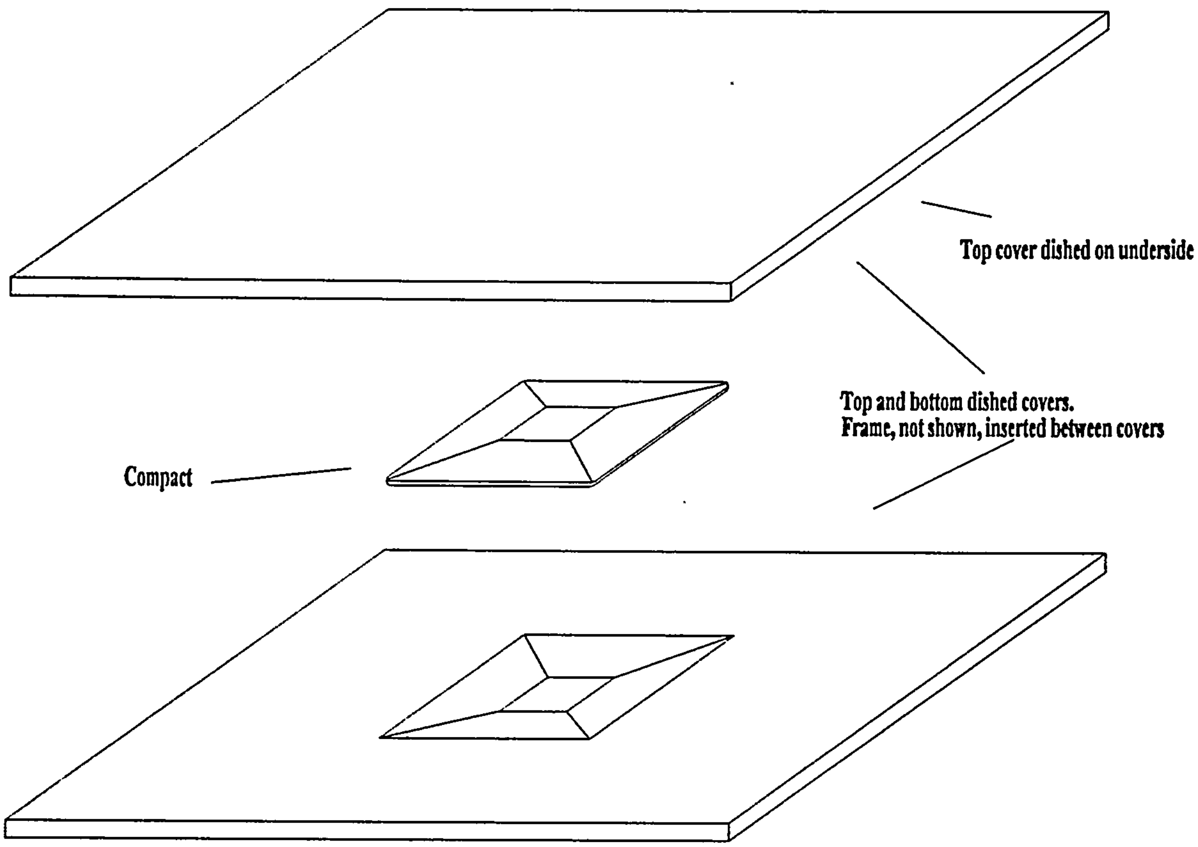


Fig. 3.13. Clamshell design for compact/cover plate assembly.

The manufacturing process involved making two compacts for each fuel core. A dished bottom punch was fabricated to yield a dual gradient in the bottom of each compact. The fuel was poured into the die, swept flat, and then pressed flat using a flat upper die. Then, two compacts were placed with the flat sides together and packed into the dished covers with a frame added to ensure proper fitup. Lots 23 and 24 were both made of eight compacts with loadings of 2.8 and 3.0 Mg U/m^3 respectively. One lot of 12 compacts (lot 25) with a loading of 3.5 Mg U/m^3 was made for a total of 14 plates. The assembled packs for two of the higher-loaded plates were electron beam welded, and the remaining packs were welded using the conventional inert gas weld.

During compact production, the problem of nonuniform compaction ratios was evident in all compacts. Sufficient compacts were acceptable for packing although the low-density areas in the center of the compact did produce some voids. During hot roll, all but the lower-loaded plates (lot 23) were unacceptable because of multiple breaches in the cladding over the low-density areas. The lower-loaded plates displayed some core stretching and low-density areas on the X-rays, but continued processing was possible. Further information on this last set of development plates was not available in time for this report.

3.5 SPHERICAL FUEL DEVELOPMENT

During the writing of this report, the last phase of development was started. This phase involved using spherical fuel particles* in lieu of the comminuted fuel traditionally used in production and previous development at B&W. The compact configuration was the same as that described in Sect. 3.3, and the loadings were 3.0 and 4.8 g U/cc. Although no information is available for this report, one advantage of using spherical fuel is expected to be the reduction of oxidation in the fuel core during hot roll because of the reduced surface area of each fuel particle. Other advantages may exist, but only limited work has been done using spherical U_3Si_2.

3.6 DUAL FUEL GRADIENT SYNOPSIS

The concept of fabricating dual gradients was proven to be feasible, and the details of how different loadings would perform were evaluated. After manufacturing over 50 plates, the next step would have been to determine a suitable compact design for producing the final ANS fuel gradients and then to address the most efficient method for producing the plates. The principal controlling factor appears to be the uneven compaction ratio and its effect on the density of the compact over a given region. Figure 3.14 illustrates the problem of uneven compaction ratios' producing nonuniform core densities. Note that a flat-swept fuel powder over an irregular bottom surface produces higher densities in the thinner compact edges than in the thicker section. To determine if this will be an area of concern, the controlling parameters such as final edge thickness and fuel core centering must be evaluated. The plates that were not centered did not exhibit this phenomenon. The centered compacts may need a process limitation, such as limited fuel volume fraction or thicker core edges, which may limit the maximum gradient potential. Should a drastic gradient be required, a floating die could be employed that would distribute the fuel such that the compaction densities are relatively uniform. This procedure would, however, require a large one-time expense because the compact manufacturing process would have to be redesigned for this particular purpose. The floating die may also eliminate the need for split compact processing in centered fuel if both the upper and lower gradients can be pressed at one time.

*The depleted uranium fuel powder was donated by the Korean Atomic Energy Research Institute through the RERTR Program via ANL.

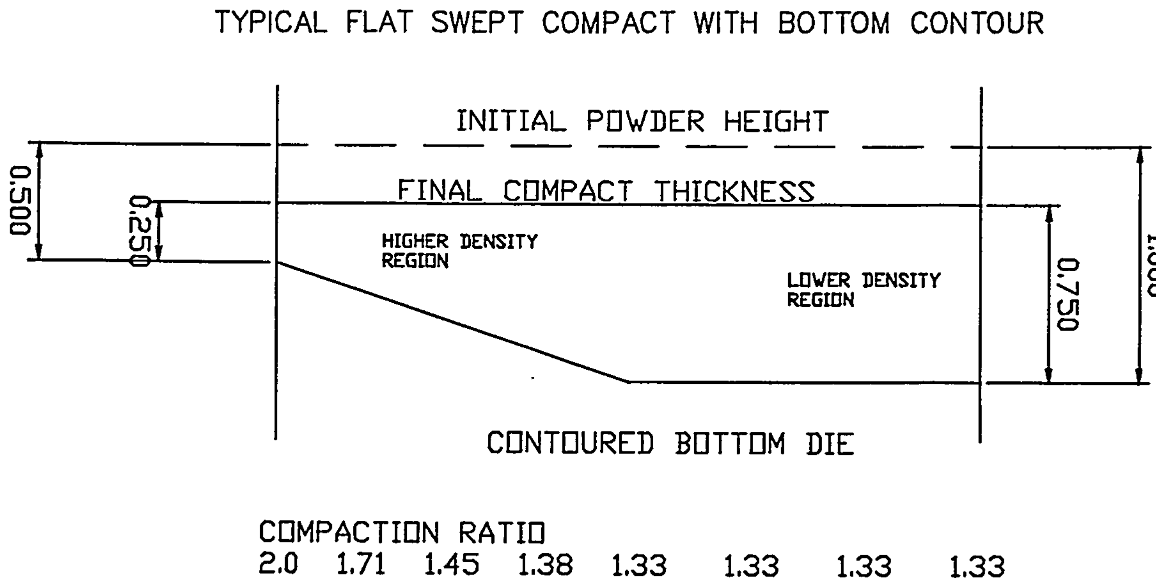


Fig. 3.14. Effects of contour on compaction ratio and thus density.

4. FUEL DISTRIBUTION AND HOMOGENEITY

During fuel fabrication development, more emphasis has been placed on the homogeneity and reproducibility of the fuel distribution than on whether or not the actual intended gradient was achieved. If the process is reproducible and the fuel has adequate homogeneity, then the desired fuel gradient can be achieved by fine tuning the process. Nevertheless, there is some limited data on how well the generic dual fuel gradients were achieved. More data on the variability of the fuel density around the nominal value and the sensitivity of the inspection to spot overloads are also presented.

The introduction of lengthwise (in the plate, axial in the reactor) fuel gradients necessitated modifying the homogeneity scanner for digital data acquisition. A 2-mm-(0.080-in.-)diam collimated X-ray beam is passed through the plate, and the intensity of the beam is measured on the opposite side. This spot is scanned over the length of the plate; the beam then indexes over 1.5 mm (0.060 in.) and scans the next lengthwise track so that the entire plate is inspected. The scanner used for HFIR was an analog system. Since there is only a radial gradient (width of the plate), the desired fuel value is constant along the length of any track. The scanner passes over standards designed for HFIR plates that consist of nominal, +12%, −12%, and +27% values for each track. A color code is sprayed on a chart at any time the acceptance standards are violated.

Since the fuel density varies along the length of the track in the ANS plates, actual numerical values proportional to the X-ray absorption at each spot are required to compare to the absorption of standards to evaluate the loading. The homogeneity scanner was modified for digital data acquisition by taking the voltage from the photomultiplier tube (which is proportional to the X-ray intensity through the plate), inverting and amplifying it, and converting it to a number called "counts" with an analog/digital converter. The electronics can be adjusted so that the resulting counts ranging from zero (for low absorption) to 65,536 (typically representing ~90% absorption) are proportional to the fuel loadings in the plate. The data acquisition program continually samples the counts reading as the scan progresses. After the scan moves about 1.3 mm (0.050 in.) along the length of the plate, the data points obtained for this length are averaged. The average and the maximum value over this short distance are recorded as "local" and "maximum" values, which can be numerically analyzed and subjected to acceptance or rejection criteria. The scanning data presented in Sect. 3 and below in this section are plots of these local averages vs position along the length of the plate. The maximum values are used for the "hot spot" acceptance criteria of +27% for HFIR (and +20% for ANS). The "hot channel" (+12% for HFIR) is applied to a running average of these local readings 12 mm (0.5 in.) in length.

4.1 HOMOGENEITY

The first lot of ANS graded developmental plates containing U_3Si_2 showed fuel segregation and "waviness" in the fluoroscope and in conventional radiographs. The results were so discouraging that further evaluation of these plates was discontinued. In fact, quantitatively, the plates were probably not as bad as they appeared in radiography because the very low volume fraction of high-density particles exaggerated the inhomogeneity compared to conventional plates. It was decided to produce a direct comparison of the U_3Si_2 to U_3O_8 by making some HFIR outer element plates using standard HFIR procedures and dies except substituting the silicide for the oxide fuel. There could not be an exactly comparable substitution because of the higher density of the silicide particles. It was decided to use the identical weights of fuel compound, which resulted in a higher U loading (1.35 vs. 1.25 Mg U/m^3) and a lower volume fraction of fuel (0.13 vs. 0.18) in the silicide plates. The silicide fuel also had a larger particle-size distribution than the oxide (particles up to 150 μm vs up to 90 μm). The blending, compacting, and rolling procedures were identical to the HFIR procedures. These plates were designated lots 7, 8, and 9, consisting of six plates each using three different silicide powder lots. Their fabrication is discussed in Sect. 2.2.

Examination of the X-ray scanning results show the eighteen silicide HFIR plates to be essentially identical. Comparison of individual tracks and track averages show that reproducibility is excellent from plate to plate with these three fuel powder lots. Interestingly, the scanning data for the silicide plates indicate lower counts, i.e., lower fuel loading, for the silicide plates than for the oxide plate even though the actual uranium loading is higher. This finding simply confirms the known fact that X-ray absorption in the plates, and thus indicated fuel loading, is sensitive to a number of factors, including fuel particle size, fuel particle density, fuel volume fraction, and meat thickness. Thus, standards for the X-ray scanner must be referenced back to realistic prototypes of the particular fuel being tested. Three transverse plots from a production HFIR oxide plate are in Fig. 4.1, plotted with the transverse plots of the four standards. The "local spot" values fall above the nominal standard line in the center of the plate and fall below the nominal on the edges (especially the thin edge). This effect is accomplished deliberately in compacting to sweep fuel toward the center and decrease rejections because of spot overloading in the thin edge. A similar plot is in Fig. 4.2 for a silicide HFIR plate. The data fall between the nominal and the −12% standards in the center and decrease on the edges to a slightly lesser extent than for the oxide plate. Actual measurements of the meat thickness made on microstructural examination of the plates show that the meat thicknesses are identical in the center and that the silicide meat thicknesses are slightly thicker on the edges. This change in profile is a consequence of the gradient's being imposed on the loose powder fill prior to compacting. Powder mixes with different bulk densities will result in a different profile in the finished, densified plate. Longitudinal plots of the local spot from the oxide and silicide plates are in Figs. 4.3 and 4.4. Track 18 is in the center of the hump, and tracks 9 and 37 are to either side. The meat extends from about track 4 to 48, as can be seen from Figs. 4.1 and 4.2. The variability in the values appears to be about the same for the silicide as for the oxide. For a comparison, the standard deviations of the counts for all the tracks over the meat of several of the plates were examined. The standard deviation for tracks 4 through 48 are averaged and compared in Table 4.1. The counts for the various tracks range from about 42,000 to 59,000 counts, so this does not represent a true standard deviation for the counts, but should be a meaningful comparison. We conclude that the homogeneity as measured by the standard deviation of the counts within a track is the same for the oxide and silicide plates; i.e., production plates from could be made from silicide powder with homogeneities as good as those of the HFIR oxide plates.

Later, further improvements in homogeneity of the silicide were realized by decreasing the size of the largest particles to 74 µm. An illustration of the homogeneity and reproducibility obtained in lots 17 and 18 is shown in Figs. 4.5–4.7. These plots are the center tracks (local spot) of eight individual plates, four from lot 17 and four from lot 18, as a function of position along the length of the plate. The ±10% lines are estimated by converting the counts to metal thickness, calculating ±10% thickness, then converting back to counts based on metal standards scanned with the plates. They do not represent exact changes in fuel content, but should be an approximation for fuel loading changes. The length gradient was broken into three straight lines to attempt to obtain a numerical "goodness of fit" for the thousands of data points that result from the scanning so that comparisons could be made among plates and lots. This effort was not completed because of the ending of the program. However, it was concluded that the graphic representation of the data shows that the reproducibility and homogeneity in the current process for the 1.3-Mg U/m^3 loading level are more than adequate to develop fabrication procedures for plates that meet the ANS requirements.

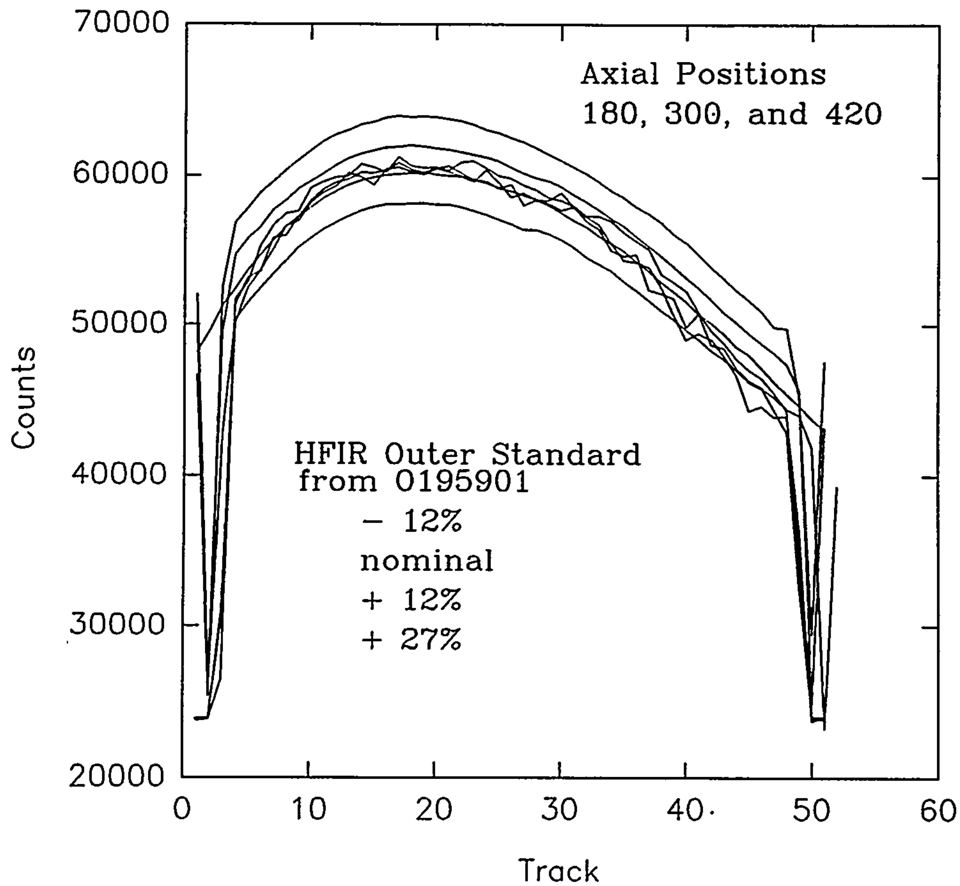


Fig. 4.1. Transverse plot of scanning of HFIR oxide plate. Three positions (irregular lines) and the −12%, nominal, +12%, and +27% standards (smoother curves in that order bottom to top).

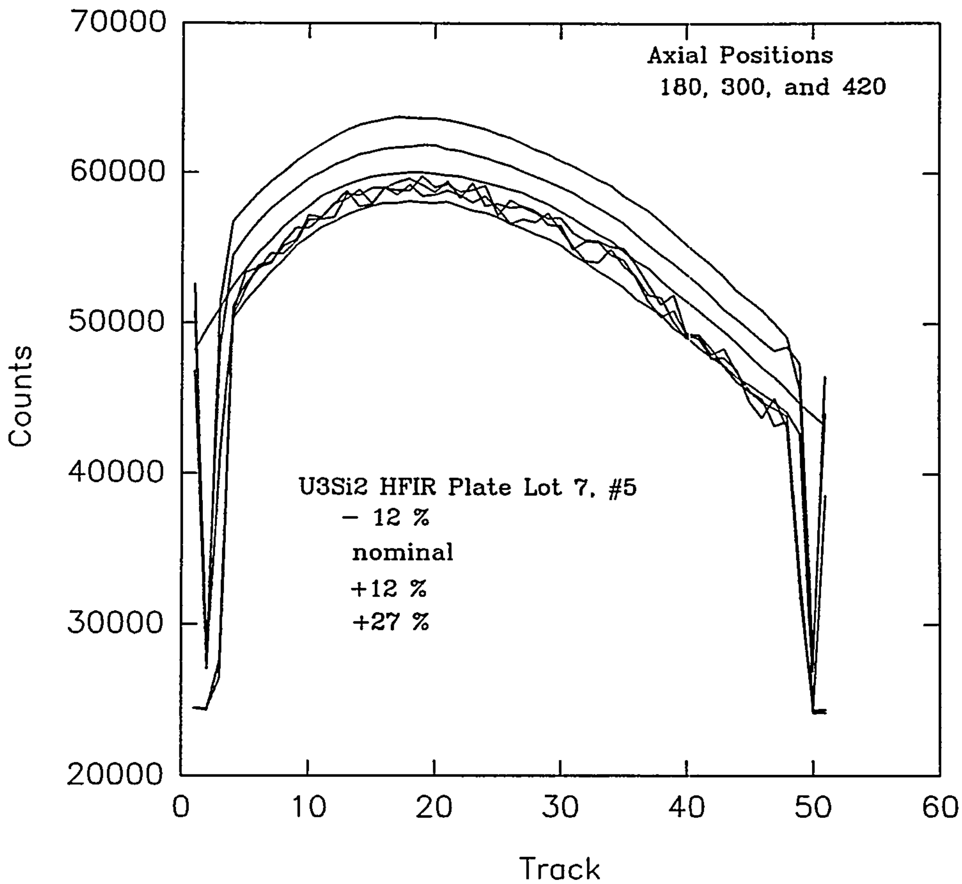


Fig. 4.2 Transverse plot of scanning of HFIR silicide plate. Three positions (irregular lines) and the −12%, nominal, +12%, and +27% standards (smoother curves in that order bottom to top.)

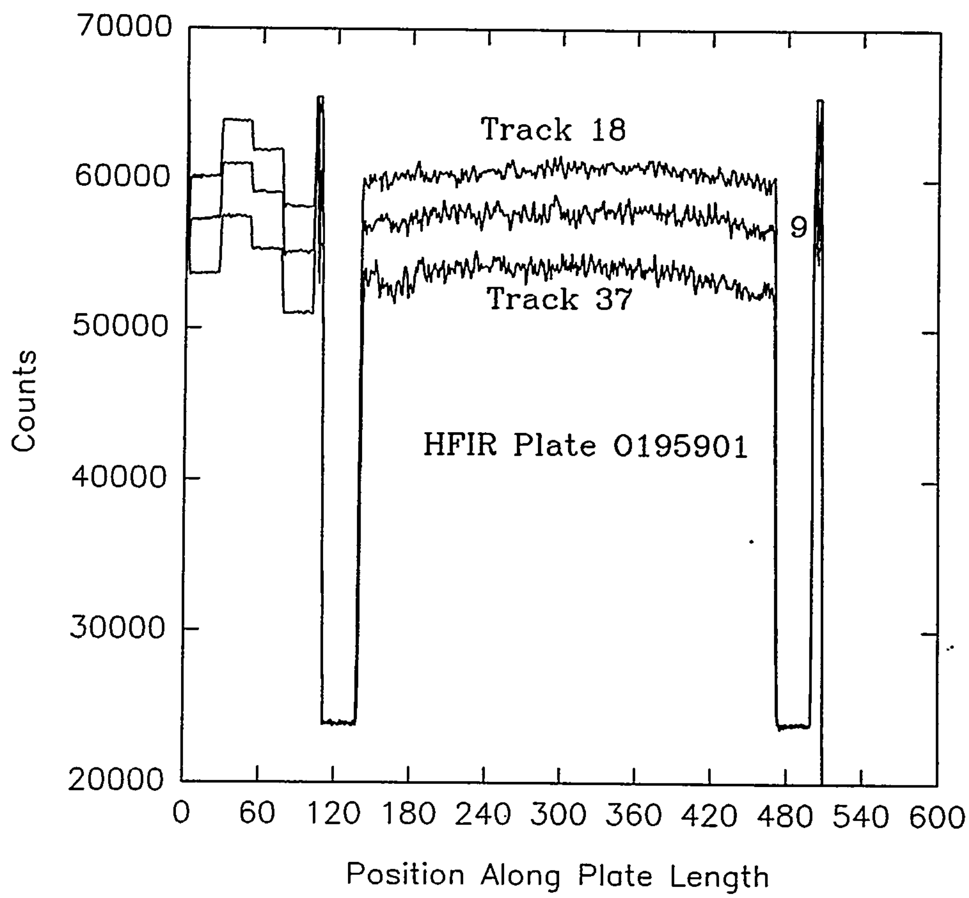


Fig. 4.3. Axial plots of scanning of HFIR oxide plate. Three tracks and their respective nominal, −12%, +12%, and +27% standards.

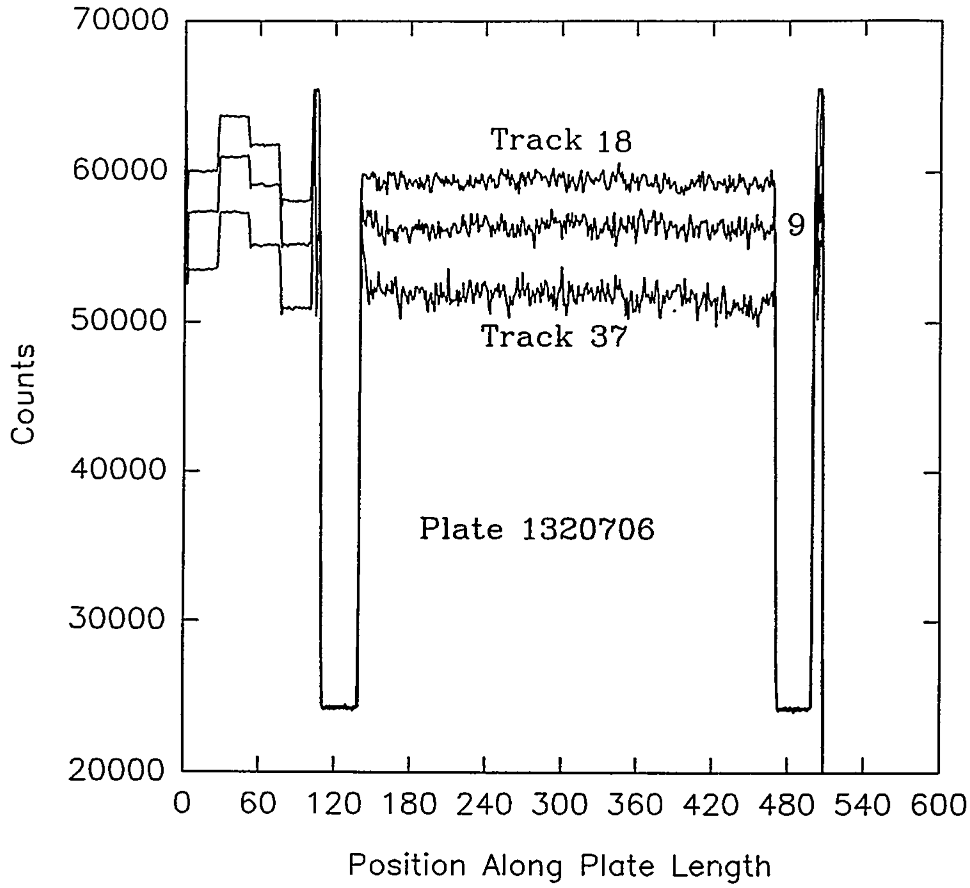


Fig. 4.4. Axial plots of scanning of HFIR silicide plate. Three tracks and their respective nominal, –12%, +12%, and +27% standards.

Table 4.1 Homogeneity comparison for oxide and silicide plates

Fuel plate type	Average standard deviation (42,000 to 59,000 counts)
Oxide HFIR plate	625
Silicide plates (3), lot 7	572
Silicide plates (4), lot 8	621
Silicide plates (4), lot 9	676

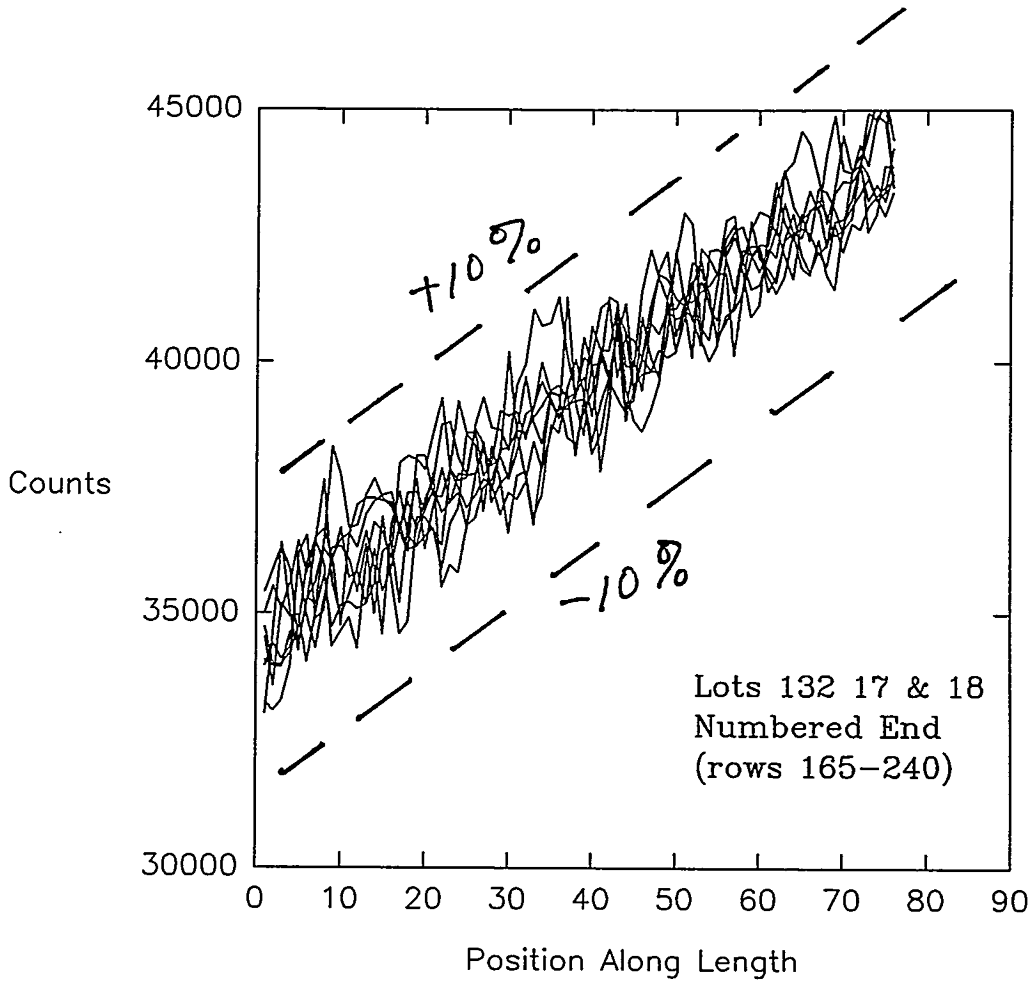


Fig. 4.5. Axial plots of scanning the numbered end of lots 17 and 18 plates. The center track of eight individual plates along with the calculated ±10% deviations from the nominal.

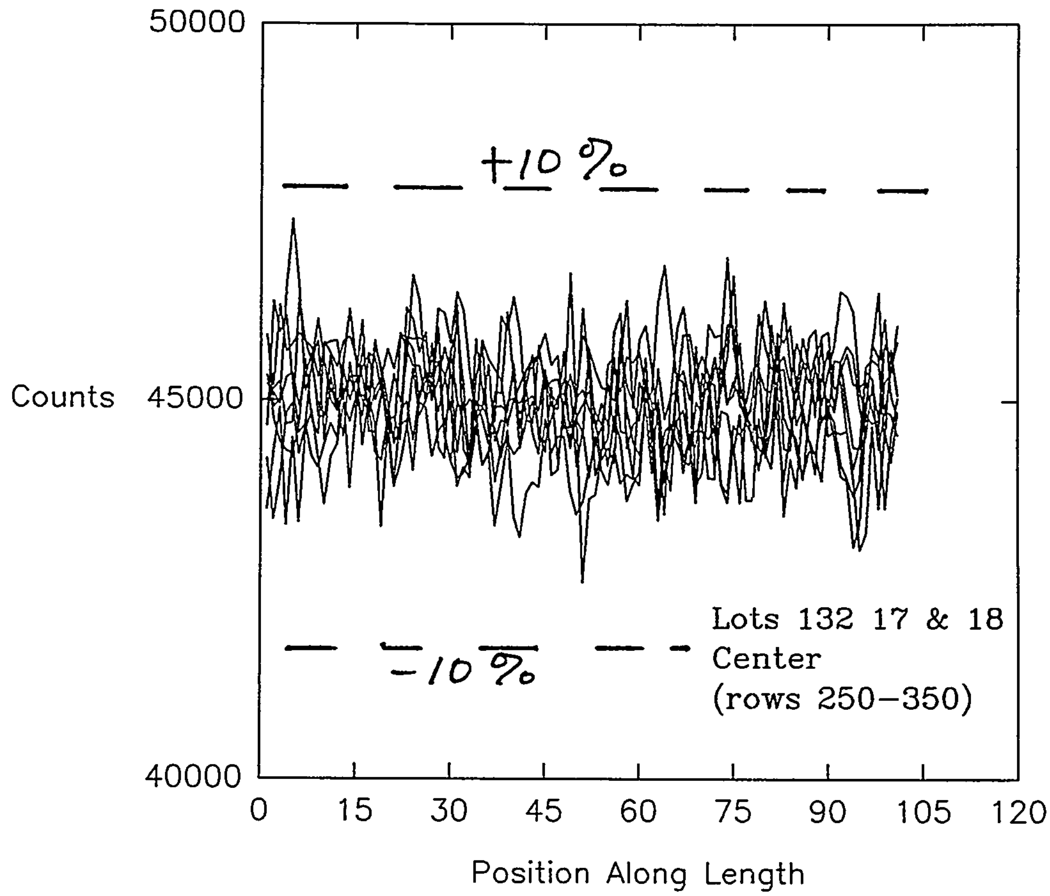


Fig. 4.6. Axial plots of scanning the center section of lots 17 and 18 plates. The center track of eight individual plates along with the calculated ±10% deviations from the nominal.

