Tooling Strategy for Point Lepreau Retubing

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1. Introduction

The Point Lepreau Generating Station was the first CANDU 6 unit to be licensed for operation, beginning commercial operation in 1983. It will now become the first CANDU 6 to undergo full refurbishment. As part of the overall project, all 380 fuel channels and associated feeders will be removed and replaced. In order to undertake this project, it was necessary to design and develop over fifty "first-of-a-kind tools" for fuel channel and calandria tube replacement. This paper outlines the complexity of the retube tooling project, the strategy for the engineered tooling systems development, and current status.

2. Retubing a CANDU 6 Reactor

The scope of the Point Lepreau CANDU 6 retube project includes the large-scale replacement of all reactor fuel channels, calandria tubes and feeder components (Figure 1).

The process to replace the fuel channels and calandria tubes is as follows:

Removal Process

- Remove Feeders
- Remove positioning assembly
- Cut end fitting from annulus bellows
- Cut pressure tube
- Remove end fittings
- Remove pressure tube
- Release and remove calandria tube insert
- Remove calandria tube
- Transfer all removed material to the waste storage facility

Inspection and Installation process

- Install upper Feeders
- Inspect calandria vessel and remove any debris
- Inspect calandria tube sheet bore
- Inspect bellows
- Inspect lattice tube
- Prepare fuel channel components for installation
- Install calandria tube

- Roll and inspect calandria tube insert
- Insert fuel channel sub-assembly and verify position with Tubesheet and Datum plane measurement system
- Install annulus spacers and verify position
- Install second end fitting
- Inspect end fitting to pressure tube rolled joint
- Weld end fittings to bellows
- Install positioning assemblies
- Install lower Feeders

