NEW DEVELOPMENT IN PHWR FUEL ASSEMBLY FABRICATION

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ABSTRACT

In the conventional process of PHWR fuel assembly fabrication, zircaloy-4 bearing and spacer pad welding is carried out on the zircaloy-4 fuel sheaths after loading and encapsulation of the UO_2 fuel pellets. In some cases, this method could lead to damage of the pellets and protective graphite coating on the inner surface of the zircaloy-4 sheath. To overcome this problem, a novel method has been developed, where appendages are first welded on empty fuel sheaths by supporting from inside followed by loading of pellets and encapsulation.

1.0 INTRODUCTION:

A 19-element 220 MWe PHWR fuel assembly comprises of one element in the center, six elements in the inner circle and twelve elements in the outer-circle. In this conventional method of fuel assembly fabrication as shown in Fig.1, the uranium oxide fuel pellets loaded in zircaloy-4 cladding having graphite coating on the inner surface followed by resistance welding of end plugs. Next the resistance welding of tiny appendages called spacer pads on the periphery of each of all the 19 fuel elements for inter-element spacing and bearing pads along the length of all the 12 outer circle elements for spacing between the coolant tubes and the fuel assembly. The design of these appendages is such as to ensure uniform passages for the desired coolant flow around the surfaces of every element and to avoid hot-spots and subsequent fuel failures in an operating reactor.

When appendages are welded on a free open tube, it is observed that the fuel sheath gets depressed locally to an extent of 125-200 μm at the welds. The pellet-clad gap is maintained in the range of 25-50 μm only. As a result, when the spacers and bearing pads are welded on encapsulated fuel elements, the pellets support the fuel sheath during the welding process and, in turn, get locked-up and may even develop cracks. The protective graphite coating of the sheath is also sometime seen to flake off at the welds. This renders the inside sheath surface at the welds vulnerable to failure in the operating reactor. In the event of rejection of the fuel element subsequent to the appendage welds, difficulty is faced in retrieval of the pellets. Most of the time these UO_2 pellets are damaged and sent for dissolution, precipitation, calcination and reduction to obtain sinterable grade UO_2 powder.

However, in view of the shortcomings of the conventional process, a new method has been developed which is inexpensive and yields superior quality welds. In addition, it is easier to retrieve the loaded UO_2 pellets in undamaged conditions for reloading, in the event of rejection of fuel assemblies.[1]

2.0 DESIGN CONSIDERATIONS:

The existing electrical resistance welding process has not been changed. Attention was given mainly on the method of supporting the sheath from inside during resistance welding of appendages i.e. zircaloy-4 bearing and spacer pads. Essentially a long mandrel is used for which the following factors were kept in mind.

a) Accommodate variations in ID of the tube within tolerances.
b) Shall not induce scratches on the inside sheath
c) Shall not damage the chamfered edge of the tube.
d) Selection of material suitable for thermal stress cycling.
e) Mandrel material compatible with sheath.
f) Precise positioning of the tube within $\pm$ 50μm with respect to the weld-head.
g) Possibility to admit inert gas between the support and sheath to avoid oxidation.
h) Shall be electrically isolated.
i) Simplicity in design for good maintainability.
j) Easy adoptability to the spacer and bearing pad welding machines in use for fuel production at present.

The appendage welds should conform to all the Quality Assurance specifications with respect to strength, weld metallurgy, positioning and orientation etc., They shall be free from visual defects like weld expulsion, sparking, weld oxidation, etc.,

3.0 EXPERIMENTAL:

A self-adjusting type sheath support system meeting all the above requirements has been successfully developed and incorporated in one number each of spacer pad and bearing pad welding machines. Welding parameters were optimized and the process was established. Welds produced through this method were subjected to evaluation and subsequently the machines were qualified for regular production use. The spacer pad and bearing pad welding process developed is explained in the following paragraphs.

