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THE BAFFLE-BARREL-BOLTING ANALYSIS PROGRAM: EVOLUTION AND TECHNICAL ACCOMPLISHMENTS

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INTRODUCTION

In Westinghouse pressurized water reactors (PWR) the reactor core is surrounded by baffle plates, which provide lateral restraint for the fuel assemblies at the core boundary. Baffle plates are attached to horizontal supports called former plates by baffle-former bolts. The formers are attached to the core barrel which also provides vertical support for the core.

Since 1989, successive UT inspections in some European plants have revealed a trend of progressive indications in stainless steel baffle-former bolts. In the United States, one outgrowth of this was the authorization in 1997 of a Westinghouse Owners Group program, called the Baffle-Barrel Bolting (B^3) Program, one task of which was the development of an overall analysis methodology for evaluating the acceptability of reduced baffle-former bolting distributions. For many aspects of the B^3 Program, established, U.S.NRC-approved analysis techniques were used. This paper will focus, however, on the improved techniques developed in the B^3 Program, stressing the need for them and the technical aspects of their implementation.

The B^3 analysis program addresses the possibility of reduced baffle-former bolting in Westinghouse U.S. domestic plant designs with respect to the relevant design criteria. Since safety is the overriding motivation for the program, faulted events have received the most in-depth attention. This focus has been reinforced by the fact that the loads produced by the loss-of-coolant-accident (LOCA) have usually been the most limiting of all those considered. Consequently, much of the presentation below deals with the development of analysis techniques and acceptance criteria to demonstrate that LOCA-induced loads on the bolts and the fuel assemblies will be acceptable with significantly reduced baffle-former bolting. A discussion of the other faulted, normal, and upset analyses performed as part of the program will also be presented.

OVERVIEW OF ANALYSIS APPROACH

The analysis approach recognizes the need to demonstrate safety and therefore begins with the analysis of faulted events, LOCA and seismic (SSE). For most cases, the LOCA event will be the more limiting. The first step in the process is the determination of the type of break to be analyzed and its break-opening time. For most cases, leak-before-break (LBB) was assumed applicable only to the main coolant piping, leaving an accumulator line break and a pressurizer surge line break as the limiting breaks. A MULTIFLEX 3.0 (Reference 1) analysis is then performed to generate the time history input for subsequent analysis.

The next step is the selection of candidate bolting distributions for analysis. For plants whose interest is in demonstrating bolt degradation to be acceptable, the number of bolting distributions to be considered is limited. For plants considering bolt replacement, the selection of candidate distributions will be an iterative process because of the need to minimize the number of replacement bolts. Each assumed distribution is subjected to a series of analyses. The first is a time-history finite element analysis of the baffle-former-barrel (BFB) region (Figure 1) with the candidate bolting distribution(s). This analysis uses the pressure-time histories and core plate displacement-time histories generated from MULTIFLEX 3.0 data and calculates transient bolt stresses and baffle displacements. The first acceptance criterion is that all bolts assumed intact must have stresses below allowable levels. If this criterion is not satisfied, the distribution is rejected or revised.

If a candidate distribution has acceptable bolt stresses, a fuel grid impact analysis is performed with the WEGAP (Reference 2) program, using the calculated baffle and core plate displacement time-histories as input. If calculated grid impact loads are acceptable, they are used to assess fuel rod fragmentation and control rod insertability. If these are satisfactory, the bolting distribution is considered acceptable for the LOCA event. If not, the assumed distribution is rejected of revised or core coolability demonstrated by another method. The latter option is outside the scope of the present paper. By putting various candidate distributions through this process, a roster of LOCA-acceptable bolting patterns is defined. These are evaluated against SSE-induced loads by a process similar to that for the LOCA. The last step of the process is to evaluate candidate distributions against normal/upset conditions to address non-safety concerns. These analyses will not be discussed in detail, but only to identify their nature:

1. Thermally-induced low cycle fatigue of intact bolts.
2. Flow-induced vibration and the resulting high cycle fatigue of intact bolts.
3. Baffle-jetting and core bypass flow increases caused by larger baffle gaps.