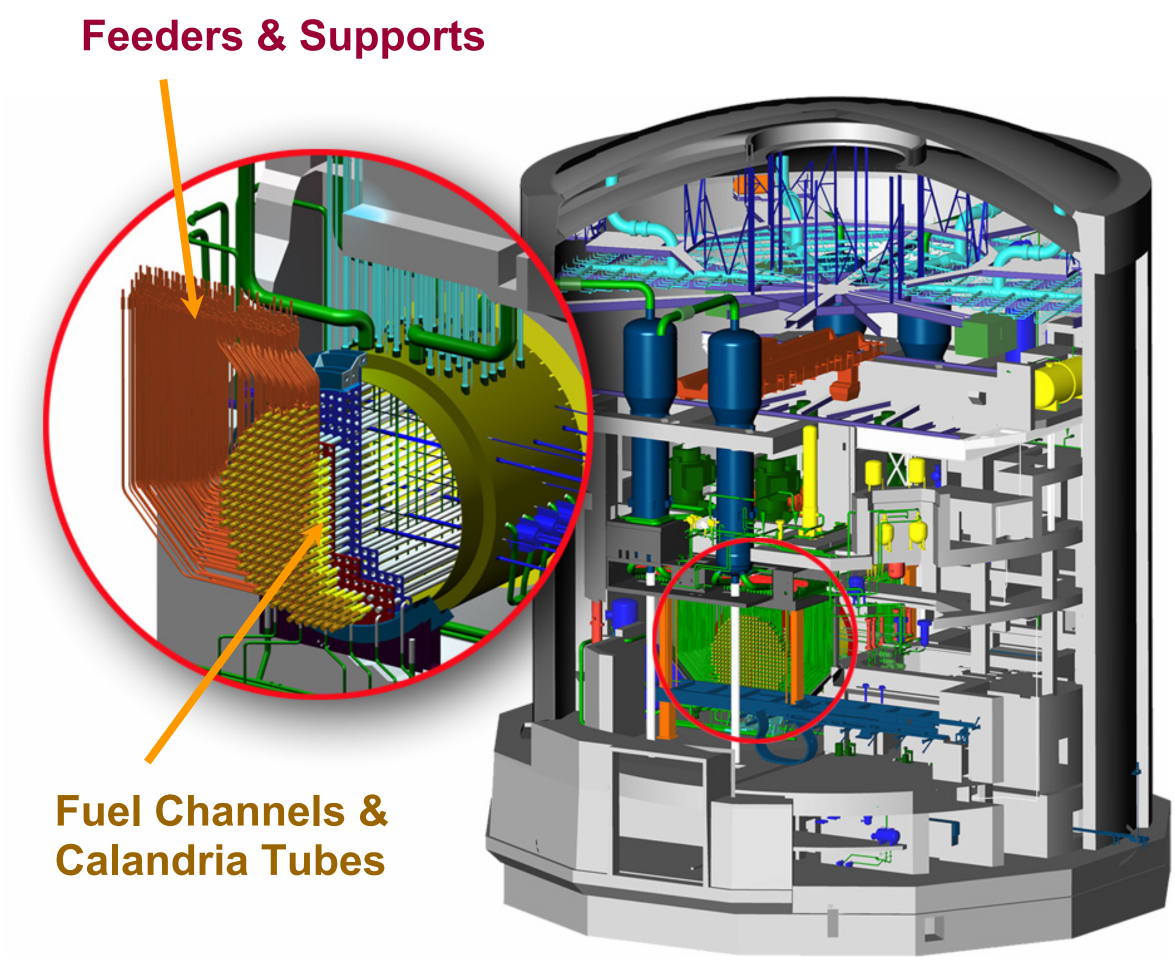


Figure 1- Retubing Major Component Replacement Scope

3. Tooling Scope and Schedule

The schedule represented the greatest challenge for tool delivery. The project officially started August 2005 and the complete tools are to be delivered at the AECL Saint John facilities for training in the last quarter of 2007. When the mobilization, packing, and shipping periods are taken into consideration, there was effectively less than 24 months for the tools to be designed built and delivered to site.

The major scope of work in this period included the following:

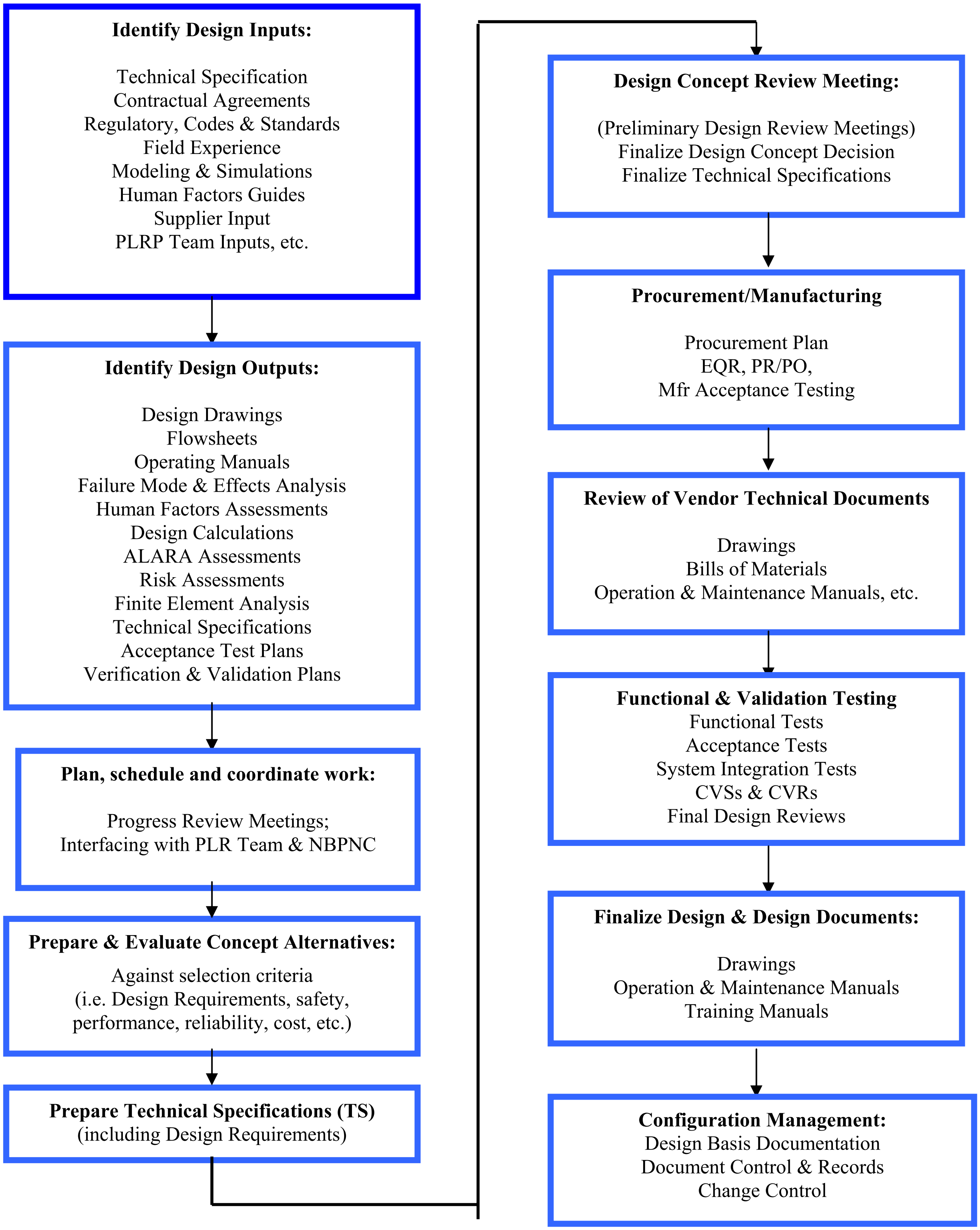
- Concept design and formal design reviews
- Detailed design and formal design reviews
- Proof of principle and prototype testing
- Manufacture
- Functional Testing and Acceptance Testing
- Integration and Integration Testing
- Packing and shipping

The client and end user of the specialized tooling is the AECL Point Lepreau Site Implementation team. The general Tooling Systems Requirements (TSRs) was defined by the AECL Retube Pre-Site Program department, they were also involved with the tooling design review process. The specific toolsets and equipment to be designed and delivered by AECL Retube Systems comprise of the following main toolsets:

- Fuel Channel Removal Tooling
- Calandria Tube Removal Tooling
- Inspection Tooling
- Calandria Tube Installation tooling
- Fuel Channel Installation tooling
- Annulus Gas System tooling
- Contingency Tooling; and
- Common Tooling

The overall project design workflow is illustrated in Figure 2 and is based on AECL's overall quality assurance framework.

Design Workflow - Figure 2



4. Number of Tools

In total there are approximately one hundred engineered tools (fifty are first-of-a-kind) for removal, installation and inspection processes. The most critical tools that were first-of-a-kind were the removal and inspection tools. Even though some of the installation tools were of new design, most were derivatives of tools used for new reactor construction.

5. Tool Delivery Strategy

Soon after the contract was signed in August 2005 a level 4 tooling schedule was prepared in conjunction with a resource plan. From this it was clear that the traditional AECL strategy of doing the design, assembly and testing process in-house, using machine shops to manufacture the components and in-house personnel for assembly, electrical and controls integration would not meet the schedule with our available resources.

Therefore, several new suppliers had to be qualified and a design-build strategy implemented in a relatively short time frame. Potential suppliers from New Brunswick and Southern Ontario were sourced and evaluated for capabilities, experience and project management. Since most of the complex tools required substantial automation, suppliers from the automotive sector, that were going through a down turn in their business, were looked at in detail, and eventually choosen to do much of this work.

Although the automotive suppliers were extremely adept at designing and building automation systems there was an obvious discomfort at moving into the nuclear industry as the perception was that the nuclear industry introduced many risks and unknowns, perceived beauracracy, regulation and nuclear issues such as radiation and nuclear quality standards.