3.1 Spacer Pad Welding Process: The fuel tube is mounted over the support system and held in a chuck. The mandrel is actuated. The spacer pad is placed on the fuel tube with the help of a pick-up arm and retained on the fuel tube at the required helix angle with the help of a template, which also acts as the element clamp. The weld-head is actuated to exert the required electrode force. An inert gas shroud is created around the spacer-pad. Welding is done. A capacitor-discharge type power source with an associated pulse transformer provides the required energy for welding. The mandrel is de-actuated and the tube indexed to facilitate welding of the next spacer. This is repeated to weld spacers at all the required angular intervals. A photograph of the machine is given at Figure-2.

3.2 Bearing Pad Welding Process: Three bearing pads are welded along the length on each of the outer circle elements of the fuel assemblies. Three numbers of spacer pads also are to be welded at the central section for each of these outer circle elements. For convenience, the spacers are welded first. The fuel tube is mounted over the self-adjusting sheath support system in de-actuated condition and positioned appropriately with respect to the spacers welded already. All the three bearing pads are simultaneously fed on to the fuel tube. Each bearing pad is retained in a specific location on the tube with the help of a two-part template mechanism. The welding at all the projections of three bearing pads is carried out simultaneously. An AC synchronous power source with a transformer and an associated micro-processor-controlled weld control unit wherein the weld and squeeze cycles can be programmed, provides the required energy for welding. A photograph of the machine is given at Figure-3.

Figure – 4 shows an array of the tubes with appendage welds produced using the new process. More than 200 numbers of 19 element 220 MWe PHWR fuel assemblies have been produced by this new process and 50 numbers are already loaded into the reactors for in-pile testing. Figure – 5 shows the flow-chart of the new fuel assembly fabrication process.

4.0 RESULTS & DISCUSSIONS:

All the usual Quality Assurance checks which include measurement of strength, positional accuracies, etc., specified for the welds on loaded elements were carried out at both the equipment/process qualification and regular production stage. The new process successfully passed these tests.

In addition, the following tests have also been carried out:

a) Measurement of the sheath depression at the weld-spots.
b) Damage to the fuel tubes inflicted by the support system.
c) Inside surface inspection.
d) Any other visual defects.

The results are as follows:

a) The sheath depressions at the welds could be maintained at a value of < 10 μm at all the welds on all the tubes used.
b) No scratches were noticed on the inside surfaces of the tubes.
c) 35 tubes out of a total of 1,131 were found to have one of their chamfered edges damaged slightly during the initial phase. But subsequently this problem has also been overcome.
d) Surface marks of slight oxidation (sparking) were observed at some points of contact of the fuel tube with the fixed bottom electrode.
e) The appendage-to-sheath gap is noticed to be more. This is as expected.

Figure - 6 to Figure - 9 show a comparison of the trends in the variation of the arithmetic mean (X-bar) and standard deviation (σ) pertaining to typical weld strength values of samples from thirty five production lots each from both a) existing process of welding the appendages on loaded fuel elements and b) the new process of welding the appendages on empty tubes with self adjusting weld support system. Figure - 10 to Figure - 13 show the micro-structure of the longitudinal and cross sections at the welds made by the new process as compared to the earlier process.

5.0 CONCLUSION:

5.1 Advantage of the new process : The advantages of new method of manufacturing PHWR fuel assemblies are as follows :

a) Integrity of pellet is maintained during manufacturing.
b) In the event of rejection of fuel element at subsequent stages, the fuel pellets can be easily salvaged in undamaged condition for reloading into new fuel tubes.
c) Reduces the number of stages of handling the radioactive material.
d) Reduction in the total number of fabrication stages.
e) The graphite-coating of fuel tubes could be done subsequent to appendage welding.
f) Overall process is more economical.

5.2 Manufacturing Experience : More than 200 such 19 element PHWR fuel bundles were manufactured by this new process and in-house developed equipments. Based on the experience gained, NFC is now poised to manufacture equipments for resistance welding machines for bearing pad and spacer pads for in-house applications and exports.