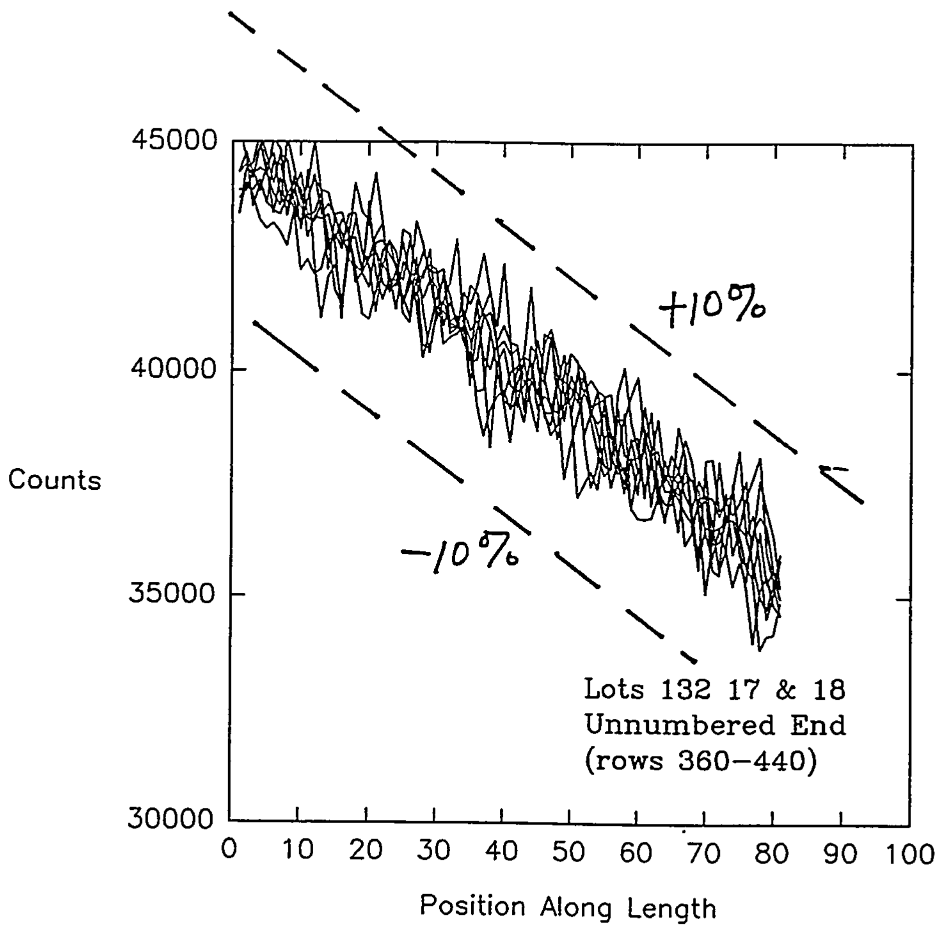


Fig. 4.7. Axial plots of scanning the unnumbered end of lots 17 and 18 plates. The center track of eight individual plates along with the calculated ±10% deviations from the nominal.

4.2 FUEL LOADING

The generic dual grading picked for the development studies has characteristics similar to those that would have been required for the final ANS design. The fuel has a zone in the center of the plate where fuel loading is constant, with the fuel loading tapering toward both edges and ends. The plates produced approach the design grading well for a first iteration. The very thin meats were not achieved, but uniform meat thicknesses as thin as 0.18 mm (0.007 in.) were achieved, which is consistent with the guidelines given the designers. The gradients were uniform and did not vary significantly end to end. The sketches in Figs. 4.8 and 4.9 depict the design value, the value as determined by X-ray, and the value determined by metallographic measurement for the edges and ends of the plates as a percentage of the nominal center section. The meat thickness of a lot 17 plate is shown in Figs. 4.10 and 4.11 as a function of location in the plate. These results indicate that it is feasible to produce fuel plates with the dual grading of the type required by ANS. Much work remains to select the final fabrication procedures and to develop the data base that will allow accurate assessments of the degree to which fuel loadings can be controlled for a given design.

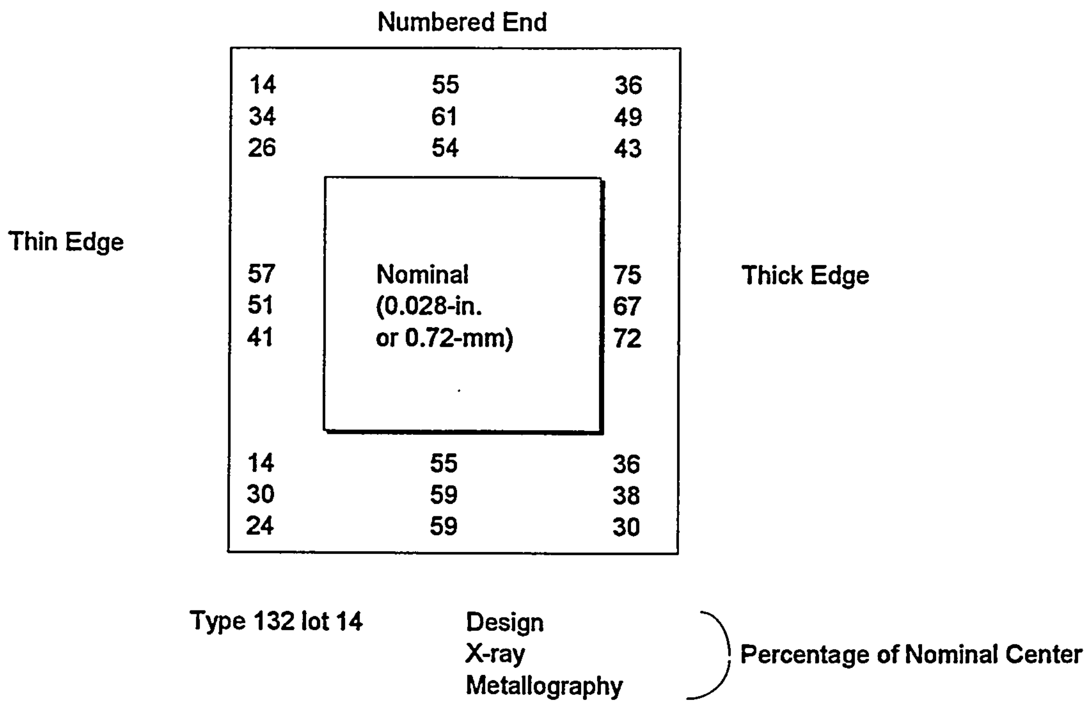


Fig. 4.8. Lot 14 plate (not to scale), showing the values of meat thickness as determined by X-ray and metallography at various locations compared to the design value as percentage of the nominal center section.

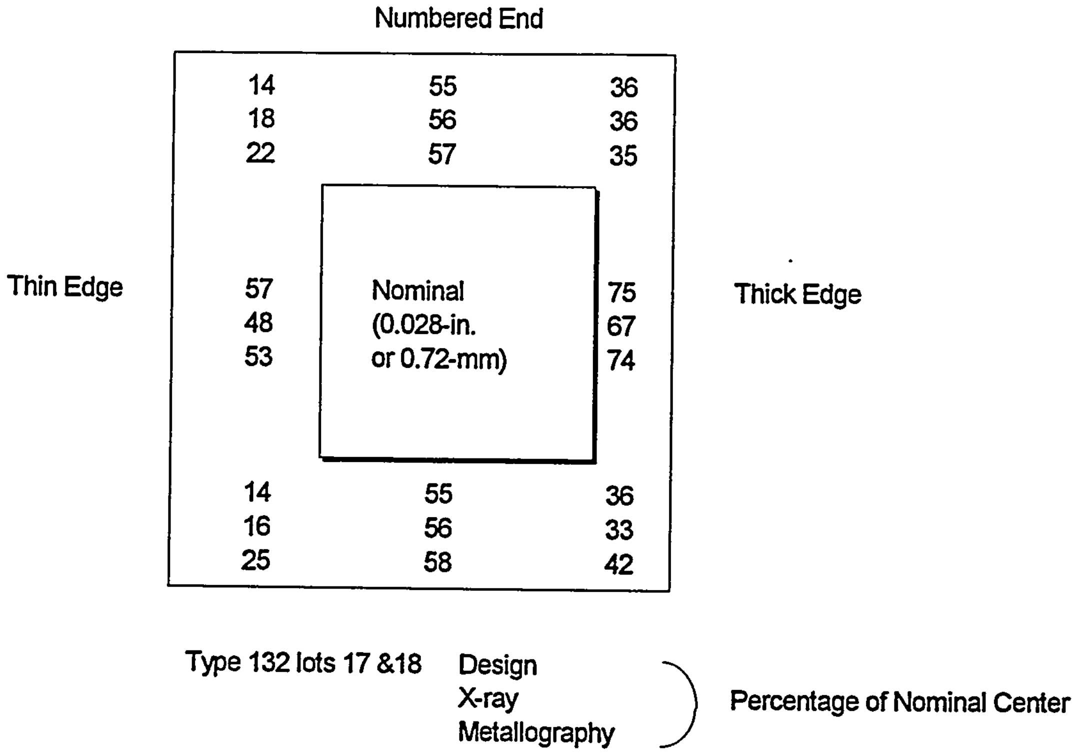


Fig. 4.9. Lot 17 plate (not to scale), showing the values of meat thickness as determined by X-ray and metallography at various locations compared to the design value as percentage of the nominal center section.

4.3 DETECTION OF HIGH FUEL DENSITY SPOTS

The transmission X-ray homogeneity scanner is set up to detect and reject plates that exceed a given value for any individual maximum spot reading. This value is 27% over the nominal loading for HFIR, and the value used thus far in design for ANS is 20% over the nominal value. The smallest area in which it is possible to obtain data with the present system is the 2-mm-(0.080-in.-)diam spot of the collimated X-ray beam and detector. Nothing is known of how the overload is distributed within this spot. Therefore, for the maximum "hot spot" analysis, the safety analysts assume the worst possible fuel distribution within that 2-mm spot. They also assume that the hot spot is adjacent to the largest undectable (1-mm) nonbond with no heat flow through the nonbond, in the worst place in the core, and at the worst time in the cycle. For lower power density reactors, these ultraconservative assumptions can result in acceptable temperatures and heat fluxes at the hot spot. However, for the ANS, these assumptions resulted in excessive temperatures in a very small spot.[3] Thus, either some of the conservatism needs to be removed from the calculation, additional information is needed, or a higher temperature needs to be justified for the small spot. The assumption made for the fuel concentration modeled in the calculation is that all of the excess fuel in the spot is concentrated in a cylinder at the maximum justifiable concentration. The maximum concentration was taken to be 50% density, which is the bulk density of the fuel powders.

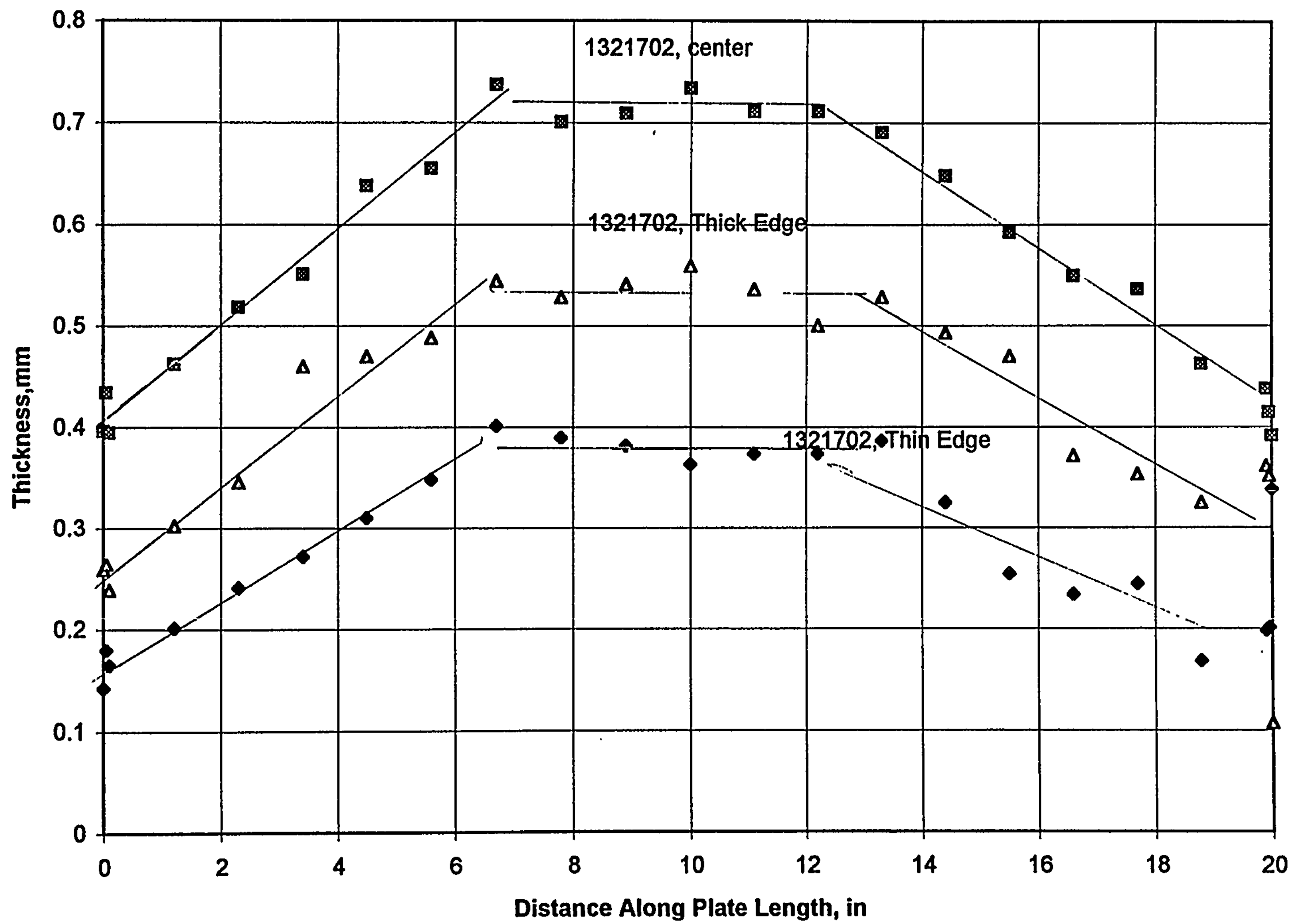


Fig. 4.10. Metallographic measurements of meat thickness along the length of a lot 17 plate at the center, thick edge, and thin edge of the plate.

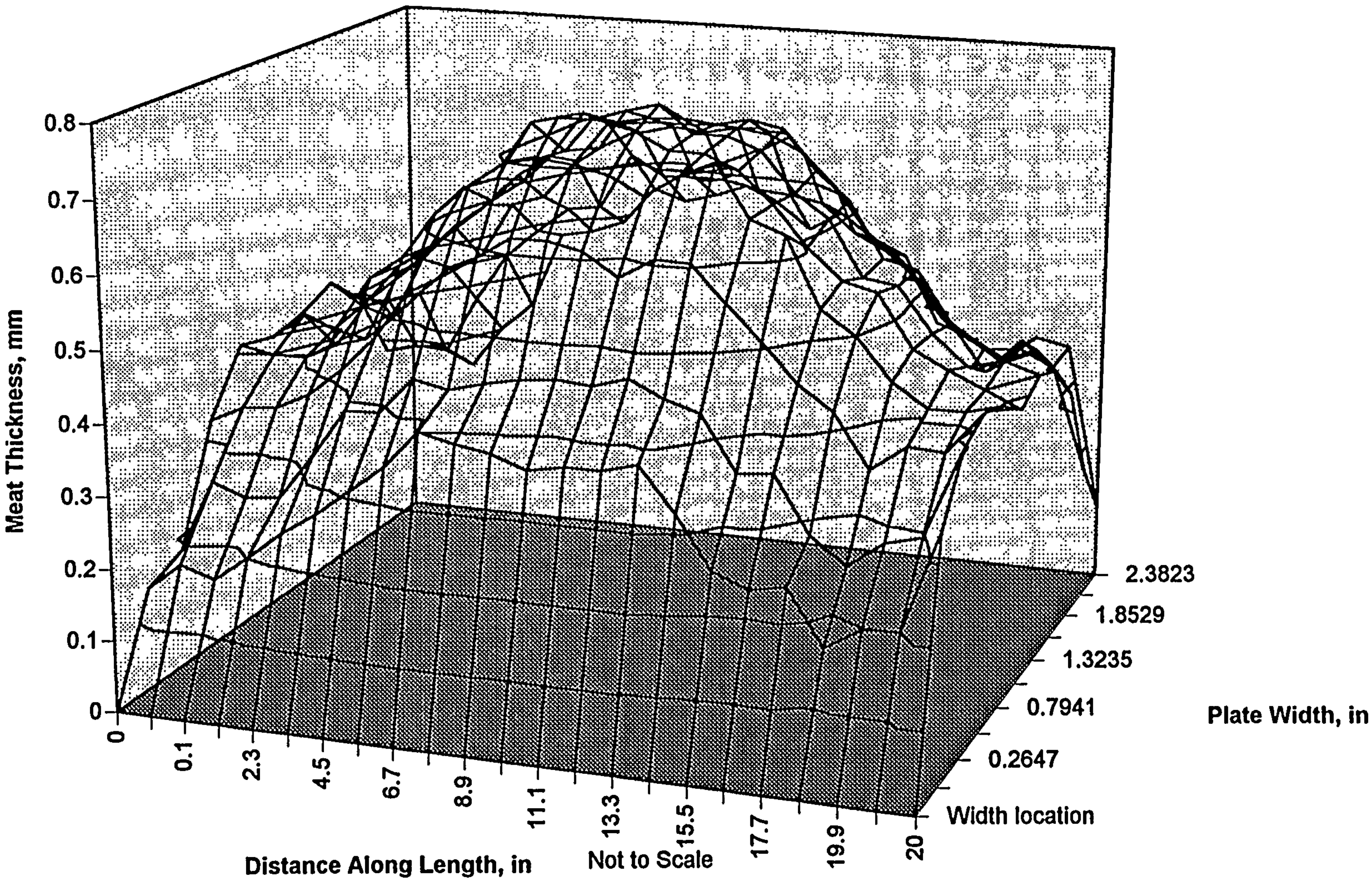


Fig. 4.11. Metallographic measurements of meat thickness of a lot 17 plate as a function of length and width of the plate. The length is not to scale since the three measurements on the end are at almost the same location.

Dispersions containing 50% fuel typically contain 15% voids and 35% aluminum matrix as roll bonded. This mixture has low thermal conductivity, which exacerbates the problem. The diameter of this concentrated fuel zone is ~0.5 mm (0.020 in.) for the 20% overload in normal fuel.

Some plates were scanned with tungsten wires on them to determine the sensitivity of the scanner with its 2-mm-diam beam to these small high-density areas. The tungsten wires were 0.13, 0.25, and 0.76 mm (0.005, 0.010, and 0.030 in.) in diameter. The substrate plates were aluminum, representing the approximate X-ray absorption of the 1.3-Mg U/m^3 loading, and aluminum plus stainless steel, representing the 3.5-Mg U/m^3 loading. The wires are readily apparent on plots of counts vs track and position, as shown in Figs. 4.12 and 4.13. These figures are the "maximum spot" values in each case although the wires show up just as readily on the "average local spot" data. The maximum spot data are more logical for comparisons of values because the wire has a good chance of being in the exact center of a spot as the scan crosses it. Comparing the effects on X-ray absorption in Table 4.2, the extra absorption as the wire is crossed agrees reasonably well with the portion of the area of the 2-mm circle intersected by the wire. Thus, as expected, the sensitivity of the scanner to high-density spots depends on the planar area of the spot as well as on its density. For example, the high-density cylinder in the hot spot model would not show up as a >20% fuel spot in normal fuel because it occupies only a little over 6% of the area of the 2-mm beam. This phenomenon gives additional incentive to narrow the inspection beam size.

There was a brief investigation of inspection with a microfocus X-ray and real-time computer analysis of the image from a charge-coupled device camera. The plates inspected were supplied by ANL and used tungsten powder as a surrogate for fuel so that the plates could be examined in the laboratory of the X-ray vendor.* The loading of the plates represented ~5 Mg U/m^3 in volume fraction of tungsten. The results are very promising, although no numerical analysis could be completed for this report. The same tungsten wires used for the scanner analysis were placed on these plates and were readily apparent. The setup used gave a pixel size of ~0.08 mm (0.003 in.). Each pixel has an intensity value associated with it so that analysis could be done by computer on a very fine scale. The magnification is controlled by geometry (i.e., placing the plate closer to the X-ray source or to the camera) and can be changed to cover a wide area (about one-fourth of a plate for this machine) or to get more detail. Individual tungsten particles were easily discerned in the plate at the higher magnifications. It is recommended that this technique be carefully investigated if this fuel development resumes in the future.

*TRONIX, Inc., Branford, Conn.

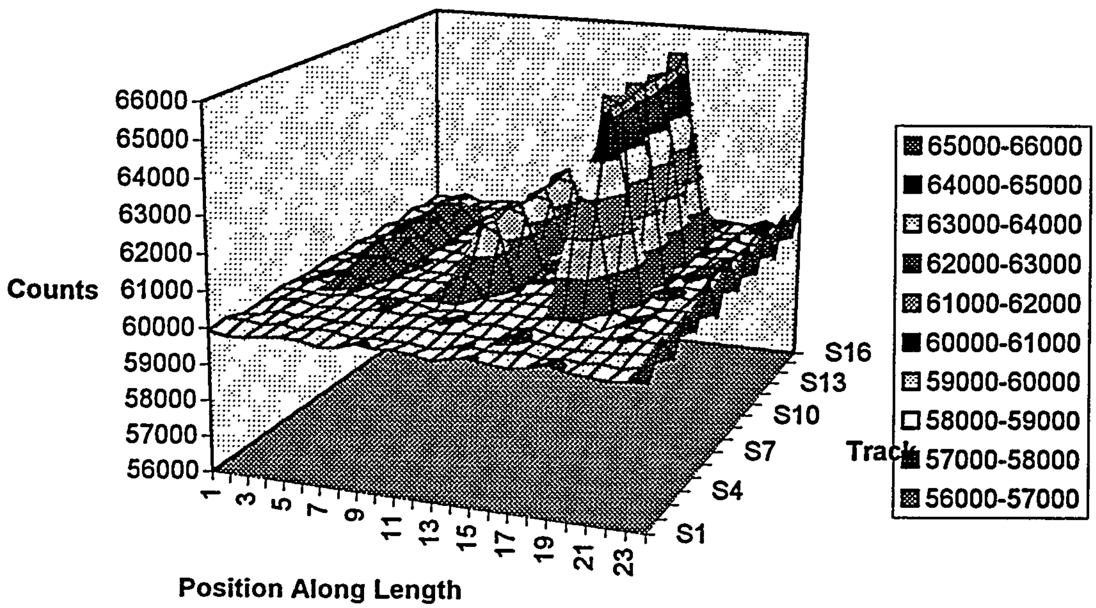


Fig. 4.12. X-ray scan of 0.13-, 0.25-, and 0.76-mm-diam tungsten wires aluminum equivalent to a fuel loading of 1.3 Mg U/m^3.

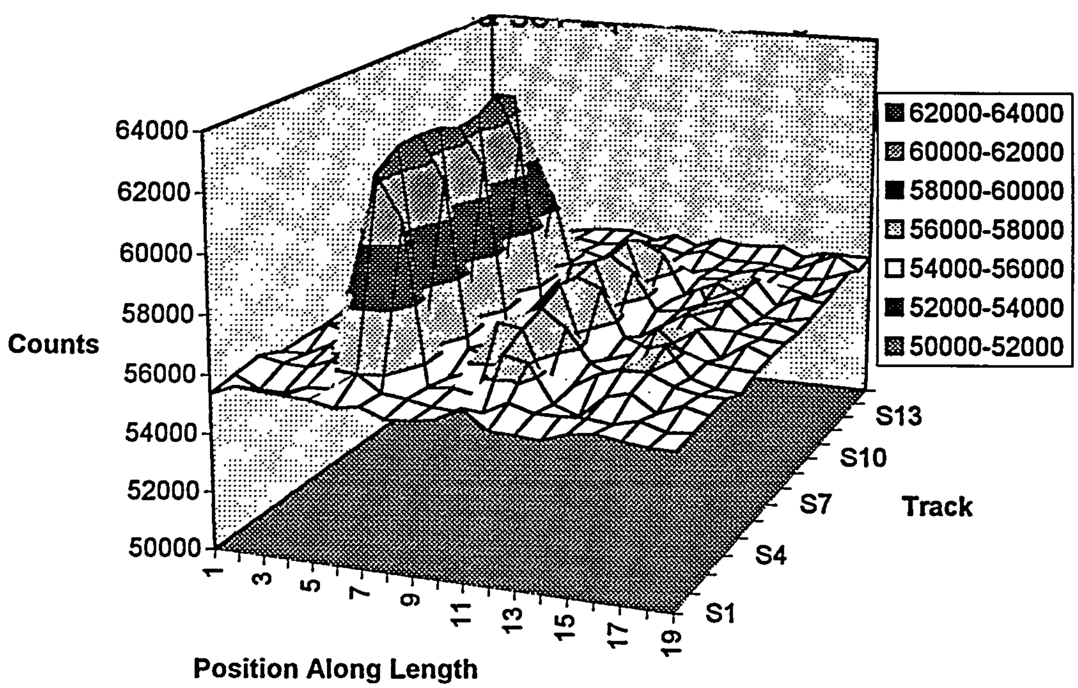


Fig. 4.13. X-ray scan of 0.76-, 0.25-, and 0.13-mm-diam tungsten wires on aluminum and stainless steel equivalent to a fuel loading of 3.5 Mg U/m^3.

Table 4.2 X-Ray absorption of wires on aluminum standard

Sampled area	Counts	Fractional transmission	Loss of transmission (%)	Area occupied by wire (%)
Matrix	59,923	24.5		
0.13-mm wire	60,713	23.5	4.3	8
0.25-mm wire	61,743	22.1	10.0	16
0.76-mm wire	65,535	17.0	31.0	48

5. CONCLUSIONS AND RECOMMENDATIONS

The fuel fabrication development for the ANS has answered two key questions crucial to the performance of the reactor. It is feasible to produce plate fuel graded in the axial as well as the radial direction without a major departure from the well-proven techniques used for the HFIR fuel. Plates containing U_3Si_2 dispersions can be fabricated with fuel homogeneity as good as that of plates containing U_3O_8 dispersions. These conclusions are based on fuel densities of up to 1.7 Mg U/m^3 for the highly enriched uranium designs. Fabrication of higher-loaded fuels near the end of the program gave promising results for fuel densities up to 3.5 Mg U/m^3, but less thorough evaluation was possible for these. The X-ray homogeneity scanner was successfully upgraded to digital data acquisition and control to enable the testing of fuel with an axial gradient. High-density fuel spots ("hot spots") did not appear to be a problem. However, in order to test for them adequately for the very high power density of the ANS, a smaller spot size is required for the homogeneity testing equipment. It may be possible simply to use a smaller collimated beam with the existing equipment, but investigating real-time microfocus X-ray techniques, which look very promising, is recommended.

6. REFERENCES

1. G. L. Copeland et al., *Advanced Neutron Source Final Preconceptual Reference Core Design*, ORNL/TM-11234, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., August 1989, p. 6.

2. *Safety Evaluation Report Related to the Evaluation of Low-Enriched-Uranium Silicide-Aluminum Dispersion Fuel in Non-Power Reactors*, NUREG-1313, U.S. Nuclear Regulatory Commission, July 1988.

3. G. E. Giles, *Advanced Neutron Source Reactor Thermal Analysis of Fuel Plate Defects*, ORNL/TM-13072, Lockheed Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., August 1995.

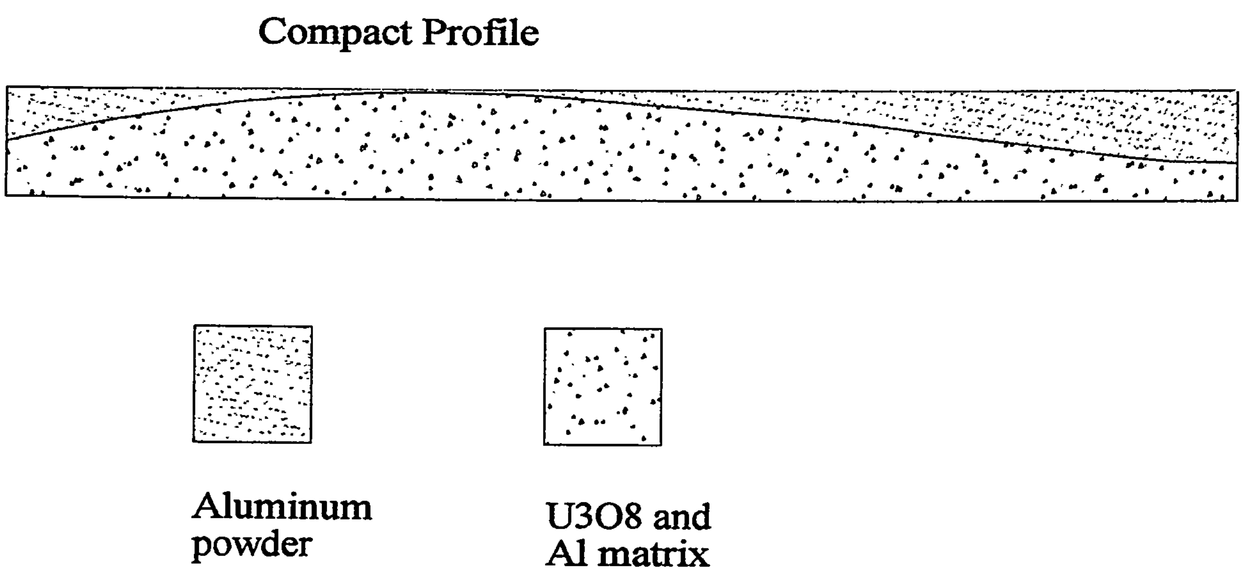
Appendix A. GRAPHICAL REPRESENTATIONS OF THE ANS DEVELOPMENT PROCESS

Appendix A. GRAPHICAL REPRESENTATIONS OF THE ANS DEVELOPMENT PROCESS

This appendix is included to include further information about the development process that was omitted from the text of the report.

A.1 DESIGN COMPARISON

The following three figures detail for comparison the different types of compact designs that govern the development of ANS plates. The HFIR compact design is included so that similarities may be drawn in reference to a known production process.



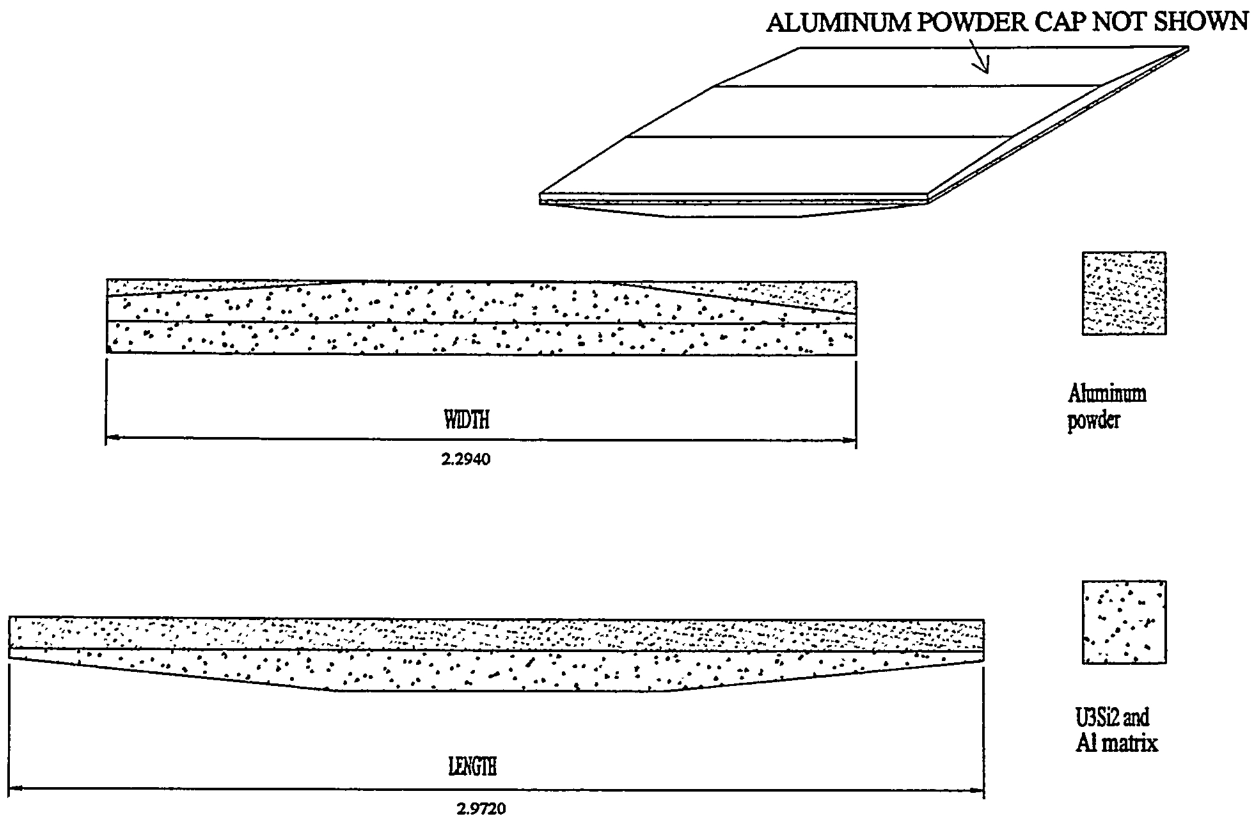
Nominal dimensions

Compact size (in): L 2.167, W 2.643, & th 0.269

Core Size (in): L 20.0, W 2.758, & th 0.0275 to 0.0095

Gms Uranium: 20.0215
Gms U235: 18.62

Fig. A.1. HFIR outer compact design, gradient contour, B&W type 000 plates.



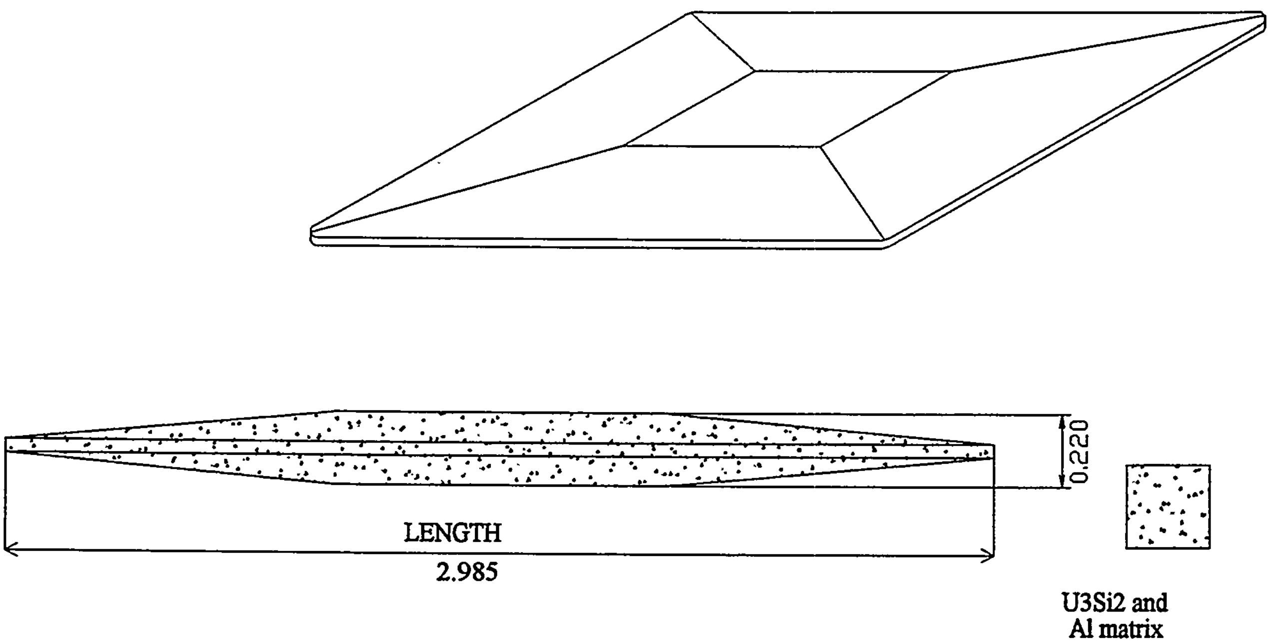
Nominal values

Compact size (in): L 2.972, W 2.294, th 0.218 to 0.228

Core size (in): L 20.00 +/-0.025, W 2.3 to 2.4, th 0.0038 to 0.0298

Loading	Gms U_3Si_2	Gms Uranium	Gms U235
1.3	22.96	21.13	0.05
1.7	29.76	27.39	0.06
3.0	38.51	48.33	0.11
3.5	61.27	56.39	0.12
4.8	84.02	77.32	0.165

Fig. A.2. ANS development compact design, dual-gradient contour, B&W type 132 plates, B&W die type 85.