It became readily apparent that AECL could not have a typical customer-supplier relationship with these new suppliers to the nuclear sector. They had never been exposed to the nuclear sector and had no knowledge of nuclear reactors, nuclear systems and radiological environments. As they could not be relied on to independently design nuclear tooling, AECL developed partnerships with them to provide specialist training and design support, which established the pre-requisite infrastructure for a successful project. This also provided the “comfort zone” required to engage and improve the confidence of the senior management of these new suppliers.

AECL then moved rapidly to the conceptual design phase in parallel with qualified suppliers. The complexity of the tools determined at what phase of design a contract would be put in place with suppliers. For tools based on existing designs, AECL designed the tools and released manufacturing drawings for supplier to “build to print”. For relatively simple new tools, AECL released the concept design as part of the tender package and the suppliers proceeded to finish the detailed design and to build. For tools of high complexity, AECL provided the concept and approximately 30% of the detail design. In order to reduce risk a decision was made that the contracts would be spit into two phases, the production of the first set of tools and after successful testing the remaining production tools would be built. Tenders were issued and suppliers were selected based on their proposal, experience and ability to deliver. Regardless of the relative split of responsibility for the design process between AECL and the suppliers, the design workflow was strictly adhered to, and suppliers were directly integrated into AECL design review process.

6. Use of 3D Laser Scanning

One important engineering tool used as part of the concept and detailed design was Laser Scanning. Laser Scanning accurately and efficiently gathers 3D point data from any environment. Generation of this 3D point data is achieved by taking precise 3D pictures/scans of an environment at various locations. Each of these scan files is embedded with millions of three dimensional coordinate points relative to the 3D Laser Scanner's location.

Laser Scanning creates a complete as-built or current condition virtual environment of 3D point data (Figure 3). This allows designers to evaluate the as-built plant condition and avoid unnecessary and costly plant walk-downs. Tooling can then be designed to eliminate interferences or collisions between new parts or equipment in an existing area. Typical scans take 4-5 minutes per scan and are accurate to 2 mm over a 30 m distance.

7. Use of Simulation

In order to reduce the overall design and build cycle, state-of-the-art computer engineering tools were utilized. AECL primarily uses a combination of ROBCAD and Solid Edge software for concept design. ROBCAD is a computer simulation tool that allows evaluation of different scenarios so that the safest and fastest possible design solution can be implemented. Solid Edge is a mechanical design and drafting software. By using simulation during the concept design phase, AECL can reduce the overall design cycle times. In many cases AECL was able to go from design to proof of principle testing of key components/sub-assemblies to the production system, eliminating the need for building a complete prototype system. Complete tooling systems can be designed and evaluated for interferences and interactions of the tools with each other and with their environment (Figure 4). Simulation can identify a variety of design problems or issues long before manufacturing begins, allowing them to be resolved digitally, before impacting on schedules or budgets. The ability to model hazardous environments and to simulate the actions of humans and machines within them can also eliminate the need for expensive mock-ups and reduce overall project risk.