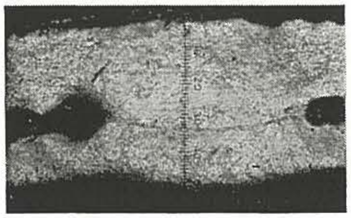
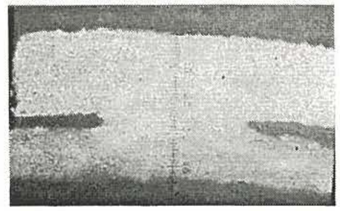
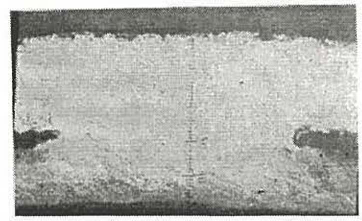
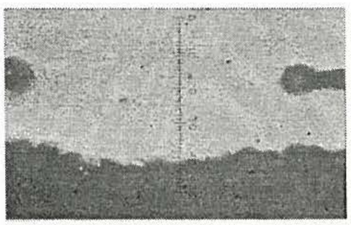
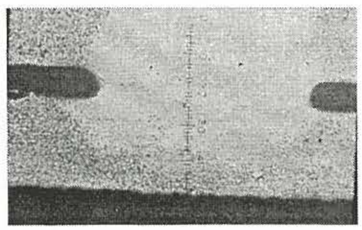
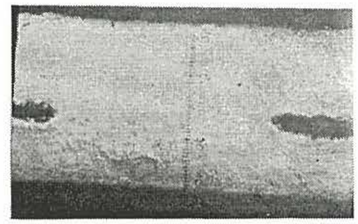
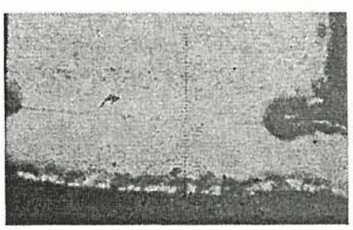
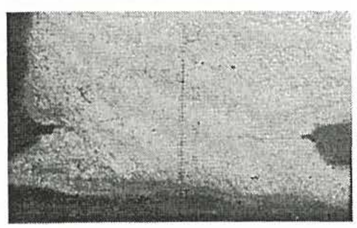
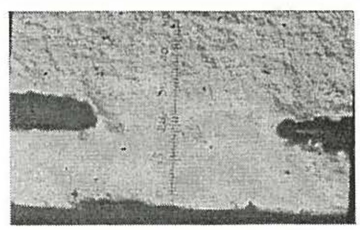
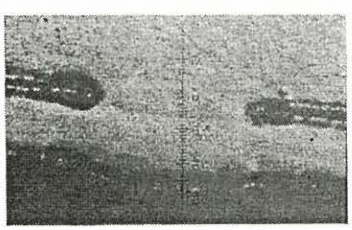
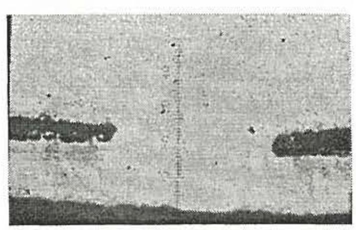
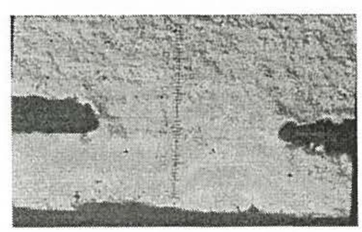
6.0 ACKNOWLEGEMENT:

Authors are grateful to the Colleagues from Equipment & Development, Production, Quality assurance and Maintenance section of PHWR fuel group of Nuclear Fuel Complex for their active cooperation and contributions in making the modified process a success.

7.0 REFERENCE:

1. Dr.GANGULY.C, "PHWR FUEL PERFORMANCE IN INDIA", Conference Proceedings Sixth International Conference on CANDU Fuel, Niagara Falls, Canada, Vol. II Page No. 19–26, September,26-30,1999.

