DESIGN VERIFICATION of the CANFLEX™ FUEL BUNDLE

- QUALITY ASSURANCE REQUIREMENTS FOR MECHANICAL FLOW TESTING

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ABSTRACT

As part of the design verification program for the new fuel bundle, a series of out-reactor tests was conducted on the CANFLEX[1] 43-element fuel bundle design. These tests simulated current CANDU 6 reactor normal operating conditions of flow, temperature and pressure. This paper describes the Quality Assurance (QA) Program implemented for the tests that were run at the testing laboratories of Atomic Energy of Canada Limited (AECL) and Korea Atomic Energy Research Institute (KAERI).

INTRODUCTION

As part of the qualification of the design of the CANFLEX fuel bundle to be used in CANDU 6 reactors, a series of out-reactor (mechanical flow and thermalhydraulic) tests was performed under normal-operating conditions that are representative of operating CANDU 6 reactors. The hydraulic performance, mechanical integrity, strength, resistance to refuelling impacts and cross-flow, and fretting endurance of the CANFLEX bundle were verified in a series of tests in the KAERI Hot Test Loop Facility in Korea. The compatibility of the bundle design with the CANDU 6 fuelling machine was verified in the AECL Sheridan Park Laboratories in Canada. The mechanical flow tests are the tests that were performed in AECL's Sheridan Park Laboratories in Canada, and by KAERI in Korea. Thermalhydraulic tests were performed at the Chalk River Laboratories.

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[1] CANFLEX™ (CANDU Flexible Fuelling) and CANDU® are registered trademarks of AECL.

This paper describes two aspects that were considered during the out-reactor testing of the CANFLEX fuel bundle. The quality assurance (QA) approach is described first. Second, the methodology that was used for planning, taking of test records, and reporting of the test results is discussed.

CANFLEX BUNDLE DESIGN

The CANFLEX design is a 43-element fuel-bundle assembly offering improved operating and safety margins, compared to the standard 37-element fuel bundle, for operating CANDU reactors. The CANFLEX bundle design includes critical heat flux (CHF) enhancement devices leading to higher critical channel power (CCP) in a full-length fuel channel, compared to 37-element fuel bundles. The lower heat rating of the CANFLEX fuel elements at current bundle powers leads to lower fuel temperatures. Hence less free fission-gas inventory is produced under normal operating conditions compared with the free fission-gas inventory produced in standard 37-element fuel elements.

The CANFLEX bundle consists of 2 fuel element sizes: small-diameter elements in the outer and intermediate rings, and larger-diameter elements in the inner and centre rings (see Figure 1). Special buttons are attached to the elements at 2 planes, to provide improved heat-transfer and hence critical heat flux enhancement. To maintain compatibility of the new bundle design with the design of existing CANDU 6 reactor systems, the basic overall dimensions of the CANFLEX fuel bundle were designed to be the same as those of the 37-element fuel bundle. The small-diameter elements of the outer ring result in a slightly larger end-plate diameter compared with end-plate diameter of the standard 37-element bundle. Consequently, the bearing pad heights of the bundle are designed to be larger than those of the 37-element bundle. This makes the CANFLEX bundle fully compatible with the sidestop/separator assembly of the CANDU 6 fuelling machine. The sidestop/separator assembly is an important component in the fuelling machine. The fuel bundle dimensions must be compatible with this assembly.

The fuel bundle, in all other respects, is designed to be equivalent to the 37-element bundle, to be "transparent" to all reactor systems. To verify this, tests were performed for pressure drop, bundle strength under a number of situations such as radial cross-flow, and a test of the long-term fretting performance. The latter test was to be verified in a series of runs, which are currently approximately half-completed. These tests are described in a companion paper at this conference [1].

QUALITY ASSURANCE

A fully implemented and effective quality assurance program is an essential requirement for the design and test activities of any new reactor component. Clearly, a new design of fuel bundle falls into this category. A poorly planned or ineffective program will add enormous costs to qualification of the component, and could ultimately prevent the design qualification from being completed successfully.

