Westinghouse

Technical Bulletin

An advisory of a recent technical development pertaining to the installation or operation of Westinghouse-supplied nuclear plant equipment. Recipients should evaluate the information and recommendation, and initiate action where appropriate.

1000 Westinghouse Drive, Cranberry Township, PA 16066

Subject: **Westinghouse NSSS PWR Thermal Shield Degradation**	Number: **TB-19-5**
System(s): **Thermal Shield Flexures and Support Block Cap Screws**	Date: October 9, 2019
Affects Safety-Related Equipment Yes ☐ No ☒	Shop Order: 42

PURPOSE

The purpose of this Technical Bulletin (TB) is to provide the thermal shield operating experience (OE) from Salem Unit 1 during the spring 2019 refueling outage. Additionally, this TB provides clarity on existing Materials Reliability Program (MRP) OE notification [1] inspection recommendations for the thermal shield support block (TSSB) cap screws. A TSSB cap screw is also referred to as a thermal shield support block bolt. The recommendations provided here are meant as a supplement to these recommendations and MRP-227-A guidance [2] and do not replace or supersede them.

SUMMARY

During the spring 2019 outage, Salem Unit 1 identified thermal shield support degradation in the form of failed TSSB cap screws (Figure 7) and crack-like indications in thermal shield flexures (Figure 6). Westinghouse nuclear steam supply system (NSSS) plants that have thermal shields are also potentially affected by this failure mechanism. Operating in this condition can be an asset management concern. To that end, this TB provides details on the TSSB cap screw and flexure issues to provide affected licensees a basis for OE and inspection recommendations. This issue was entered into the Westinghouse corrective action program and was determined not to affect plant safety. Westinghouse determined that there is no impact to operability because the degradation does not affect the core cooling or rod cluster control assembly (RCCA) insertion capability.

Additional information, if required, may be obtained from Benjamin Leber, leberba@westinghouse.com, (412) 374-4533.

Author:
*Eric M. Benacquista
Reactor Vessel Lower Internals
Design and Analysis

Verifier:
*Bryan M. Wilson
Structural Design and Analysis
Engineering

Reviewer:
*William J. Catullo
Licensing

Approver:
*Camille T. Zozula
Licensing

*Electronically approved records are authenticated in the electronic document management system

BACKGROUND

Thermal shields are present around the reactor internals core support barrel in 31 operating Westinghouse NSSS pressurized water reactors (PWRs). The thermal shield is a passive structure whose function is to reduce the neutron fluence on the reactor pressure vessel in the core region (Figure 1). This extends the life of the reactor pressure vessel by mitigating the effects of irradiation on the vessel material. The thermal shield has a support design that uses several types of hardware at multiple locations. The exact thermal shield support design varies across 2-, 3-, and 4-loop plant configurations. These designs include different quantities and configurations of attachment hardware but function in a similar manner. In all configurations, the thermal shield rests on a lug and the designs use austenitic stainless steel dowel pins to carry thermal shield vertical and circumferential shear forces and austenitic stainless steel cap screws to carry tension (radial thermal shield loads) (Figure 2, cap screws in Section A-A, dowel pin in Section B-B). Note that the exact configuration of this hardware varies by plant design. The lower edge of the thermal shield is supported by integral flexures which allow relative thermal growth axially between the thermal shield and core barrel and restrain the thermal shield radially and circumferentially (Figure 3).