TABLE – 1: COMPARISON OF MICRO-STRUCTURES OF APPENDAGE WELDS

	On Empty Fuel Tubes Without Mandrel Support	On Tubes Loaded With Pellets (Fuel Elements)	On Empty Fuel Tubes With Mandrel Support
SPACER PAD WELD TRANSVERSE			
SPACER PAD WELD LONGITUDINAL			
BEARING PAD WELD TRANS VERSE			
BEARING PAD WELD LONGITUDINAL			

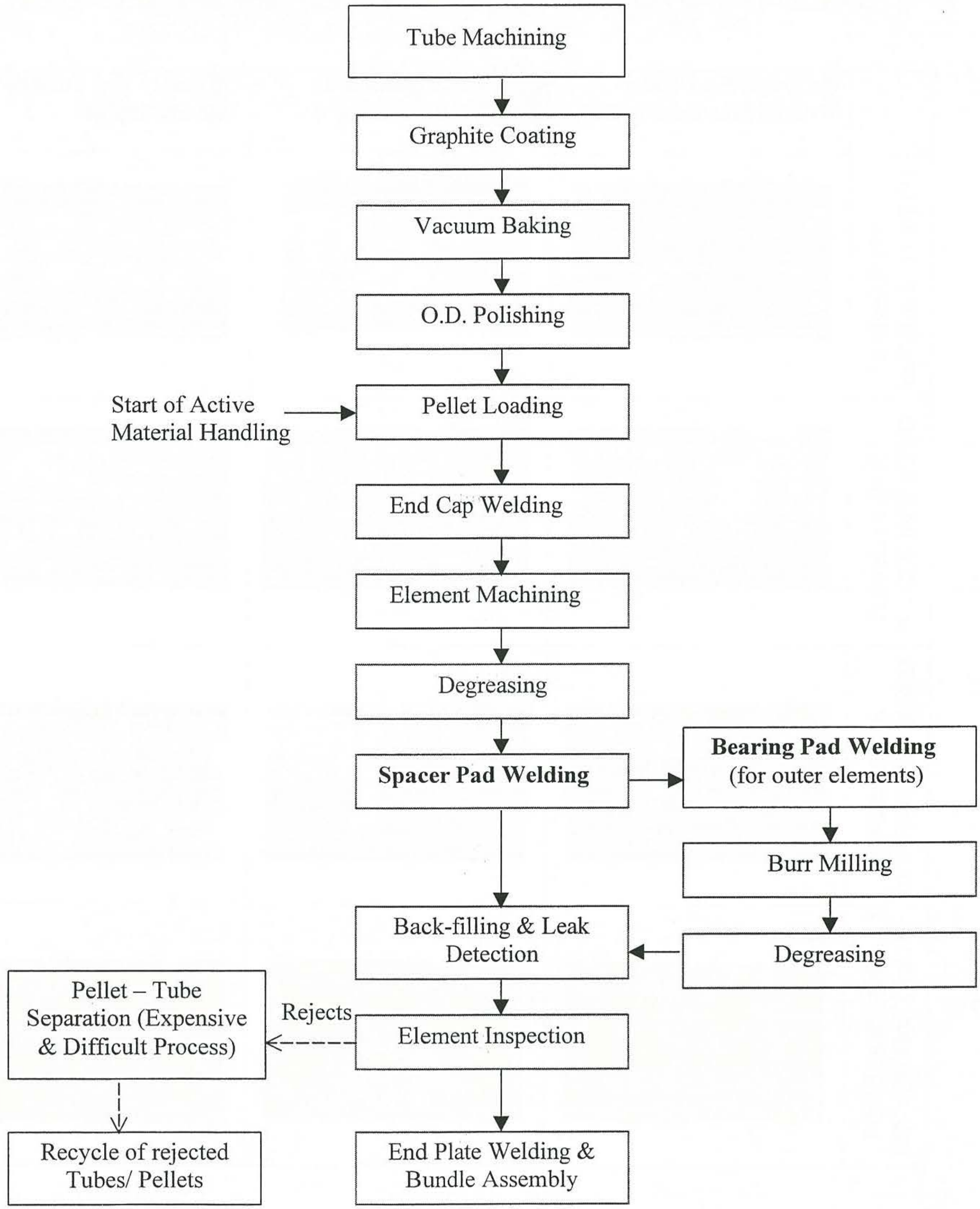


FIG 1: CONVENTIONAL PROCESS FLOW SHEET FOR MANURACTURING 220 MWe PHWR FUEL ASSEMBLY.