For the CANFLEX program, QA requirements were recognized as an essential part of the design and test activities. The Canadian Standards Association series of standards, known as the N286 series [2], were prepared to respond to the need by utilities, the regulators and industries for standards, and to define and provide guidance for quality throughout the life cycle of a nuclear plant. The role of the quality program standard is to provide the means by which the designer and the testing laboratories can be assured that the specified requirements and activities are accomplished in a planned, systematic and documented fashion. The design and, indeed, the performance of the new fuel bundle design must be adequately checked and assured at all stages of the design process. Recognizing this, a well-planned and implemented QA program was provided for this program according to the CAN3 N286.2 standard [3], with the objective of ensuring that the design activities were fully compliant with all Canadian regulatory codes and standards. Following all design and testing activities, the overall QA program will provide assurance that the design and test activities were fully performed as planned, and that this new fuel bundle will meet all design and fuel performance requirements.

For the mechanical flow tests, another series of standards, the CAN3 Z299 series of Quality Program Standards [4] was used. The Z299.3 Quality Verification Program was selected as being most suitable for performing and reporting on the various tests. This standard was used within the overall project QA program to supplement the N286.2 standard, where appropriate. Here, evidence of planning of the tests plus controls on test procedures, the recording and reporting of data, and instrument calibration, were considered essential elements of a good test.

DESIGN VERIFICATION PLAN

A Design Verification Plan (DVP) is a documented summary of all the design verification activities that are required to be implemented under N286.2 QA program on an engineering project such as this. An important part of this document is that it defines what documents such as specifications, test procedures and reports are required. A series of AECL procedures specifies how each type of document is to be prepared, what it should contain, and how it is to be reviewed and approved. These procedures were used in this program.

The DVP for design and development of the CANFLEX bundle calls for design verification through various tasks that include design analysis and verification through out-reactor and in-reactor tests. The list of mechanical flow tests is given in Table 1. In addition to the other design activities such as analyses, these are the tests required to qualify the bundle for use in CANDU 6 reactors. Table 1 also identifies the types of documents needed for the satisfactory accomplishment of each task.

LABORATORY REQUIREMENTS

The AECL and KAERI laboratories have adopted quality programs that provide an inspection and test plan for each laboratory operation. They include, for example, operating procedures and the design or configuration-control procedure for each test rig. Operations that are repetitive in nature are covered; these include rig operating instructions such as start-up procedures, procedures for chemical and oxygen control during shutdowns and normal operation, and for pH control and its measurement. In addition, instrument calibration and inspection procedures that are to be used, including those to be used by the metrology laboratory to measure dimensional changes to the fuel bundles, are included.

The designers of the fuel, as the "users" of the information from the testing program, defined the tests that were needed in the design verification part of the work. They produced test requirements documents that defined the test conditions and the criteria to be satisfied in the test. In turn, the laboratories wrote test procedures that had to be reviewed and approved by the designers. This was not always an easy task as the designers were anxious that the new fuel design should be more than adequate to handle the current operating conditions, particularly of flow, which in this case requires the test rig to operate at or near its design capability. This was done to take account of the changing conditions as the reactor systems age. For example, the coolant mass flows in the fuel channels have tended to increase, first because the "design" values were originally slightly conservative, and second, the pressure-tube diameters are increasing slightly because of diametral creep, allowing coolant mass flows to increase. Agreement was reached that tests would indeed consider the increased flows, and hence the acceptance criteria for the different tests were adjusted to take this into account.

QUALIFICATION TESTING

The manner of recording all details of the test and the data generated during the test is very important. Planning for the test must be suitably rigorous if the test is an important one in "qualifying" a component. In our case, this is the fuel bundle design and its capability to operate satisfactorily under certain specified in-reactor conditions. This planning leads into the details of how to perform the test, and finally reporting the results. Proving that the test was conducted as specified and that the results can stand rigorous examination and peer review is an important part of the final test report.

When planning qualification or proof tests, the details to be recorded must be sufficient to allow the test to be repeated exactly, even several years later. This means that detailed records must be kept of the rig design and configuration (the components and instrumentation and calibrations in the rig). Of course, the personnel doing the work must be adequately trained and must understand the QA requirements.

By following a set of procedures that define how to prepare the various documents, and subjecting each document to rigorous review and comment before approving them, all the above requirements were met during the out-reactor qualification testing of the CANFLEX bundle.