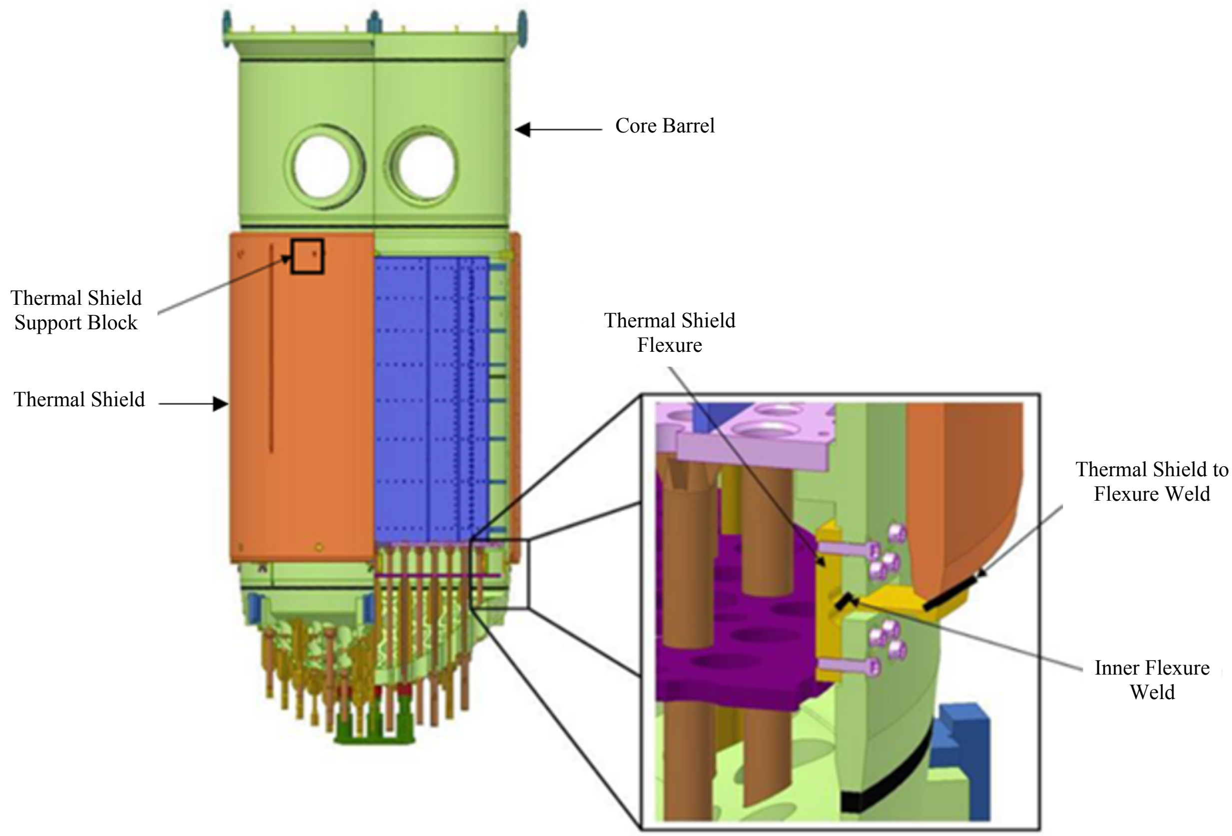

Figure 1 - Typical Westinghouse PWR 4-Loop Thermal Shield Layout

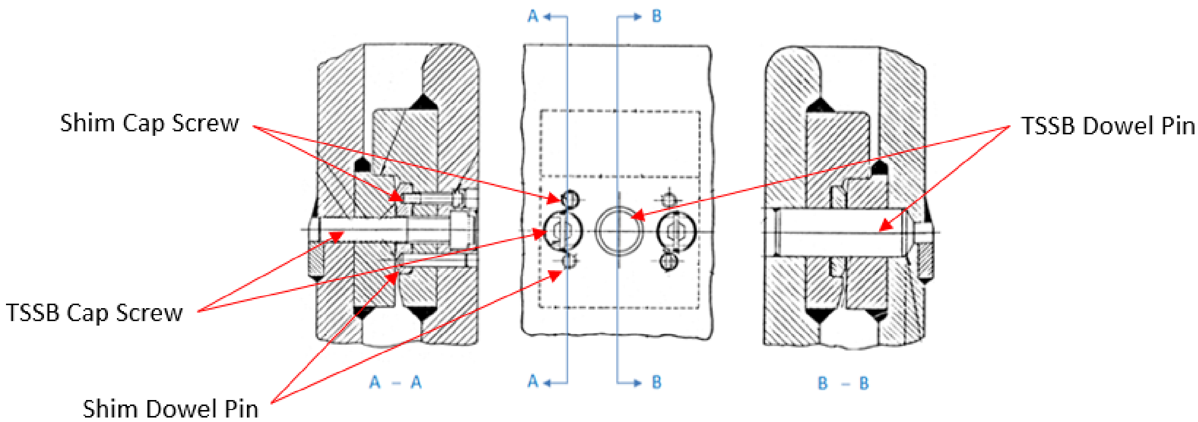

Figure 2 - Thermal Shield Support Block Assembly Diagram (Not Representative of All Configurations)