Estimated nominal values

Compact size (in): L 2.985 +/- 0.010, W 2.294 +/- 0.010,
max thickness - 0.212 to 0.245

Core size (in): L 20.50 +/-1.5, W 2.25 to 2.45, th 0.003 edge to 0.030 center

Loading	Gms U3Si2	Gms Uranium	Gms U235
2.8	48.98	45.50	.115
3.0	52.48	48.50	.123
3.5	61.22	57.00	.144
4.8	84.02	77.32	.193

Fig. A.3. ANS development compact design, centered dual-gradient contour, B&W type 132 plates, B&W die type 85.

A.2 COMPACT MANUFACTURE CONFIGURATION

The following procedure was used for lots 12, 14 through 22:

Step 1. The contoured die, pc 1 (see Fig. A.4), is placed inside the die block shown, pc 2.
Step 2. The width contour sweep platen, pc 3, is placed on top of the die block, pc 2.
Step 3. The fuel powder matrix is poured into die cavity and swept using a flat sweep blade not shown.
Step 4. The flat aluminum powder sweep platen, pc 4 is placed over pc 3.
Step 5. The aluminum powder matrix is poured into die cavity and swept flat using a flat sweep blade not shown.
Step 6. The powders are lowered into pc 2 and the platens are removed. A flat top die punch, not shown, is placed on the top of the aluminum powder and the powder is pressed.

For lot 13, the bottom punch, pc 1 was replaced with a flat punch, and an additional platen contoured for the length gradient was employed to sweep a bottom layer of aluminum matrix powder prior to proceeding with step 2.

Lots 23 through 25 used the bottom punch shown as pc 5, and each compact was made up of two half compacts. The fuel matrix was swept flat directly onto the die block pc 2 and then pressed. The platens were not used.

Lots 26 and 27 were manufactured using the same technique as the original steps 1 through 6 above.

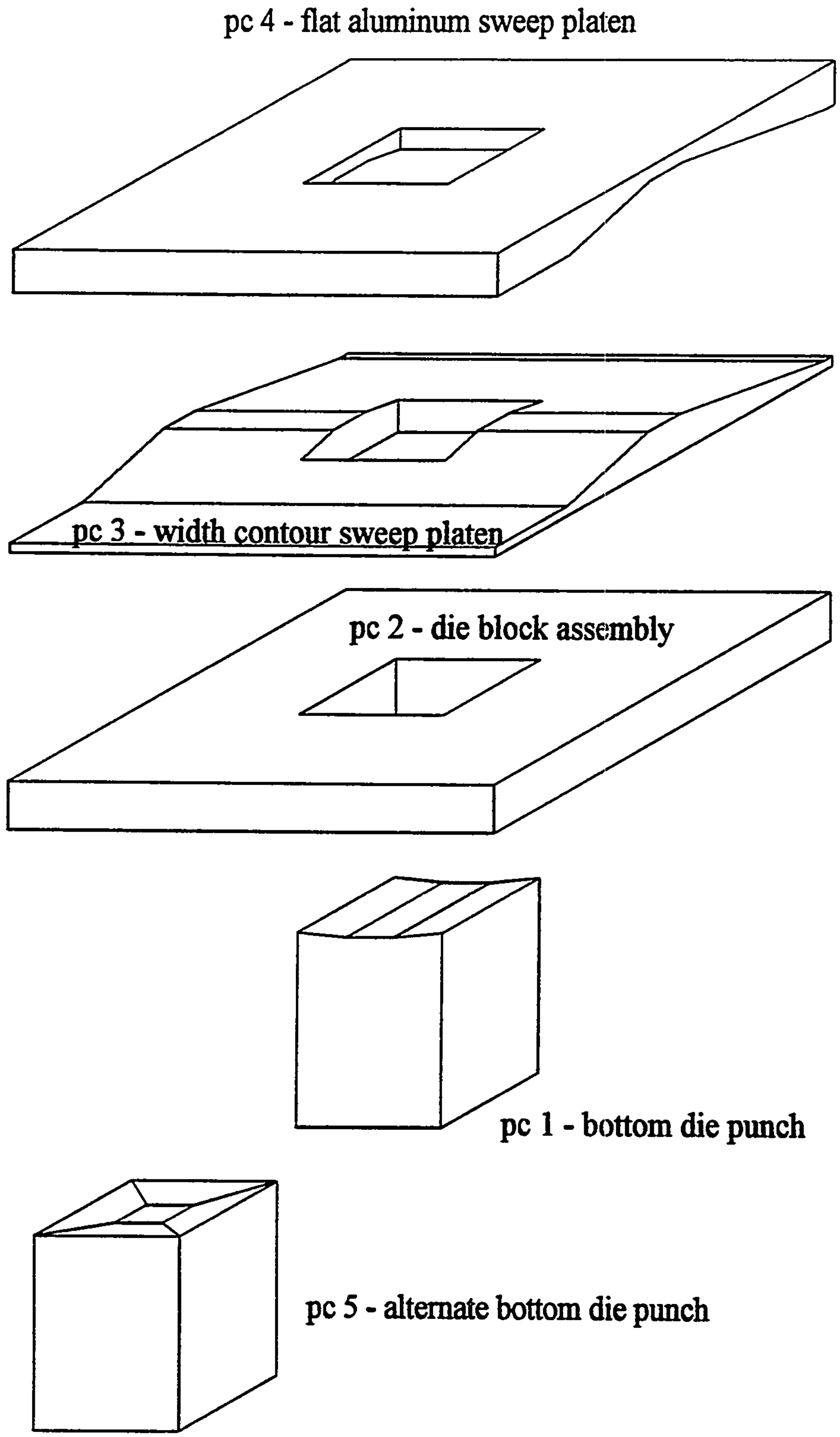


Fig. A.4. Compact manufacture procedure.

A.3 COMPACT AND FRAME DESIGN

The compact configuration was designed to ensure that the gradients in both the lateral and longitudinal directions would be easy to recognize on X-ray during the plate process. Figure A.5 shows the details the compact manufactured in lots 12 through 22, 26, and 27, and gives an idea of what the intended fuel distribution would be. The top aluminum filler which was used on all compact lots is not shown for clarity.

The wedge inserts were used in lots 14, 19, 20, 21, 22, 26, and 27 and are shown in Fig. A.6. These inserts were placed in the void space on the bottom of the length view in Fig. A.5. The frame design is shown in Fig. A.7. Note that the frame thickness was varied up to 0.004" to best match the as pressed compact thickness.

The frames used in lots 17 and 18 are shown in Fig. A.8. Note that the wedges were machined into the frames so no wedge inserts were used.

The compacts designed for lots 23, 24, and 25 were manufactured in two parts and are shown in Fig. A.9. The drawing used to manufacture the frames for the centered compacts is shown in Fig. A.10.

The covers, not shown, were manufactured to meet the width and length of the frames. The cover thickness was nominally 0.070" and varied according to actual frame thickness requirements.

Figure A.11 is an actual photograph of a lot 12 compact. The length gradient from one end to the other on one side of the compact is clearly evident.

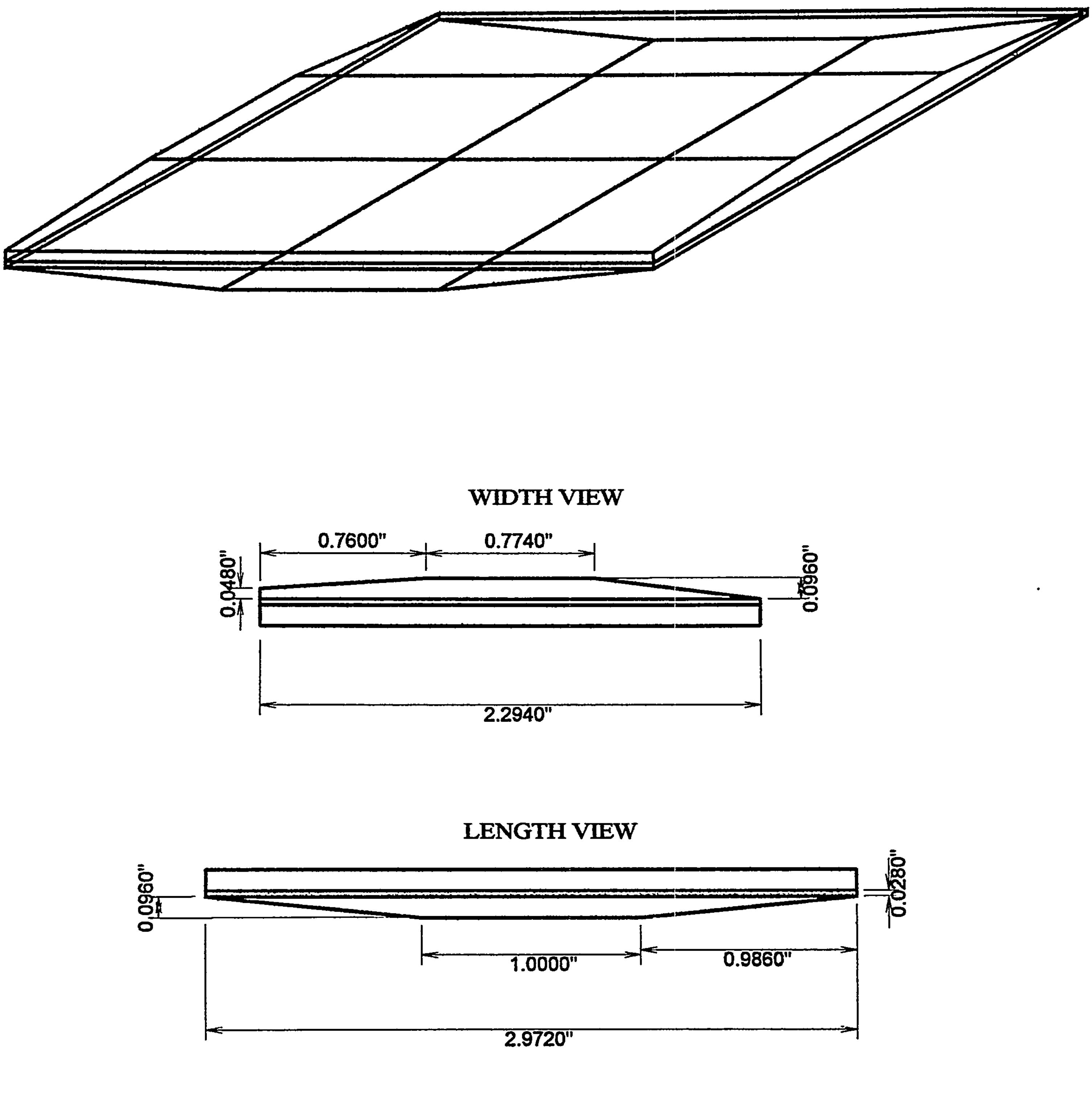


Fig. A.5. Compact configuration details for lots 12–22, 26, and 27.

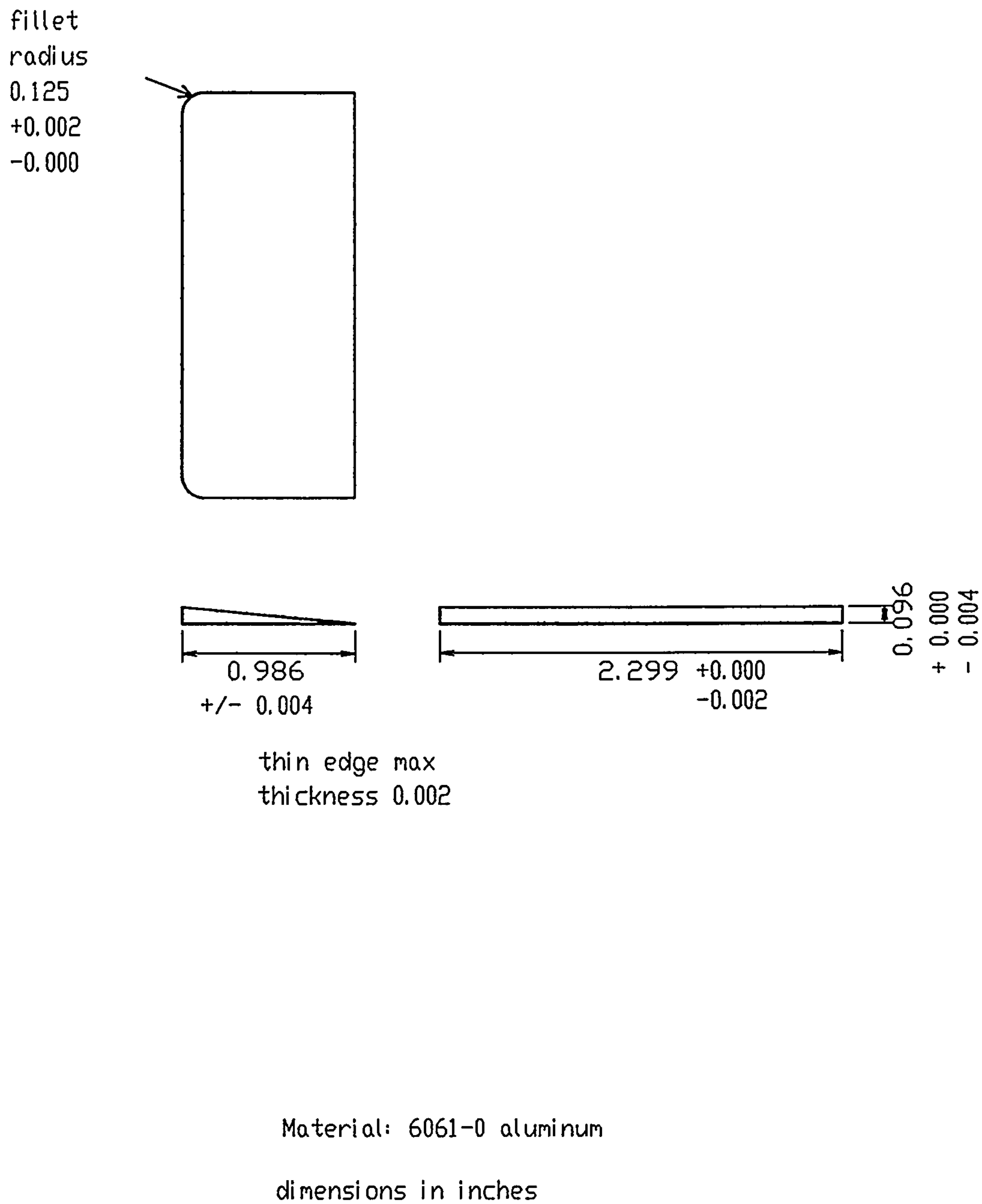
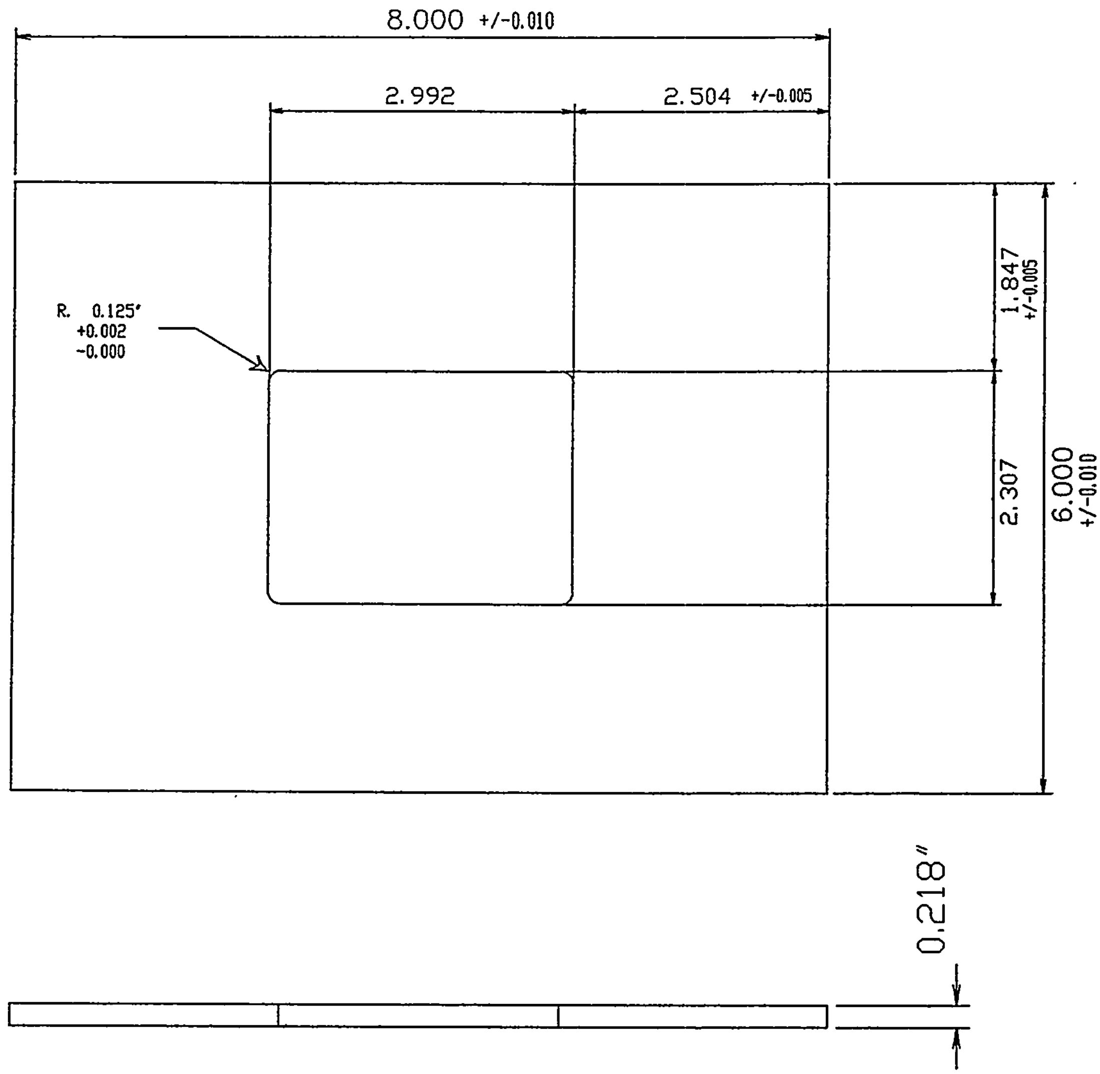


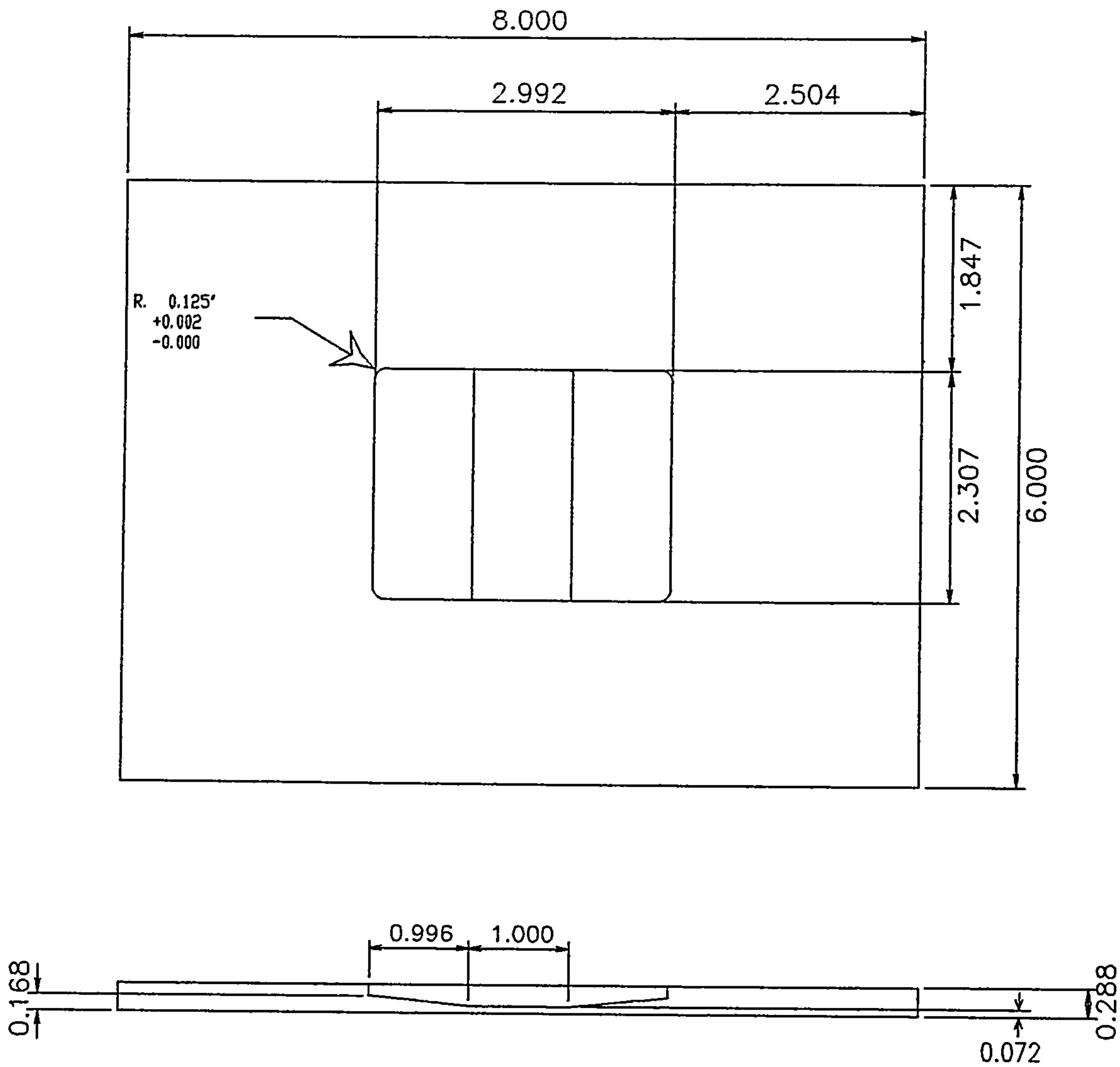
Fig. A.6. Wedge insert design.



NOTES:
1. ALL TOLERANCES +/- 0.001" UNLESS OTHERWISE NOTED.
2. HANDWORK INSIDE CORNERS AS NECESSARY.

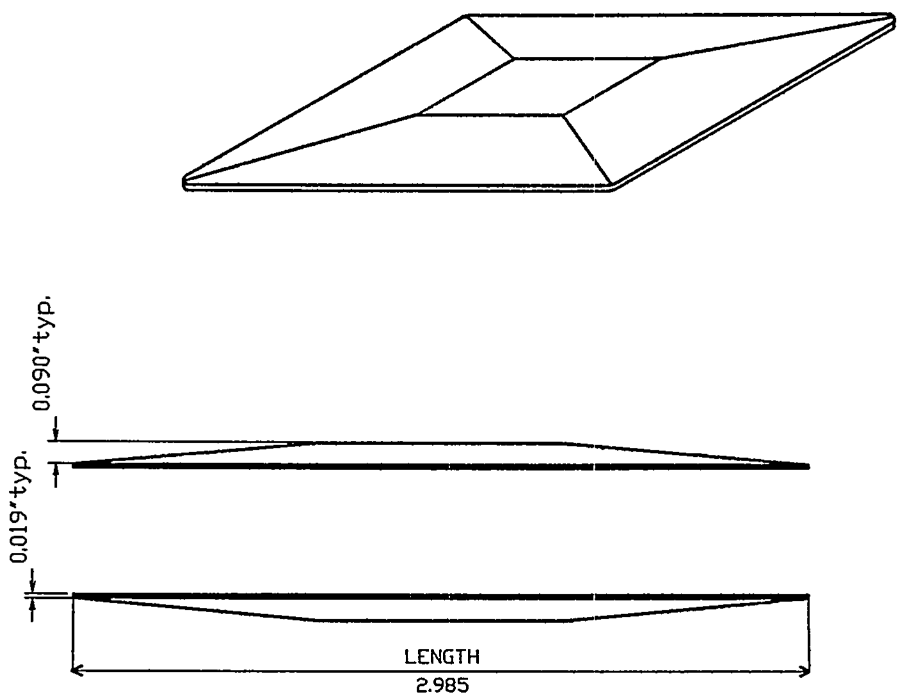
MATERIAL: ALUMINUM ALLOY 6061-0

Fig. A.7. Frame design.



NOTES:
1. ALL TOLERANCES +/- 0.001" UNLESS OTHERWISE NOTED.
2. HANDWORK INSIDE CORNERS AS NECESSARY.

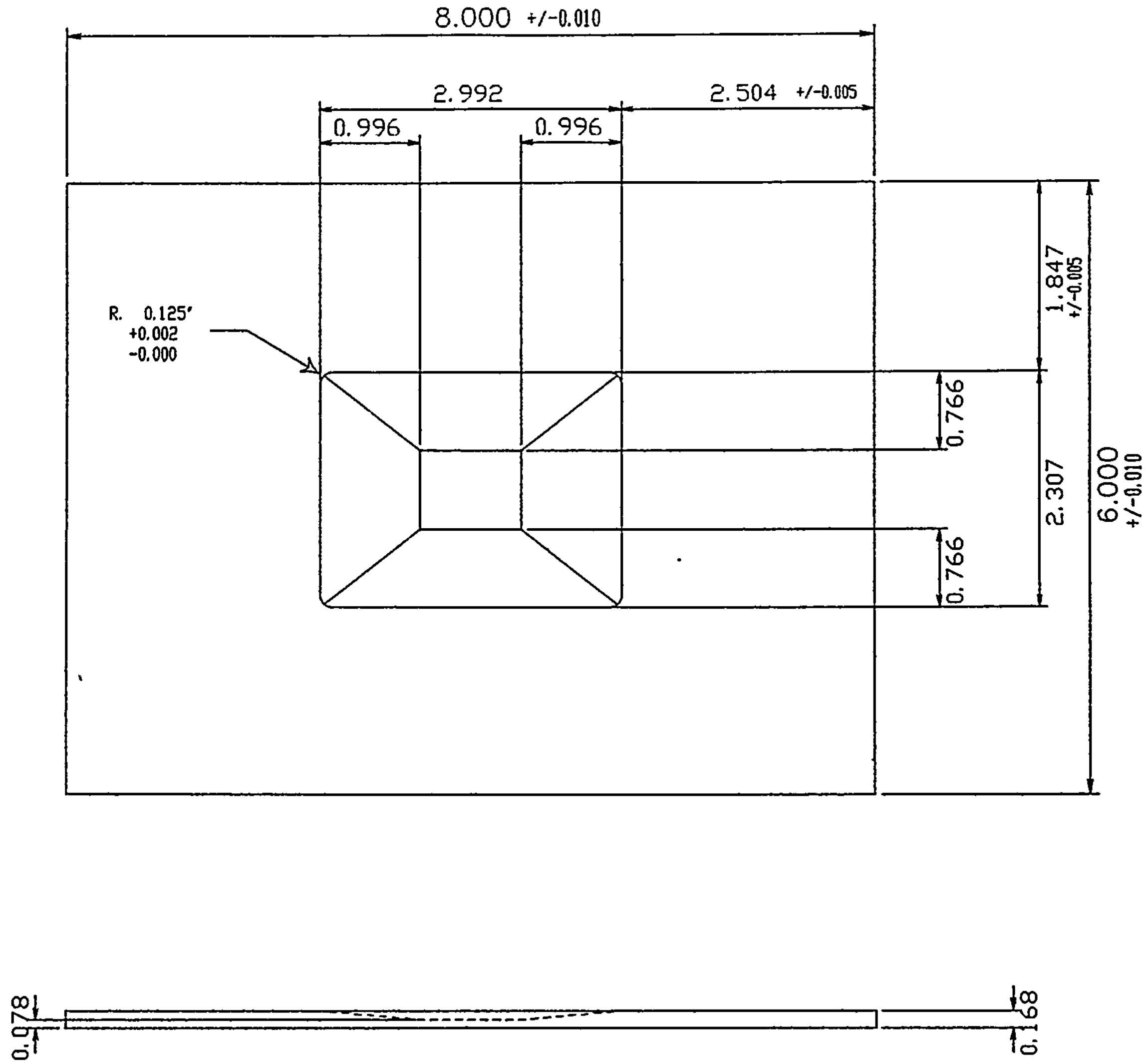
Fig. A.8. Dished frame design from lots 17 and 18.



Estimated nominal values

Compact size (in): L 2.985 +/– 0.010, W 2.294 +/– 0.010,
max thickness – 0.212 to 0.245

Fig. A.9. Compact configuration design for lots 23–25.



NOTES:
1. ALL TOLERANCES +/- 0.001" UNLESS OTHERWISE NOTED.
2. HANDWORK INSIDE CORNERS AS NECESSARY.

MATERIAL: ALUMINUM ALLOY 6061-0

Fig. A.10. Dished frame design for centered compacts.

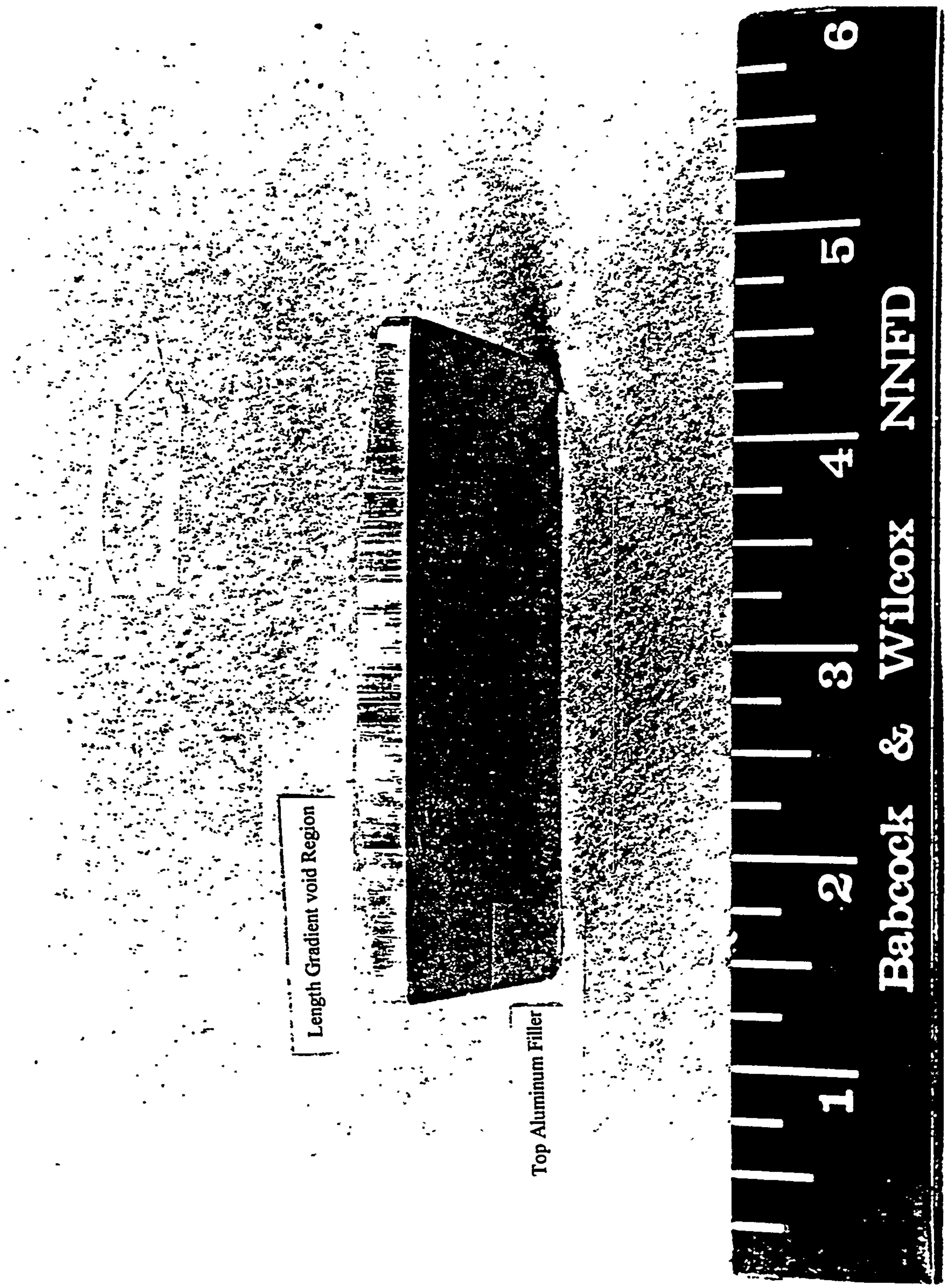


Fig. A.11. Photograph of lot 12 compact.