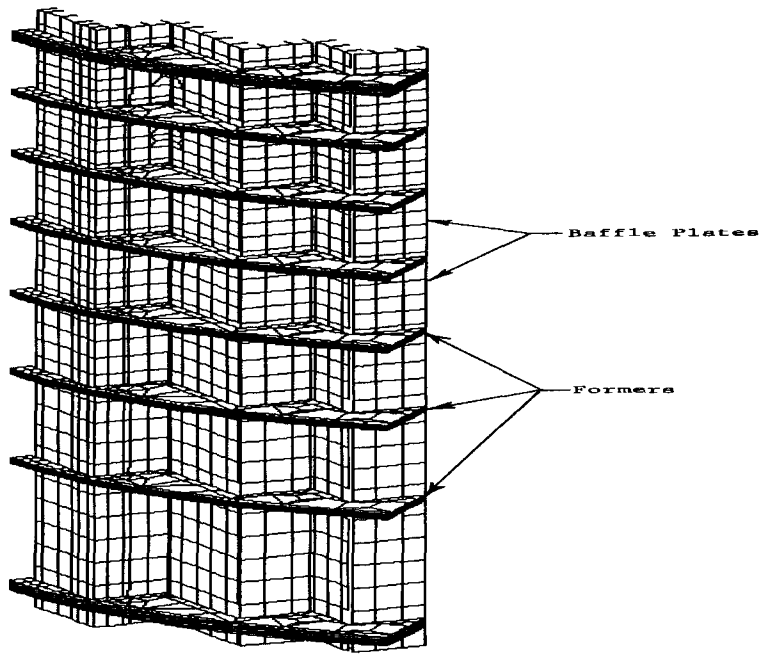

Figure 1 One-Eighth Baffle-Former Model

PLANT GROUP ANALYSIS SEQUENCE

The grouping of plants and the sequence of acceptable bolting analyses were influenced by two factors: anticipated "worst case groups," and the hierarchy of planned bolt replacement campaigns. Leak-before-break (LBB) was used to limit the sizes of the breaks considered, the extent of LBB application depending on the plant group. Plant groupings considered many factors. The number of loops is an indication of plant size. 4-Loop plants have the most coolant and therefore depressurize at slower rates for a given break size than do plants with fewer loops. The fuel type affects the fuel assembly dynamics and the fuel grid impact loads. The BFB thermal-hydraulic configuration has a significant effect on the transmission of the LOCA acoustic wave into that region and, thus, the transient loads on the baffle plates and baffle-former bolts. Of primary significance is the downflow/upflow distinction. In downflow plants, the LOCA acoustic wave for cold leg breaks is strongest at the core barrel inlet holes (see Figure 2a) and propagates from that point into the BFB region. For upflow plants (Figure 2b) there are either no core barrel holes or they have been plugged during upflow conversion, so that the LOCA acoustic wave enters the BFB region only through the bottom and top fluid interfaces with the core. These are more benign entry points because wave transmission into the BFB region via these points reduces baffle pressure loads. In the downflow configuration, the opposite occurs. In standard upflow plants, relief holes in the baffle plates enhance the upflow pressure equilibration effect.

To address other parameter variations, conservative assumptions were made. For instance, if baffle-former bolt length varies within the group, the shortest bolts were simulated, because these are most susceptible to bending stresses. The same applies to the thermal shield/neutron pad difference: the former is more limiting with respect to fuel grid impact loads and was therefore used in analytical models.