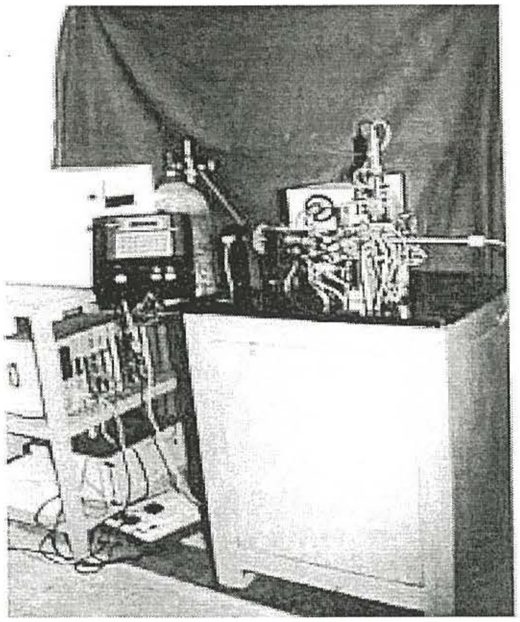


FIG 2: INDIGENOUS EQUIPMENT DEVELOPED FOR RESISTANCE WELDING OF Zr– 4 SPACER PADS ON Zr-4 FUEL CLADDING

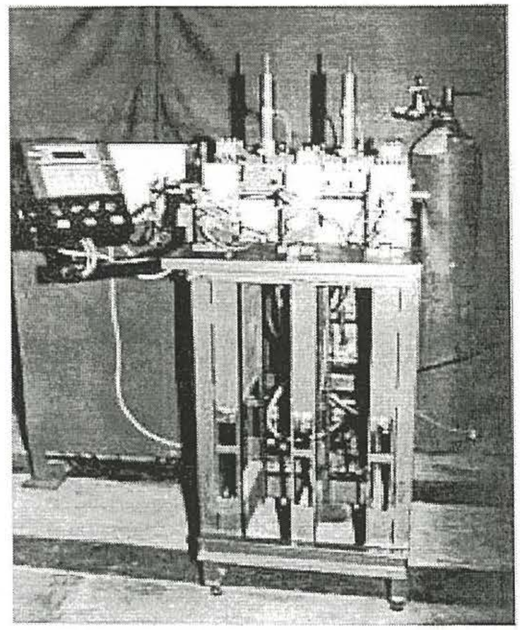


FIG 3: INDIGENOUS EQUIPMENT DEVELOPED FOR RESISTANCE WELDING OF Zr – 4 BEARING PADS ON Zr-4 FUEL CLADDING.

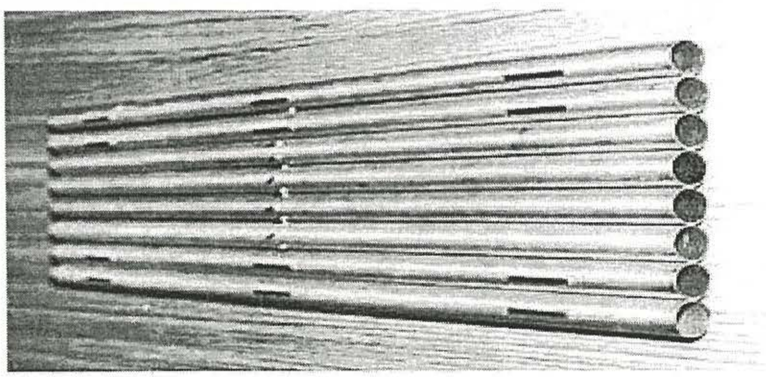


FIG 4: Zr – 4 FUEL CLADDING TUBE WITH RESISTANCE WELDED Zr – 4 BEARING AND SPACER PADS PRIOR TO FUEL PELLET LOADING AND ENCAPSULATION.

