Implementation of Canflex Bundle Manufacture - From "Bench Scale" to Production

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Abstract

Zircatec Precision Industries (ZPI) has been involved with the development of the 43 element Canflex bundle design since 1986. This development included several "prototype" campaigns involving the manufacture of small quantities of test bundles using enriched fuel. Manufacturing and inspection methods for this fuel were developed at ZPI as the design progressed. The most recent campaign involved the production of 26 bundles of the final Canflex design for a demonstration irradiation in the Point Lepreau Generating Station.

This presentation will explore issues pertaining to the introduction of a new product line from initial trial quantities to full production levels. The Canflex fuel experience and a brief review of development efforts will be used as an example.

Canflex History - Concept to Prototype

As has been described elsewhere during this conference (for example session 2a); the Canflex bundle requires two sizes of fuel elements; 8 large (13.5 mm nom. dia.) and 35 small (11.5 mm nom. dia.). In extending the traditional 37 element bundle design (Figure 1), the Canflex development has required the manufacturer to combine what are essentially two separate production lines for the two sizes of fuel into one bundle. The increased number of sheaths and the addition of the mixer tabs (buttons) has presented an added challenge (Table 1).

Zircatec has been involved with the manufacturing development of Canflex fuel since 1986. Early work involved the manufacture of enriched fuel pellets and sheath assemblies for test fuel bundles. During the 1989 - 1994 period we developed tooling and procedures for the manufacture of several (3 - 6) Canflex design (Mk III) bundles for irradiation at CRNL. These bundles were manufactured with 2.26% enriched fuel. The uniqueness of this bundle design - two fuel element sizes required considerable innovation in manufacturing process flow control and tooling design. Due to the small scale of the early work these were not serious issues. However, as the scale of the campaigns increased, so did the attention that was paid to future production level manufacturing issues.

As is usual with all new product development activities, the initial campaigns were conducted at a small scale. Most of the early campaigns involved the processing of 20 - 100 kg of UO_2 powder (1 - 6 bundle equivalent quantities) and the production of small quantities of tubing. For example, pellet pressing was done in presses which we would consider "laboratory scale"; braze runs were small and brazing was done in a "one off' fashion using a small scale brazing unit; end cap welding was done in a laboratory scale, manually operated welding unit. This early work included:

- Development of processes for control of density and microstructure of Canflex UO_2 pellets; this work involved examining the feasibility of restricting the sintered density and resinter density stability to user defined limits. Approximately 2 - 5 kg UO_2 of pellets were produced. Laboratory scale equipment was used for this production.

- Small scale manufacture of enriched and natural UO_2 pellets to the then (1986 - 1989) current Canflex pellet design. During this work initial scoping tests were conducted in order to establish the tooling designs for the Canflex pellets. This enabled the procurement of prototype tooling for small scale manufacture. Pellet manufacture proceeded after tooling procurement. The work also included the development of sampling plans and inspection procedures for these pellets. Approximately 100 - 200 kg UO_2 of pellets were fabricated. The requirement of enriched UO_2 necessitated the maintaining of the ZPI enriched fuel licence and Criticality Control Procedures. Production was done using laboratory scale processes in a semi-automated fashion.

- Small scale manufacture of bundles; six complete bundles were manufactured with thin and thick wall tubes. Again, laboratory units were used for pellet production and bundle assembly. In addition to routine procedures already in place or which could be modified readily for Canflex manufacture the following additional work was done. Appendage design(s) were finalized and shop floor manufacturing documentation developed. End cap welding procedures and process control parameters were developed for both thicknesses of tubes. Previously used tooling was refined and modified and special tooling was designed where required, for example for mixer tab manufacture. Welding procedures were developed for the mixer tabs and strength parameters were established. Tooling for assembly was also designed and assembly procedures were developed. Some iterative design changes were implemented. Inspection procedures specific to some of the Canflex issues were also developed, (for End Plates, Spacers, End Caps, Subassemblies, Fuel Stacks, Elements and Bundles) albeit for small scale manufacture. Since the work involved enriched fuel, Criticality Control Procedures were followed.