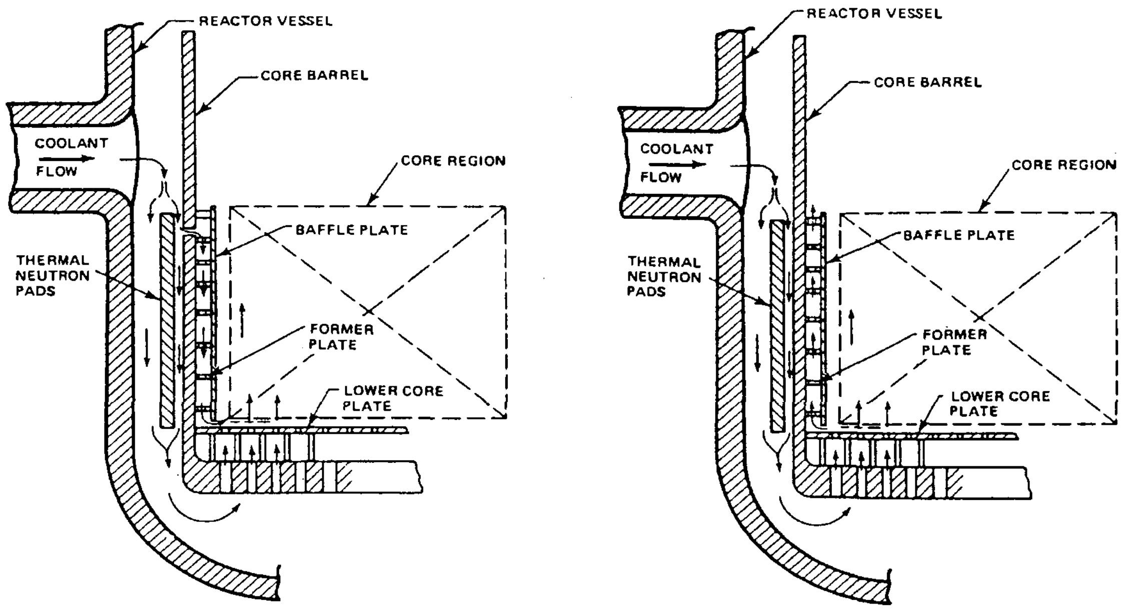

Figure 2 Baffle-Barrel Region Flow Configurations

FAULTED LOAD ACCEPTANCE CRITERIA

The ultimate faulted acceptance criterion is core coolability; fuel peak clad temperature (PCT) shall not exceed established limits. The methodology outlined above attempts to circumvent the need for core coolability analyses by appealing to criteria whose satisfaction precludes the need for such analyses:

a. Fuel grid impact loads must remain below the grid strength.
b. Baffle-former bolt stresses must remain below ASME Code Appendix F allowable membrane and bending stresses.
c. Control insertability must be assured.
d. Fuel rod fragmentation must not occur.

Although criteria c and d are usually satisfied if criterion a is satisfied, control rod insertability and fuel rod fragmentation evaluations are always performed. For the present discussion, however, only criteria a and b are considered.

Fuel Grid Impact Loads

Because faulted events can result in significant core plate motions, fuel grid impacting with the baffle plates is possible. If reduced bolting results in significant baffle displacements, fuel grid impacting can be further aggravated.

Baffle-Former Bolt Stresses

Although both LOCA and seismic events produce core plate motions, the seismic event is displacement forced , whereas the LOCA event is pressure forced. This is an important distinction to make in the understanding of calculated baffle-former bolt stresses. For the seismic event, core plate motions are the only driver. By contrast, acoustic wave propagation in the LOCA event leads to direct pressure loads which produce larger baffle-former bolt stresses than core plate motions can. Except for small breaks, these are significantly larger than their seismic counterparts. The same applies to baffle motions: LOCA-induced displacements are larger.

These trends suggest that, if a bolting distribution yields acceptable baffle-former bolt stresses when subjected to the LOCA event, it is likely that this acceptability will apply to the seismic event as well. This does not mean that seismic fuel grid impact loads will be acceptable; as noted above, seismic core plate motions can lead to fuel grid impacting. What it does mean is that seismic baffle plate motions will usually be small and that seismic fuel grid impact loads are not likely to be strongly affected by the assumed bolting distribution. That is, they will be essentially the same for acceptably reduced bolting distributions as they will for the all-bolts-intact condition. For these reasons the LOCA event is typically the limiting faulted event.