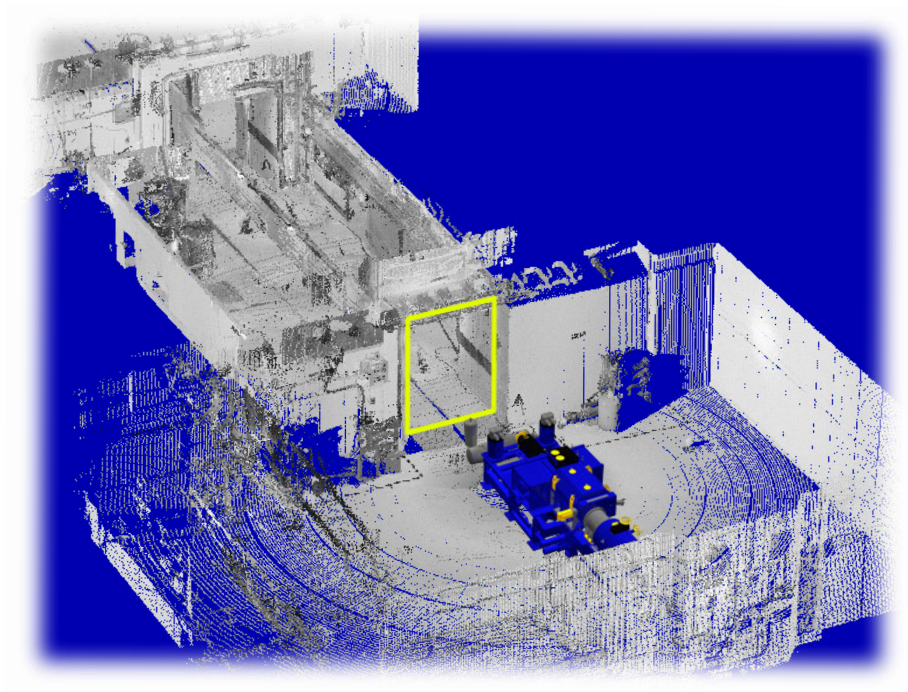


Figure 3 - 3D Laser Scan point data with 3D CAD model overlaid

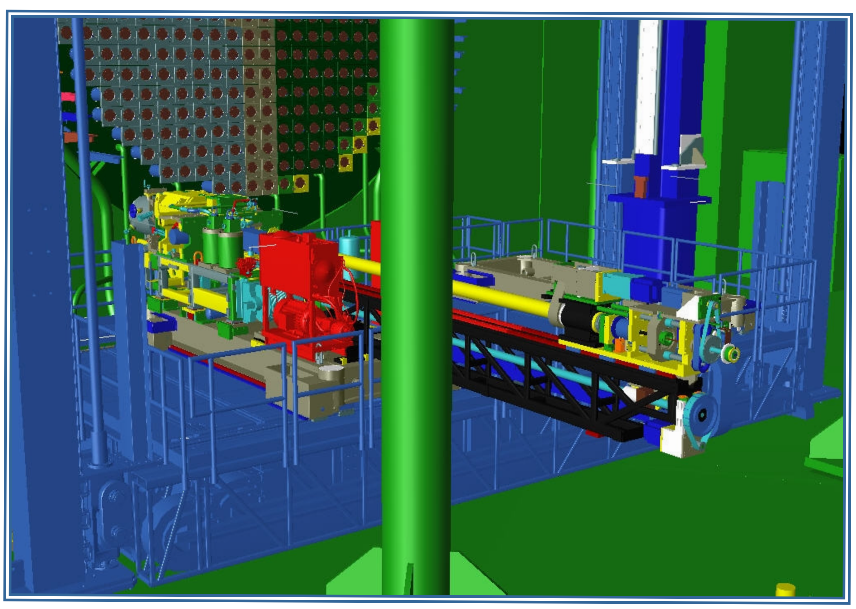


Figure 4 – Simulation of the Volume Reduction System on Fuel Channel Platform

8. Design Interfaces

In order to delivery quality products, multiple engineering and scientific disciplines were involved in the design process. Key assessments were prepared by the various disciplines to provide documented input for tooling designers. For example:

- Hazard (Risk) Assessments were conducted to ensure that items such as standard machine guarding, E-stops and light curtains were designed and applied in accordance with industry standards.
- ALARA assessments were prepared by radiation physics experts to ensure that shielding and radiation protection features were incorporated in tooling design and radiation field kept as low as possible.
- Failure Mode and Effects Analyses were prepared to identify normal and abnormal tool failure modes and ensure acceptable design features and recovery capability were addressed.
- Human Factors design guides were prepared and utilized by the designers, and Human Factors experts participated in Design Reviews and prepared Human Factors Assessments.
- Finite Element Analysis was completed as required on critical components.