Much of this early work involved an iterative process whereby ZPI jigs and fixtures were developed in response to design requirements. These early manufacturing procedures were designed to satisfy small production runs (1 - 6 units) and although well suited to these quantities both manufacturing and inspection methods were manually intensive and not implemented with high volume product flow in mind.

Manufacturing Feasibility - the 26 Bundle Demonstration Irradiation

Manufacturing is the science and art of transforming a design concept into a viable product line.

Thus, a manufacturer has to develop, implement and maintain a process which a) delivers a product that meets all specifications of the design concept and b) operates with the least amount of interference. The process, in this context, includes all the functions that impact on ensuring that the product meets the requirements; human issues, engineering, process control, and quality assurance and quality verification.

For a new product, this process design generally occurs in several stages; although in some cases one or more of the stages can be eliminated. In most quality products the steps described in Table 2 are common. Each stage typically increases the production quantity by a factor of 5 - 10. As the stages proceed, end user contact is increased and the elements of the manufacturing process, i.e., process design as well as process control and quality verification and assurance tools - are further refined. The table reflects the activities and attributes of each stage during the Canflex development. Thus, where at the prototype manufacture stage one-off production and inspection methods are still viable and correct to use, this would by no means apply at the higher production level of Manufacturing Feasibility and beyond. Also imperative at this stage is the implementation of all quality program procedures which apply to regular fuel. Thus, even though production is to a small scale and conducted using "off line" equipment, all the documentation and approval procedures used for regular fuel have to be rigorously implemented at this stage. For pre-production and production, the procedures developed during the stage of Manufacturing Feasibility would have to refined even further so that the objective of "least amount of interference with the process" can be achieved.

Figures 2 - 4 describe the process flow during the Manufacturing Feasibility phase. Twenty six bundles were produced for irradiation.

Zircaloy 4 tubing of both sizes was produced in the Zircatec tubing plant in Cobourg for use in this project. Tooling procurement for both sizes of tubing was followed by small scale tests. Process qualification and production followed. This particular campaign involved special machine set up (since the sizes are not common to routine production) for both production and inspection. Gauge tooling had also to be procured. Sampling, inspection and verification procedures were developed; where possible routine methods were implemented and/or modified.

End caps of both sizes and end plates were procured from qualified suppliers as was material for spacers, bearing pads and mixer tabs (buttons). Tooling was developed for the manufacture of the appendages and inspection gages and procedures were also developed. Manufacturing of the appendages (including Be coating) proceeded after appropriate qualification of processes. Production tooling was used on a "time shared" basis.

Laboratory tooling was developed for welding/brazing and inspection of the sheaths. Qualification and verification of quality proceeded using this tooling; process control issues related to the thinner than traditional sheath wall were resolved. The sheaths were graphite coated and prepared for end cap welding using production equipment.

Pellet production proceeded in parallel using laboratory presses; both sizes of pellets were pressed, sintered and ground. Sampling plans and inspection procedures were modified accordingly for the two sizes/quantity of pellets. End pellets were appropriately sized for both diameters in order to provide the requisite control of stack length. The pellets were assembled into stacks of the correct length in order to meet the requirements and loaded.

End cap welding etc. was done, again, on laboratory tooling and the requisite material(s) were assembled into "kits" for final bundle manufacture. The bundles were assembled on an appropriately designed and qualified fixture and made ready for final inspection, pack and ship procedures. Shipment to site was using qualified transport with a regular fuel load.

This phase of the project involved some tooling development; in general, the tooling and equipment used was still "off-line" from routine production in plant. SPC methodologies were introduced for quality verification etc. Manufacturing tolerances were refined to take into account process capability limits. Qualification/Inspection procedures were also refined. Some activity involved the feedback/iteration of design limits etc; and some design constraints were revisited and refined in light of manufacturing difficulties. There was significant and critical end user involvement during this phase, for example, formal acceptance of plans/qualification procedures by the end user.