2-LOOP DOWNFLOW AND CONVERTED UPFLOW PLANTS

The 2-Loop group was analyzed first because one plant in the 2-Loop group was scheduled for an early baffle-former bolt replacement and the 2-Loop plant size is the smallest in the United States. Although it was suspected that the downflow BFB configuration might produce higher LOCA-induced bolt stresses because peak baffle pressure loads are higher, it was not entirely obvious. Since both downflow and converted upflow configurations existed within this group, calculations were done for both to determine which was limiting. From these early efforts, it was found that a) because of the "rebound" acoustic wave, peak bolt stresses in the downflow design were higher than those in the converted upflow design by a factor of about two, and b) neither configuration could tolerate significant reductions in baffle-former bolting. Improvements to the calculational technique were therefore needed.

Fluid-Structure Interaction Simulation

The first improvement was to develop a fluid-structure interaction model to reduce pressures on the baffle plates by allowing the structural motion to mitigate some of the LOCA loads. In an earlier program, a hydrodynamic mass technique was developed to do this, but this was impractical for a one-eighth simulation (Figure 1) because the "full" hydrodynamic mass matrix that had to be added to the structural mass matrix was too large. What was done was to adapt a technique developed (Reference 3) in the 1980s in which the BFB fluid was simulated by compressible fluid elements, the fluid in the former holes by mass and (linear) dashpot elements, and the fluid-structure interface conditions by linear constraint equations. This simulation was improved by three-dimensionalizing it and using quadratically-dependent dashpot elements, in line with the behavior of classical turbulent flow (Figure 3). The constraints imposed between structure and fluid required that the volume displacements of compressible fluid elements be equal to the volume displacements of the baffle and former elements immediately adjacent to them.

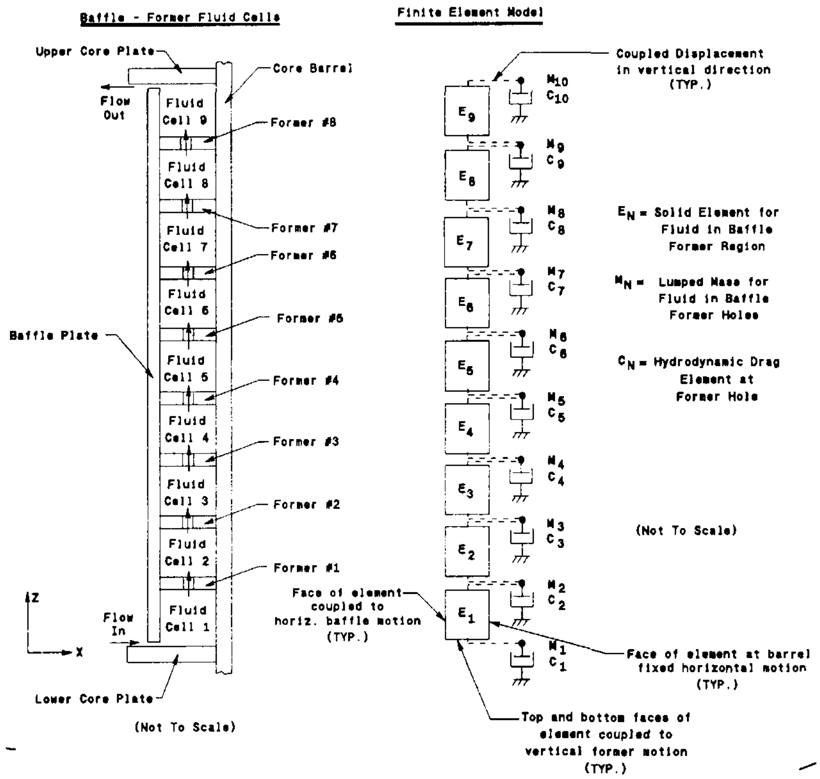

Figure 3 Converted Upflow Baffle-Former-Barrel Fluid Model

To prove this technique, analyses were developed to compare the fluid dynamics of the improved simulation with the steady-state and acoustical pressures predicted by independent thermal-hydraulic calculations. Figure 4 compares a "rigid wall" MULTIFLEX 3.0 calculation of transient baffle pressure differentials to a similar "rigid wall" calculation by the improved BFB model. The agreement is quite good and is representative of the agreement obtained for all plant groups analyzed.