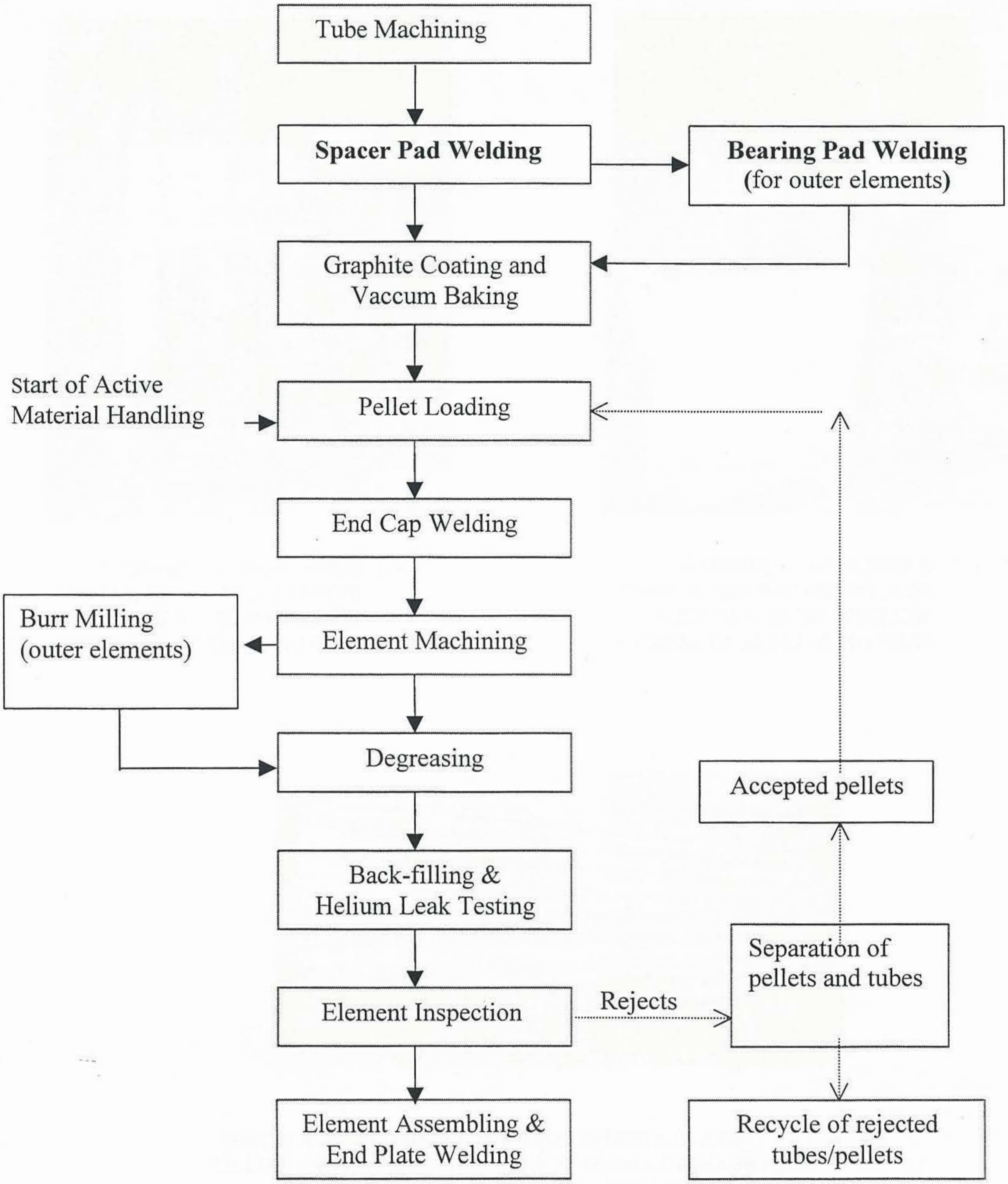


FIG 5 : NEW PROCESS FLOW SHEET FOR MANUFACTURING
PHWR 220 FUEL BUNDLE

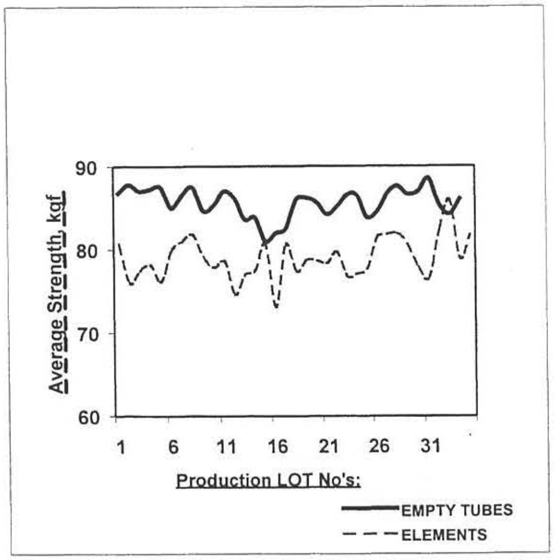


FIG 6 : COMPARISON OF AVERAGE WELD STRENGTH OF SPACER PAD WELDS

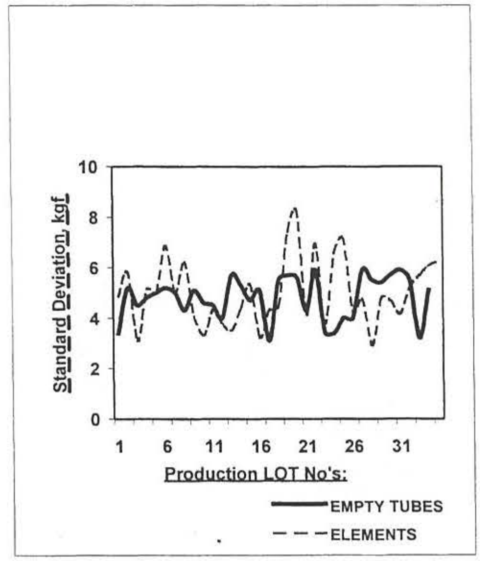