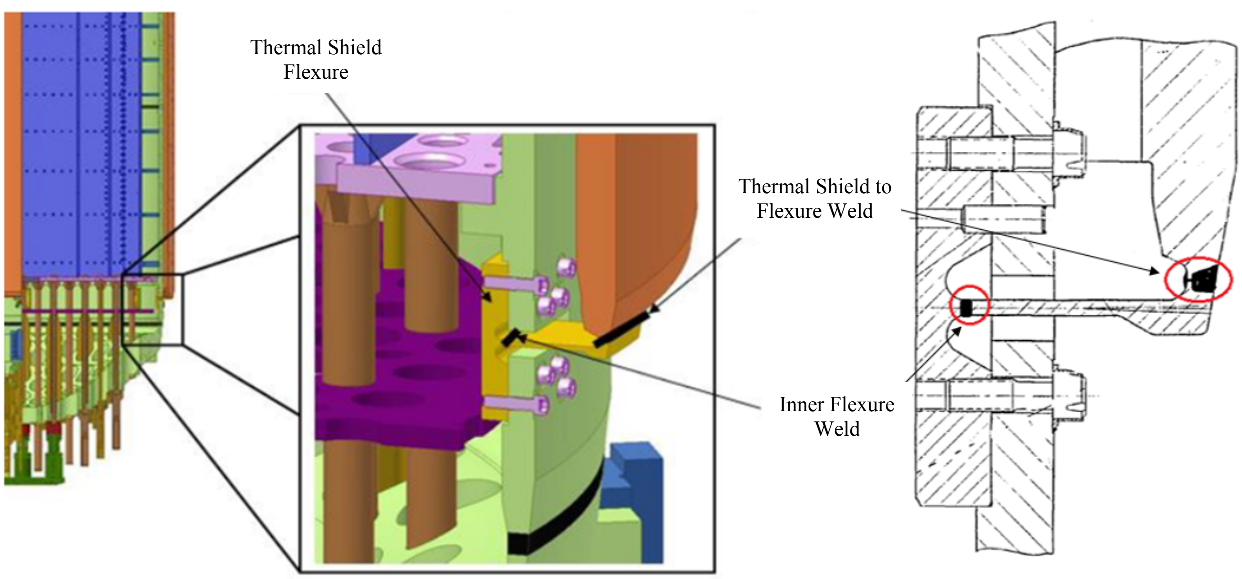

Figure 3 - Example Thermal Shield Flexure (in Yellow) Showing Weld Locations

The Salem Unit 1 thermal shield support configuration contains eight support blocks and eight flexures. Each support block includes two large support block cap screws and a larger dowel pin (by design, the as-installed conditions may vary, e.g., additional dowel pins) and smaller cap screws and dowel pins that support the shims. Figure 1 shows additional smaller hardware for the retention of shims internal to the block assembly. The condition of these small shim cap screws and shim dowel pins does not affect the functionality of the support blocks. The number of block assemblies and thermal shield flexures will vary by plant design. To understand the expected configuration of the hardware, utilities should confirm their plant specific design configuration or consult with their original equipment manufacturer (OEM) prior to any potential inspections.

In the spring of 2019, Salem Unit 1 discovered four failed TSSB cap screws (severed under the head), two at the 202 degree support location and two at the 292 degree support location (Figure 4). The dowel pin visually appeared intact along with its retention weld at both locations.