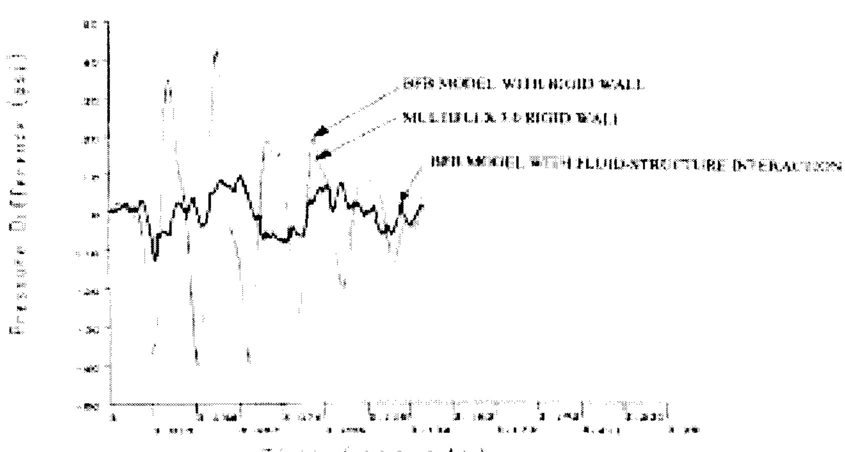

Figure 4 Comparison of MULTIFLEX 3.0 to BFB Model Baffle Pressure Difference – Time Histories With and Without Fluid-Structure Interaction

This comparison demonstrates the correctness of the fluid dynamics in the improved BFB model simulations, but does not directly verify the fluid-structure interaction methodology. To do this, comparisons with data from fluid-structure interaction tests performed at Bettis Atomic Power Laboratory (Reference 4) were made. A typical test assembly consisted of a containment vessel with a piston to create an acoustic pulse, an inner structure that could be "rigid" or "flexible," the fluid between, and the transient pressure and deflection instrumentation employed. Fluid-structure analysis models of the test assemblies were created and predictions compared to test data (Reference 5). These comparisons illustrated that the models accurately predicted the peak pressure reductions observed in the "flexible" test runs and also accurately simulate the test section pressure-time histories in both "solid" and "flexible" cases. Reference 5 also discusses additional analysis/test comparisons in which a surge tank was hydraulically connected to the test vessel. Excellent agreement was also obtained in these comparisons.

Detailed Bolt Joint Simulation
In the original 2-Loop BFB model, the joints between the baffle plates and formers were simulated as linear elastic pipe elements; either a closed joint or an open joint could be simulated this way but nothing between. What early LOCA calculations revealed was that neither of these assumptions was necessarily valid for the entire transient. To address this uncertainty, a non-linear bolted joint simulation was developed (Reference 6). In this simulation, each joint was modeled with a pipe element for the bolt and gap elements on each side of it attached by rigid links to simulate the baffle-former interface. This allows a joint to separate, and to separate independently from each side if the system forces demand it. In addition, the interfaces between the baffles and formers were given a capability to simulate the lateral restraint of friction. The parameters employed to simulate the joints were based on detailed calculations of joint behavior and on joint test data.

With the fluid-structure interaction methodology and bolted joint simulation described above, it was possible to show that about 50% of the baffle-former bolts were needed to demonstrate safe operation of 2-Loop downflow plants. This was later improved to 20% by assuming LBB could be applied down to six inch lines. Later calculations for converted upflow lowered this to about 20% for the larger breaks. These were substantial improvements over the initial calculations.

3-LOOP DOWNFLOW AND CONVERTED UPFLOW PLANTS (NEWER DESIGNS)
When the 3-Loop analysis began, the conventional wisdom was that plant size was one of the more important parameters affecting baffle-former bolt stresses. Coolant depressurization rates being a decreasing function of plant size, 3-Loop plants were expected to be less limiting for baffle-former bolt stresses than 2-loop plants. This intuition was based on previous calculations of LOCA-induced fuel grid impacting. What was not appreciated at the close of the 2-Loop effort was that depressurization rate was not the only significant parameter affecting bolt stresses; the baffle-former hydraulics also had a strong influence on the depressurization of the baffle-former region and thus on the bolt stresses. For a downflow plant, the depressurization of the vessel downcomer influences the BFB depressurization rate via the core barrel holes connecting the two regions. A high hydraulic resistance for these holes reduces the BFB depressurization rate; a low hydraulic resistance increases it.