DOCUMENTATION

Detailed *Test Specification* documents were prepared by the designers for each proof test of the CANFLEX fuel bundle and were reviewed and approved by senior designers. The specifications clearly identified the objectives of the tests. The specifications included a checklist of activities and items to be covered to make sure that all important activities were covered for each qualification test. The checklist was derived from CAN3-N286.2-86, Appendix D. Although Appendix D is not mandatory, the requirements given in the appendix show how a program is to be run. The checklist was modified to suit each test, to ensure that the test would be fully repeatable and that the objectives of the test would be met. Additional items on each checklist defined how and by whom the different steps or checks would be implemented. By using the checklist all important items would be covered and not left to chance. The specifications included appropriate acceptance criteria for determining that the test had been satisfactorily accomplished and that the fuel bundle had met the design targets or set of design requirements.

As required by the test specifications, *Test Procedures* were prepared by test laboratory personnel to define tests to demonstrate the capability of the fuel bundle to operate as required under the conditions specified in the test specifications. The test procedures also described the test methods, data recording and the instrumentation planned for each test. The test procedures identified suitable QA check points to ensure independent checking and surveillance of important items during the test. These test procedures were reviewed and approved by the engineers responsible for the CANFLEX bundle design. The purpose of this review by the designers was to verify that they considered the documents adequate for the test. They also had to agree that the test, as specified, would be sufficient to adequately demonstrate the performance of the bundle.

Finally, *Test Reports* were prepared by the test engineers to present the data, analyze the results and give the test conclusions. In other words, the reports documented the evidence that the bundle design met the specified requirements and acceptance criteria defined in the test specifications and procedures. These reports were also reviewed and commented on by the designers before the reports were accepted and approved by the CANFLEX Program Managers from AECL and KAERI.

TEST RESULTS AND CONCLUSIONS

All CANFLEX mechanical flow tests, with the exception of the fretting endurance test that is being continued, were performed satisfactorily at the testing laboratories of Atomic Energy of Canada Limited and Korea Atomic Energy Research Institute. They followed a well-planned, quality-verification program that demanded and received good quality assurance, fully compliant with the relevant Canadian Quality Assurance standards.

REFERENCES

1. Chung, C.H., Chang, S.K., Suk, H.C., Alavi, P., and Oldaker, I.E., "Performance of the CANFLEX Fuel Bundle from Out-reactor Testing", to be presented at the 5th International Conference on CANDU Fuel, Toronto, Canada, 1997 September.

2. CSA N286 Series of Quality Assurance Standards for Nuclear Power Plants, Canadian Standards Association, 1986 to 1994.

3. CSA Standard CAN3-N286.2-86, Design Quality Assurance for Nuclear Power Plants, Canadian Standards Association, July 1986.

4. CSA CAN3-Z299-85 series of Quality Program Standards, Canadian Standards Association, 1985 (Reaffirmed 1991, re-reaffirmed 1996).

Mechanical Flow Qualification Tests		Verification	
Task Activity - Preparation of Documents	Responsibility	Verification Activity	Responsibility
1. Compatibility with CANDU 6 Fuelling Machine and Fuel Channel			
Compatibility Test Specification	AECL	Review of Test Specification	AECL-KAERI
Compatibility Test Procedure	AECL	Review of Test Procedure	AECL-KAERI
Compatibility Test Report	AECL	Review of Test Report	AECL-KAERI
Assessment of Compatibility with Fuel Channel	AECL	Review of Assessment Report	AECL-KAERI
2. Refuelling Impact Test			
Refuelling Impact Test Specification	AECL-KAERI	Review of Test Specification	KAERI-AECL
Refuelling Impact Test Procedure	KAERI	Review of Test Procedure	KAERI-AECL
Refuelling Impact Test Report	KAERI	Review of Test Report	KAERI-AECL
3. Endurance / Fretting Wear Test			
Endurance Test Specification	AECL-KAERI	Review of Test Specification	AECL-KAERI
Endurance Test Procedure	KAERI	Review of Test Procedure	KAERI-AECL
Endurance Test Report	KAERI	Review of Test Report	KAERI-AECL
4. Strength Test			
Strength Test Specification	AECL-KAERI	Review of Test Specification	AECL-KAERI
Strength Test Procedure	KAERI	Review of Test Procedure	KAERI-AECL
Strength Test Report	KAERI	Review of Test Report	KAERI-AECL
5. Cross-Flow Test			
Cross-Flow Test Specification	AECL-KAERI	Review of Test Specification	AECL-KAERI
Cross-Flow Test Procedure	KAERI	Review of Test Procedure	KAERI-AECL
Cross-Flow Test Report	KAERI	Review of Test Report	KAERI-AECL
6. Pressure Drop Test			
Pressure Drop Test Specification	AECL-KAERI	Review of Test Specification	AECL-KAERI
Pressure Drop Test Procedure	KAERI	Review of Test Procedure	KAERI-AECL
Pressure Drop Test Report	KAERI	Review of Test Report	KAERI-AECL