9. Testing

Three basic categories of testing was performed: proof of principle testing, functional/acceptance testing, and integration testing.

Proof of principle testing was done during the design phase to prove critical design features. This was required as the first-off tools were manufactured within one year of the start of design and time for building and testing a prototype was not available. Proof of principle testing typically consisted of bench testing on key assemblies or components. For example, a combination of testing on a lathe and then bench testing was done to determine the Bellows Cutting Tool forces and behaviour with a high degree of confidence.

Functional testing, also called acceptance testing, was done to prove that the completed tool functions as required. This testing is done on each individual tool and incorporates a full range of testing such as a complete tool cycle, checks on tool interlocks, and testing of critical drives at their full design load.

Integration testing is completed on the first-off tools, after functional testing is complete. The tools for the different steps and phases of the retube operations are assembled as sets, and tested to confirm the tools in the sets all interface properly. For example, the Volume Reduction System is mounted on the Heavy Workable, which is supported on the Fuel Channel Platform as part of Fuel Channel Removal Tooling integration testing.

Again, AECL in the interest of schedule is using one of the major tooling supplier's facilities for all integration testing operations. If any of the largest and heaviest tools, such as the Volume Reduction System or End Fitting Transfer Station, require immediate rework, it can be performed on the premises without incurring the schedule delay and expense associated with shipping the tooling between AECL and the supplier's site.

Design issues and modifications identified through functional and integration testing will be incorporated into the remaining production tooling. Formal design change control procedures are utilized to ensure that the design basis documentation for all tooling is accurately maintained.

In addition to verifying the tooling Operating and Maintenance Manuals, Integration Testing provides an opportunity to develop and refine tooling Training Manuals which will be delivered along with the tooling.