Appendix B. CORE CONFIGURATIONS

LOT	CORE CONFIGURATION	U3Si2	Al matrix	Loading	U Vol %
		gms	gms	gU/cc	ccU/cc
132-01	6 inch die, dual gradient	28.01	14.45	1.3	30.0%
132-02	6 inch die, dual gradient	22.41	11.58	1.05	30.0%
123-03	6 inch die, dual gradient	33.11	16.82	1.55	30.0%
132-04	6 inch die, dual gradient	28.01	14.45	1.3	30.0%
132-05	6 inch die, dual gradient	22.41	11.58	1.05	30.0%
132-06	6 inch die, dual gradient	33.11	16.82	1.55	30.0%
132-07	HFIR die, single gradient, U3Si2	23.43	37.5	1.37	12.1%
132-08	HFIR die, single gradient, U3Si2	23.34	37.51	1.36	12.1%
132-09	HFIR die, single gradient, U3Si2	23.18	37.44	1.35	12.3%
132-10	HFIR die, dual gradient, U3Si2, graded bottom punch for length contour	23.18	37.44	1.35	12.3%
132-11	not used				
132-12	Dual gradient, void on length gradient	22.96	38.27	1.31	12.2%
132-13	Dual gradient, swept Al powder on length gradient	22.96	38.27	1.31	12.2%
132-14	Dual gradient, wedge inserts on length gradient	22.96	38.27	1.31	12.2%
132-15	Dual gradient, sprayed aluminum on length gradient	22.96	38.27	1.31	12.2%
132-16	Dual gradient, sprayed aluminum on length gradient in frames	22.96	38.27	1.31	12.2%
132-17	Dual gradient, wedges machined into frame on length gradient	22.96	38.27	1.31	12.2%
132-18	Dual gradient, wedges machined into frame on length gradient	22.96	38.27	1.31	12.2%
132-19	Dual gradient, wedge inserts on length gradient	29.67	36.81	1.7	15.4%
132-20	Dual gradient, wedge inserts on length gradient	52.37	31.7	3	27.1%
132-21	Dual gradient, wedge inserts on length gradient	61.1	29.74	3.5	31.6%
132-22	Dual gradient, wedge inserts on length gradient	83.79	24.63	4.8	43.4%
132-23	Dual gradient, centered fuel, symetrical compact	48.88	32.49	2.8	25.3%
132-24	Dual gradient, centered fuel, symetrical compact	52.37	31.7	3	27.1%
132-25	Dual gradient, centered fuel, symetrical compact	61.1	29.74	3.5	31.6%
132-26	Dual gradient, wedge inserts on length gradient,spherical fuel	52.73	31.57	3	27.4%
132-27	Dual gradient, wedge inserts on length gradient,spherical fuel	84.36	24.42	4.8	43.9%

Appendix C. DESTRUCTIVE EVALUATION

Appendix C. DESTRUCTIVE EVALUATION

The following pages include the details of the ANS development plate and compact destructive evaluations that were performed.

Section C.1 shows the instructions for DE of both plates and compacts.

Section C.2 contains the DE results for plates as well as selected photos of different DE sections. The top layer of filler aluminum and the bottom wedge insert are evident in these sections. Both cross sections, T-20 and T-18, show the graded top aluminum filler across the width of the plate from the x-end (left core edge) to the middle, to the y-end (opposite edge). Looking from section T-20 on the end of the core to section T-18 which is more towards the longitudinal center of the core the wedge decreases as the core becomes thicker.

Section C.3 contains the DE results for a compact.

Section C.4 is comprised of a comparison between the design compact thicknesses at given points and the corresponding fuel core thicknesses. Scale is 10 on graph equals 0.010 inches.

C.1 DE INSTRUCTIONS

NOTES:

RECORD EXACT LOCATION OF ALL SECTIONS RELATIVE TO THE ID END.
THERE ARE 23 TOTAL PLANES OF EVALUATION.

ALL TRANSVERSE SECTIONS SHALL HAVE 10 EQUALLY SPACED READINGS WITH THE FIRST AND THE LAST READING BEING ON THE OUTER EDGE OF THE FUEL. NOTATE THE EXACT SPACING USED.

THE MEASUREMENTS ON THE THREE PLANES OF EVALUATION LOCATED AT EACH END SHALL HAVE A MAXIMUM AND MINIMUM CORE THICKNESS AND THE LOCATION FOR EACH SECTION.

23 TOTAL TRANSVERSE SECTIONS.

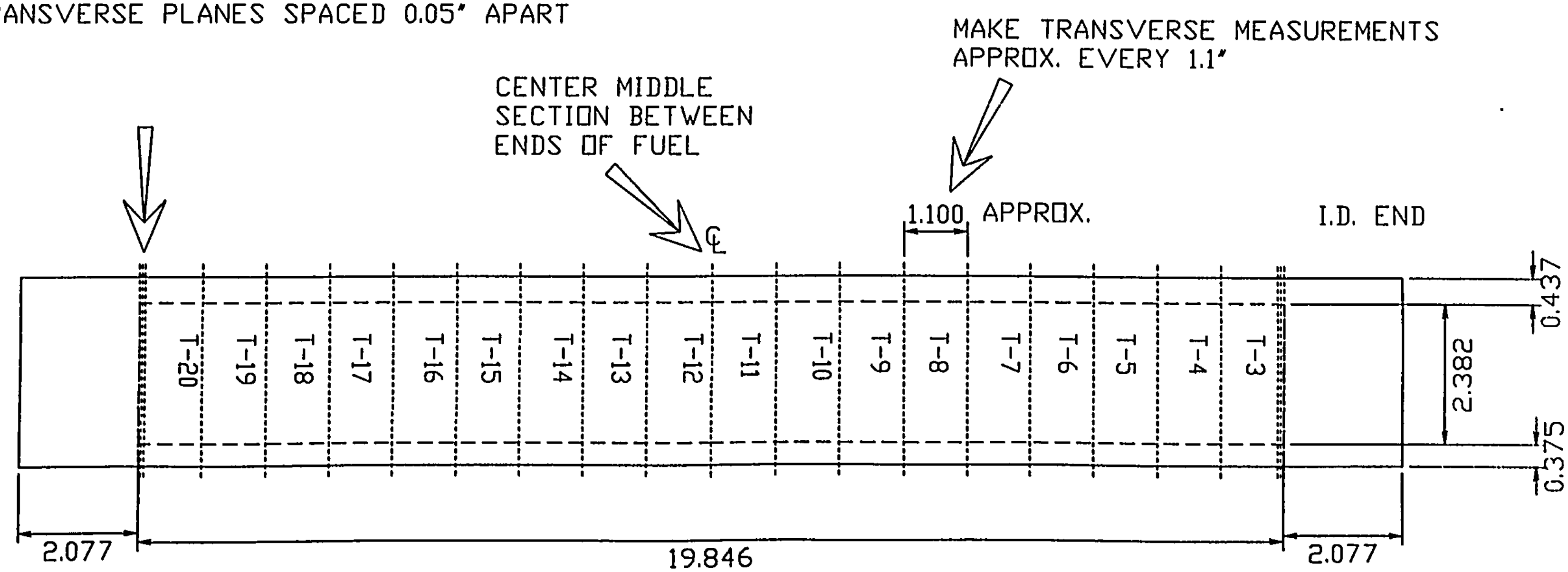
ALL INFORMATION IS NEEDED SO THAT THE DATA MAY BE ACCURATELY PLOTTED AND STUDIED.

TAKE PHOTOGRAPHS OF SIMILAR PORTIONS OF MOST TRANSVERSE SECTIONS. ADDITIONAL PHOTOS SHOWING THE FULL SECTION OF SELECTED SECTIONS SHOULD ALSO BE TAKEN AT THE DISCRETION OF THE LAB TECH. PHOTOS REQUIRED OF PARTIAL SECTIONS FOR PLATES:

132-020-01
132-022-01

SECTIONS: T-1, T-2, T-3, T-4, T-6, T-11, & T-12.

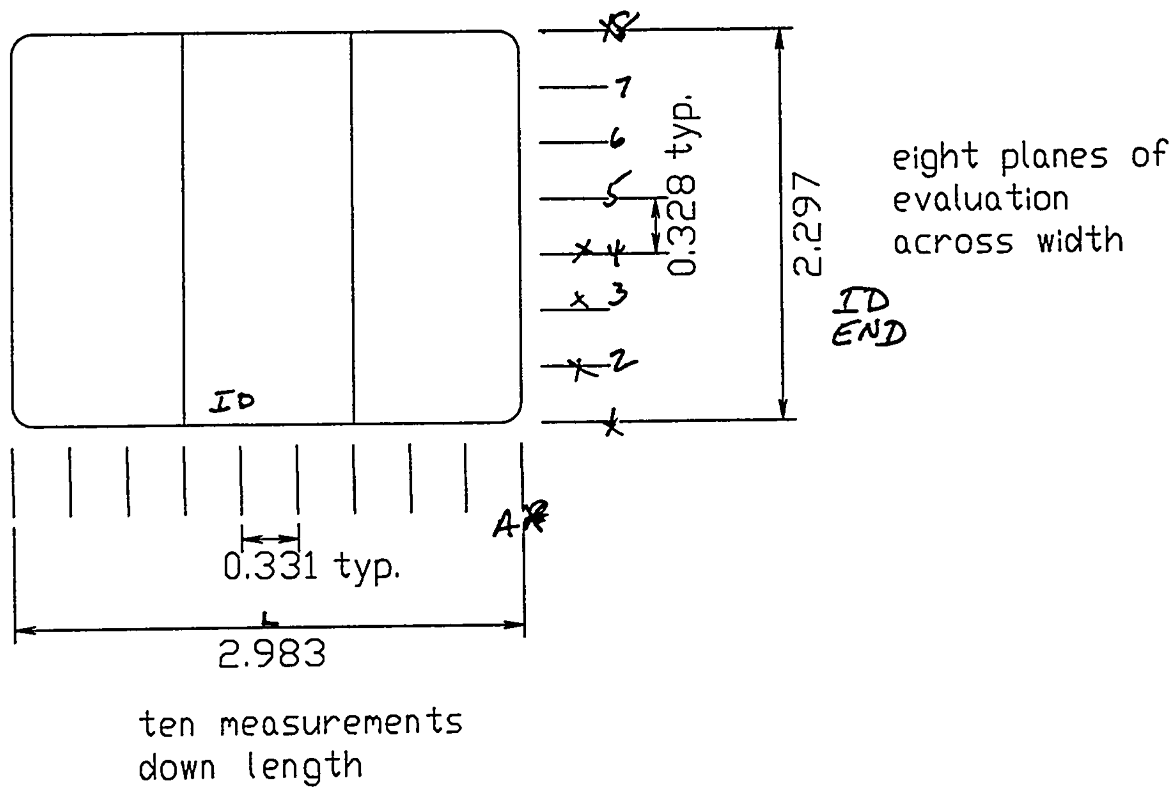
ON EACH END, GRIND TO FUEL THEN TAKE 3 TRANSVERSE PLANES SPACED 0.05" APART



DE COMPACT 132-12-01 FOR ALUMINUM FILLER AND SILICIDE POWDER THICKNESS

INCREMENTAL GRIND EDGES (FIRST AND LAST EVALUATION PLANES) TO ENSURE ACCURATE MEASUREMENT AND TO CLEAR ANY SMEARED FUEL.

PHOTOGRAPH SHALL BE TAKEN AT OPERATORS DISCRETION.



C.2 PLATE DE RESULTS

Prog: OPCOMP	RTRFE - QC	Date:02/14/94
	MET LAB DE INSPECTION DATA	Time:13:35
Rev. 0	ALUMINUM FUEL PLATES (ALL TYPES)	

Plate No.132-0014-03 NPN No. E77

PLATE SUMMARY

SECTION	CLAD-CORE-CLAD DIMENSIONS	---------- GRAIN GROWTH ---------- CLAD / FRAME	CLAD / CORE
T- 1	Accept	N/A	N/A
T- 2	Accept	N/A	N/A
T- 3	Accept	N/A	N/A
T- 4	Accept	N/A	N/A
T- 5	Accept	N/A	N/A
T- 6	Accept	N/A	N/A
T- 7	Accept	N/A	N/A
T- 8	Accept	N/A	N/A
T- 9	Accept	N/A	N/A
T-10	Accept	N/A	N/A
T-11	Accept	N/A	N/A
T-12	Accept	N/A	N/A
T-13	Accept	N/A	N/A
T-14	Accept	N/A	N/A
T-15	Accept	N/A	N/A
T-16	Accept	N/A	N/A
T-17	Accept	N/A	N/A
T-18	Accept	N/A	N/A
T-19	Accept	N/A	N/A
T-20	Accept	N/A	N/A
T-21	Accept	N/A	N/A
T-22	Accept	N/A	N/A
T-23	Accept	N/A	N/A

PLATE LIMITS:

PLATE AVERAGES:

Avg Top Clad	10.5
Avg Core Thk	18.7
Avg Bot Clad	17.3
Avg Plate Thk	52.3
Avg Clad Diff	6.8

PLATE MINIMUM:

Minimum Clad 8.4

CLAD-CORE-CLAD
INSPECTOR: J. J. CALLAHAN DATE: 02/10/94

AUDITOR: V. D. DOWNS DATE: 02/14/94

Prog: OPCOMP	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:02/14/94 Time:13:35
Rev. 0		

Plate No.132-0014-03 NPN No. E77

TRANSVERSE CLAD-CORE-CLAD DIMENSIONS (in mils)

SECTION T- 1 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.4	11.3	10.4	10.8	11.1	9.8	10.9	10.3	10.0	10.2	10.6
Fill Thk	3.2	3.3	0.6	0.5	0.5	3.0	1.4	5.7	9.6	9.6	3.7
Core Thk	3.7	13.6	17.6	18.2	16.5	15.4	16.7	13.2	8.3	4.2	12.7
Bot Clad	34.0	24.1	23.7	22.8	24.2	24.1	23.3	23.1	24.4	28.3	25.2
Plate Thk	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3

Core Width = 2178.0 Top Min Clad = 9.8 Bot Min Clad = 21.2

SECTION T- 2 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.1	10.3	9.6	9.1	9.1	9.4	9.8	9.8	10.8	10.3	9.9
Fill Thk	5.1	3.7	2.5	1.8	2.4	2.1	3.7	5.6	9.0	11.0	4.7
Core Thk	13.8	14.7	16.0	18.0	16.8	17.6	15.3	12.9	9.7	8.4	14.3
Bot Clad	22.4	23.6	24.2	23.5	24.1	23.3	23.5	24.1	22.9	22.7	23.4
Plate Thk	52.4	52.3	52.3	52.4	52.4	52.4	52.3	52.4	52.4	52.4	52.4

Core Width = 2232.1 Top Min Clad = 9.1 Bot Min Clad = 21.8

SECTION T- 3 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.6	9.9	9.4	10.0	9.8	10.0	9.4	10.2	10.2	10.7	10.[illegible]
Fill Thk	6.8	4.7	3.5	1.7	2.4	2.4	3.4	5.4	10.0	10.7	5.[illegible]
Core Thk	12.5	13.6	16.2	17.0	15.4	15.9	16.2	13.4	8.4	7.4	13.[illegible]
Bot Clad	22.3	24.0	23.1	23.4	24.6	23.9	23.2	23.2	23.6	23.4	23.[illegible]
Plate Thk	52.2	52.2	52.2	52.1	52.2	52.2	52.2	52.2	52.2	52.2	52.[illegible]

Core Width = 2263.7 Top Min Clad = 9.4 Bot Min Clad = 21.1

SECTION T- 4 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG
Top Clad	9.7	9.8	10.7	10.5	11.4	10.1	10.3	10.2	10.6	10.2	10.[illegible]
Fill Thk	7.7	6.7	4.6	2.5	2.5	2.7	3.2	6.4	10.1	12.6	5.[illegible]
Core Thk	13.2	14.7	15.6	17.5	18.1	17.8	18.0	14.9	11.5	9.2	15.[illegible]
Bot Clad	21.6	21.0	21.2	21.7	20.2	21.6	20.7	20.7	20.1	20.2	20.[illegible]
Plate Thk	52.2	52.2	52.1	52.2	52.2	52.2	52.2	52.2	52.3	52.2	52.[illegible]

Core Width = 2375.3 Top Min Clad = 9.7 Bot Min Clad = 18.0

SECTION T- 5 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG
Top Clad	9.9	9.8	10.9	10.7	10.2	10.2	10.2	9.8	9.8	10.4	10.[illegible]
Fill Thk	8.4	5.9	3.9	2.1	2.3	2.8	3.1	6.1	10.1	13.0	5.[illegible]
Core Thk	13.5	16.5	17.6	20.1	19.5	19.8	19.5	17.0	13.0	8.9	16.[illegible]
Bot Clad	20.5	20.0	19.8	19.4	20.3	19.4	19.4	19.4	19.4	20.0	19.[illegible]
Plate Thk	52.3	52.2	52.2	52.3	52.3	52.2	52.2	52.3	52.3	52.3	52.[illegible]

Core Width = 2379.4 Top Min Clad = 9.8 Bot Min Clad = 17.1

Prog: OPCOMP Rev. 0	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:02/14/94 Time:13:35

Plate No.132-0014-03 NPN No. E77

SECTION T- 6 --------------------- Station ID ---------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.2	10.1	10.0	10.6	11.3	10.1	10.7	10.6	10.6	10.3	10.6
Fill Thk	6.5	6.3	4.5	2.5	2.4	2.5	3.0	6.7	11.1	14.4	6.0
Core Thk	16.2	17.9	19.2	21.2	20.1	21.7	20.6	17.8	13.2	10.2	17.8
Bot Clad	18.4	18.0	18.5	18.0	18.5	18.0	18.0	17.2	17.4	17.4	17.9
Plate Thk	52.3	52.3	52.2	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3

Core Width = 2374.3 Top Min Clad = 10.1 Bot Min Clad = 14.7

SECTION T- 7 --------------------- Station ID ---------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.9	9.6	9.9	11.1	9.6	10.6	10.3	10.2	9.8	10.9	10.3
Fill Thk	8.5	7.1	4.8	2.7	3.1	2.6	2.7	7.0	10.7	14.4	6.4
Core Thk	17.2	19.4	21.8	22.2	23.4	22.6	23.8	18.9	15.4	11.0	19.6
Bot Clad	15.7	16.2	15.8	16.3	16.2	16.5	15.5	16.2	16.4	16.0	16.1
Plate Thk	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3

Core Width = 2371.0 Top Min Clad = 9.6 Bot Min Clad = 13.6

SECTION T- 8 --------------------- Station ID ---------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.7	10.2	10.8	10.2	9.8	10.5	10.9	10.2	10.5	11.4	10.5
Fill Thk	8.0	6.6	4.6	3.3	3.3	2.2	2.3	5.2	10.9	14.0	6.0
Core Thk	18.6	20.2	22.2	23.5	24.0	25.5	24.3	22.3	15.8	12.0	20.8
Bot Clad	15.0	15.3	14.7	15.3	15.2	14.1	14.8	14.6	15.1	14.9	14.9
Plate Thk	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3

Core Width = 2363.2 Top Min Clad = 9.8 Bot Min Clad = 12.3

SECTION T- 9 --------------------- Station ID ---------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.7	11.2	10.2	10.6	10.4	10.8	11.5	10.7	10.7	10.8	10.8
Fill Thk	9.0	6.9	4.9	2.0	2.1	3.5	3.4	6.2	11.7	17.1	6.7
Core Thk	20.7	21.4	24.9	27.3	27.3	25.5	25.3	23.3	17.9	12.3	22.6
Bot Clad	11.9	12.8	12.3	12.4	12.5	12.5	12.1	12.1	12.0	12.1	12.3
Plate Thk	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3

Core Width = 2353.0 Top Min Clad = 10.2 Bot Min Clad = 10.1

SECTION T-10 --------------------- Station ID ---------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.9	11.4	10.2	10.3	10.6	10.6	10.6	11.1	10.4	11.9	10.8
Fill Thk	8.6	6.2	4.8	2.8	2.6	2.0	2.1	6.5	11.6	16.8	6.4
Core Thk	21.5	23.3	26.5	28.6	27.9	28.7	28.6	23.9	18.9	12.5	24.0
Bot Clad	11.3	11.4	10.8	10.6	11.2	11.0	11.0	10.8	11.4	11.1	11.[illegible]
Plate Thk	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.[illegible]

Core Width = 2374.3 Top Min Clad = 10.2 Bot Min Clad = 8.4

Prog: OPCOMP	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:02/14/94 Time:13:35
Rev. 0		

Plate No.132-0014-03 NPN No. E77

SECTION T-11 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.3	10.5	10.2	10.3	11.3	10.5	10.0	9.6	10.1	11.3	10.5
Fill Thk	9.3	6.9	5.5	4.1	2.0	3.1	2.4	7.1	13.0	17.3	7.1
Core Thk	21.1	23.9	25.0	26.5	28.3	27.7	28.6	24.6	18.0	12.4	23.6
Bot Clad	10.6	11.0	11.6	11.4	10.6	11.0	11.2	11.0	11.2	11.3	11.1
Plate Thk	52.3	52.3	52.3	52.3	52.2	52.3	52.2	52.3	52.3	52.3	52.3

Core Width = 2349.0 Top Min Clad = 9.6 Bot Min Clad = 8.5

SECTION T-12 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.0	10.5	10.2	10.7	10.6	10.0	10.6	10.9	10.2	11.0	10.6
Fill Thk	9.9	8.7	5.1	2.4	2.5	2.5	3.1	5.5	11.6	17.9	6.9
Core Thk	20.9	22.3	26.2	29.1	28.9	28.8	26.9	24.8	19.2	12.8	24.0
Bot Clad	10.5	10.8	10.9	10.1	10.4	11.0	11.7	11.2	11.3	10.6	10.9
Plate Thk	52.3	52.3	52.4	52.3	52.4	52.3	52.3	52.4	52.3	52.3	52.3

Core Width = 2349.3 Top Min Clad = 10.1 Bot Min Clad = 9.0

SECTION T-13 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.9	10.6	11.2	10.1	9.9	10.1	10.5	10.2	10.5	11.6	10.6
Fill Thk	11.4	6.6	4.5	2.5	2.4	1.8	3.6	6.0	13.1	18.6	7.1
Core Thk	19.4	23.8	25.9	28.9	29.8	29.0	27.1	23.9	17.5	11.4	23.7
Bot Clad	10.6	11.4	10.8	10.9	10.3	11.5	11.2	12.3	11.3	10.8	11.1
Plate Thk	52.3	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2352.4 Top Min Clad = 9.9 Bot Min Clad = 8.5

SECTION T-14 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.9	11.4	10.9	10.8	10.5	10.1	10.4	10.7	10.2	12.0	10.8
Fill Thk	10.4	7.0	4.0	3.1	2.3	2.5	2.5	7.0	12.7	17.8	6.9
Core Thk	20.4	22.5	26.0	27.8	28.1	29.4	29.5	24.1	18.8	11.7	23.8
Bot Clad	10.7	11.5	11.5	10.7	11.5	10.4	10.0	10.6	10.7	10.9	10.9
Plate Thk	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2357.7 Top Min Clad = 10.2 Bot Min Clad = 8.7

SECTION T-15 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.4	10.3	10.5	10.2	10.3	10.2	9.8	9.7	11.2	11.2	10.4
Fill Thk	9.0	6.5	3.6	3.2	2.1	2.4	2.0	5.8	10.3	16.0	6.1
Core Thk	21.1	23.6	26.0	26.7	27.7	27.6	28.3	24.5	18.7	14.1	23.8
Bot Clad	11.9	12.0	12.3	12.3	12.3	12.1	12.3	12.4	12.2	11.1	12.1
Plate Thk	52.4	52.4	52.4	52.4	52.4	52.3	52.4	52.4	52.4	52.4	52.4

Core Width = 2369.7 Top Min Clad = 9.8 Bot Min Clad = 9.2

Prog: OPCOMP	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:02/14/94 Time:13:35
Rev. 0		

Plate No.132-0014-03 NPN No. E77

SECTION T-16 ---------- Station ID ----------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.0	9.9	10.0	9.9	9.8	9.4	9.8	10.3	9.8	11.0	10.1
Fill Thk	8.6	6.3	4.6	2.2	1.6	2.1	3.3	4.9	11.6	15.3	6.1
Core Thk	19.4	21.6	23.2	26.2	26.6	26.7	25.8	22.5	16.5	12.9	22.1
Bot Clad	13.3	14.6	14.6	14.1	14.4	14.1	13.5	14.7	14.5	13.2	14.1
Plate Thk	52.3	52.4	52.4	52.4	52.4	52.3	52.4	52.4	52.4	52.4	52.4

Core Width = 2382.6 Top Min Clad = 9.4 Bot Min Clad = 11.3

SECTION T-17 ---------- Station ID ----------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.2	10.1	9.7	9.0	10.9	10.1	10.5	9.7	10.0	9.8	10.0
Fill Thk	8.3	5.7	5.5	2.7	2.2	2.5	1.8	6.3	10.3	14.8	6.0
Core Thk	18.1	19.9	21.3	24.5	22.3	23.1	24.2	19.7	15.7	11.8	20.1
Bot Clad	15.8	16.7	15.9	16.2	17.0	16.7	15.9	16.7	16.4	16.0	16.3
Plate Thk	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2397.0 Top Min Clad = 9.0 Bot Min Clad = 14.0

SECTION T-18 ---------- Station ID ----------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.9	10.7	10.2	10.1	9.9	9.1	10.5	9.8	10.2	11.7	10.2
Fill Thk	8.4	6.9	4.5	2.3	2.5	2.2	3.0	5.6	9.9	14.3	6.0
Core Thk	16.3	17.0	19.5	22.6	22.4	23.0	20.8	19.0	14.5	9.7	18.5
Bot Clad	17.8	17.8	18.2	17.4	17.6	18.1	18.1	18.0	17.8	16.7	17.8
Plate Thk	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2400.2 Top Min Clad = 9.1 Bot Min Clad = 15.7

SECTION T-19 ---------- Station ID ----------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.4	10.6	10.1	10.7	10.0	10.1	9.4	9.8	9.4	9.9	10.0
Fill Thk	8.8	6.6	4.1	2.0	2.0	1.6	2.9	7.4	10.5	15.5	6.1
Core Thk	14.6	15.6	18.8	20.8	21.5	22.3	21.3	16.3	13.2	8.1	17.3
Bot Clad	18.6	19.6	19.4	18.9	18.9	18.4	18.8	18.9	19.3	18.9	19.0
Plate Thk	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2400.1 Top Min Clad = 9.4 Bot Min Clad = 16.8

SECTION T-20 ---------- Station ID ----------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.4	10.0	10.2	10.0	10.2	10.3	10.1	11.0	10.8	10.3	10.4
Fill Thk	7.3	6.4	4.7	2.9	3.1	2.1	3.4	6.7	11.0	12.8	6.0
Core Thk	11.6	14.1	15.5	17.6	17.3	18.3	17.2	13.6	9.6	7.4	14.2
Bot Clad	22.1	21.9	22.0	21.9	21.8	21.7	21.7	21.1	21.0	21.9	21.7
Plate Thk	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2393.6 Top Min Clad = 10.0 Bot Min Clad = 20.0

Prog: OPCOMP Rev. 0	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:02/14/94 Time:13:35

Plate No.132-0014-03 NPN No. E77

SECTION T-21

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.7	10.2	10.6	11.0	10.6	10.6	11.8	11.1	10.2	11.5	10.8
Fill Thk	11.1	3.6	3.4	2.2	2.6	2.5	1.3	5.9	8.9	11.5	5.3
Core Thk	8.6	16.0	16.2	18.5	16.3	17.8	17.1	14.0	11.4	7.1	14.3
Bot Clad	22.0	22.6	22.2	20.7	22.9	21.5	22.2	21.4	21.9	22.3	22.0
Plate Thk	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2271.0 Top Min Clad = 10.2 Bot Min Clad = 19.7

SECTION T-22

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.6	10.9	11.7	10.1	9.7	10.3	10.6	10.7	11.5	10.7	10.7
Fill Thk	6.7	3.7	2.7	2.3	1.8	2.0	3.1	5.7	8.7	11.3	4.8
Core Thk	11.7	15.5	16.5	17.8	17.6	17.9	17.6	14.2	11.3	9.4	15.0
Bot Clad	23.4	22.3	21.5	22.2	23.3	22.2	21.1	21.8	20.9	21.0	22.0
Plate Thk	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2245.6 Top Min Clad = 9.7 Bot Min Clad = 20.0

SECTION T-23

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.1	11.7	10.8	11.7	10.9	11.3	11.4	11.8	11.7	11.8	11.4
Fill Thk	6.0	3.5	2.3	1.4	1.1	2.2	1.8	5.1	7.1	8.5	3.9
Core Thk	11.5	15.3	17.8	17.8	19.0	17.6	18.2	13.4	4.3	2.8	13.8
Bot Clad	23.8	21.9	21.5	21.5	21.3	21.3	21.0	22.1	29.3	29.3	23.3
Plate Thk	52.4	52.4	52.4	52.4	52.3	52.4	52.4	52.4	52.4	52.4	52.4

Core Width = 2192.4 Top Min Clad = 10.9 Bot Min Clad = 20.0

LONGITUDINAL CLAD-CORE-CLAD DIMENSIONS (in mils)

Prog: OPCOMP Rev. 1.0	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:04/28/94 Time:11:43

Plate No.132-0017-02 NPN No. E77

PLATE SUMMARY

SECTION	CLAD-CORE-CLAD DIMENSIONS	GRAIN GROWTH CLAD / FRAME	GRAIN GROWTH CLAD / CORE
T- 1	Accept	N/A	N/A
T- 2	Accept	N/A	N/A
T- 3	Accept	N/A	N/A
T- 4	Accept	N/A	N/A
T- 5	Accept	N/A	N/A
T- 6	Accept	N/A	N/A
T- 7	Accept	N/A	N/A
T- 8	Accept	N/A	N/A
T- 9	Accept	N/A	N/A
T-10	Accept	N/A	N/A
T-11	Accept	N/A	N/A
T-12	Accept	N/A	N/A
T-13	Accept	N/A	N/A
T-14	Accept	N/A	N/A
T-15	Accept	N/A	N/A
T-16	Accept	N/A	N/A
T-17	Accept	N/A	N/A
T-18	Accept	N/A	N/A
T-19	Accept	N/A	N/A
T-20	Accept	N/A	N/A
T-21	Accept	N/A	N/A
T-22	Accept	N/A	N/A
T-23	Accept	N/A	N/A

PLATE LIMITS:

PLATE AVERAGES:

Avg Top Clad	10.4
Avg Core Thk	18.8
Avg Bot Clad	17.7
Avg Plate Thk	52.7
Avg Clad Diff	7.3

PLATE MINIMUM:

Minimum Clad 8.3

CLAD-CORE-CLAD
INSPECTOR: J. J. CALLAHAN DATE: 04/25/94

AUDITOR: V. D. DOWNS DATE: 04/28/94

Prog: OPCOMP	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:04/28/94 Time:11:43
Rev. 1.0		

Plate No.132-0017-02 NPN No. E77

TRANSVERSE CLAD-CORE-CLAD DIMENSIONS (in mils)

SECTION T- 1 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.9	11.3	11.7	10.7	10.9	9.9	10.1	10.8	10.8	10.9	10.8
Fill Thk	5.7	5.4	1.5	1.1	2.1	2.0	1.5	2.7	6.4	6.5	3.5
Core Thk	5.6	6.5	12.8	16.1	15.6	16.1	17.0	15.1	10.9	10.2	12.6
Bot Clad	30.5	29.6	26.8	24.8	24.2	24.8	24.2	24.1	24.6	25.2	25.9
Plate Thk	52.7	52.8	52.8	52.7	52.8	52.8	52.8	52.7	52.7	52.8	52.8

Core Width = 2197.8 Top Min Clad = 9.9 Bot Min Clad = 22.4

SECTION T- 2 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	12.5	10.9	10.8	10.6	10.5	11.3	10.8	10.8	10.6	11.9	11.1
Fill Thk	8.2	7.0	3.5	2.4	1.4	2.9	2.5	3.2	6.0	5.9	4.3
Core Thk	7.1	10.6	13.7	15.7	17.1	15.3	15.8	15.1	11.4	10.4	13.2
Bot Clad	25.0	24.3	24.8	24.1	23.8	23.2	23.6	23.6	24.8	24.5	24.2
Plate Thk	52.8	52.8	52.8	52.8	52.8	52.7	52.7	52.7	52.8	52.7	52.8

Core Width = 2241.1 Top Min Clad = 10.5 Bot Min Clad = 22.0

SECTION T- 3 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.2	10.8	10.6	10.3	11.1	11.0	10.8	10.2	9.9	10.5	10.5
Fill Thk	11.2	7.0	4.3	2.6	1.8	2.7	3.1	3.7	6.8	7.3	5.1
Core Thk	6.5	9.9	13.9	15.8	15.5	14.9	15.2	15.8	11.3	9.4	12.8
Bot Clad	24.7	24.9	23.8	23.8	24.1	23.9	23.5	22.8	24.5	25.3	24.1
Plate Thk	52.6	52.6	52.6	52.5	52.5	52.5	52.6	52.5	52.5	52.5	52.5

Core Width = 2259.3 Top Min Clad = 9.9 Bot Min Clad = 20.5

SECTION T- 4 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.2	10.2	10.1	9.9	10.6	10.6	10.6	10.2	10.5	10.1	10.3
Fill Thk	12.0	10.4	5.7	2.9	2.3	1.9	2.5	4.2	5.7	8.2	5.6
Core Thk	7.9	10.1	14.8	17.8	18.2	18.6	18.9	17.5	14.7	11.9	15.0
Bot Clad	22.6	21.9	22.0	21.9	21.5	21.4	20.6	20.7	21.7	22.4	21.7
Plate Thk	52.7	52.6	52.6	52.5	52.6	52.5	52.6	52.6	52.6	52.6	52.6

Core Width = 2372.9 Top Min Clad = 9.9 Bot Min Clad = 18.6

SECTION T- 5 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.7	9.5	9.6	9.4	9.5	10.7	10.2	9.8	9.5	10.2	9.9
Fill Thk	13.3	10.7	6.9	3.2	3.3	1.9	1.9	4.9	6.3	8.6	6.1
Core Thk	9.5	12.6	16.4	20.6	20.4	20.3	21.0	18.3	17.5	13.6	17.0
Bot Clad	19.2	19.8	19.7	19.4	19.5	19.7	19.6	19.7	19.3	20.2	19.6
Plate Thk	52.7	52.6	52.6	52.6	52.7	52.6	52.7	52.7	52.6	52.6	52.6

Core Width = 2373.0 Top Min Clad = 9.4 Bot Min Clad = 16.7

Prog: OPCOMP
Rev. 1.0

RTRFE - QC
MET LAB DE INSPECTION DATA
ALUMINUM FUEL PLATES (ALL TYPES)

Date:04/28/94
Time:11:43

Plate No.132-0017-02 NPN No. E77

SECTION T- 6 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.8	9.8	9.5	10.2	10.3	10.2	10.2	10.6	10.5	9.4	10.2
Fill Thk	13.5	9.5	6.9	2.7	2.4	2.8	2.3	3.4	6.2	8.1	5.8
Core Thk	10.7	15.3	18.3	21.9	21.7	22.0	22.4	21.6	19.2	18.1	19.1
Bot Clad	17.7	18.1	17.9	17.9	18.3	17.7	17.7	17.1	16.9	17.1	17.6
Plate Thk	52.7	52.7	52.6	52.7	52.7	52.7	52.6	52.7	52.8	52.7	52.7