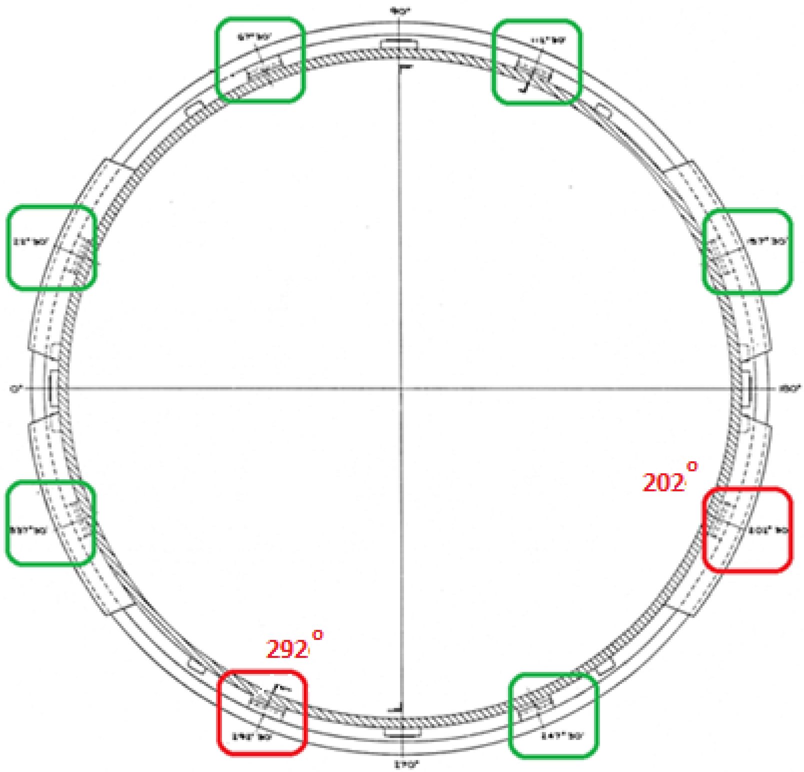

Figure 4 - Salem Unit 1 Thermal Shield Support Block Layout, Failed Cap Screws in Red (From Top Looking Down)

The TSSB cap screw failure was identified due to difficulties removing the upper internals assembly during refueling operations. Once the upper internals were removed, visual examinations of interfacing surfaces revealed a TSSB cap screw shank protruding through the core barrel inner diameter at the elevation of the upper core plate. The holes for the TSSB cap screws at Salem Unit 1, and all other impacted plants identified in Table 1, are threaded the entire way through the core barrel at the elevation of the upper core plate. This configuration could result in the shank portion of the cap screw to potentially unthread toward the interior of the barrel due to normal operating vibrations after separation from the cap screw head. Observations of the visible markings on both the end of the protruding cap screw and the outer surface of the upper core plate (see Figures 8 and 9) were completed. Based on the observations, the investigation concluded that the protruding cap screw interfered with the upper core plate which increased the force required to remove the upper internals assembly. The remaining 15 TSSB cap screws were ultrasonically inspected, resulting in the identification of three more potential failures. Replacement efforts confirmed the three additional TSSB cap screws were also severed under the head. Salem Unit 1 reviewed prior inspection video of this region and identified this condition has existed for a number of previous cycles but did not impede the installation or removal of the upper internals. Prior to the sticking of the upper internals in the spring 2019 outage, there were no alarms recorded on the loose parts monitoring system. The discovery process and ensuing inspections at Salem Unit 1 did not reveal any missing parts that may be loose in the NSSS.

In 1988, Beaver Valley Unit 1 was the only other reported incident of a Westinghouse plant with TSSB cap screws failing and eventually protruding through the inner diameter of the core barrel. The Beaver Valley failure did not result in interference with the upper internals and was discovered during visual examination around the top surface of the baffle-former assembly in preparation for a separate reactor internals service. The cap screw was replaced in 1988 and Beaver Valley Unit 1 has been in operation ever since with no further TSSB cap screw or flexure degradation reported at any location.