Production Issues

The primary issues with production level scale-up are:

- The increased number of elements in the fuel as compared with traditional 37/28 element fuel,
- The fact that the bundle design incorporates two sizes of elements,
- The thinner sheath wall
- The greatly increased number of appendages on the Canflex 43 element design and
- The increased number of braze planes.

The impact of combining what are essentially two separate production lines for the two sizes is summarized in Table 3. The increased number of elements aggravates bundle assembly procedures. Further, the introduction of Canflex as a new product line requires, in fact, the maintaining of two additional processes for each size of tube, pellet and end cap. In addition, each size of pellet stack requires a set of end pellet sizes appropriately designed to provide the degree of control for stack length. The thinner sheath wall requires the introduction of new production level control techniques. Finally, product flow of appendage manufacture, too, is an issue, since with Canflex twelve different appendage types are required in addition to the traditional seven.

At ZPI we anticipate that a pre-production stage of manufacture will allow us to isolate, tackle and solve these problems so that Canflex can be finally introduced as a viable standard product line into the CANDU system.

Table 1: Component Requirements: Canflex vs Regular 37 Element Fuel

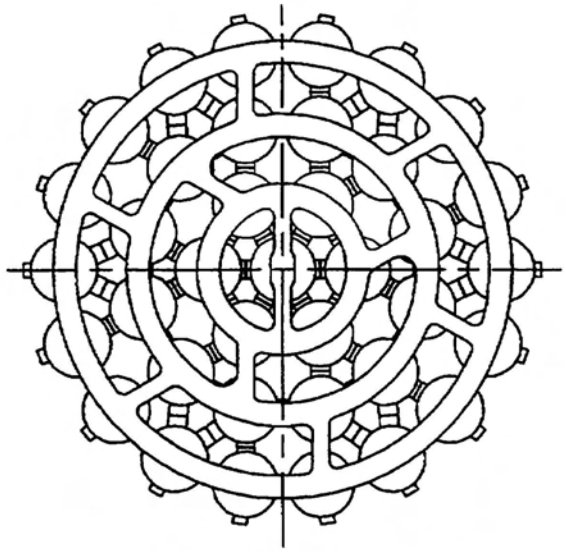
Item	Required for Canflex	Required for 37 element Fuel
Total Sheath	43 (8 + 35)	37
Total End Cap	86 (16 + 70)	74
End Plate	2	2
Total Pellets	1340 (~ 220 + ~ 1120)	1036
Total End Pellets	86 (16 + 70)	74
Spacers	182	156
Mixer Tabs	224	
Bearing Pads	63	54
Total Appendages	469	210
Total Parts	2020	1431