TABLE 1. Examples of Documents Needed for Performing the Design Verification Tests

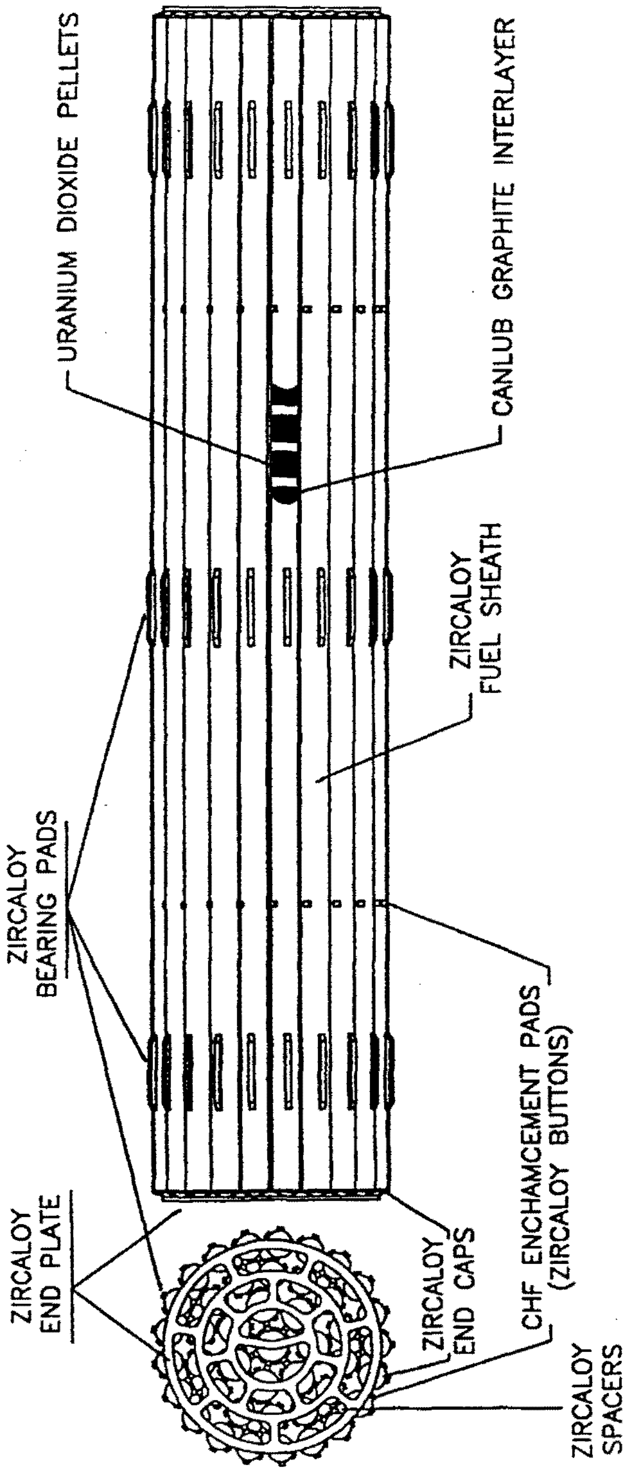

Figure 1: CANDU 6 Reactor, CANFLEX-NU 43-Element Fuel Bundle