In response to the TSSB cap screw failures discovered at Salem Unit 1, external visual inspections of the thermal flexures were recommended and performed to confirm the conditions of the thermal shield supports. Salem Unit 1 identified crack-like indications at the transitions of two flexures, one at 180 degrees and another at 236 degrees (Figure 5 and Figure 6). The extent of the cracking has not been sized, only estimated through non-qualified visual inspection, as of the publication of this TB. Visual indications were also identified but could not be characterized other than as anomalies around the interior flexure welds at the 180, 236, 270, and 304 degree locations.

Operability Assessment

Failure of a single thermal shield support component results in an increase in loading on the remaining components. As the degradation progresses to the remaining hardware at that support block, to the point of a complete loss of radial support, this will also affect the dynamic response of the thermal shield. The change in loading causes an increased likelihood of further degradation of the thermal shield support blocks and flexures. Prior to the Salem Unit 1 OE, varying stages of progressive thermal shield degradation were identified at other Westinghouse and Combustion Engineering (CE) pressurized water reactors with different support configurations. Although the designs have support systems which are significantly different than the support system used at Salem Unit 1 and the applicable plants identified herein, this other OE provides insight into the nature of progressive thermal shield failure. CE plants in particular feature snubbers at the upper support location which could loosen over time, resulting in instability. Similarly, early Westinghouse PWRs featured an “inverted” thermal shield support design with the flexures as the upper supports. These designs were subject to larger levels of vibration, which resulted in a documented degradation of the thermal shield. The other Westinghouse plants referenced in this section are early plant designs which are no longer in service and the CE plants referenced have taken actions to prevent further thermal shield degradation through various actions including complete thermal shield removal.

The thermal shield is a passive component to decrease reactor vessel embrittlement over time. It does not have an active safety function. Even in the postulated worst-case condition of a total failure of all thermal shield supports, the thermal shield will come to rest on the core barrel lower radial supports and will not significantly impede the reactor coolant flow or shutdown capability of the reactor. Furthermore, its passive function of reducing reactor vessel embrittlement is not affected by this short drop in elevation. Fractured components are also a potential source of foreign material affecting the NSSS and the fuel. However, the degradation that has been experienced has had minimal foreign material impact and is well within what has been dispositioned previously as having no significant safety impact. Therefore, degradation of the thermal shield and its support components is an asset management issue. It should be noted that a severely degraded thermal shield may increase local vibratory loading on the core barrel at the remaining support locations. Due to the lack of safety significance, amount of redundant hardware, multiple methods of detection, and long time period expected for this level of degradation to occur, the core barrel loading has not been evaluated as it is not considered to be a credible risk. During the thermal shield degradation progression, it would be identified through examinations already required by typical aging management programs (such as MRP-227 or ASME Section XI inspections), or the recommendations provided by this TB. There also exists potential for detection through vibration monitoring techniques such as metal impact or neutron noise monitoring.

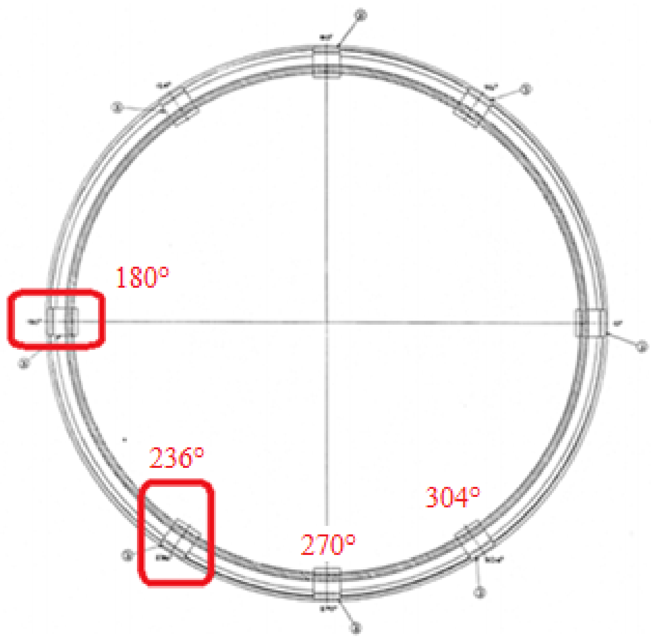

Figure 5 - Thermal Shield Flexure Layout, Flexures with Confirmed Crack-Like Indications in Red (From Bottom Looking Up)