Core Width = 2367.5 Top Min Clad = 9.4 Bot Min Clad = 15.3

SECTION T- 7 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.4	10.2	10.3	10.6	10.0	10.3	9.9	11.2	10.6	10.6	10.4
Fill Thk	14.6	11.6	6.0	2.0	2.4	2.6	2.7	3.9	6.8	7.9	6.1
Core Thk	12.2	15.4	21.0	24.5	25.1	23.6	24.3	22.2	20.7	18.5	20.8
Bot Clad	15.5	15.6	15.5	15.5	15.3	16.2	15.8	15.4	14.6	15.6	15.5
Plate Thk	52.7	52.8	52.8	52.6	52.8	52.7	52.7	52.7	52.7	52.6	52.7

Core Width = 2364.4 Top Min Clad = 9.9 Bot Min Clad = 12.9

SECTION T- 8 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.6	10.4	10.6	10.8	10.6	11.0	10.6	10.6	10.0	11.3	10.7
Fill Thk	15.1	11.4	6.7	2.3	2.3	3.3	2.8	4.8	8.7	9.0	6.6
Core Thk	13.7	17.4	22.0	26.2	25.8	24.9	25.5	24.5	21.0	19.2	22.0
Bot Clad	13.3	13.5	13.4	13.4	14.0	13.5	13.8	12.8	13.0	13.2	13.4
Plate Thk	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7

Core Width = 2355.8 Top Min Clad = 10.0 Bot Min Clad = 10.9

SECTION T- 9 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.9	11.2	10.9	10.6	10.9	9.9	10.6	11.1	10.6	10.7	10.7
Fill Thk	15.4	12.5	6.3	2.5	1.7	2.5	2.4	4.0	6.8	9.3	6.3
Core Thk	15.8	17.0	23.2	27.5	29.0	28.6	28.1	26.8	24.2	21.4	24.2
Bot Clad	10.6	11.9	12.2	12.0	11.0	11.6	11.5	10.7	11.0	11.2	11.4
Plate Thk	52.7	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6	52.6

Core Width = 2345.7 Top Min Clad = 9.9 Bot Min Clad = 8.3

SECTION T-10 ---------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.9	10.6	10.6	10.8	10.6	10.7	10.9	10.7	10.9	10.9	10.8
Fill Thk	14.9	12.7	5.9	2.3	2.6	2.5	2.5	3.9	7.7	9.6	6.5
Core Thk	15.3	17.5	24.4	27.9	27.6	28.6	27.7	26.4	23.1	20.8	23.9
Bot Clad	11.6	11.9	11.8	11.6	11.9	10.9	11.6	11.7	11.0	11.4	11.5
Plate Thk	52.7	52.7	52.7	52.6	52.7	52.7	52.7	52.7	52.7	52.7	52.7

Core Width = 2343.3 Top Min Clad = 10.6 Bot Min Clad = 8.7

Prog: OPCOMP Rev. 1.0	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:04/28/94 Time:11:43

Plate No.132-0017-02   NPN No. E77

SECTION T-11 — Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.7	10.9	10.6	10.9	10.7	9.9	10.4	10.8	10.9	10.2	10.6
Fill Thk	15.2	12.2	5.9	2.6	2.7	2.1	2.7	4.0	7.5	9.3	6.4
Core Thk	15.0	17.9	24.4	27.7	27.9	29.2	28.1	26.9	23.2	21.3	24.2
Bot Clad	11.8	11.7	11.8	11.5	11.4	11.5	11.5	11.0	11.1	11.8	11.5
Plate Thk	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.6	52.7

Core Width = 2338.3   Top Min Clad = 9.9   Bot Min Clad = 8.7

SECTION T-12 — Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.7	10.2	10.9	10.9	10.1	10.0	10.4	10.5	10.2	11.0	10.5
Fill Thk	15.8	12.9	6.6	2.4	2.6	1.7	2.6	4.0	8.5	8.3	6.5
Core Thk	14.3	18.1	24.0	27.3	28.9	29.7	28.2	26.7	23.1	22.0	24.2
Bot Clad	11.9	11.4	11.2	12.1	11.1	11.3	11.4	11.4	10.8	11.4	11.4
Plate Thk	52.7	52.6	52.7	52.7	52.7	52.7	52.6	52.6	52.6	52.7	52.7

Core Width = 2337.9   Top Min Clad = 10.0   Bot Min Clad = 8.9

SECTION T-13 — Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.6	11.3	11.1	11.3	10.9	11.1	11.0	10.4	11.2	10.6	11.0
Fill Thk	15.6	11.8	6.7	3.9	2.7	2.4	2.9	4.1	7.3	9.5	6.7
Core Thk	14.7	17.9	22.8	26.3	28.0	28.2	28.0	27.1	22.7	21.1	23.7
Bot Clad	11.8	11.6	12.0	11.2	11.1	11.0	10.8	11.1	11.4	11.5	11.4
Plate Thk	52.7	52.6	52.6	52.7	52.7	52.7	52.7	52.7	52.6	52.7	52.7

Core Width = 2339.0   Top Min Clad = 10.4   Bot Min Clad = 9.2

SECTION T-14 — Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.7	10.4	10.7	11.0	10.9	11.4	10.7	10.5	9.8	11.7	10.8
Fill Thk	15.2	12.4	7.1	2.6	2.3	2.2	1.9	4.4	8.9	9.9	6.7
Core Thk	14.7	18.5	23.9	27.5	28.0	28.2	28.4	26.8	22.5	19.7	23.8
Bot Clad	12.0	11.3	11.0	11.6	11.5	10.9	11.7	11.0	11.4	11.3	11.4
Plate Thk	52.6	52.6	52.7	52.7	52.7	52.7	52.7	52.7	52.6	52.6	52.7

Core Width = 2341.6   Top Min Clad = 9.8   Bot Min Clad = 8.8

SECTION T-15 — Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.0	11.0	10.7	11.1	11.3	10.6	10.2	10.3	10.9	10.7	10.8
Fill Thk	15.1	12.0	6.5	1.7	2.2	2.5	1.9	4.0	6.8	8.4	6.1
Core Thk	15.2	17.6	23.8	28.4	27.2	27.5	28.0	25.9	22.2	20.8	23.7
Bot Clad	11.4	12.1	11.6	11.5	11.9	12.0	12.5	12.4	12.7	12.8	12.1
Plate Thk	52.7	52.7	52.6	52.7	52.6	52.6	52.6	52.6	52.6	52.7	52.6

Core Width = 2344.9   Top Min Clad = 10.2   Bot Min Clad = 9.7

Prog: OPCOMP	RTRFE - QC MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Date:04/28/94 Time:11:43
Rev. 1.0		

Plate No.132-0017-02 NPN No. E77

SECTION T-16 -------------------- Station ID --------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.8	10.6	10.6	9.7	10.2	10.6	11.0	9.7	10.9	10.4	10.4
Fill Thk	16.3	10.5	5.8	3.5	2.6	2.1	1.7	4.3	6.3	8.3	6.1
Core Thk	12.8	17.0	21.9	25.5	25.5	25.3	25.8	24.0	20.6	19.4	21.8
Bot Clad	13.8	14.6	14.4	14.0	14.4	14.7	14.2	14.7	14.9	14.6	14.4
Plate Thk	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7

Core Width = 2361.0 Top Min Clad = 9.7 Bot Min Clad = 12.5

SECTION T-17 -------------------- Station ID --------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.5	10.9	10.2	10.5	10.4	9.9	9.6	10.4	9.7	10.5	10.2
Fill Thk	16.7	11.2	5.9	1.6	2.4	2.6	2.4	5.1	6.4	7.8	6.2
Core Thk	10.0	14.0	20.0	24.8	23.3	24.0	24.2	21.5	19.6	18.5	20.0
Bot Clad	16.5	16.5	16.6	15.7	16.6	16.2	16.4	15.7	17.0	15.9	16.3
Plate Thk	52.7	52.6	52.7	52.6	52.7	52.7	52.6	52.7	52.7	52.7	52.7

Core Width = 2375.8 Top Min Clad = 9.5 Bot Min Clad = 13.5

SECTION T-18 -------------------- Station ID --------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.8	10.0	10.1	10.4	9.4	9.7	10.6	9.8	9.9	10.6	10.0
Fill Thk	15.9	11.3	7.2	2.9	3.6	4.3	2.2	4.4	6.8	9.3	6.8
Core Thk	9.2	14.2	17.9	21.0	21.6	20.9	21.1	20.1	18.0	14.6	17.9
Bot Clad	17.7	17.2	17.5	18.4	18.1	17.8	18.8	18.3	18.0	18.2	18.0
Plate Thk	52.6	52.7	52.7	52.7	52.7	52.7	52.7	52.6	52.7	52.7	52.7

Core Width = 2386.8 Top Min Clad = 9.4 Bot Min Clad = 16.1

SECTION T-19 -------------------- Station ID --------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.8	9.8	9.9	10.2	10.0	10.7	10.6	11.0	10.7	10.6	10.3
Fill Thk	14.1	11.8	6.3	2.9	2.2	1.8	1.9	4.7	6.4	7.9	6.0
Core Thk	9.6	11.1	16.6	19.7	21.1	20.6	20.6	17.4	15.3	13.9	16.6
Bot Clad	19.2	20.0	19.9	19.8	19.3	19.5	19.5	19.6	20.3	20.3	19.7
Plate Thk	52.7	52.7	52.7	52.6	52.6	52.6	52.6	52.7	52.7	52.7	52.7

Core Width = 2391.0 Top Min Clad = 9.8 Bot Min Clad = 16.3

SECTION T-20 -------------------- Station ID --------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.4	9.9	10.4	9.8	10.2	9.9	9.9	10.6	9.5	9.1	9.9
Fill Thk	14.2	11.3	6.7	3.4	2.6	2.6	4.0	5.4	7.5	8.7	6.6
Core Thk	6.6	9.7	13.7	17.4	18.2	18.1	17.7	16.0	14.3	12.8	14.5
Bot Clad	22.5	21.7	21.8	22.1	21.6	22.0	21.1	20.7	21.4	22.0	21.7
Plate Thk	52.7	52.6	52.6	52.7	52.6	52.6	52.7	52.7	52.7	52.6	52.7

Core Width = 2386.0 Top Min Clad = 9.1 Bot Min Clad = 19.3

Prog: OPCOMP	RTRFE - QC	Date:04/28/94
Rev. 1.0	MET LAB DE INSPECTION DATA ALUMINUM FUEL PLATES (ALL TYPES)	Time:11:43

Plate No.132-0017-02 NPN No. E77

SECTION T-21 --- Station ID ---

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.1	10.0	9.9	9.4	9.4	9.5	10.2	9.1	9.1	8.7	9.5
Fill Thk	10.3	7.2	3.2	2.5	1.8	2.9	2.9	4.0	5.5	5.4	4.6
Core Thk	7.8	11.1	15.1	16.1	17.2	16.4	15.1	14.6	14.5	14.2	14.2
Bot Clad	24.4	24.4	24.5	24.7	24.2	23.9	24.4	24.9	23.5	24.4	24.3
Plate Thk	52.6	52.7	52.7	52.7	52.6	52.7	52.6	52.6	52.6	52.7	52.7

Core Width = 2258.7 Top Min Clad = 8.7 Bot Min Clad = 21.7

SECTION T-22 --- Station ID ---

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.9	10.9	10.7	9.1	9.8	9.1	9.9	9.1	9.4	10.6	9.9
Fill Thk	9.4	5.6	1.9	2.4	1.5	2.0	1.8	3.4	5.2	4.5	3.8
Core Thk	7.9	11.6	15.0	16.1	16.3	16.9	17.1	15.5	13.6	13.8	14.4
Bot Clad	24.4	24.6	25.1	25.1	25.1	24.6	23.9	24.7	24.5	23.8	24.6
Plate Thk	52.6	52.7	52.7	52.7	52.7	52.6	52.7	52.7	52.7	52.7	52.7

Core Width = 2222.6 Top Min Clad = 9.1 Bot Min Clad = 23.6

SECTION T-23 --- Station ID ---

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.7	9.0	8.7	10.1	10.1	9.8	9.5	10.4	10.9	10.8	9.9
Fill Thk	3.9	2.7	2.3	1.1	1.0	1.5	2.6	3.6	4.2	7.0	3.0
Core Thk	13.3	16.5	17.3	16.6	15.4	16.3	15.5	13.2	7.5	4.2	13.6
Bot Clad	25.8	24.5	24.3	24.9	26.1	25.1	25.1	25.5	30.1	30.7	26.2
Plate Thk	52.7	52.7	52.6	52.7	52.6	52.7	52.7	52.7	52.7	52.7	52.7

Core Width = 2168.9 Top Min Clad = 8.7 Bot Min Clad = 23.3

LONGITUDINAL CLAD-CORE-CLAD DIMENSIONS (in mils)

èëë£
¤Prog: OPCOMP RTRFE - QC Date:06/08/95¤
¤ MET LAB DE INSPECTION DATA Time:08:21 ¤
¤Rev. 1.0 ALUMINUM FUEL PLATES (ALL TYPES) ¤
àëë¥

Plate No.132-0021-01 NPN No. F26

PLATE SUMMARY

SECTION	CLAD-CORE-CLAD DIMENSIONS	GRAIN GROWTH CLAD / FRAME	GRAIN GROWTH CLAD / CORE
T- 1	Accept	N/A	N/A
T- 2	Accept	N/A	N/A
T- 3	Accept	N/A	N/A
T- 4	Accept	N/A	N/A
T- 5	Accept	N/A	N/A
T- 6	Accept	N/A	N/A
T- 7	Accept	N/A	N/A
T- 8	Accept	N/A	N/A
T- 9	Accept	N/A	N/A
T-10	Accept	N/A	N/A
T-11	Accept	N/A	N/A
T-12	Accept	N/A	N/A
T-13	Accept	N/A	N/A
T-14	Accept	N/A	N/A
T-15	Accept	N/A	N/A
T-16	Accept	N/A	N/A
T-17	Accept	N/A	N/A
T-18	Accept	N/A	N/A
T-19	Accept	N/A	N/A
T-20	Accept	N/A	N/A
T-21	Accept	N/A	N/A
T-22	Accept	N/A	N/A
T-23	Accept	N/A	N/A

PLATE LIMITS:

PLATE AVERAGES:

Avg Top Clad	9.4
Avg Core Thk	19.7
Avg Bot Clad	15.1
Avg Plate Thk	50.8
Avg Clad Diff	5.7

PLATE MINIMUM:

Minimum Clad 6.1

CLAD-CORE-CLAD
INSPECTOR: J. J. CALLAHAN DATE: 06/06/95

AUDITOR: B. TRIPLETT DATE: 06/08/95

ëëë

¤Prog: OPCOMP ¤Rev. 1.0

RTRFE - QC

MET LAB DE INSPECTION DATA

ALUMINUM FUEL PLATES (ALL TYPES)

Date:06/08/95¤
Time:08:21 ¤

àëëë¥

Plate No.132-0021-01

NPN No. F26

TRANSVERSE CLAD-CORE-CLAD DIMENSIONS (in mils)

SECTION T- 1

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.4	10.0	10.5	9.1	10.0	10.2	9.3	9.6	10.1	9.8	9.9
Fill Thk	13.1	11.8	12.3	13.8	12.2	11.1	12.6	10.4	11.3	10.7	11.9
Core Thk	17.0	15.1	14.4	17.0	18.0	19.9	17.2	15.3	10.3	10.5	15.5
Bot Clad	10.3	13.7	13.4	10.9	10.4	9.4	11.5	15.4	19.1	19.8	13.4
Plate Thk	50.8	50.6	50.6	50.8	50.6	50.6	50.6	50.7	50.8	50.8	50.7

Core Width = 2206.6 Top Min Clad = 9.3 Bot Min Clad = 7.6

SECTION T- 2

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.7	9.7	9.1	9.1	9.4	9.9	9.4	9.4	9.8	9.8	9.5
Fill Thk	12.3	10.8	12.6	11.5	11.6	10.4	10.4	10.8	12.3	11.0	11.4
Core Thk	13.5	16.9	18.6	20.3	19.7	20.8	21.4	15.5	8.6	6.8	16.2
Bot Clad	15.1	13.2	10.3	9.8	10.0	9.6	9.5	14.9	20.1	23.2	13.6
Plate Thk	50.6	50.6	50.6	50.7	50.7	50.7	50.7	50.6	50.8	50.8	50.7

Core Width = 2236.9 Top Min Clad = 9.1 Bot Min Clad = 6.1

SECTION T- 3

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.6	9.9	10.2	8.4	9.4	8.8	8.7	9.4	9.8	10.0	9.5
Fill Thk	11.8	10.4	10.0	11.0	9.3	11.6	10.6	11.8	11.6	11.0	10.9
Core Thk	10.7	16.9	18.1	20.1	21.5	20.0	19.1	13.5	8.4	7.6	15.6
Bot Clad	17.3	13.2	11.9	10.8	10.1	10.2	12.0	15.8	20.7	21.9	14.4
Plate Thk	50.4	50.4	50.2	50.3	50.3	50.6	50.4	50.5	50.5	50.5	50.4

Core Width = 2268.5 Top Min Clad = 8.4 Bot Min Clad = 6.7

SECTION T- 4

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.1	9.6	10.2	10.6	9.7	10.3	10.7	10.2	10.2	10.2	10.2
Fill Thk	9.7	11.0	10.5	9.3	10.1	10.3	9.5	10.5	10.3	10.5	10.2
Core Thk	11.9	14.0	16.8	20.3	19.8	20.0	20.3	13.9	9.5	5.4	15.2
Bot Clad	18.8	16.0	13.3	10.7	11.3	10.3	10.4	16.3	20.9	24.7	15.3
Plate Thk	50.5	50.6	50.8	50.9	50.9	50.9	50.9	50.9	50.9	50.8	50.8

Core Width = 2380.1 Top Min Clad = 9.6 Bot Min Clad = 8.1

SECTION T- 5

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	8.6	10.1	9.5	9.2	8.7	9.3	9.0	8.7	9.0	9.2	9.1
Fill Thk	9.3	8.4	9.0	8.7	10.3	7.7	9.3	9.6	9.4	8.8	9.1
Core Thk	14.3	16.5	19.5	21.4	21.0	22.8	21.6	17.7	10.8	8.0	17.4
Bot Clad	18.5	15.7	12.8	11.5	10.8	11.1	11.0	14.8	21.5	24.7	15.2
Plate Thk	50.7	50.7	50.8	50.8	50.8	50.9	50.9	50.8	50.7	50.7	50.8

Core Width = 2380.5 Top Min Clad = 8.6 Bot Min Clad = 8.7

¤Prog: OPCOMP RTRFE - QC Date:06/08/95
MET LAB DE INSPECTION DATA Time:08:21
¤Rev. 1.0 ALUMINUM FUEL PLATES (ALL TYPES)

Plate No.132-0021-01 NPN No. F26

SECTION T- 6 Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.4	9.4	9.4	8.9	9.4	10.0	10.2	9.0	9.1	10.4	9.5
Fill Thk	6.7	6.7	7.5	7.7	8.1	6.1	6.4	7.0	6.8	5.3	6.8
Core Thk	16.9	19.6	20.3	23.2	22.7	23.6	22.5	20.2	14.0	10.2	19.3
Bot Clad	17.5	14.9	13.5	11.0	10.6	11.1	11.6	14.3	20.7	24.7	15.0
Plate Thk	50.5	50.6	50.7	50.8	50.8	50.8	50.7	50.5	50.6	50.6	50.7

Core Width = 2374.2 Top Min Clad = 8.9 Bot Min Clad = 7.8

SECTION T- 7 Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	8.8	9.5	10.0	9.2	9.1	9.9	10.2	9.6	9.5	9.3	9.5
Fill Thk	4.7	4.6	3.9	5.0	5.2	4.9	4.5	5.0	4.5	4.1	4.6
Core Thk	19.3	20.0	23.3	25.2	24.9	25.4	24.7	21.5	14.9	12.5	21.2
Bot Clad	17.5	16.3	13.3	11.3	11.4	10.6	11.4	14.6	21.7	24.7	15.3
Plate Thk	50.3	50.4	50.5	50.7	50.6	50.8	50.8	50.7	50.6	50.6	50.6

Core Width = 2371.2 Top Min Clad = 8.8 Bot Min Clad = 8.1

SECTION T- 8 Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.6	9.3	9.5	9.4	9.8	9.1	9.8	9.9	10.2	9.2	9.6
Fill Thk	3.0	2.1	2.5	3.0	2.5	2.8	2.7	2.8	2.2	2.6	2.6
Core Thk	19.7	22.2	25.0	27.0	26.5	28.3	26.6	22.6	16.1	12.0	22.6
Bot Clad	18.4	17.1	13.7	11.4	12.0	10.5	11.7	15.5	22.1	27.0	15.9
Plate Thk	50.7	50.7	50.7	50.8	50.8	50.7	50.8	50.8	50.6	50.8	50.7

Core Width = 2355.1 Top Min Clad = 9.1 Bot Min Clad = 8.9

SECTION T- 9 Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	8.6	9.1	9.1	8.3	9.5	9.4	9.4	8.5	8.7	9.0	9.0
Fill Thk	0.6	0.7	0.6	1.2	0.5	0.6	1.2	0.4	0.4	0.8	0.7
Core Thk	22.8	24.1	26.1	29.6	28.9	29.8	28.5	26.5	17.7	14.1	24.8
Bot Clad	18.2	16.5	14.6	11.3	11.6	10.5	11.4	15.1	23.4	26.3	15.9
Plate Thk	50.2	50.4	50.4	50.4	50.5	50.3	50.5	50.5	50.2	50.2	50.4

Core Width = 2345.7 Top Min Clad = 8.3 Bot Min Clad = 7.9

SECTION T-10 Station ID

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	8.5	9.4	8.6	9.2	9.3	9.2	9.2	9.2	9.2	9.5	9.1
Fill Thk	0.6	0.8	0.7	0.8	0.5	0.5	0.6	1.0	0.5	0.3	0.6
Core Thk	24.1	23.6	27.6	28.4	29.3	29.5	28.4	24.4	17.2	14.8	24.7
Bot Clad	17.3	16.8	13.7	12.2	11.5	11.4	12.4	16.0	23.8	26.0	16.1
Plate Thk	50.5	50.6	50.6	50.6	50.6	50.6	50.6	50.6	50.7	50.6	50.6

Core Width = 2336.9 Top Min Clad = 8.5 Bot Min Clad = 8.7

èëë£
¤Prog: OPCOMP RTRFE - QC Date:06/08/95¤
¤ MET LAB DE INSPECTION DATA Time:08:21 ¤
¤Rev. 1.0 ALUMINUM FUEL PLATES (ALL TYPES) ¤
àëë¥

Plate No.132-0021-01 NPN No. F26

SECTION T-11 ---- Station ID ----

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.2	9.8	9.8	10.2	9.8	9.5	9.3	9.9	9.8	9.8	9.7
Fill Thk	0.5	0.8	0.3	0.3	0.2	0.7	0.3	0.7	0.4	0.8	0.5
Core Thk	22.8	23.9	26.7	28.8	29.6	29.5	28.7	22.7	17.1	13.7	24.4
Bot Clad	19.3	17.2	14.9	12.4	12.2	12.0	13.4	18.3	24.3	27.4	17.1
Plate Thk	51.8	51.7	51.7	51.7	51.8	51.7	51.7	51.6	51.6	51.7	51.7

Core Width = 2332.6 Top Min Clad = 9.2 Bot Min Clad = 9.8

SECTION T-12 ---- Station ID ----

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.0	8.4	8.3	8.9	9.3	8.3	8.7	8.1	8.7	8.4	8.6
Fill Thk	0.5	0.9	1.1	0.7	0.5	0.5	0.3	0.4	0.4	0.5	0.6
Core Thk	23.6	24.7	27.3	29.1	29.1	30.6	29.8	25.4	18.5	15.4	25.4
Bot Clad	17.1	16.2	13.5	11.6	11.3	11.0	11.4	16.3	22.6	25.9	15.7
Plate Thk	50.2	50.2	50.2	50.3	50.2	50.4	50.2	50.2	50.2	50.2	50.2

Core Width = 2333.4 Top Min Clad = 8.1 Bot Min Clad = 8.9

SECTION T-13 ---- Station ID ----

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	8.4	8.3	8.3	8.0	8.0	8.1	9.0	8.2	8.3	9.1	8.4
Fill Thk	0.6	0.1	0.4	0.5	0.6	0.6	0.4	0.4	0.4	0.7	0.5
Core Thk	23.7	25.7	28.5	30.6	30.8	30.7	30.1	25.2	18.6	14.8	25.9
Bot Clad	17.5	16.1	13.0	11.2	10.8	10.8	10.8	16.4	22.9	25.6	15.5
Plate Thk	50.2	50.2	50.2	50.3	50.2	50.2	50.3	50.2	50.2	50.2	50.2

Core Width = 2332.3 Top Min Clad = 8.0 Bot Min Clad = 8.3

SECTION T-14 ---- Station ID ----

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	7.1	8.5	8.7	8.7	7.1	7.6	8.3	8.7	7.9	8.2	8.1
Fill Thk	0.3	0.5	0.4	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Core Thk	25.4	25.5	27.7	31.0	32.9	32.2	30.9	25.5	19.2	15.4	26.6
Bot Clad	17.0	15.5	13.3	10.3	9.7	9.8	10.4	15.6	22.8	26.2	15.1
Plate Thk	49.8	50.0	50.1	50.2	50.1	50.0	50.0	50.2	50.3	50.2	50.1

Core Width = 2338.6 Top Min Clad = 7.1 Bot Min Clad = 8.3

SECTION T-15 ---- Station ID ----

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.3	9.4	9.1	10.0	8.9	8.7	9.4	10.4	9.8	9.8	9.5
Fill Thk	0.5	0.6	0.3	0.2	0.4	0.7	0.8	0.7	0.5	0.6	0.5
Core Thk	23.0	25.5	28.2	28.5	30.3	29.6	28.9	23.3	17.7	14.3	24.9
Bot Clad	17.5	15.0	12.9	11.8	11.1	11.6	11.6	16.3	22.8	25.9	15.7
Plate Thk	50.3	50.5	50.5	50.5	50.7	50.6	50.7	50.7	50.8	50.6	50.6

Core Width = 2337.9 Top Min Clad = 8.7 Bot Min Clad = 9.1

èëë£
¤Prog: OPCOMP RTRFE - QC Date:06/08/95¤
¤ MET LAB DE INSPECTION DATA Time:08:21 ¤
¤Rev. 1.0 ALUMINUM FUEL PLATES (ALL TYPES) ¤
àëëë¥

Plate No.132-0021-01 NPN No. F26

SECTION T-16 --------------------- Station ID ----------------------- AVG.

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	11.0	10.1	9.9	9.7	11.6	11.2	10.3	10.3	11.0	10.2	10.5
Fill Thk	0.9	2.1	1.8	2.3	0.8	1.6	2.5	2.1	1.4	2.2	1.8
Core Thk	21.3	22.6	25.2	27.2	27.4	27.4	26.6	23.8	15.4	12.6	23.0
Bot Clad	18.5	16.7	14.4	12.5	11.9	11.7	12.2	15.5	23.9	26.5	16.4
Plate Thk	51.7	51.5	51.3	51.7	51.7	51.9	51.6	51.7	51.7	51.5	51.6

Core Width = 2355.5 Top Min Clad = 9.7 Bot Min Clad = 9.7

SECTION T-17 --------------------- Station ID ----------------------- AVG.

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.0	10.1	9.8	9.9	9.9	9.8	10.1	10.1	9.4	9.8	9.9
Fill Thk	3.6	5.3	4.7	5.4	4.2	5.0	4.3	5.3	5.9	5.1	4.9
Core Thk	19.6	19.5	22.8	24.6	26.2	24.7	25.8	20.2	14.1	10.4	20.8
Bot Clad	18.4	16.6	14.2	11.6	11.2	12.2	11.4	16.0	22.1	26.3	16.0
Plate Thk	51.6	51.5	51.5	51.5	51.5	51.7	51.6	51.6	51.5	51.6	51.6

Core Width = 2365.7 Top Min Clad = 9.4 Bot Min Clad = 9.0

SECTION T-18 --------------------- Station ID ----------------------- AVG.

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.3	9.3	9.4	9.8	9.2	10.2	10.1	9.5	9.5	9.5	9.7
Fill Thk	6.4	7.3	7.8	6.9	7.4	7.0	7.4	7.1	8.1	7.0	7.2
Core Thk	16.4	18.6	20.1	23.1	23.6	22.7	22.8	18.4	11.9	9.0	18.7
Bot Clad	18.2	16.1	14.0	11.7	11.3	11.6	11.4	16.4	21.8	25.9	15.8
Plate Thk	51.3	51.3	51.3	51.5	51.5	51.5	51.7	51.4	51.3	51.4	51.4

Core Width = 2378.5 Top Min Clad = 9.2 Bot Min Clad = 9.6

SECTION T-19 --------------------- Station ID ----------------------- AVG.

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.1	9.4	8.5	9.3	9.2	9.5	9.7	9.8	8.2	9.2	9.2
Fill Thk	9.6	9.7	9.5	9.0	9.6	10.0	9.4	9.0	10.1	8.7	9.5
Core Thk	13.1	17.0	19.5	22.3	21.0	20.7	22.8	17.4	12.3	7.5	17.4
Bot Clad	19.5	15.2	13.7	10.7	11.5	11.4	10.0	15.1	20.7	25.7	15.4
Plate Thk	51.3	51.3	51.2	51.3	51.3	51.6	51.9	51.3	51.3	51.1	51.4

Core Width = 2383.7 Top Min Clad = 8.2 Bot Min Clad = 7.0

SECTION T-20 --------------------- Station ID ----------------------- AVG.

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	10.3	9.8	9.7	10.3	9.3	9.5	10.2	9.6	9.9	10.2	9.9
Fill Thk	10.8	10.9	11.5	11.2	11.4	11.4	10.7	11.9	11.4	10.6	11.2
Core Thk	13.4	15.9	17.4	18.4	20.8	19.3	19.7	14.6	9.6	6.5	15.6
Bot Clad	17.2	15.1	12.9	11.5	10.0	11.2	11.1	15.5	20.6	24.1	14.9
Plate Thk	51.7	51.7	51.5	51.4	51.5	51.4	51.7	51.6	51.5	51.4	51.5

Core Width = 2378.2 Top Min Clad = 9.5 Bot Min Clad = 8.4

àëë£
¤Prog: OPCOMP RTRFE - QC Date:06/08/95¤
¤ MET LAB DE INSPECTION DATA Time:08:21 ¤
¤Rev. 1.0 ALUMINUM FUEL PLATES (ALL TYPES) ¤
àëë¥
Plate No.132-0021-01 NPN No. F26

SECTION T-21 -------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.1	8.7	7.6	8.0	8.5	8.0	8.7	9.6	8.8	9.8	8.7
Fill Thk	11.3	11.4	11.0	12.0	10.7	11.6	11.0	10.1	11.8	10.6	11.2
Core Thk	8.5	13.1	19.7	20.6	20.9	21.0	20.6	19.7	16.2	15.1	17.5
Bot Clad	21.6	17.3	12.3	10.0	10.5	10.0	10.2	11.2	13.8	15.1	13.2
Plate Thk	50.5	50.5	50.6	50.6	50.6	50.6	50.5	50.6	50.6	50.6	50.6

Core Width = 2247.3 Top Min Clad = 7.6 Bot Min Clad = 7.1

SECTION T-22 -------------------- Station ID ----------------------

	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.1	9.5	9.9	9.3	8.5	10.1	8.8	8.3	9.3	10.2	9.3
Fill Thk	12.1	10.7	11.9	11.8	12.1	11.1	12.1	11.5	11.6	11.5	11.6
Core Thk	8.9	14.6	17.6	18.5	20.6	20.5	21.4	18.8	16.2	13.7	17.1
Bot Clad	20.7	16.0	11.5	11.2	9.7	9.2	8.6	12.3	13.8	15.5	12.9
Plate Thk	50.8	50.8	50.9	50.8	50.9	50.9	50.9	50.9	50.9	50.9	50.9

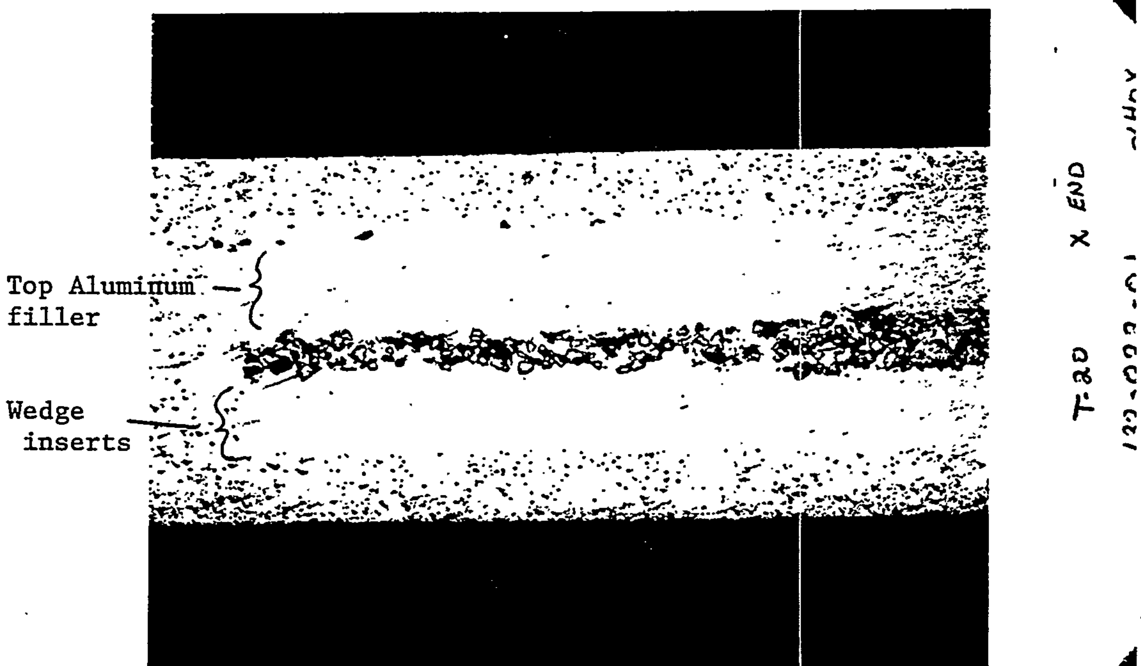
Core Width = 2205.2 Top Min Clad = 8.3 Bot Min Clad = 7.8