FIG 7: COMPARISON OF STANDARD DEVIATION OF S PACER PAD WELDS

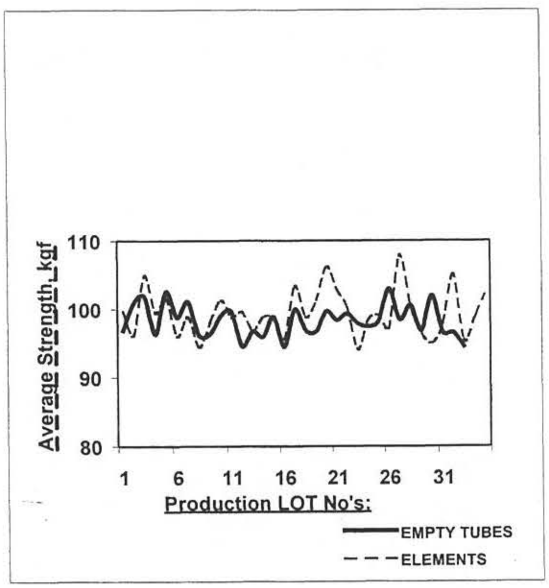


FIG 8 : COMPARISON OF AVERAGE WELD STRENGTH OF BEARING PAD WELDS

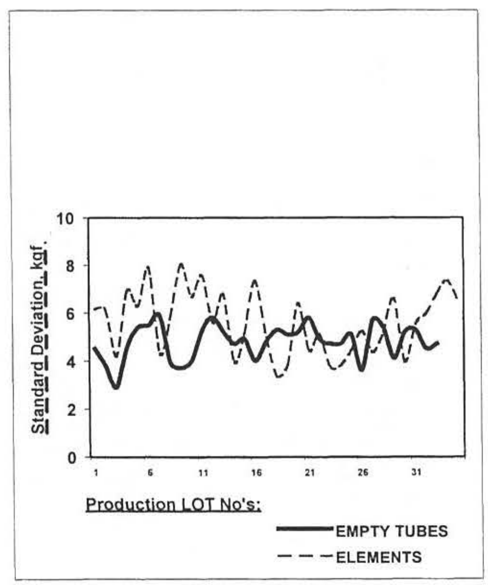


FIG 9 : COMPARISON OF STANDARD DEVIATION OF BEARING PAD WELDS