10. Retube Tooling Current Status

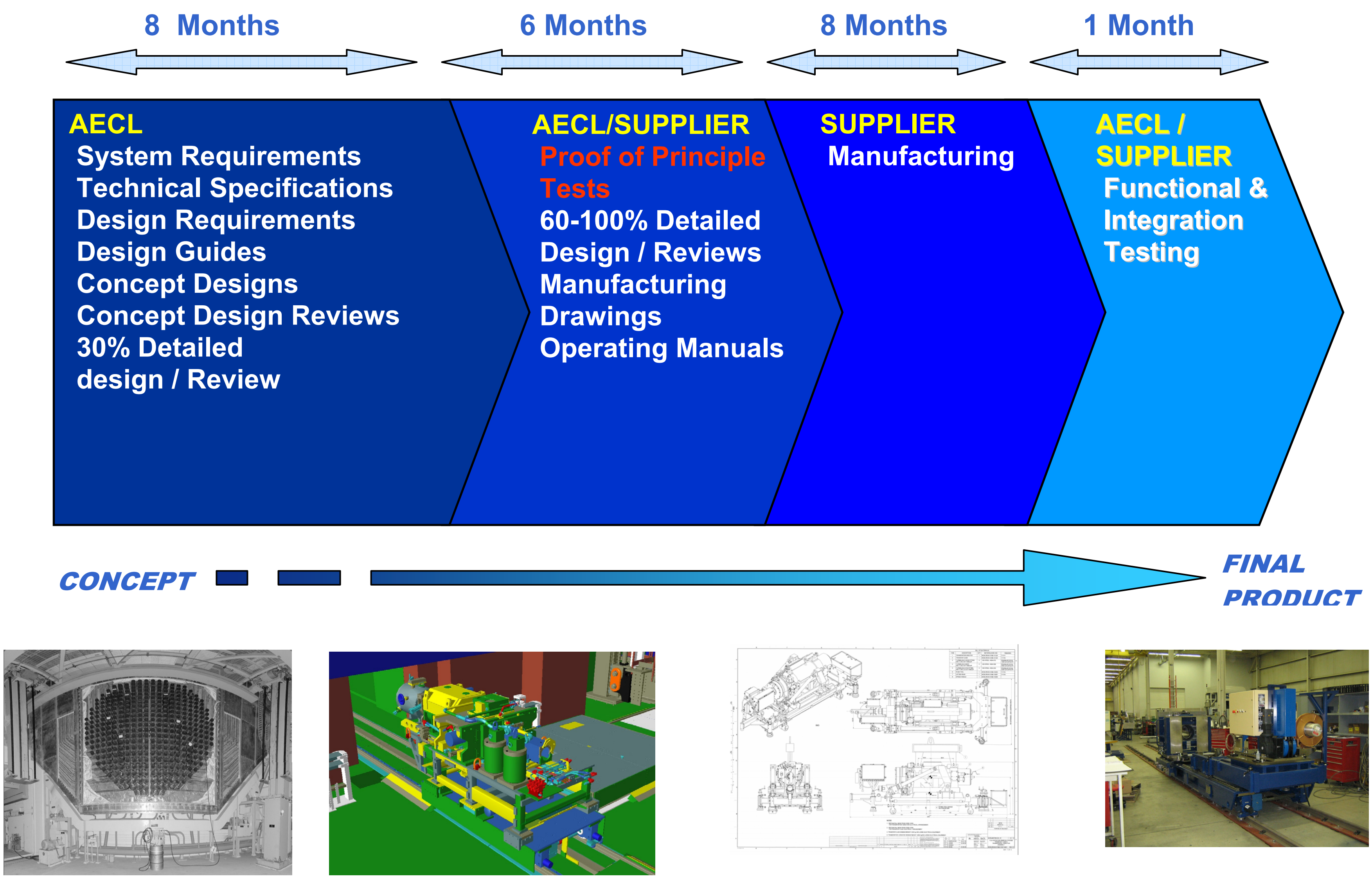
The overall Retube Tooling Design/Manufacture Cycle is illustrated in Figure 5. Over 85 Design Reviews have been completed and designs are completed for approximately 95 percent of the first-off tooling. Manufacturing of the first set of tooling is approximately 90% completed with Functional/Acceptance Testing now underway or completed for many tools. The emphasis has been to complete the Removal Tooling first, followed by the Installation Tooling as this will be the sequence for tool testing, shipment, training and deployment to site. Some of the Contingency Tooling will be the last tools manufactured.

Integration testing plans and procedures are being finalized for the start of testing in March 2007. Test facilities are nearing completion with installation of reinforced concrete floors, monorail cranes, electrical power supplies, fuel channel mock-ups and anchors for Fuel Channel Platform and electrical power supplies for calandria tube insert induction heating tool.

Shipping Plans and Training Plans are under development for the use of these tools at Point Lepreau, as is the overall Retube Tool Deployment Strategy for redeployment of these tools to other CANDU 6 stations on completion of Point Lepreau Retube.

Tooling design basis documentation such as Design Requirements, Technical Specifications, Design Review Reports, drawings, test results, Operation and Maintenance Manuals, and Training Manuals are maintained in AECL official records system.

Figure 5 - AECL Retube Tooling Design / Manufacture Cycle



11. Conclusion

The Point Lepreau Retube first-off tooling will have been designed, manufactured and tested in less than two years. Design controls were incorporated to ensure that all design requirements, along with industry best practices such as conventional risk assessments, ALARA principles, and human factors were incorporated into the design. This was achieved through AECL working in close partnership with the automotive and other non-nuclear commercial industries. This relationship builds on the strengths of AECL and its partners. It has also broadened the nuclear technological base and introduced some additional capacity and competition into the supply chain. The Canadian nuclear industry, the Canadian automotive/commercial industry and CANDU owners worldwide all stand to benefit from this business model for retube tooling development and supply. Figure 6 and 7 show the Volume Reduction system and the End Fitting and Shield Plug Transfer Station undergoing testing.

Figure 6 – Volume Reduction System

Figure 7 – End Fitting & Shield Plug Transfer Station