Table 2: Development Stages in Product Manufacture

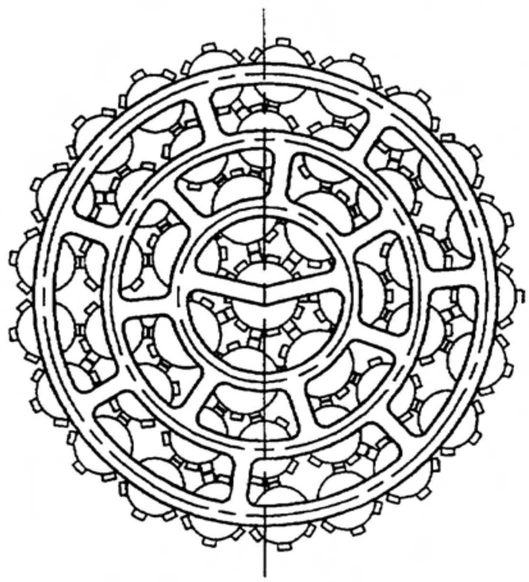
Manufacture Scale	Quantity per campaign	Activities/Attributes
Lab. Feasibility	5 - 20 kg scale; Test components, 1 - 2 test units. Product tested in research conditions.	First introduction of manufacturer into process. Develop "proof of principle" tooling and procedures; Test processing variables, e.g., sintering parameters, braze parameters etc. Develop all Manufacturing Drawings from Design Specifications. Ensure compliance. Iterative development with Designer. Little end user contact.
Prototype Manufacture	20 - 200 kg scale; 3- 6 Test units. Product tested in research conditions.	Develop tooling and procedures in preparation for routine manufacture. Tooling and equipment used still "off-line" from production equipment. Refine Manufacturing Drawings. Develop and crystallize qualification procedures. Develop Inspection Procedures for Canflex specific components. Develop QPP procedures. Detailed discussion with designer. "Heads up" to end user.
Manufacturing Feasibility	300 - 600 kg scale; 20 - 30 units. Product "full up" tested in end user facility (Current Canflex Campaign)	Further develop and fix all manufacturing procedures including all drawings, processes and techniques. Some tooling development. Tooling and equipment used still "off-line" from routine production in plant. SPC methodologies introduced for QV etc. Process capability limit analysis introduced. Qualification/Inspection procedures refined. Feedback/iteration of design limits etc. Implementation of all QPP procedures as for regular fuel production. Significant and critical end user involvement. Formal acceptance of plans/qualification procedures by end user.
Production Feasibility	300 - 500 units.	Set up and implementation of production tooling and procedures. All SPC and QV functions routine. Formal contracts with end user.
Routine Production	>5000 units	Routine manufacture.

Table 3: Manufacturing Issues: Product Lines

Item	Current	With Canflex
Bundle Types	3	4
Sheath Tubing	2	4
Pellets	2	4
End Pellets	6	12
End Caps	3	5
Bearing Pads	2	3
Spacers/Tabs	5	9