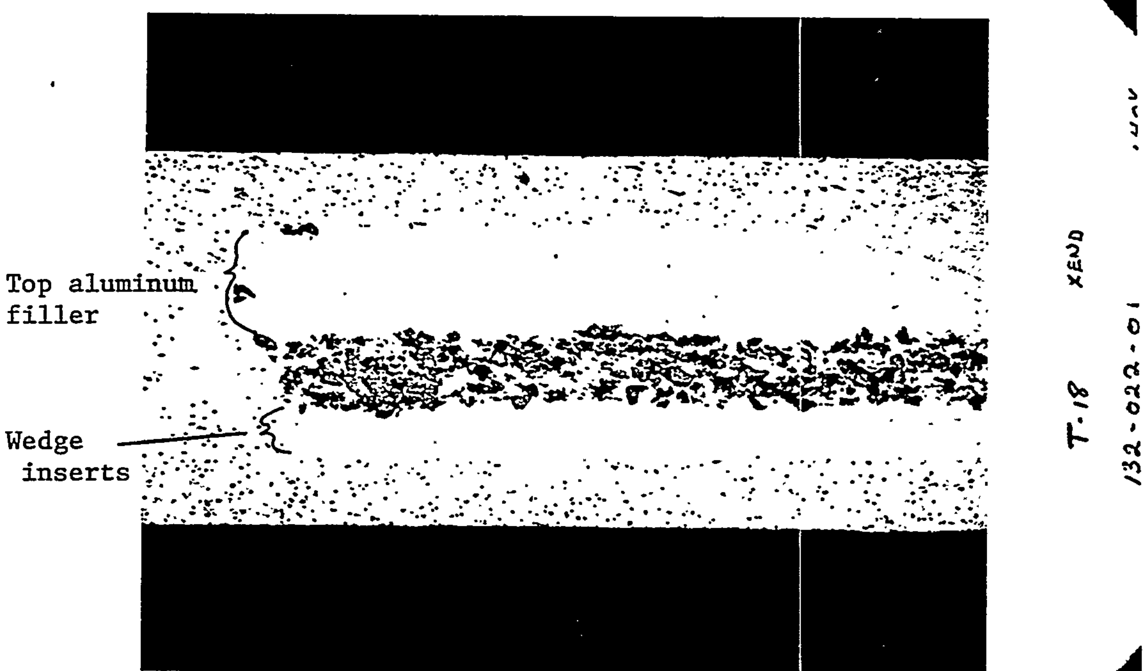
SECTION T-23 -------------------- Station ID ----------------------

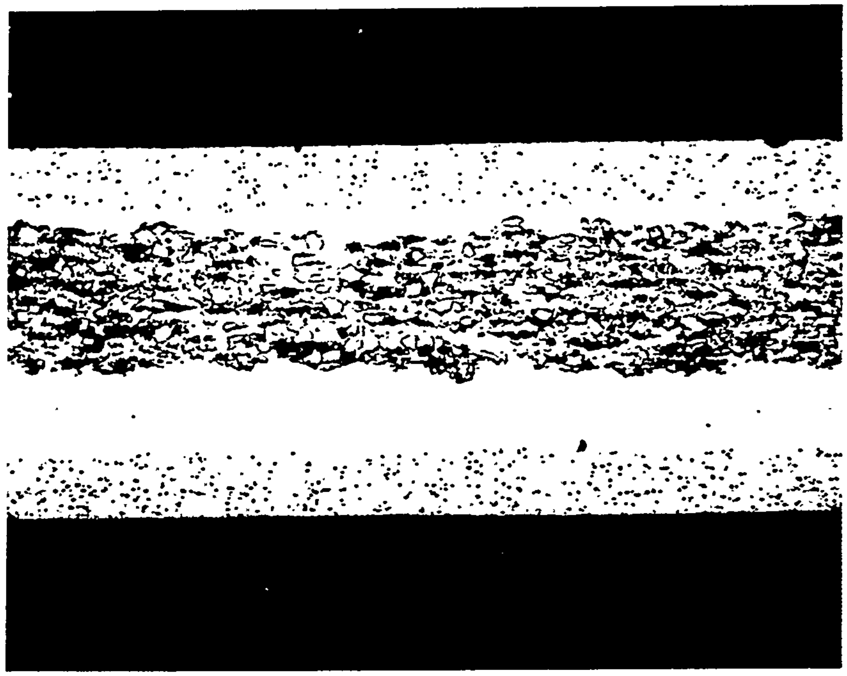
	A	B	C	D	E	F	G	H	I	J	AVG.
Top Clad	9.9	10.3	9.5	9.8	9.5	10.2	8.7	9.8	10.6	10.9	9.9
Fill Thk	19.2	21.5	24.5	25.9	26.2	27.8	28.1	24.8	21.8	22.6	24.2
Core Thk	2.7	3.3	4.5	3.7	4.9	4.0	4.7	4.9	3.7	6.1	4.3
Bot Clad	19.4	16.0	12.6	11.9	10.6	9.3	9.5	11.4	15.1	11.4	12.7
Plate Thk	51.2	51.1	51.1	51.3	51.2	51.3	51.0	50.9	51.2	51.0	51.1

Core Width = 2202.2 Top Min Clad = 8.7 Bot Min Clad = 7.2

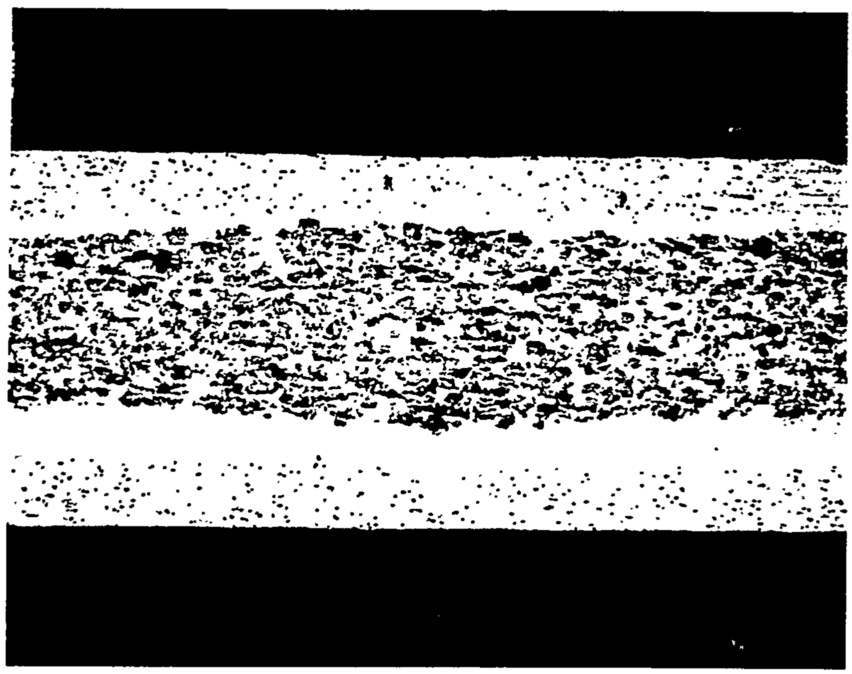
LONGITUDINAL CLAD-CORE-CLAD DIMENSIONS (in mils)


Top Aluminum filler
Wedge inserts

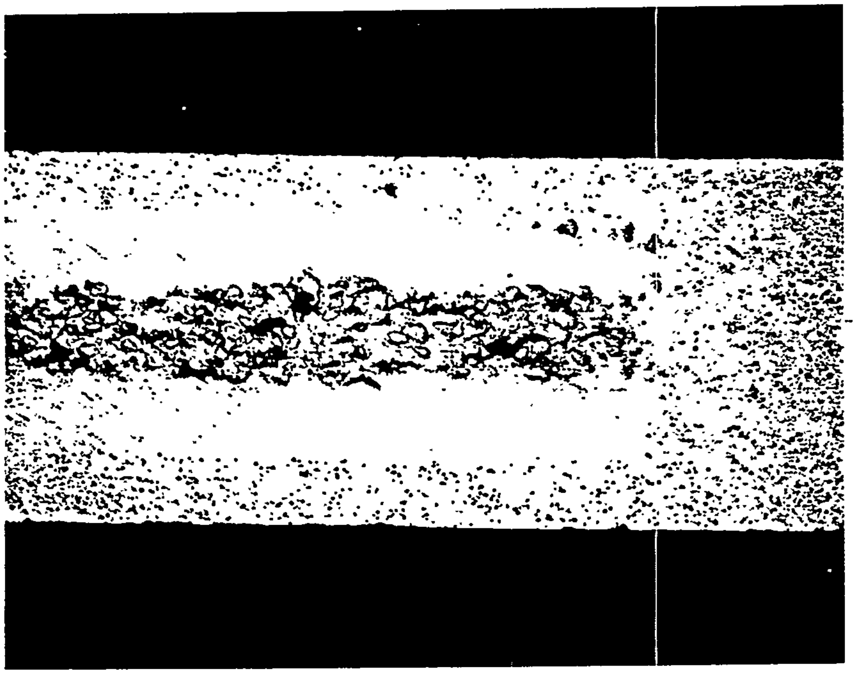

Top aluminum filler
Wedge inserts



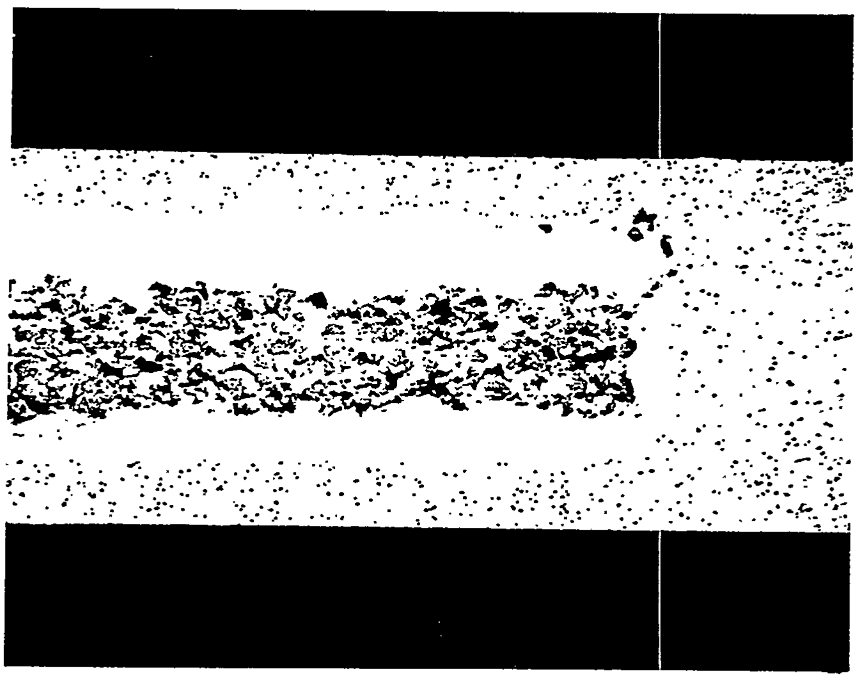
T-20 MIDDLE



T-18 MIDDLE ~40X



T-20 132.022.01 Y END ~40X



T-18 132.022-01 Y END ~40X

C.3 COMPACT DE RESULTS

Form for use in inspecting compact dimensions on ANS Type 132 Compacts.

PLATE ID: 132-12-01

SECTION #: Plane #1

WIDTH= 2.818

STATION	FILLER THK.	CORE THK.
A	51.0	84.9
B	54.3	114.7
C	49.4	145.9
D	58.0	163.6
E	52.7	168.3
F	57.5	162.6
G	53.9	166.9
H	53.8	140.8
I	53.1	113.9
J	40.9	96.1

SECTION #: Plan # 8

WIDTH= 2.821

STATION	FILLER THK.	CORE THK.
A	87.9	51.9
B	98.7	73.1
C	108.4	89.4
D	113.9	110.9
E	114.4	110.0
F	117.6	106.4
G	119.9	104.5
H	105.3	93.5
I	104.2	67.8
J	91.0	50.3

Inspector: Jerry J. Callahan Date: 3-16-94

Form for use in inspecting compact dimensions on ANS Type 132 Compacts.

PLATE ID: 131-12-01

SECTION #: Plane #2

WIDTH= 2.976

STATION	FILLER THK.	CORE THK.
A	30.4	91.4
B	42.9	122.1
C	41.7	151.3
D	46.5	175.7
E	45.0	176.8
F	45.2	176.2
G	46.1	175.4
H	47.3	143.1
I	45.3	116.3
J	26.9	94.5

SECTION #: Plane # 3

WIDTH= 2.975

STATION	FILLER THK.	CORE THK.
A	19.0	106.1
B	24.5	141.3
C	23.9	169.4
D	26.6	196.1
E	25.4	197.1
F	24.7	197.6
G	25.6	196.7
H	24.8	167.0
I	25.1	137.3
J	18.5	103.3

Inspector: Jerry J. Callahan Date: 3-16-94

Form for use in inspecting compact dimensions on ANS Type 132 Compacts.

PLATE ID: 131-12-01

SECTION #: Plane #4

WIDTH = 2.976

STATION	FILLER THK.	CORE THK.
A	13.8	112.0
B	17.2	149.1
C	18.4	175.6
D	19.1	204.2
E	20.5	202.9
F	19.2	203.8
G	18.7	204.0
H	18.7	173.9
I	18.3	145.4
J	13.5	109.8

SECTION #: Plane #5

WIDTH = 2.977

STATION	FILLER THK.	CORE THK.
A	14.4	111.2
B	16.9	149.5
C	19.2	174.6
D	21.3	202.2
E	⊛ ~~20.2~~ 19.5	203.9
F	21.7	201.8
G	20.2	203.0
H	18.0	175.6
I	18.2	145.5
J	12.8	110.0

⊛ g.g.c 3/16/94

Inspector: Jerry g. Callahan   Date: 3-16-94

Form for use in inspecting compact dimensions on ANS Type 132 Compacts.

PLATE ID: 132-012-01

SECTION #: Plane #6

WIDTH= 2.931

STATION	FILLER THK.	CORE THK.
A	23.5	105.2
B	30.5	136.5
C	26.6	168.0
D	27.7	196.0
E	26.9	197.3
F	24.2	200.0
G	27.1	196.4
H	28.4	167.6
I	31.3	136.5
J	20.9	102.6

SECTION #: Plane #7

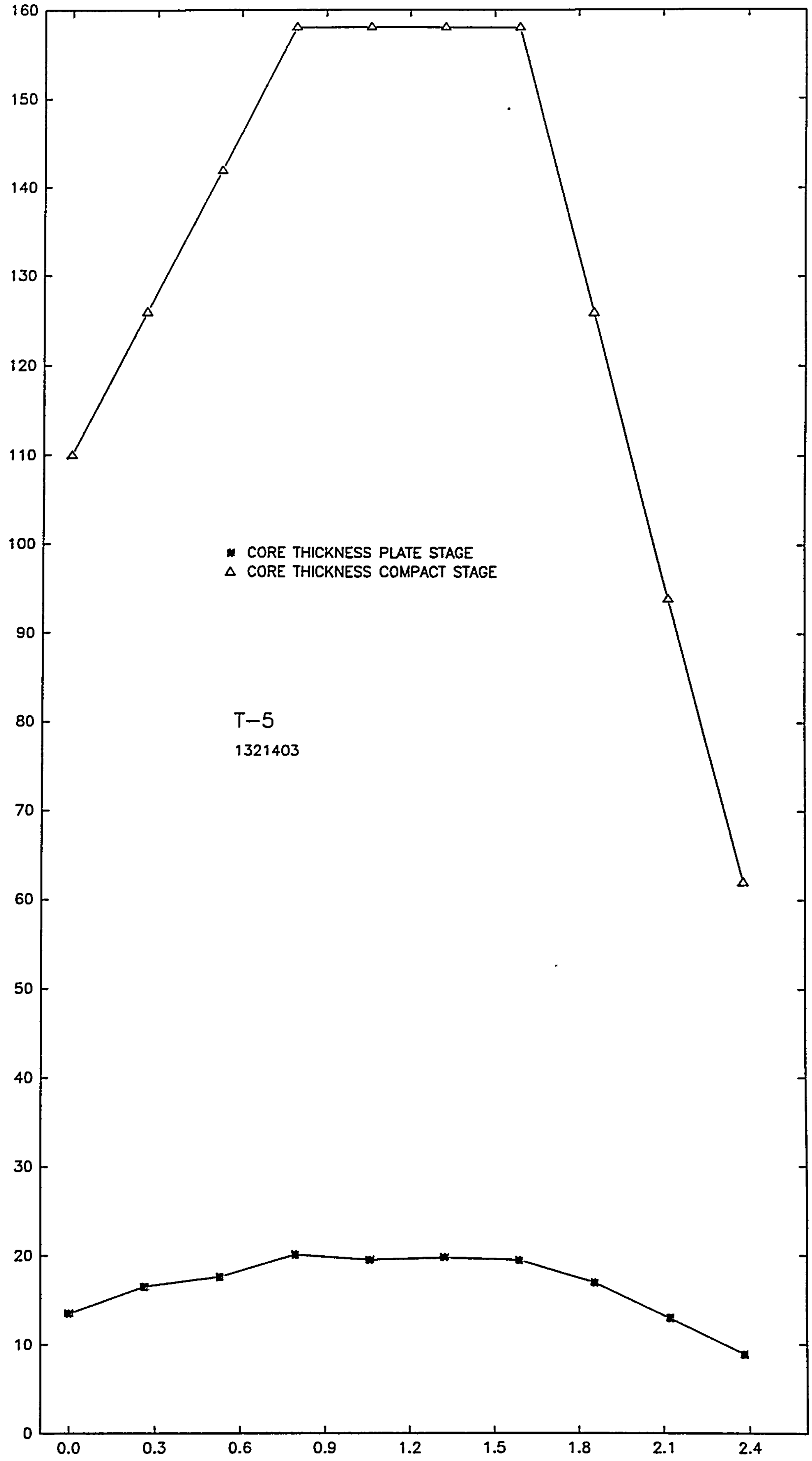
WIDTH= 2.973

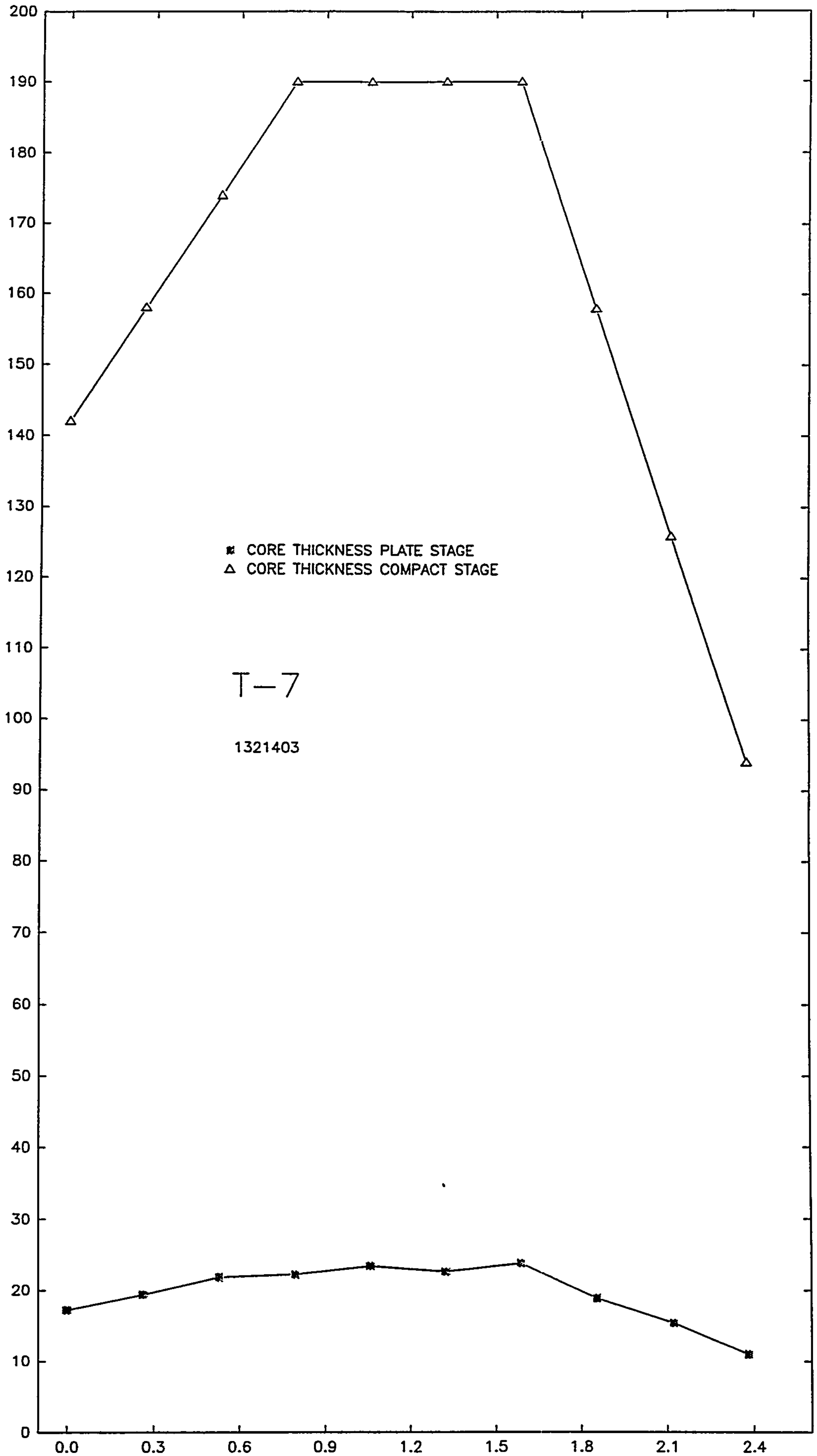
STATION	FILLER THK.	CORE THK.
A	50.3	77.0
B	58.7	108.9
C	61.3	133.7
D	68.2	155.9
E	71.7	152.4
F	71.6	152.6
G	73.6	150.6
H	65.7	128.9
I	62.7	103.1
J	49.2	75.3

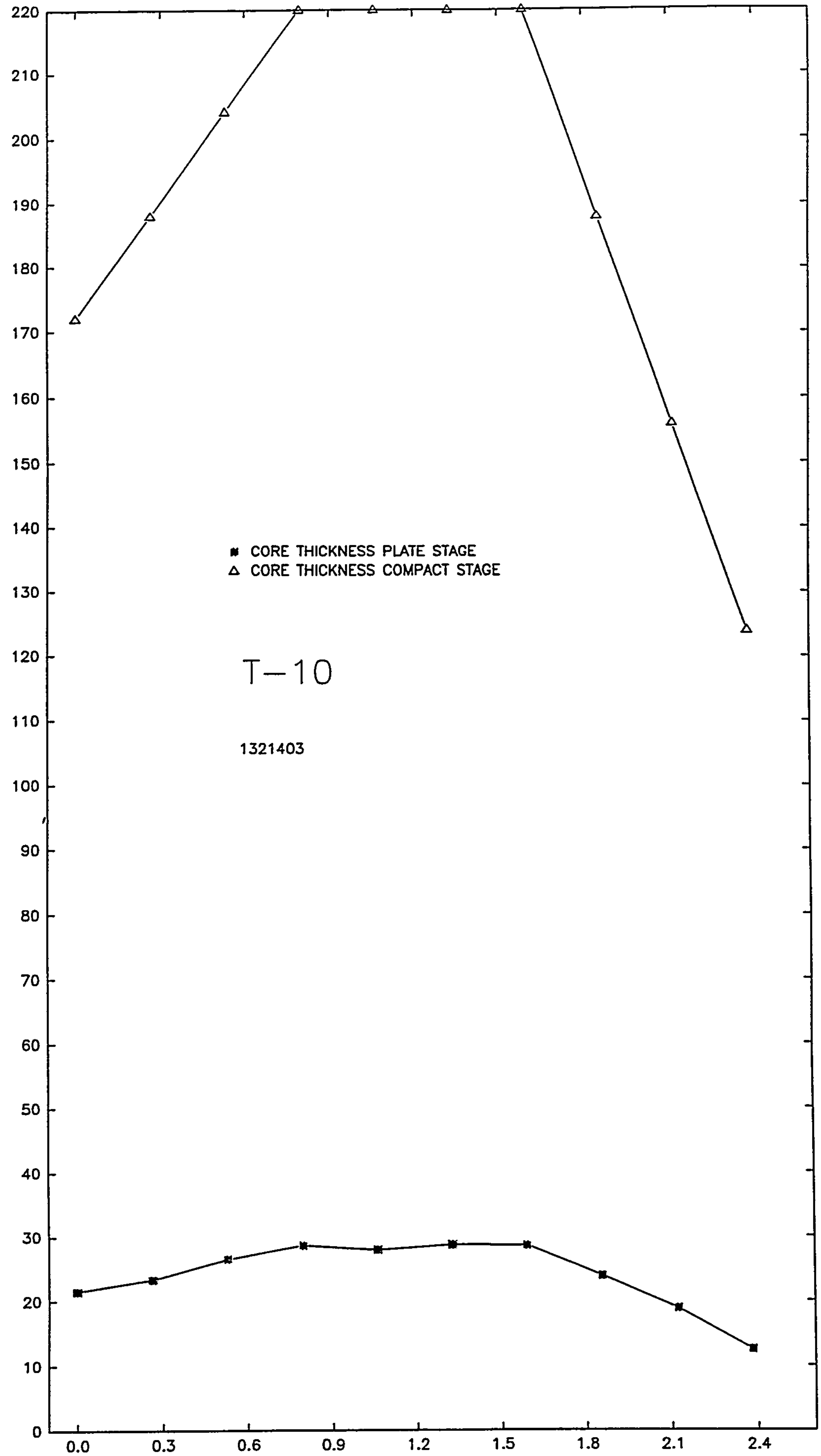
Inspector: Jerry J. Callahan

Date: 3-16-94

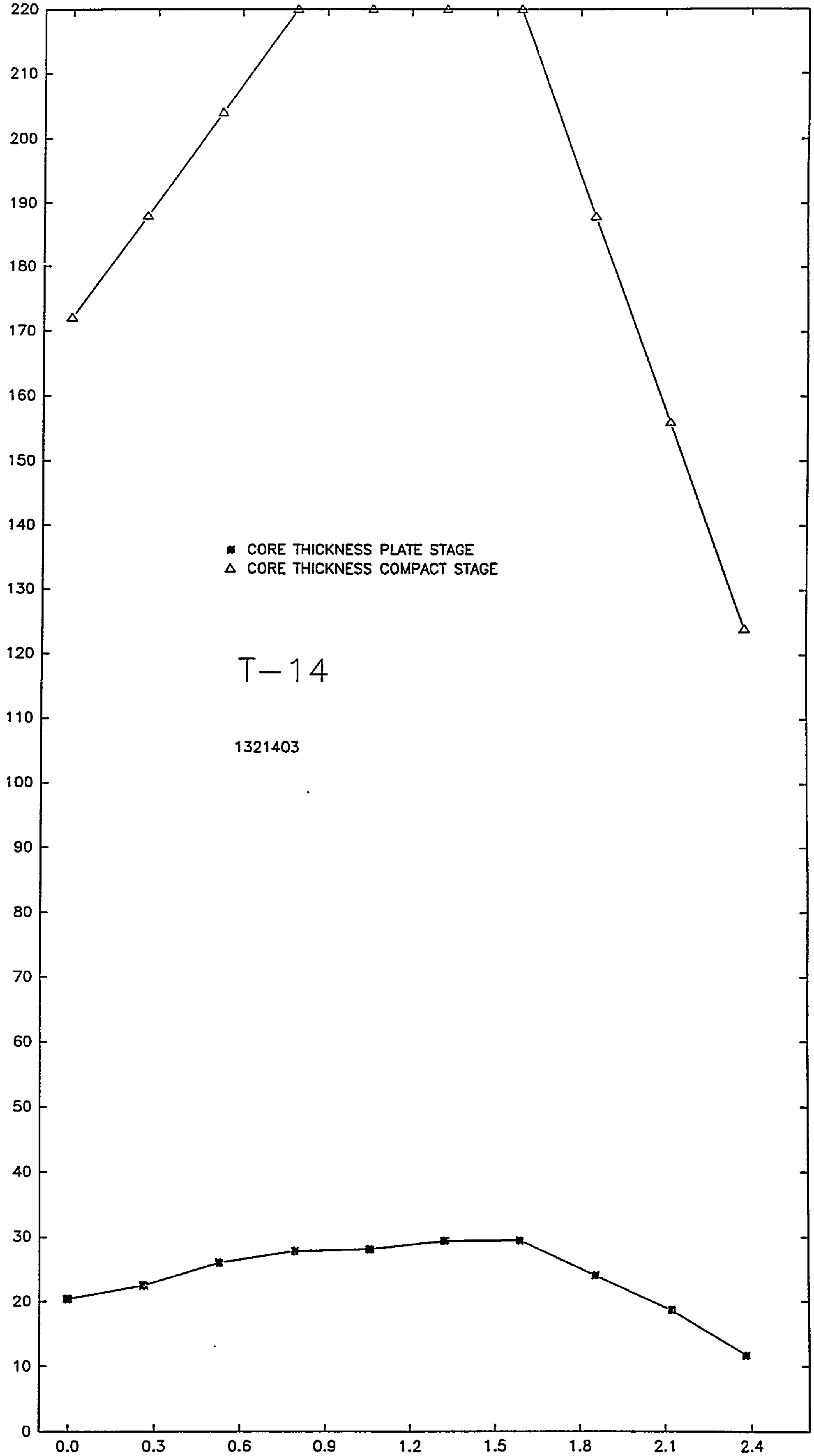
C.4 DESIGN COMPACT TO PLATE COMPARISON

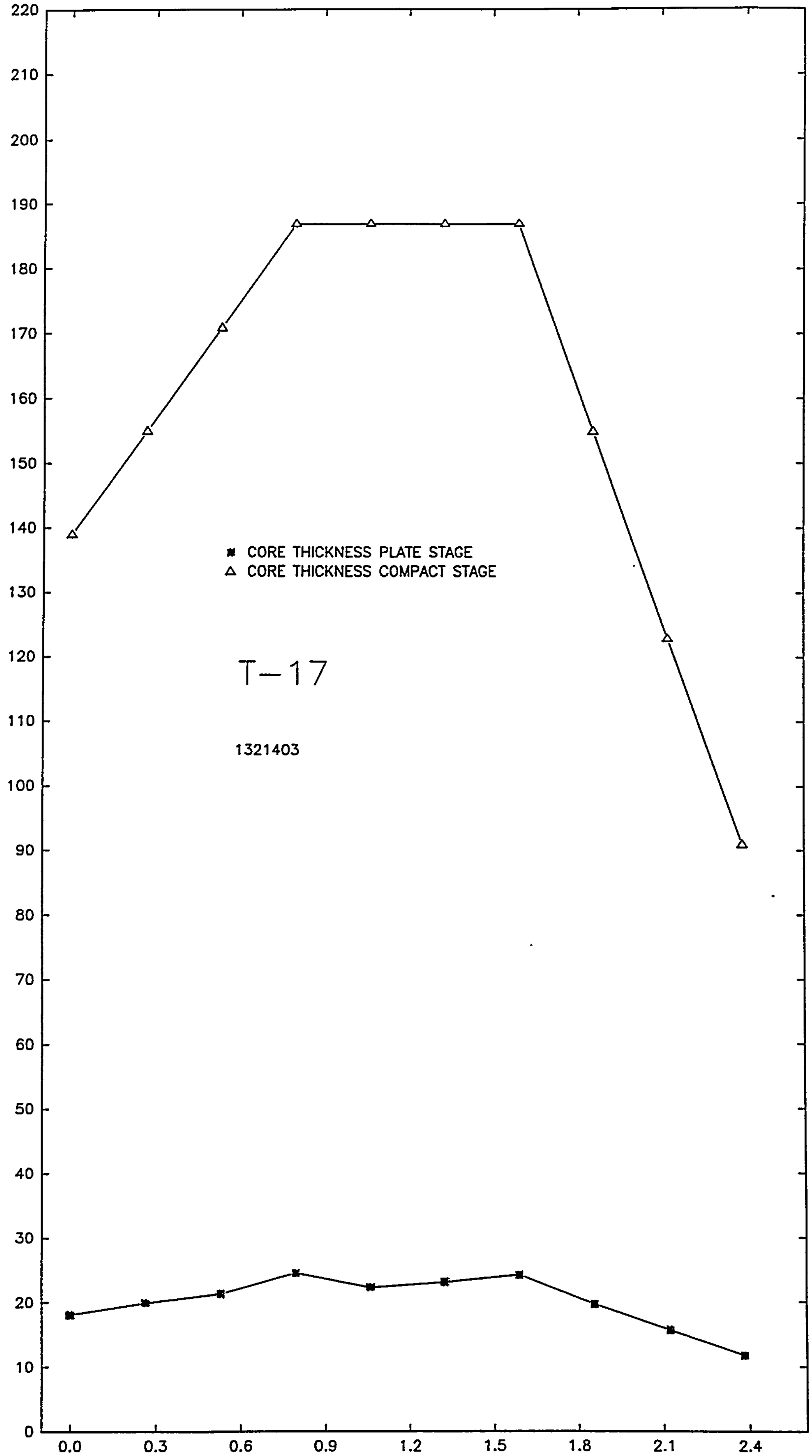

160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
CORE THICKNESS PLATE STAGE
CORE THICKNESS COMPACT STAGE
T-5
1321403


CORE THICKNESS PLATE STAGE
CORE THICKNESS COMPACT STAGE
T-7
1321403
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4

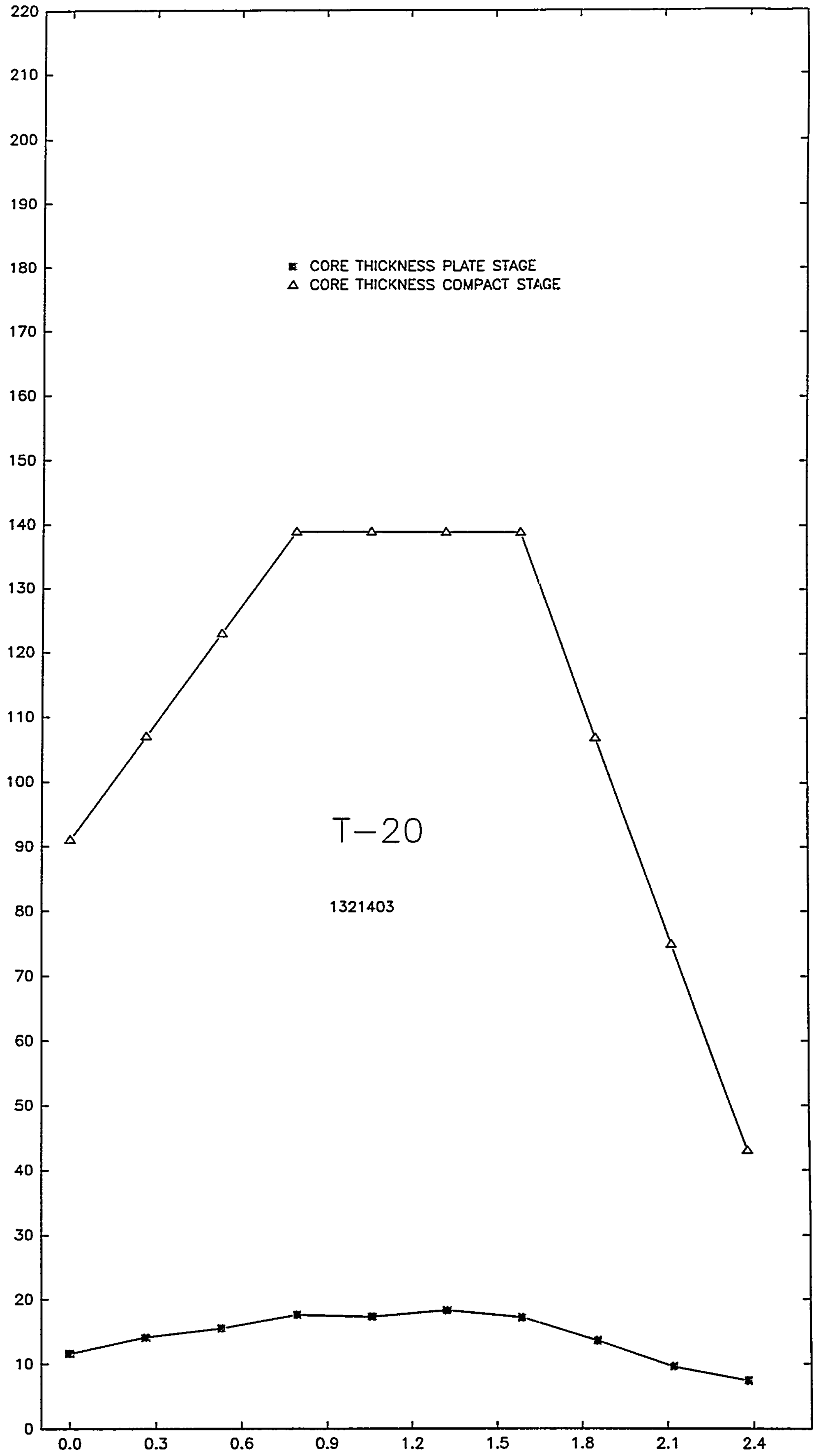


220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
CORE THICKNESS PLATE STAGE
CORE THICKNESS COMPACT STAGE
T-10
1321403


CORE THICKNESS PLATE STAGE
CORE THICKNESS COMPACT STAGE
T–14
1321403
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4



220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
CORE THICKNESS PLATE STAGE
CORE THICKNESS COMPACT STAGE
T-17
1321403



CORE THICKNESS PLATE STAGE
CORE THICKNESS COMPACT STAGE
T−20
1321403
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4

Appendix D

GRAPHICAL REPRESENTATIONS OF THE ANS HOMOGENEITY RESULTS

Appendix D. GRAPHICAL REPRESENTATIONS OF THE ANS HOMOGENEITY RESULTS

The attached information is included to provide the visual results of the development plates.