Initial calculations indicated that something was awry with intuitive expectations because it was found that, as a percent of the total, more bolts were required for the first 3-Loop downflow plants analyzed (newer designs) than were needed for the 2-Loop downflow plants. After reviewing this behavior, it was discovered that, as a percentage of the total baffle-former region cross-sectional area, the core barrel holes have about 70% more flow area in the 3-Loop downflow plants being analyzed than they do in a 2-Loop downflow plant. This is more than enough to overcome the moderate decrease in LOCA depressurization rate 3-Loop plants enjoy over 2-Loop plants. Of even more concern was the discovery that the core barrel holes in many 4-Loop downflow plants have relative flow areas somewhere between 3.2 and 4.2 times as large as a 2-Loop downflow plant. Consequently, intuitive expectations were backwards. The hierarchy of peak bolt stresses was the reverse of that for fuel grid impact loads: 4-Loop plants would have the highest LOCA-induced bolt stresses and 2-Loop plants the smallest. After proceeding with the calculations it was found that about 70% of the baffle-former bolts were needed in the newer 3-Loop downflow designs, a more limiting result than that for 2-Loop downflow, but still acceptable. A subsequent analysis for a 3-Loop converted upflow configuration yielded much fewer required bolts: approximately 20%. Figure 4 illustrates the pressure relief that occurs when reduced bolting enhances fluid-structure interaction effects.

4-LOOP DOWNFLOW PLANTS

It was concluded that 4-Loop downflow configurations were likely to be worse for bolt stresses than others because of their large core barrel flow hole areas. These plants also employ some of the shortest baffle-former bolt designs as well, an undesirable characteristic. To this point in the program elastic bolt simulations and elastic stress allowables had been used. Now it became necessary to consider plasticity, the rationale being that, for faulted events, the only thing that matters is functionality; plastic deformation can be allowed as long as fracture does not occur.

An elastic-plastic pipe element was selected to simulate the intact bolts in the BFB model. After taking a closer look at the stresses calculated by these elements, it was concluded that they were not very good. However, it was also concluded that the predicted bolt displacements were conservatively high. It was therefore decided to take the peak bolt displacements from the BFB dynamic runs and apply them as boundary conditions to more detailed elastic-plastic analyses of single bolts using a more accurate elastic-plastic element. There were three difficulties associated with this. The first was finding an appropriate element to use and demonstrating that it could be used for the purpose envisioned. A three-dimensional solid elastic-plastic element was chosen and shown to produce consistent results with equivalent stress and equivalent strain as the governing parameters. Secondly, stress and/or strain allowables had to be developed. Appendix F of the ASME Code (Reference 7) provides guidance on allowable elastic-plastic stresses for faulted conditions, but only for bolt materials in their <u>un</u>irradiated states. The B^3 Program took credit for the strengthening effects of irradiation on bolt materials when appropriate for evaluating stress allowables. Data were available to support this approach so the Appendix F rules were interpreted in terms of these data and used in the analysis of bolt stress acceptability.

Thirdly, the U.S. NRC review of the analysis methodology judged it to be acceptable, with the caveat that a demonstration be made that irradiated material ductility is sufficient to justify the use of ASME Code allowables. This was addressed by requiring calculated strain values to be less than those determined by fracture tests on irradiated bolts. With this approach, the required number of baffle-former bolts for this group was reduced to approximately 50%. Calculations were also performed for smaller breaks and for a subset of the assumed bolting distributions, and additional stress/strain margins obtained. No further reductions in bolting were analyzed, however.