37 ELEMENT CANDU 6



43 ELEMENT CANFLEX

FIGURE 1

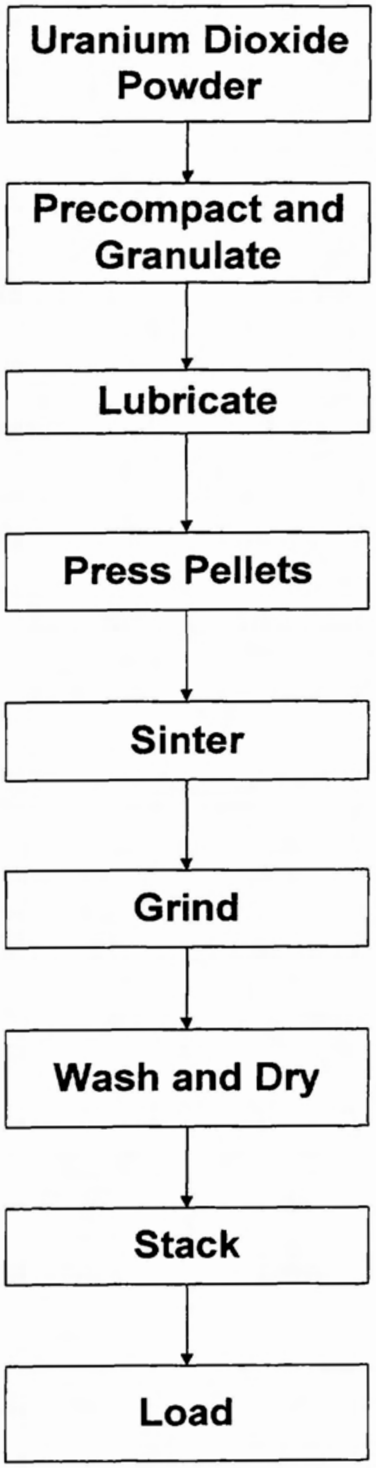


Figure 2: UO2 Pellet Manufacture