D.1 COMPACT/FINAL HOMOGENEITY RELATIONSHIP

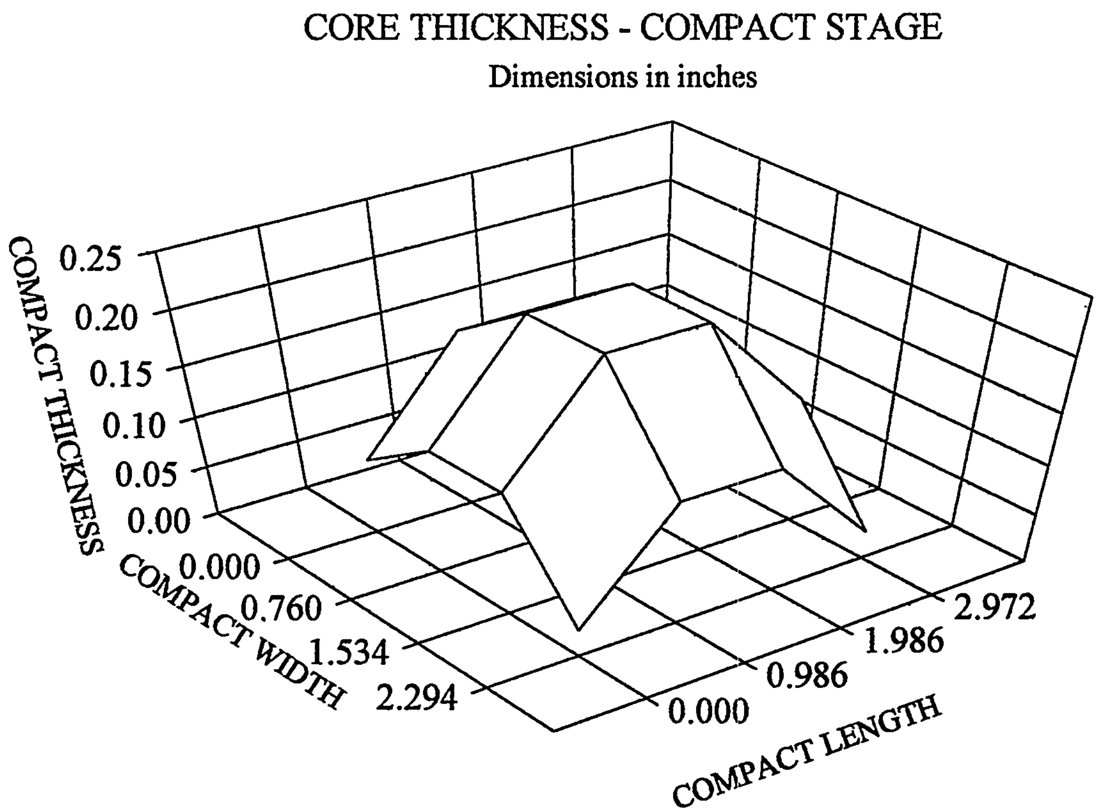
Figure D.1 shows the relationship between the compact thickness and the design final plate thickness. The reduction ratio is approximately 7.3:1 through hot roll and cold roll. Figure D.2 shows the anticipated results for a plate loaded at 1.3 g U/cc.

D.2 SAMPLE HOMOGENEITY PLOTS

Sample graphs of the digital homogeneity scan data are provided for each compact lot from lot 12 (1321204) through 22 (1322202).

D.3 LOT 14 COMPARISON

The attenuation values from the digital homogeneity scanner were averaged across the width and down the length for the plates in lot 14 to enable a visual comparison of the consistency of the gradient both longitudinally and laterally.



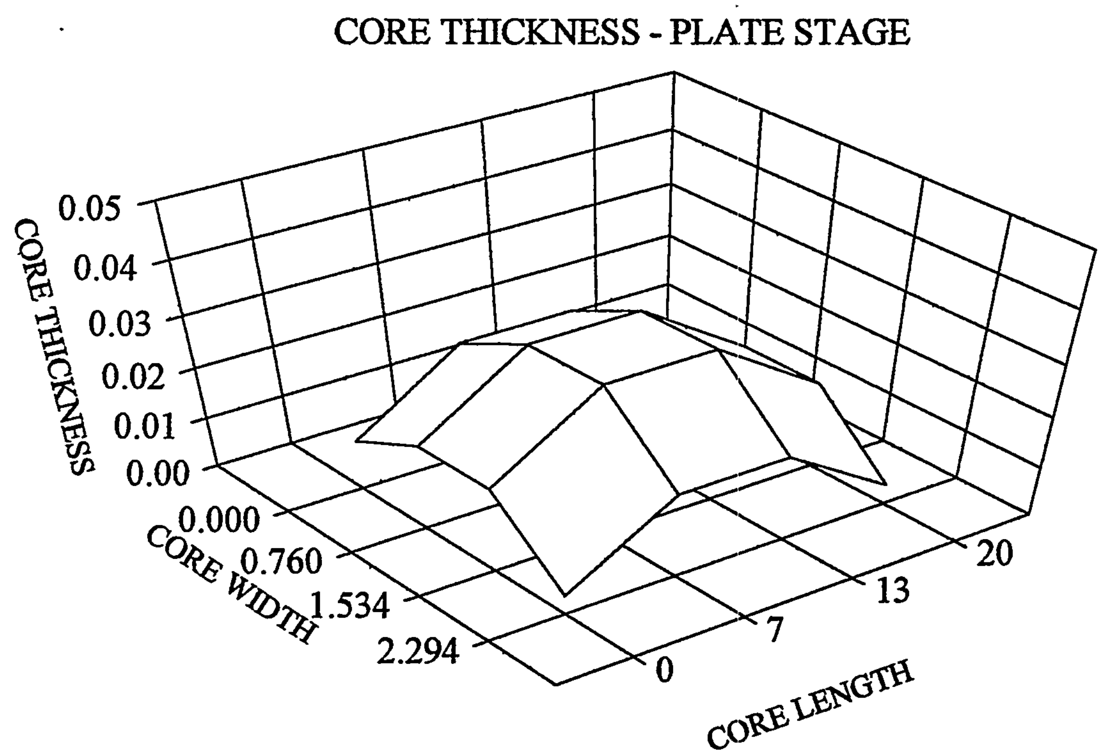


Fig. D.1. Core thickness at compact and plate stages.

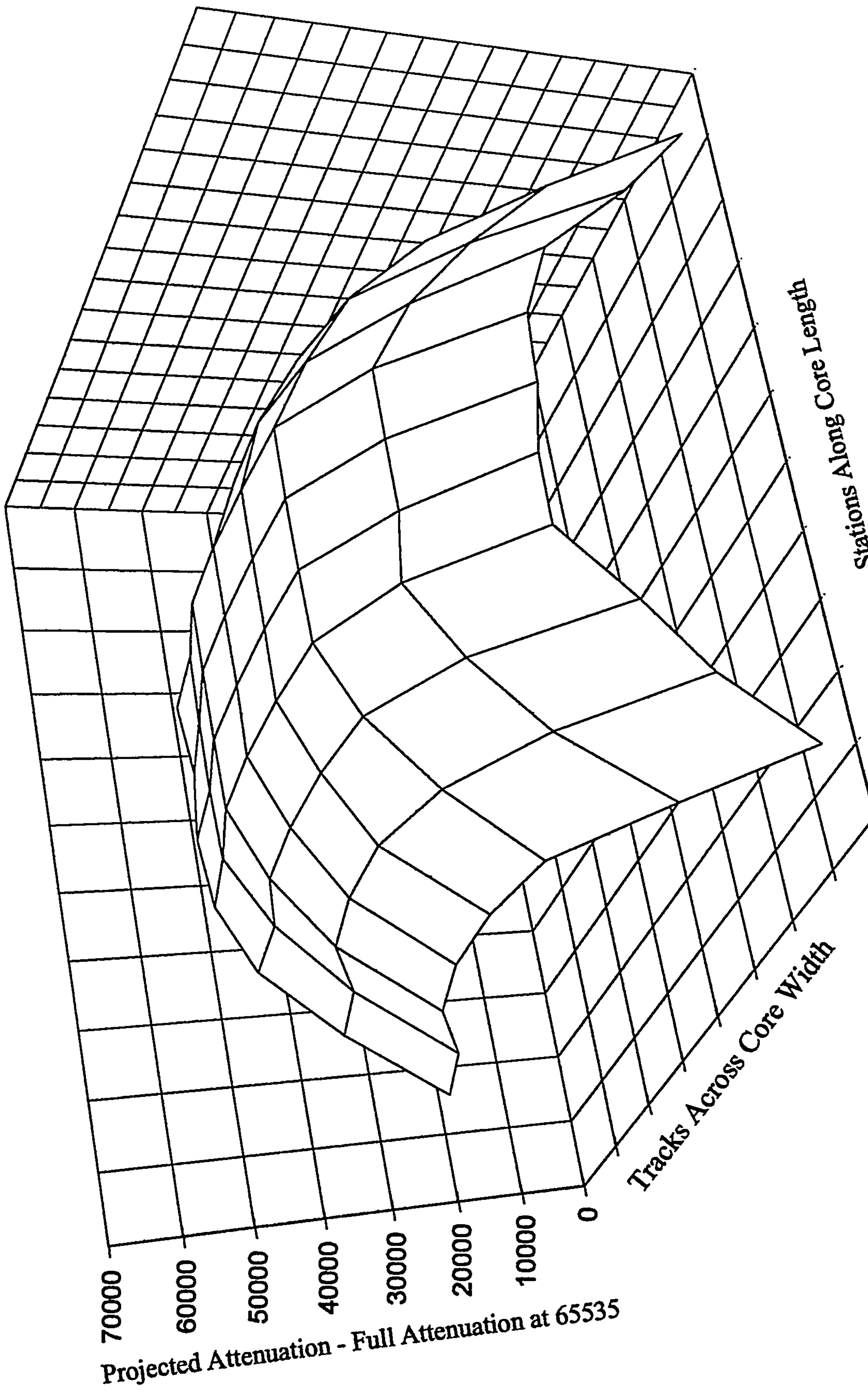
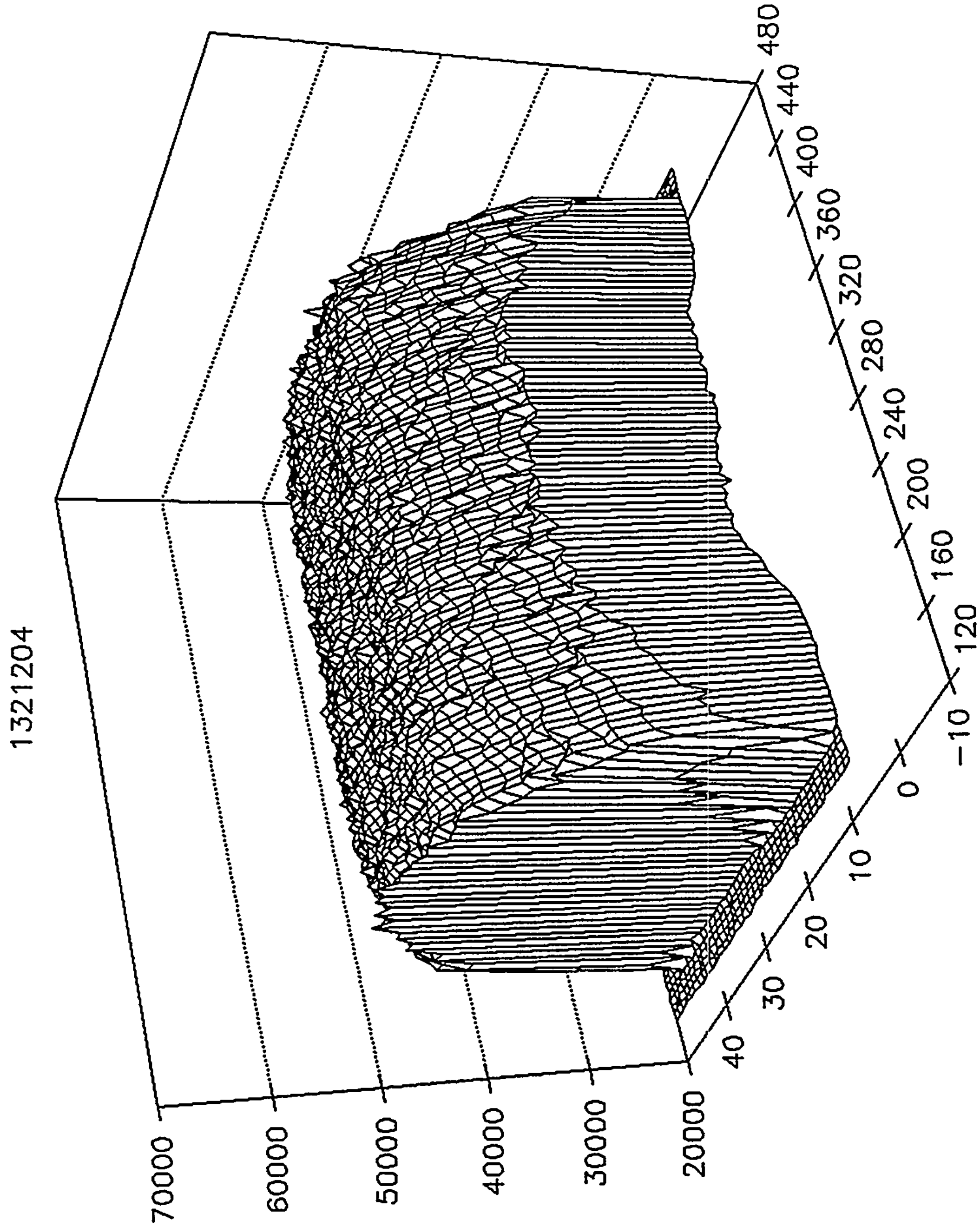
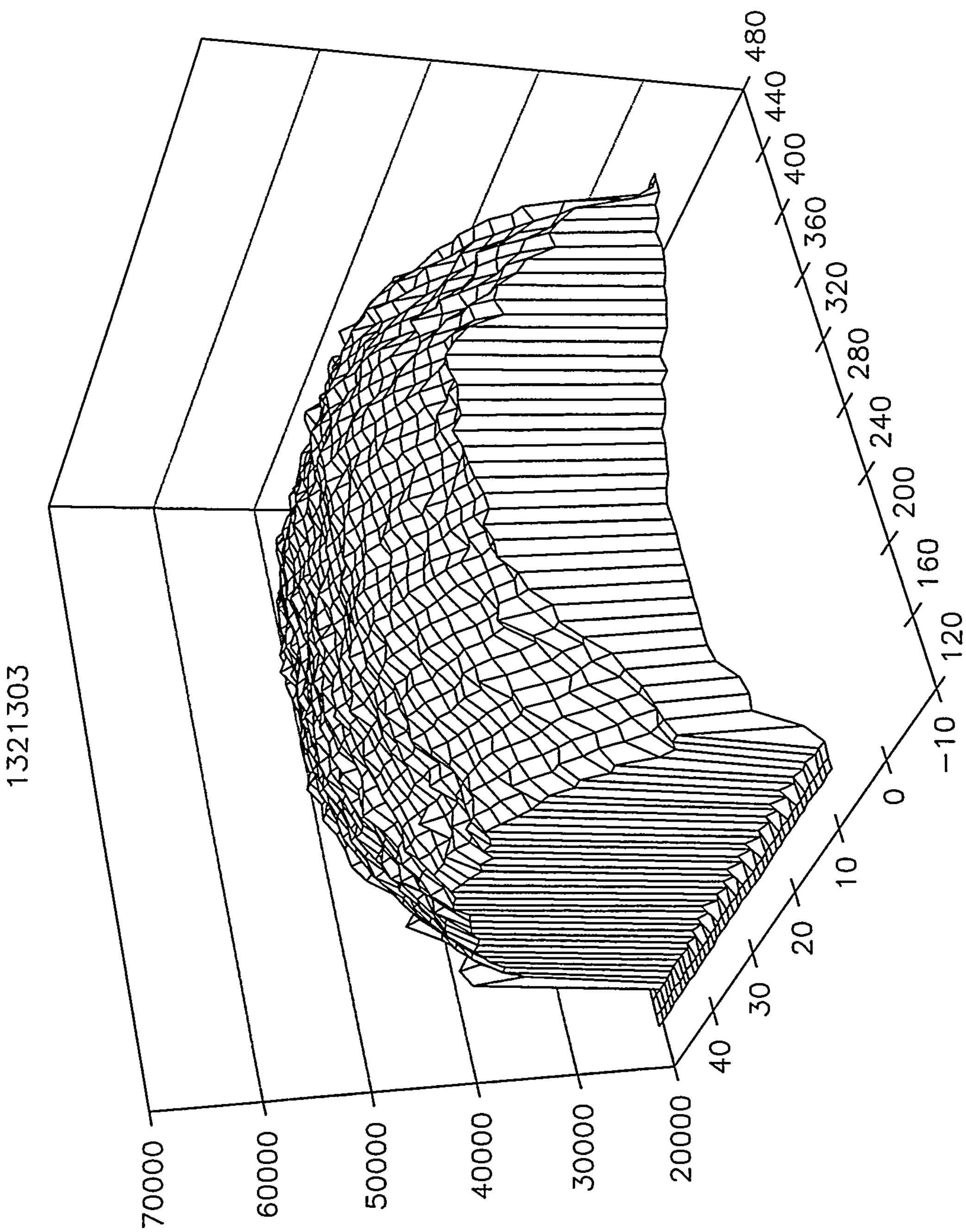
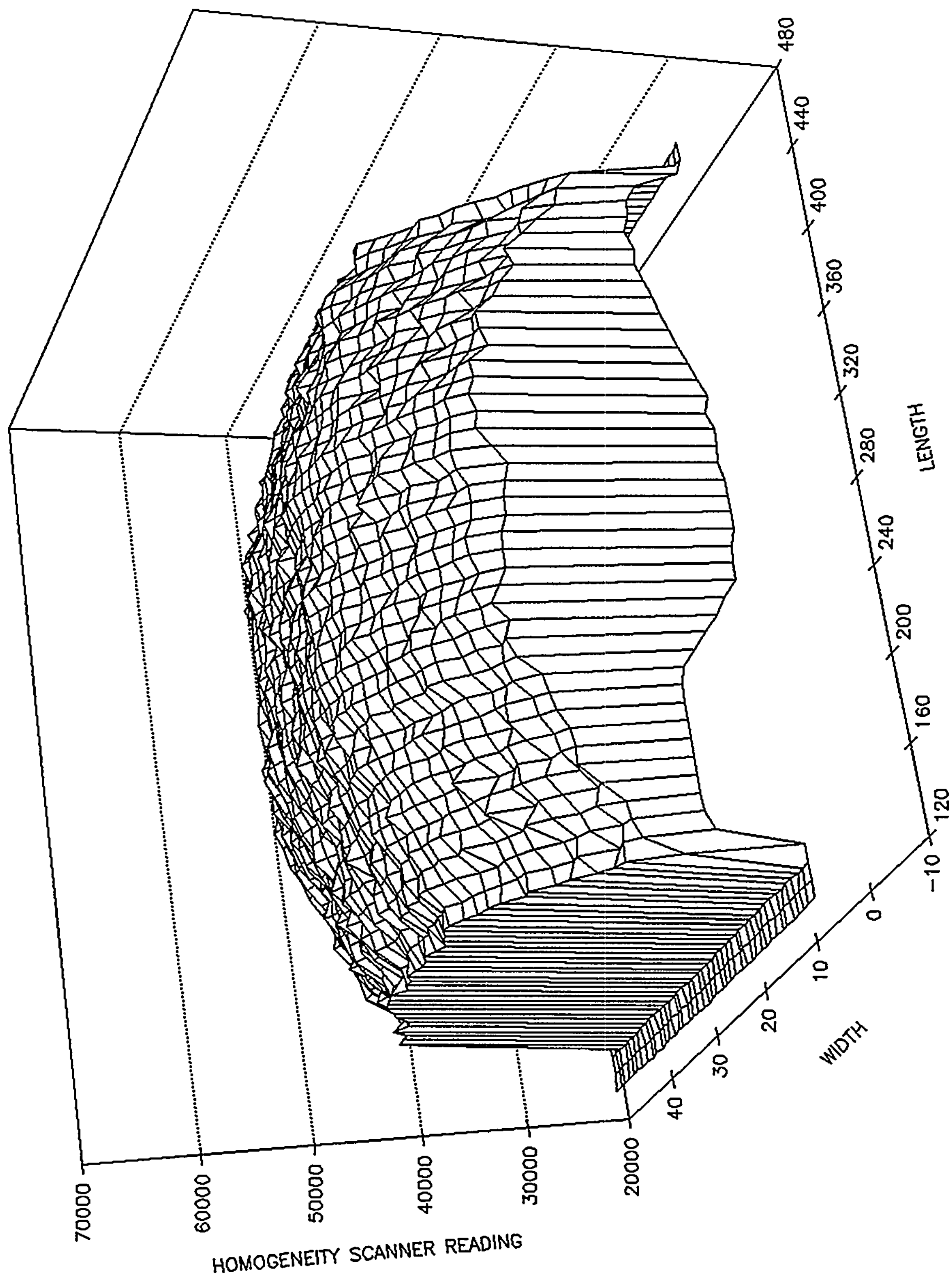


Fig. D.2. Design dual-gradient core distribution.

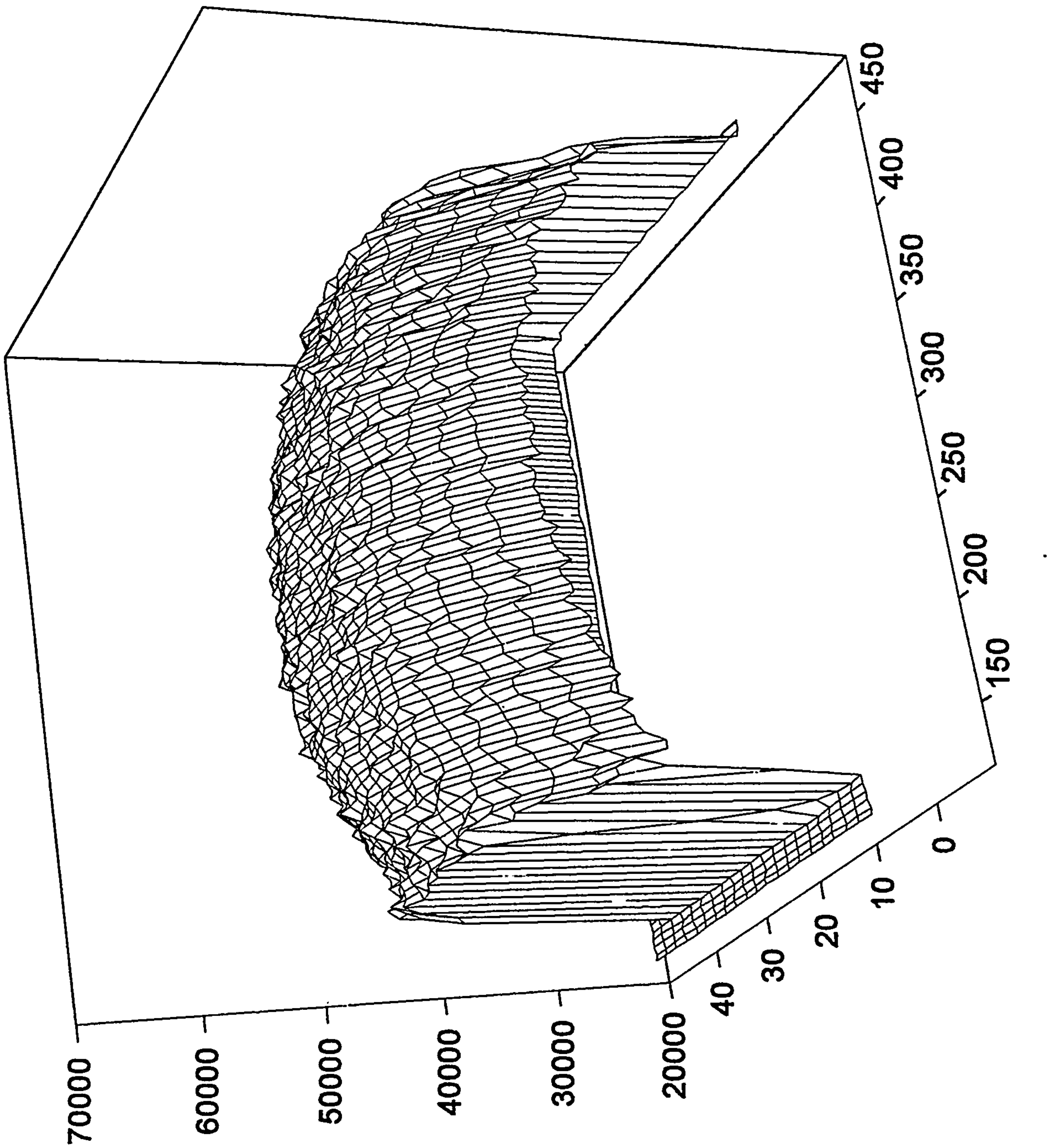

1321204
70000
60000
50000
40000
30000
20000
40
30
20
10
0
−10
120
160
200
240
280
320
360
400
440
480


1321303
70000
60000
50000
40000
30000
20000
40
30
20
10
0
−10
120
160
200
240
280
320
360
400
440
480

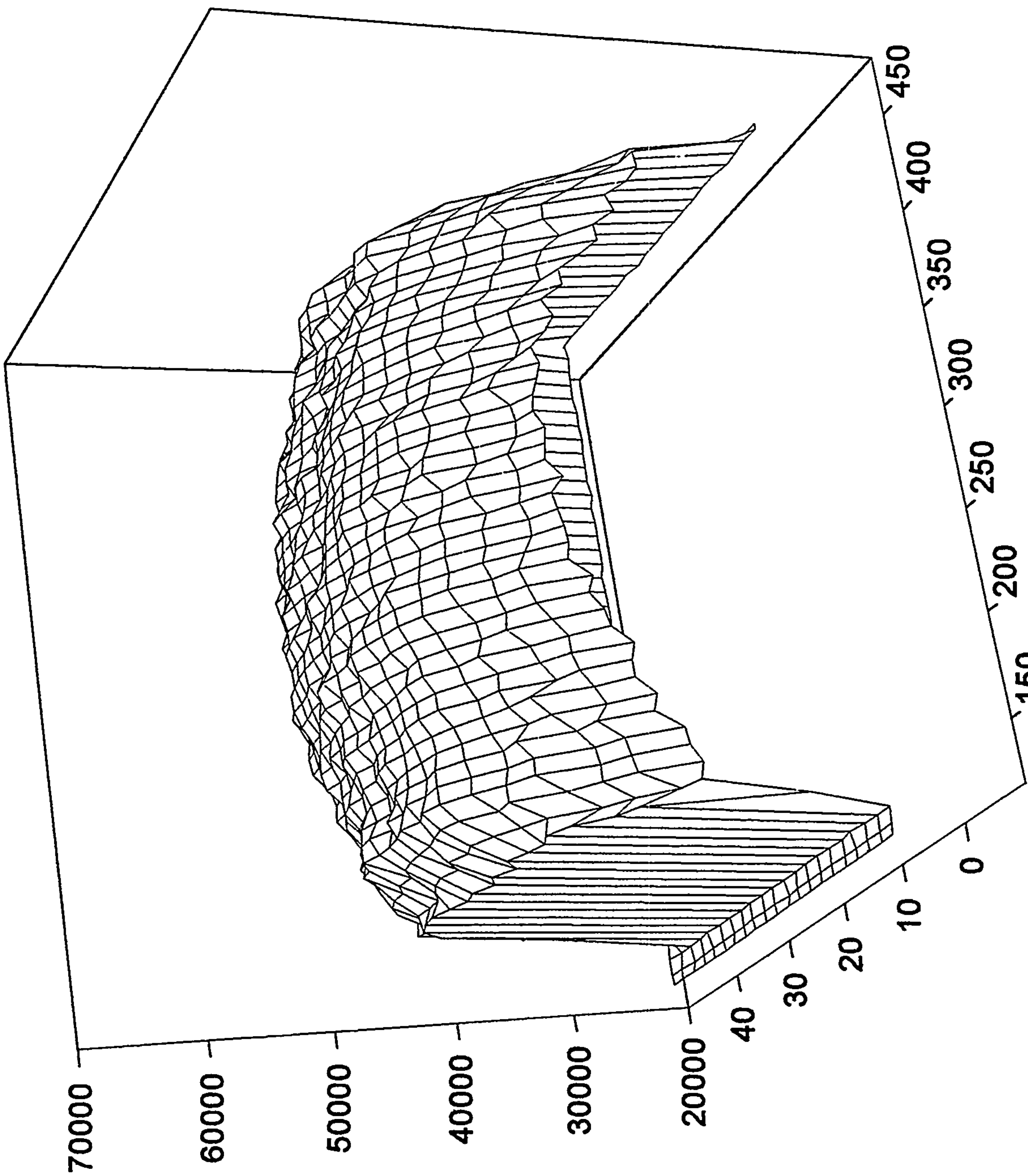
1321404


HOMOGENEITY SCANNER READING
70000
60000
50000
40000
30000
20000
WIDTH
40
30
20
10
0
-10
LENGTH
120
160
200
240
280
320
360
400
440
480