3-LOOP DOWNFLOW PLANTS (OLDER DESIGNS)
Unlike the 4-Loop groups, the older 3-Loop downflow plants have a distinctly different BFB hydraulic configuration than the newer 3-Loop downflow plants. For this reason, and because LBB was assumed applicable to six inch lines for these plants, it was not expected that acceptable bolting distributions would be common to both groups. It was expected that the smaller break size would allow operation with fewer required bolts than the newer group had permitted. The older group would, however, be the first downflow plant group for which assumed bolting distributions with less than 50% of the bolts intact were to be evaluated. With the smaller breaks, the required bolting was determined to be on the order of 20%. Even with these small breaks, however, it was necessary to use the elastic-plastic bolt simulation to achieve acceptable bolt percentages this low.

4-LOOP CONVERTED UPFLOW PLANTS
The results for the two 4-Loop converted upflow configurations were similar to previous converted upflow results: approximately 20% of the bolts were needed to assure acceptability of bolt stresses and baffle displacements. In fact, results suggested that bolting distributions with fewer than 20% of the bolts assumed to be intact were also acceptable. However, there is a point at which engineering judgment balks at such a dearth of fasteners in the structure immediately adjacent to the core. Therefore, 20% is considered to be a *de facto* lower limit for this group, even though a smaller number may be justifiable.

3-LOOP AND 4-LOOP STANDARD UPFLOW PLANTS
In the United States the dominant reactor internals style is the 4-Loop standard upflow configuration, of which there are fourteen plants. In addition, two plants have the 3-Loop standard upflow configuration. What distinguishes these plants from other designs is the as-designed upflow configuration, bolt cooling holes in the former plates, and baffle pressure relief holes. The incorporation of bolt cooling holes permits lower temperature operation of the bolts and the baffle pressure relief holes reduce pressure loads on baffle plates during a LOCA. These innovations are state-of-the art features whose value was not fully recognized in earlier designs.

For analysis purposes, the baffle pressure relief holes pose the greatest potential benefit (reduced baffle pressure loads) *and* the greatest potential source of numerical difficulties in the transient LOCA analysis. They are relatively large diameter holes with short flow path lengths, both of which reduce the time constants of the acoustical/mechanical system. However, this has not occurred. BFB time-history calculations have shown no special sensitivity to the presence of pressure relief holes and results indicate that required bolting is smaller (< 10%) than that for comparable converted upflow plants with greater bolt stress margins.

NORMAL/UPSET ANALYSIS

The effects of reduced bolting on fatigue, baffle-jetting and bypass flow were also considered, and are discussed below:

Fatigue:

There are two aspects of bolt fatigue, 1) low cycle fatigue from relative thermal growth of the baffle plates, and 2) high cycle fatigue from flow-induced vibration. The latter was addressed by modifying the analysis models that had been developed for the LOCA analysis, analyzing them harmonically at the core barrel amplitudes and frequencies, and comparing the cyclic bolt stresses to ASME Code allowables. The low cycle fatigue evaluation was more problematical. The fatigue analysis techniques that had been tried in the past to address low cycle bolt fatigue had largely been unsuccessful; bolt fatigue tests provided the proof of fatigue acceptability. But these tests didn't consider reduced bolting patterns and the potentially larger bolt displacements that may result from such distributions.

The approach used in the program takes credit for the fact that many utilities have in recent years been using low leakage core loading patterns with less baffle-barrel internal heat generation than out-in loading patterns, on which bolt fatigue tests were based. The idea was to compensate for the larger baffle-barrel thermal displacements with the smaller heat generation rates of these patterns. With this approach, it has usually been possible to show that the reduced bolting distributions of interest do not produce displacements in the remaining bolts any larger than those for a full complement of bolts with the original in-out core loading pattern. For the few remaining cases, it has often been possible to justify reduced bolting profiles that don't require bolts in the top and/or bottom formers. In some replacement campaigns, these bolts have been difficult to remove. By identifying bolt profiles that don't require bolts at these levels the replacement efforts were considerably simplified and also resulted in a simplification of the low cycle fatigue analysis.

Baffle-Jetting/Bypass Flow:

The thermal-structural analyses developed for the calculation of bolt displacements was also used to calculate baffle-baffle gaps and the resulting increases in bypass flow and baffle-jetting. It has been possible to show that baffle-jetting and bypass flow are acceptable for upflow plants with the reduced bolting patterns of interest. The difficulties have been with the downflow BFB configuration.