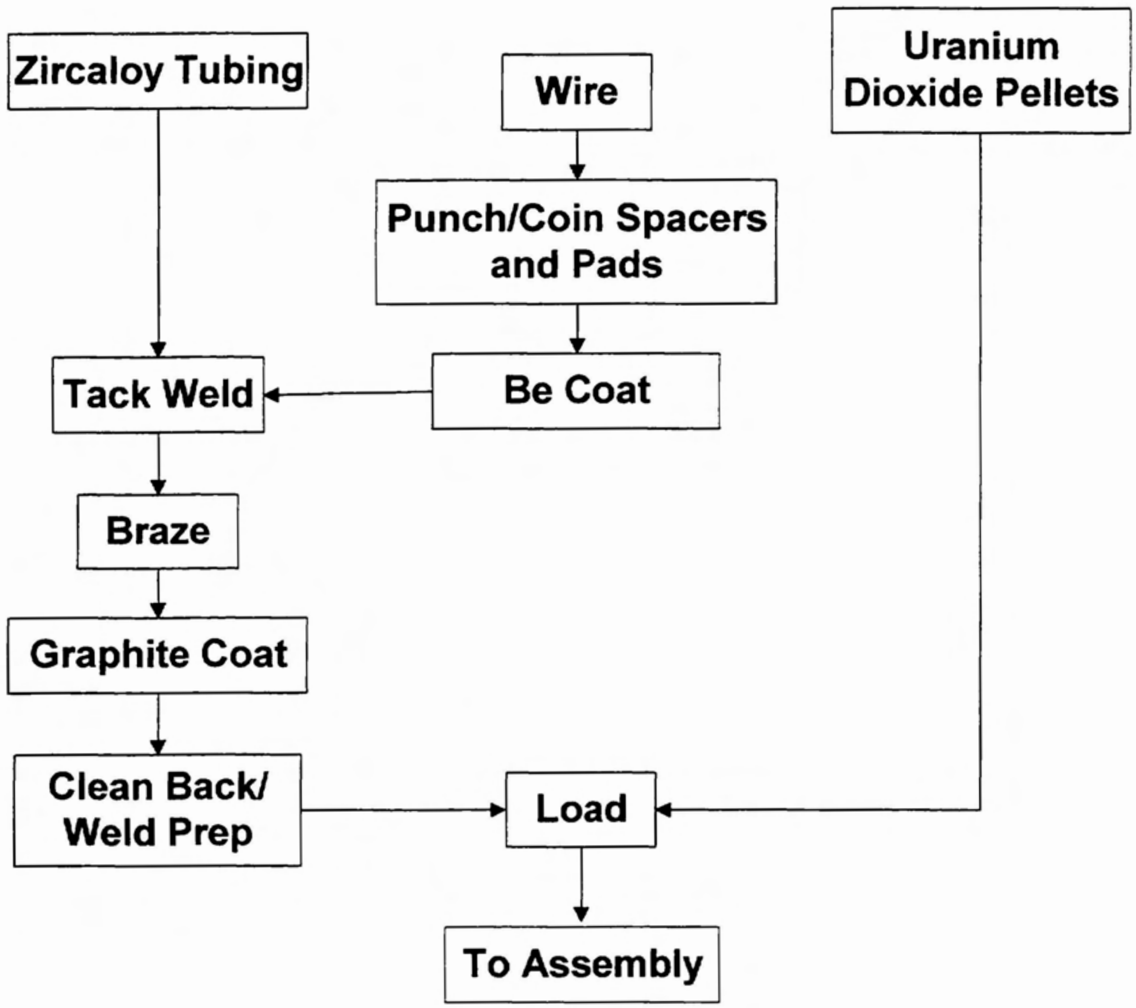


Figure 3: Element Manufacture

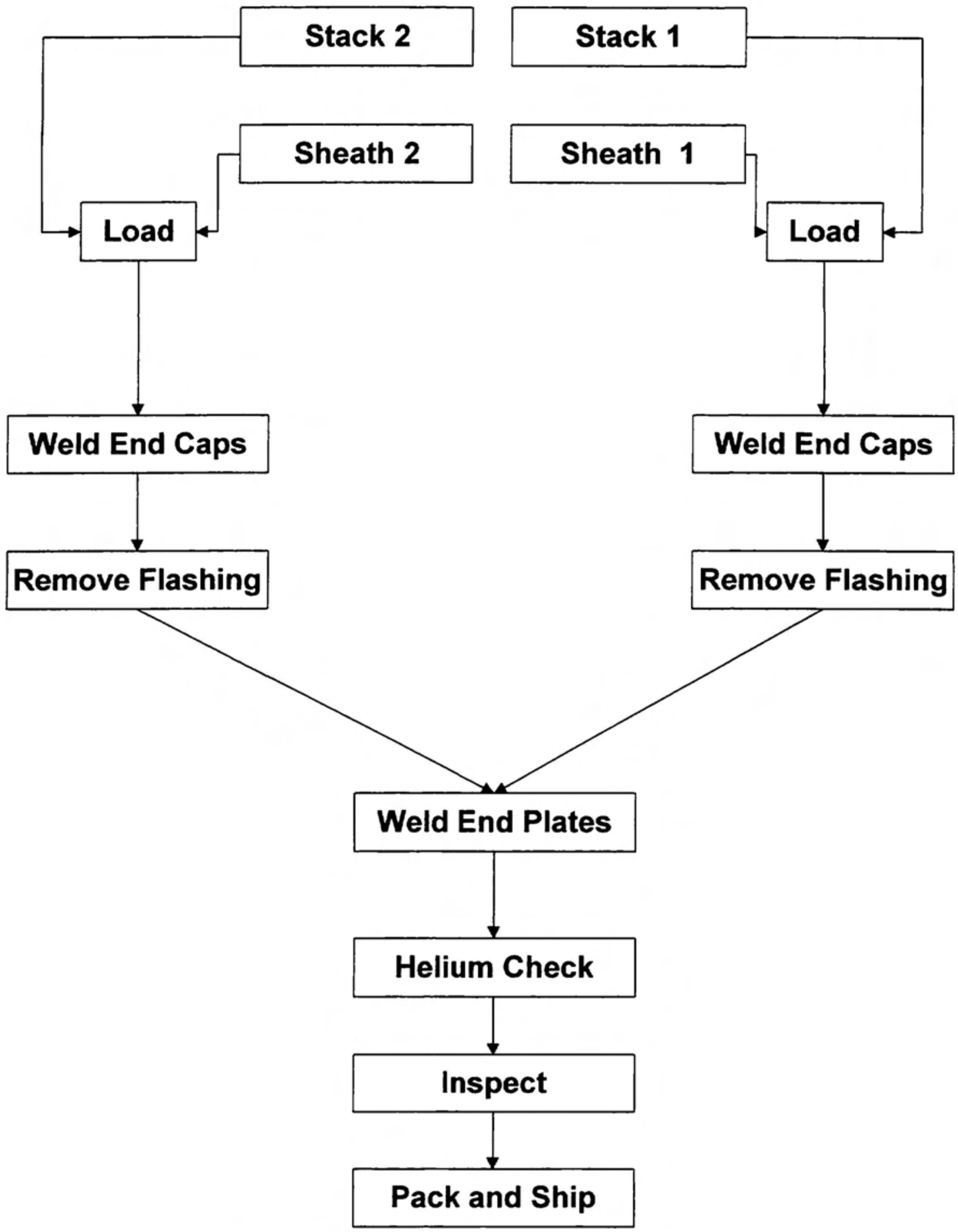


FIGURE 4 - Bundle Assembly Procedure