1321504

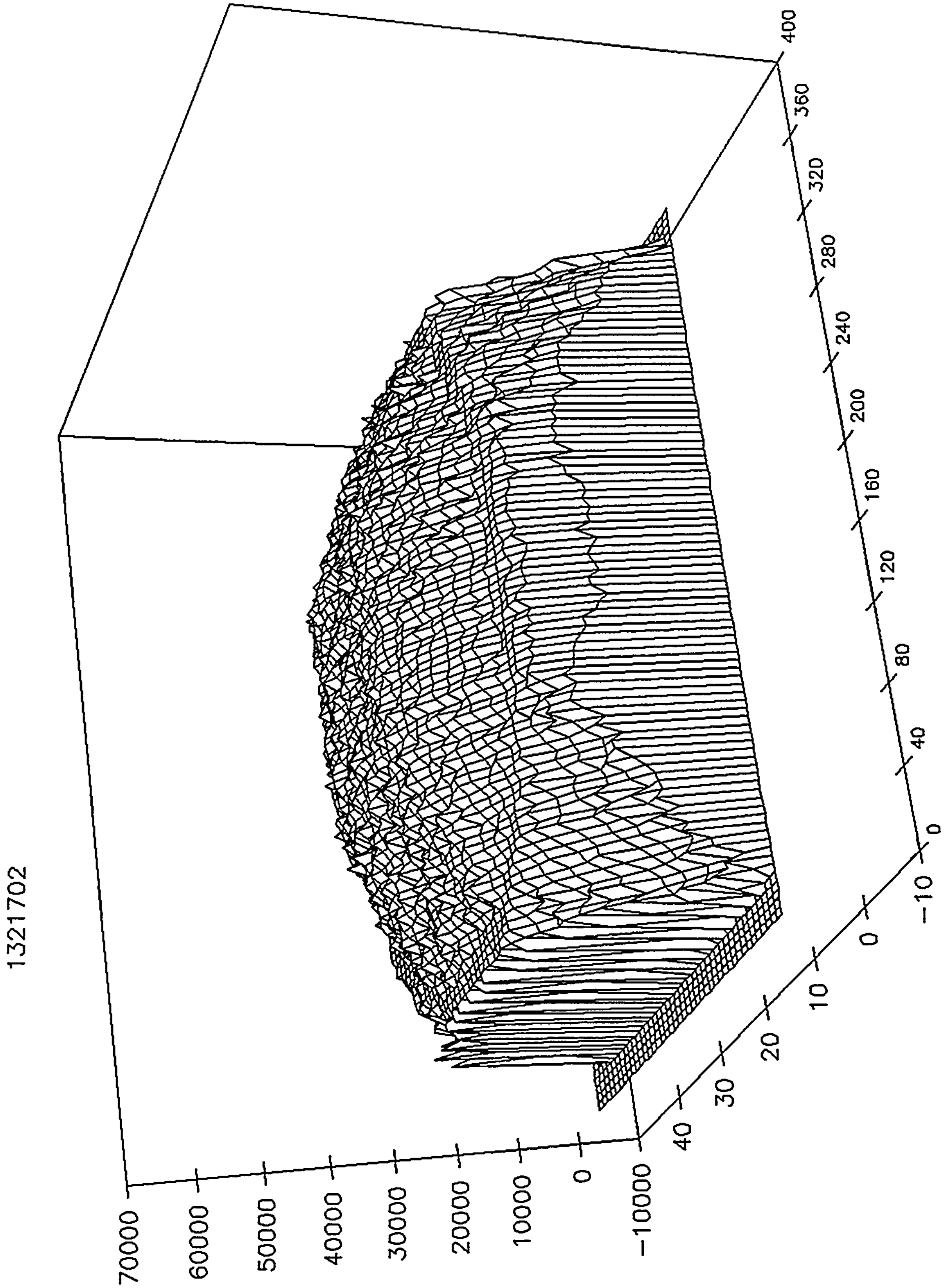

70000
60000
50000
40000
30000
20000
40
30
20
10
0
150
200
250
300
350
400
450

1321601

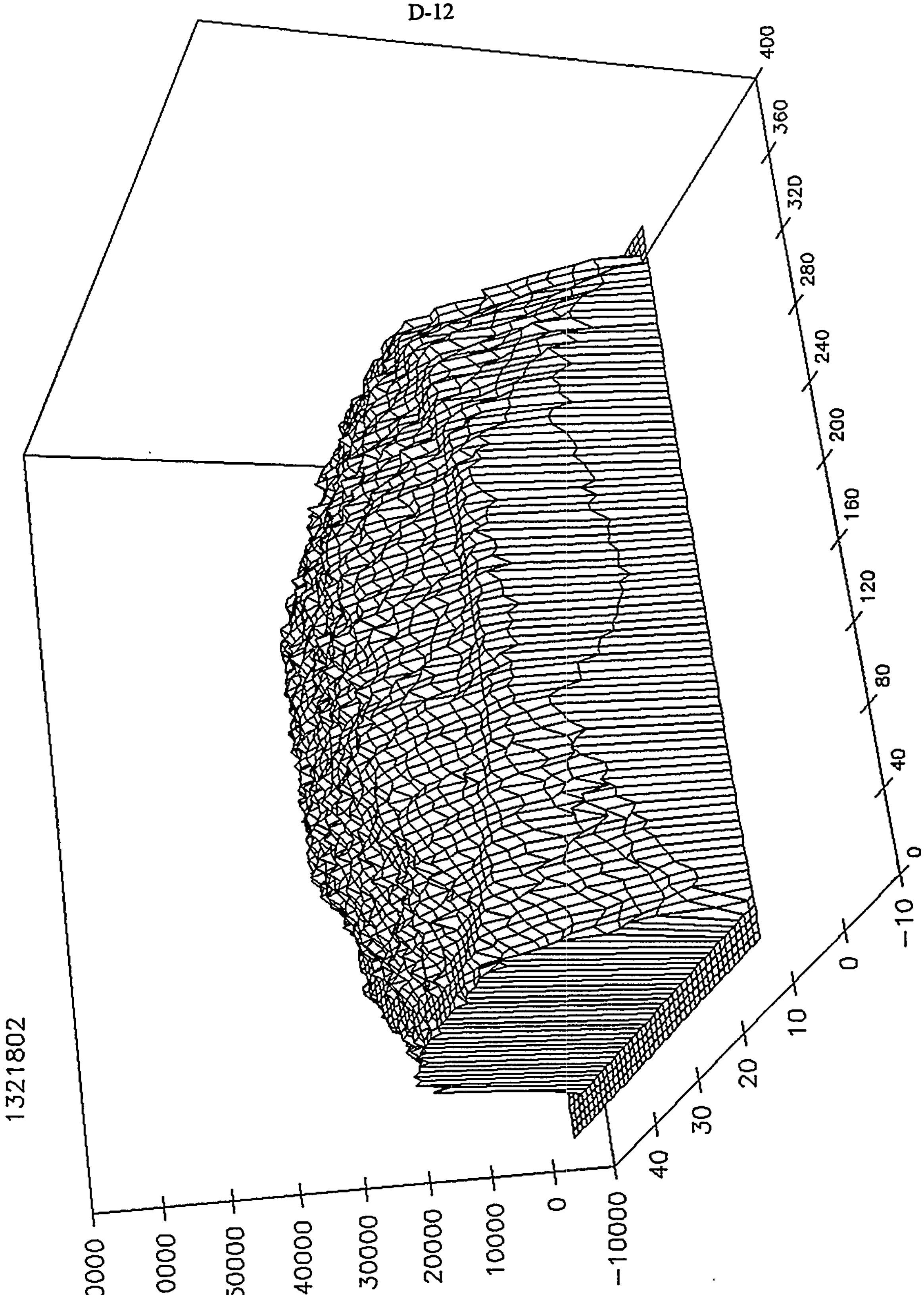


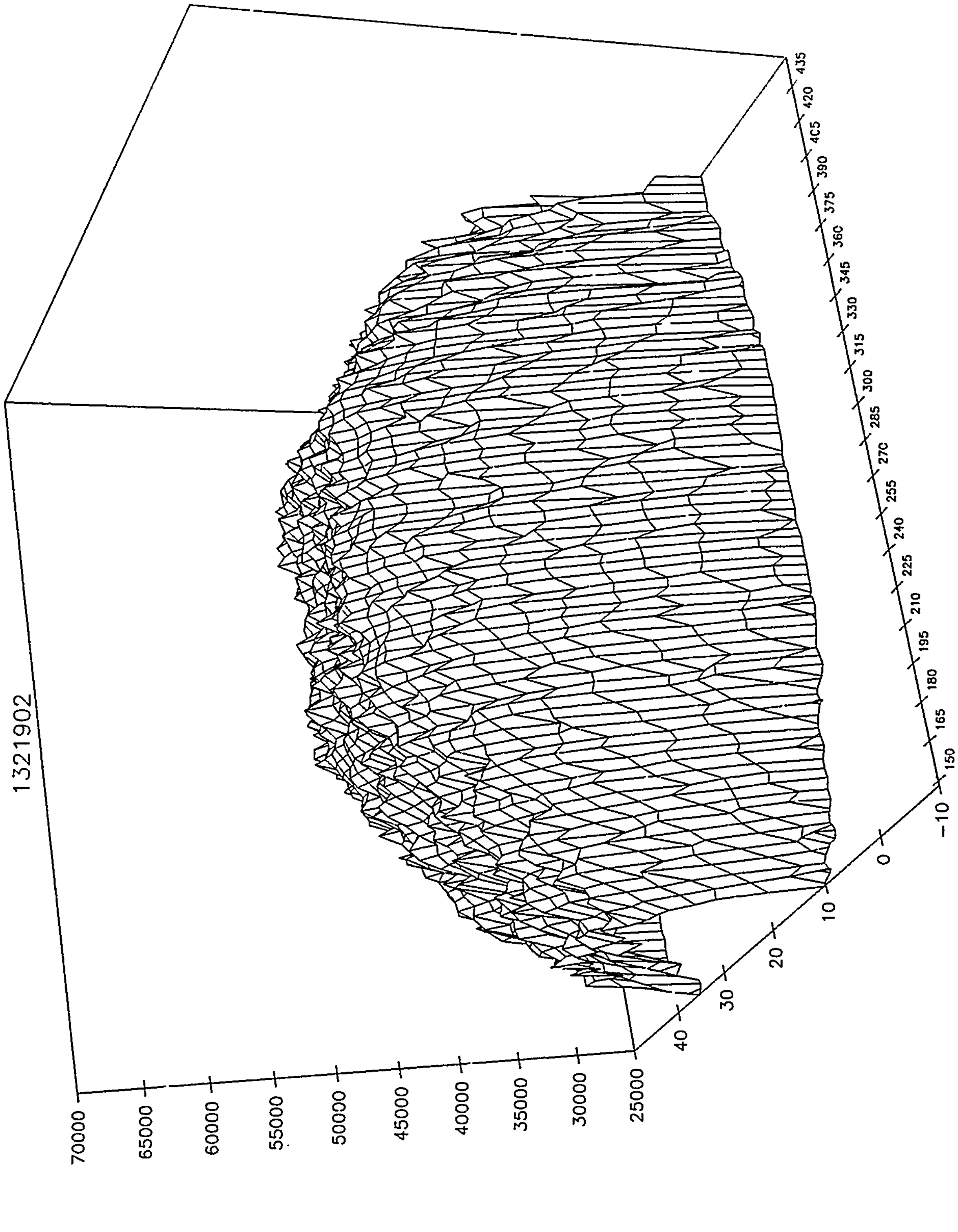
70000
60000
50000
40000
30000
20000
40
30
20
10
0
150
200
250
300
350
400
450

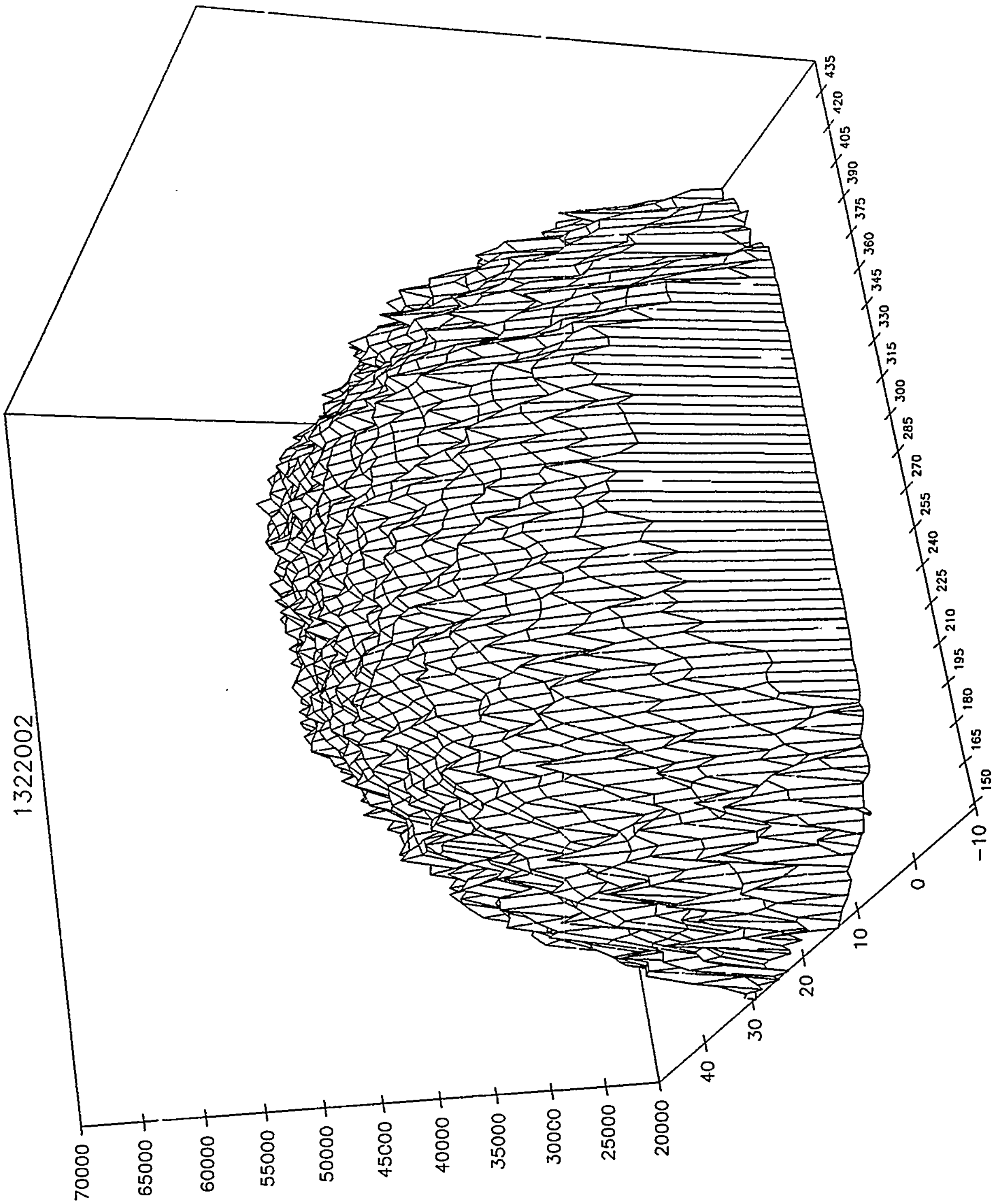
D-11

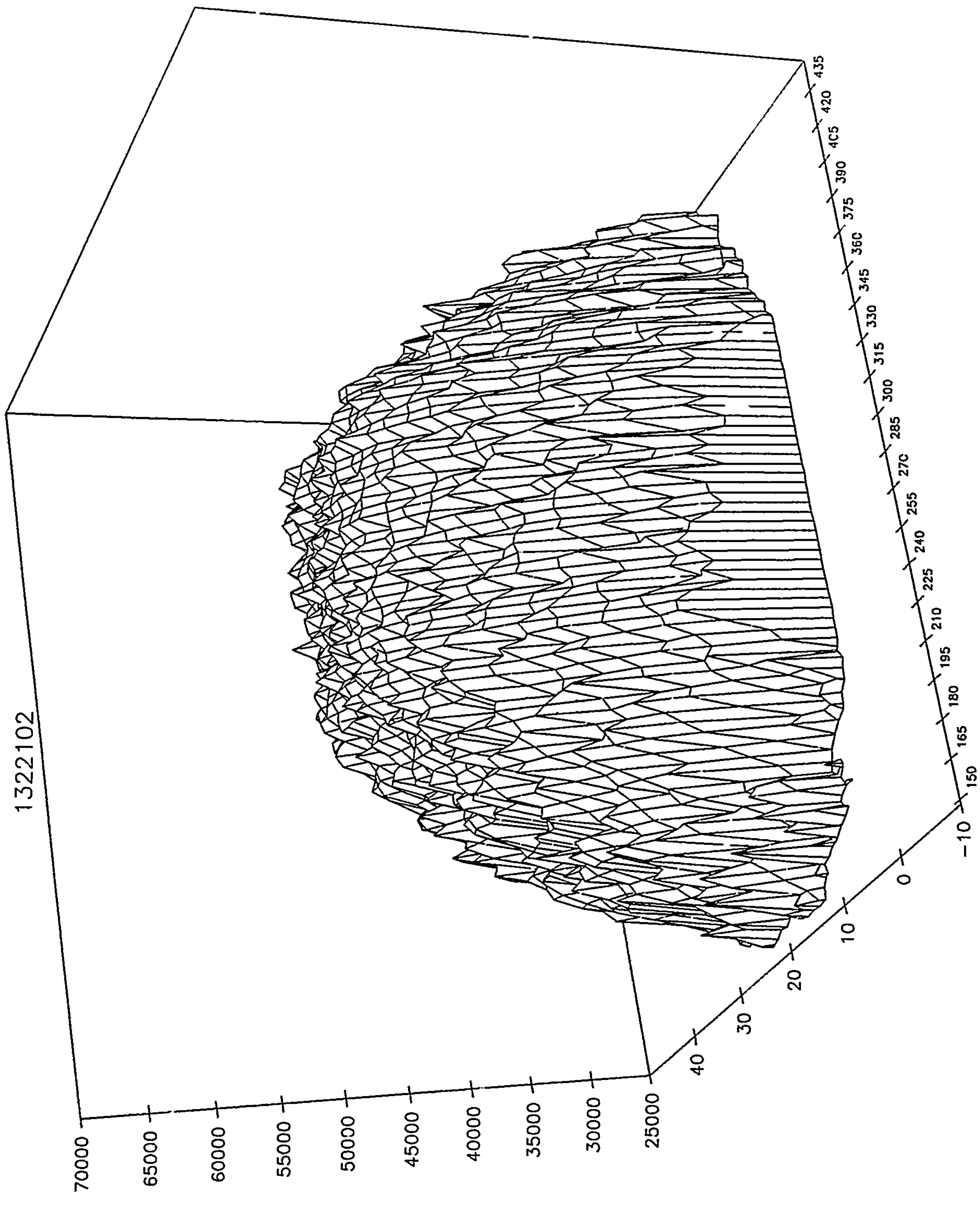


1321702
70000
60000
50000
40000
30000
20000
10000
0
−10000
40
30
20
10
0
−10
0
40
80
120
160
200
240
280
320
360
400

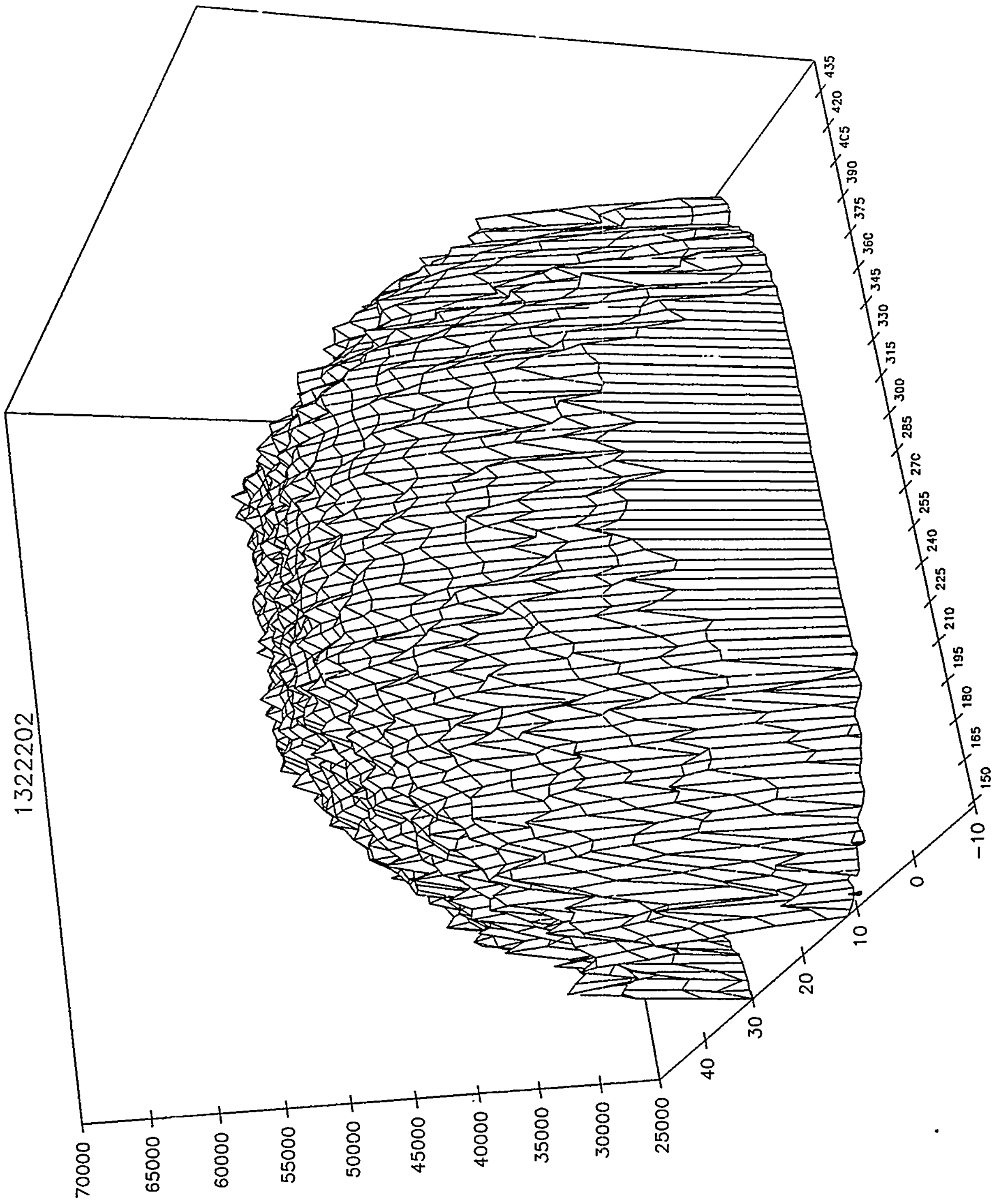

1321802
70000
60000
50000
40000
30000
20000
10000
0
−10000
40
30
20
10
0
−10
0
40
80
120
160
200
240
280
320
360
400


1321902
70000
65000
60000
55000
50000
45000
40000
35000
30000
25000
40
30
20
10
0
−10
150
165
180
195
210
225
240
255
270
285
300
315
330
345
360
375
390
405
420
435

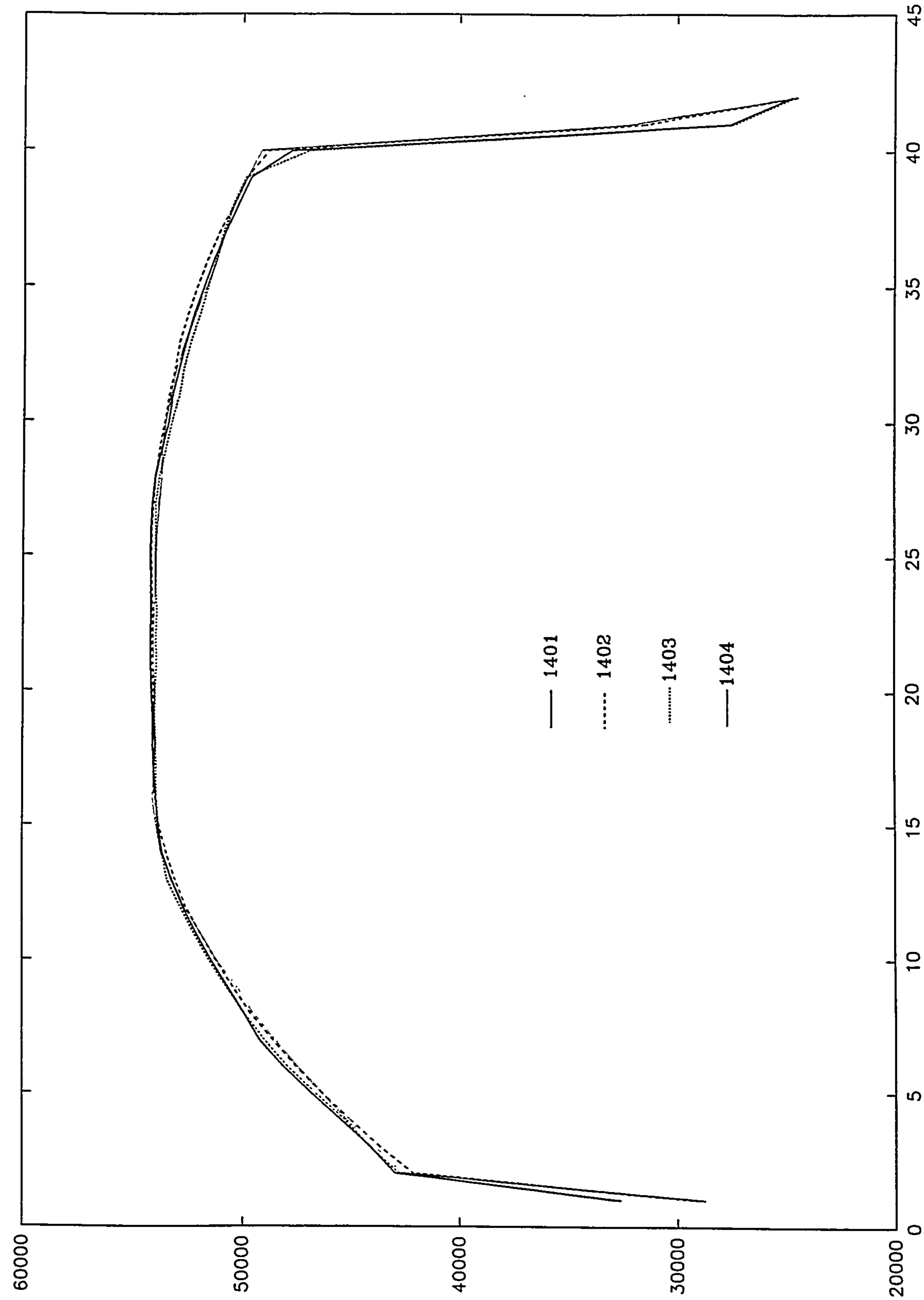

1322002
70000
65000
60000
55000
50000
45000
40000
35000
30000
25000
20000
40
30
20
10
0
−10
150
165
180
195
210
225
240
255
270
285
300
315
330
345
360
375
390
405
420
435

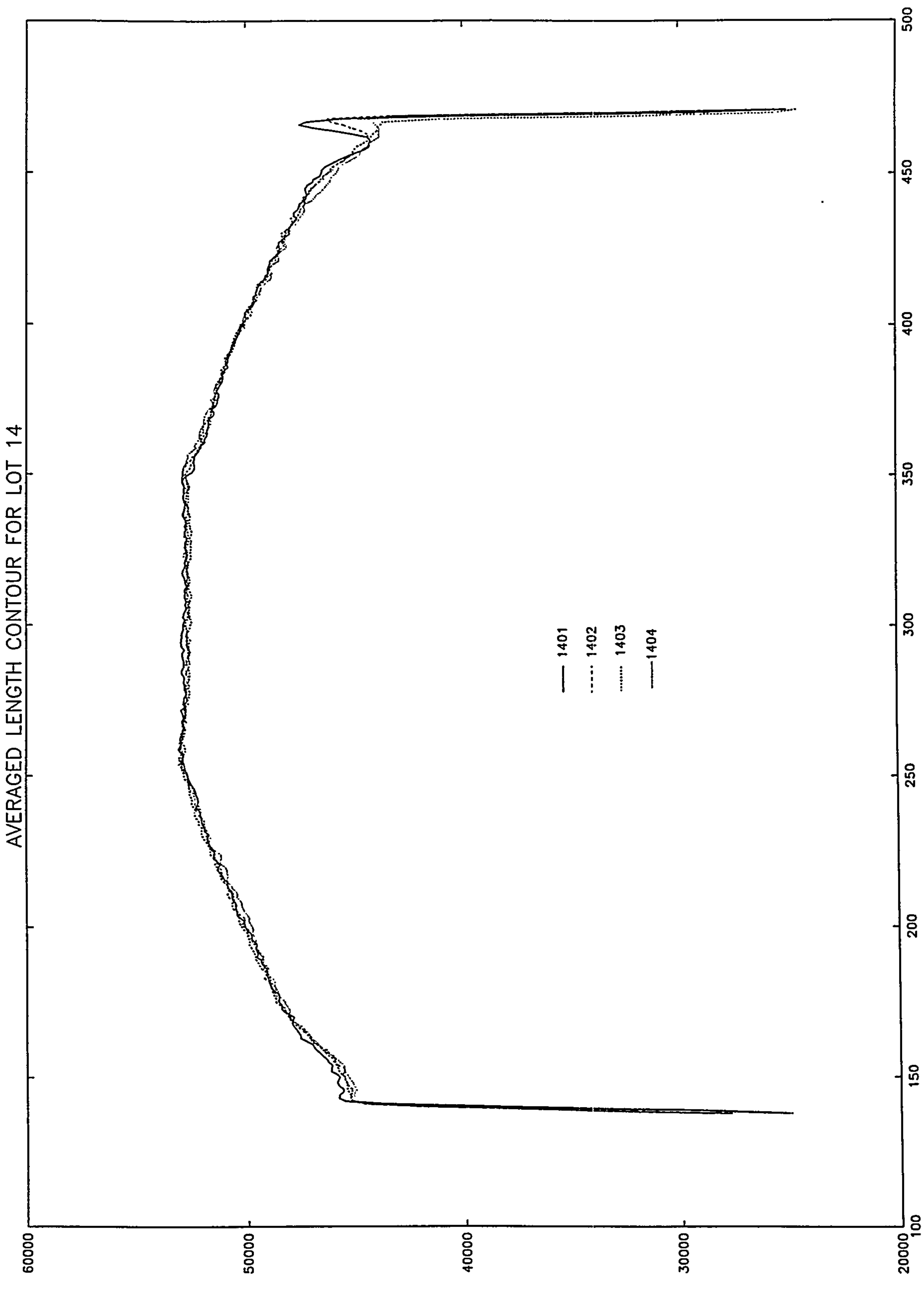

1322102
70000
65000
60000
55000
50000
45000
40000
35000
30000
25000
40
30
20
10
0
−10
150
165
180
195
210
225
240
255
27C
285
300
315
330
345
36C
375
390
4C5
420
435

D-16


1322202
70000
65000
60000
55000
50000
45000
40000
35000
30000
25000
40
30
20
10
0
−10
150
165
180
195
210
225
240
255
27C
285
300
315
330
345
36C
375
390
4C5
420
435

AVERAGED WIDTH CONTOUR FOR LOT 14





AVERAGED LENGTH CONTOUR FOR LOT 14
1401
1402
1403
1404
60000
50000
40000
30000
20000
100
150
200
250
300
350
400
450
500

Appendix E. RAW MATERIAL

Appendix E. RAW MATERIAL

E.1 URANIUM METAL

Depleted U-235 enrichment 0.2 ± 0.05 wt %

E.2 U_xSi_y POWDER

(1) Si Content 7.5 + 0.4//-0.1 wt %

(2) Major crystalline constituent:
U_3Si_2 contents shall be 80 wt % or more

(3) Impurities (ppm)

Components	Standard ppm	Components	Standard ppm
B	≤ 30	Li	≤ 10
C	≤ 1000	N	≤ 500
Cd	≤ 20	O	≤ 7000
Co	≤ 10	Fe+Ni	≤ 1000
Cu	≤ 100		
Others each	≤ 500	Others total	≤ 2500

(4) Particle Size

Particle size of U_3Si_2 shall be 74 μm or less with maximum 50% (wt %) of the particle 40 μm or less.

E.3 ALUMINUM POWDER—ALCAN 101 OR EQUIVALENT

(1) Impurities (%)

Components	Standard	Components	Standard
B	≤ 0.001	Li	≤ 0.008
Si+Fe	≤ 0.25	Cd	≤ 0.002
		Al	≤ 99.75 min

(2) Particle size

The particle size of aluminum powder shall be 125 μm or less with maximum 85 % wt % of the particles 40 μm or less.

E.4 CLADDING MATERIAL AND FRAME MATERIAL

(1) Material

The purity of the material shall be more than A6061 0-Temper or equivalent.

E.5 RAW MATERIAL TEST AND INSPECTION

All test and inspections to be performed as shown below.

INSPECTION ITEM	INSPECTION METHOD
U_3Si_2 POWDER IMPURITY ANALYSIS	CHEMICAL ANALYSIS
U_3Si_2 SILICON CONTENT	CHEMICAL ANALYSIS
U_3Si_2 PARTICLE SIZE ANALYSIS	SIEVE ANALYSIS FOR PARTICLE SIZE AND WEIGHT RATIO
ALUMINUM POWDER IMPURITY INSPECTION	CHEMICAL ANALYSIS
ALUMINUM POWDER PARTICLE SIZE INSPECTION	SIEVE ANALYSIS
CLADDING MATERIAL CHEMICAL PROPERTIES	CHEMICAL ANALYSIS
CLADDING MATERIAL STRENGTH PROPERTIES	CERTIFICATION PACKAGE

Appendix F. PARAPHRASED COMPACT AND PLATE ROUTINGS FOR ANS DEVELOPMENT PLATES

Appendix F. PARAPHRASED COMPACT AND PLATE ROUTINGS FOR ANS DEVELOPMENT PLATES

F.1 COMPACT PROCESSING STEPS

1. Set Up Die	Type 85 Die
2. Sieve aluminum powder	
3. Weigh fuel powder/al. matrix/al. filler	
4. Weigh residual U_3Si_2	
5. Blend Charges	2 Hours
6. Compact and Identify	2600 psi
7. Inspect	Length, Width, Thickness, Weight
8. Vacuum Anneal	600 deg. F for 4.5 hours

F.2 PLATE PROCESSING STEPS

1. Degrease frames and covers	
2. Assemble packs/EB weld	
3. Load Furnace	Preheat 35 minutes
4. Hot Roll, shear, identify	Per Rolling Schedule
5. Load second batch into Furnace	Preheat 35 minutes
6. Hot Roll, shear, identify	Per Rolling Schedule
7. Blister Anneal	900 deg. F - 2 hours total time
8. Unload Furnace	
9. Shear to length	Within 5" of fuel
10. Blister Inspect	Blisters/other unusual conditions
11. Cold Roll	HFIR outer templates and guide
12. Degrease	
13. Program Anneal	775 deg. F +/- 15 deg. F
14. Remove from furnace	
15. Fluoroscope punch	HFIR outer template
16. ID	Vibratool using template
17. Blank Plates	
18. Verify Conditions	
19. QC Visual	"Suspect" areas on "Suspect" plates
20. Gamma Scan	
21. Void Volume	
22. X-Ray/Homogeneity	Also Digital Homoscanner
23. Read X-Rays	Core size, location, stray particles
24. Ultrasonic Testing	Unbond and min clad
25. Dimensional Inspection	
26. Visual	Surface defects

INTERNAL DISTRIBUTION

1. D. J. Alexander
2. B. R. Appleton
3. R. L. Beatty
4–8. J. H. Campbell
9. J. E. Cleaves
10–14. G. L. Copeland
15. K. Farrell
16. D. K. Felde
17. G. F. Flanagan
18. R. M. Harrington
19. J. B. Hayter
20–23. R. L. Johnson
24. R. W. Knight
25. D. G. Morris
26. S. J. Pawel
27. C. C. Queen
28. P. L. Rittenhouse
29. R. B. Rothrock
30. J. D. Sease
31. D. L. Selby
32. R. P. Taleyarkhan
33. M. R. Upton
34. C. D. West
35. B. A. Worley
36. G. T. Yahr
37. G. L. Yoder
38. ORNL Patent Office
39. Central Research Library
40. Y-12 Technical Library
41–42. Laboratory Records Dept.
43. Laboratory Records, RC

EXTERNAL DISTRIBUTION

44–48. G. L. Hofman, Argonne National Laboratory, 9700 Cass Avenue, Argonne, IL 60439

49–53. J. E. Mays, Research and Test Reactor Fuel Elements, Babcock and Wilcox Co., P.O. Box 785, Lynchburg, VA 24505

54–58. B. W. Pace, Babcock and Wilcox Co., P.O. Box 785, Lynchburg, VA 24505

59–63. J. L. Snelgrove, Coordinator, Engineering Applications, RERTR Program, Argonne National Laboratory, 9700 Cass Avenue, Argonne, IL 60439

64. U. S. Department of Energy, ANS Project Office, Oak Ridge Operations Office, FEDC, MS-8218, P.O. Box 2009, Oak Ridge, TN 37831-8218

65–66. Office of Scientific and Technical Information, P.O. Box 63, Oak Ridge, TN 37831.