It can be anticipated that reduced bolting may present an issue for downflow plants. It cannot easily be argued that some baffle-former bolts may be non-functional but that enough intact edge bolts – whose function is to close the gaps - are available to prevent baffle-jetting damage to the fuel. Moreover, since edge bolts are typically closer to the core than other bolts, it can't be argued that their environment is more benign. The approach developed for downflow plants is the argument that there is already in place a U.S.NRC-accepted approach for addressing baffle-jetting and that, since safety is not involved, bolt pattern acceptability need not be limited to those patterns for which acceptable baffle-jetting performance can be demonstrated. What the analysis does include is a demonstration that any increases in bypass flow resulting from reduced bolting will be insignificant and, in any case, will not occur without accompanying baffle-jetting momentum flux increases. That is, the accepted U.S.NRC method for dealing with baffle-jetting will cover potential bypass flow increases as well. Nevertheless, the analysis clearly demonstrates the desirability of converting all plants with downflow BFB designs to upflow configurations.

CONCLUSIONS

The Baffle-Barrel Bolting Program to determine the acceptability of reduced baffle-former bolting in Westinghouse pressurized water reactor plants has revealed the following:

1. Safe operation with substantially reduced bolting can be demonstrated. For the present study, the limiting condition for bolt stresses was the LOCA event, which assumed LBB applies at least to the main coolant piping. Seismic-induced stresses on the baffle-former bolts have been found to be small.
2. To satisfy faulted design criteria, the downflow baffle-barrel configuration requires more baffle-former bolts to be intact than the standard upflow or converted upflow baffle-barrel configurations. The downflow configuration requires approximately 50-70% of the bolts to be functional. For converted upflow the percentage is on the order of 20-40%. For the standard upflow configuration, distributions with as few as 10% of the bolts have been shown acceptable. These values are based on assumed replacement bolt profiles which are fairly uniform. For distributions in which many bolts are assumed to be non-functional in local areas – as may be typical of some forms of bolt degradation – these percentages may be low.
3. To achieve the bolting reductions identified above, several innovative analysis modeling techniques were developed: a) baffle-former fluid-structure interaction modeling, b) detailed bolted joint representation, and c) elastic-plastic bolt simulation. These techniques yield significant bolt load reductions and remove uncertainties on bolt behavior that would otherwise be difficult to resolve. Without these improvements, demonstrating acceptable operation with significantly reduced baffle-former bolting might not be possible.
4. Typically, a reduced bolting distribution with "acceptable" bolt stresses also restrains LOCA or seismic baffle motions enough that grid impact loads for a given fuel assembly are not notably different from the all-bolts-intact condition.

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REFERENCES

1. K. Takeuchi et al, "MULTIFLEX 3.0, a FORTRAN-IV Computer Program for Analyzing Thermal Hydraulic Structural System Dynamics Advanced Beam Model," WCAP-9736, Revision 2.
2. M. D. Beaumont et al, "Verification Testing and Analysis of the 17x17 Optimized Fuel Assembly," WCAP-9402-A, August 1981.
3. R. A. Riddell, and R. E. Schwirian, "Simulation of Fluid-Structure Interaction During a LOCA Using existing Finite Element Formulations," Advances in Fluid-Structure Interaction Dynamics, (ASME) PVE Vol. 75, June, 1983, pp. 57-67.
4. D. A. Prelewicz, "Hydraulic Pressure Pulses with Structural Flexibility: Test and Analysis," WAPD-TM-1227, ERDA Research and Development Report, April 1976.

5. A. W. Harkness and R. E. Schwirian, “An Efficient Method for the Representation of Fluid-Structure Interaction in Large Structural Transient Dynamic Analyses,” presented at the 1998 International Mechanical Engineering Congress and Exposition, November 15-20, 1998, Anaheim, California.
6. M. D. Snyder, "Techniques for Evaluation of Preloaded Bolted Joints in a PWR for Faulted Events," submitted for presentation at the SMIRT 16 Conference, August 12-17, 2001, Washington, D.C.
7. ASME Boiler and Pressure Vessel Code, 1989 Edition.