Figure 6 - Thermal Shield Flexure Crack-Like Indications

Thermal Shield Support Block Cap Screw Inspection Basis

The failure of TSSB cap screws has been identified at two Westinghouse-designed plants with different thermal shield support configurations. In both scenarios, the failure was identified by a cap screw protruding into the inner diameter of the reactor core barrel. The TSSB cap screws are recessed within the core barrel wall by design. Therefore, a protruding cap screw is definitive evidence of failure. This inspection only requires a general condition determination to identify if a cap screw shank is protruding into the inner diameter of the core barrel. This inspection should be performed at the TSSB cap screw holes on the inside of the core barrel at the elevation of the upper core plate (directly above the top-most former plate and approximately even with the upper core plate pin; see Figure 7). Westinghouse 4-loop plants include eight locations, each consisting of a pattern of three holes (see Figure 8). The larger, outer two holes in the pattern are for the TSSB cap screws, the middle hole is a pressure relief hole for the dowel pin and does not require inspection. Westinghouse 3-loop plants contain a similar pattern, but only at six locations. Westinghouse 2-loop plants contain six locations each with a pattern of three holes. However, each of these holes contain a TSSB cap screw and should be inspected for a protruding cap screw.

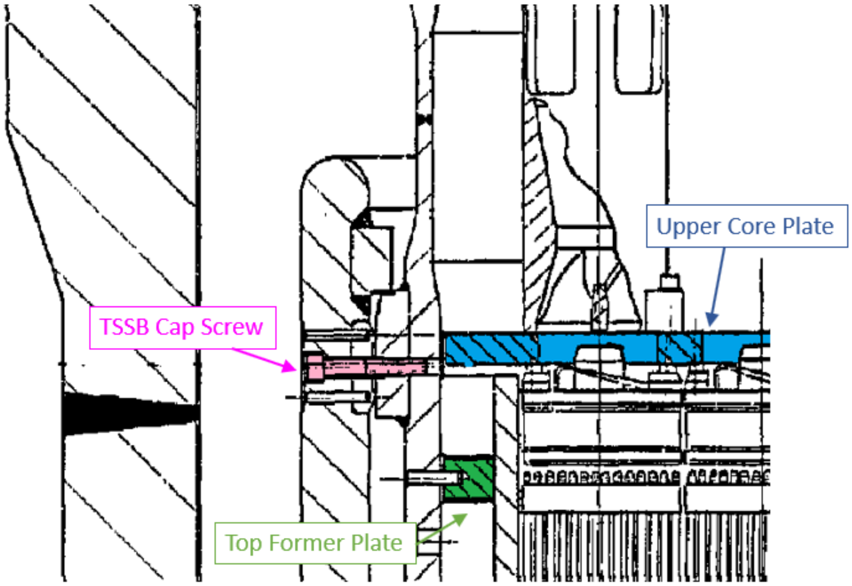

Figure 7 - Sketch of the Reactor Internals Showing Relative Positions of Components

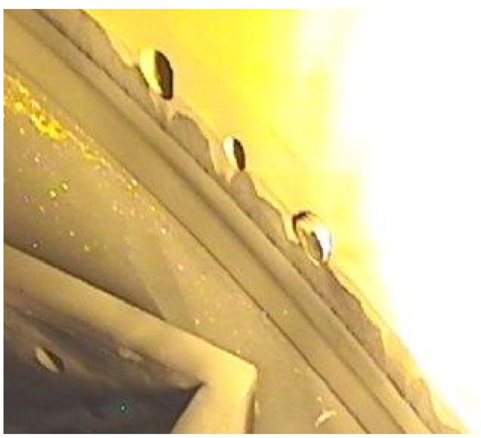

Figure 8 - Core Barrel Inner Diameter Showing Protruding Thermal Shield Support Block Cap Screw

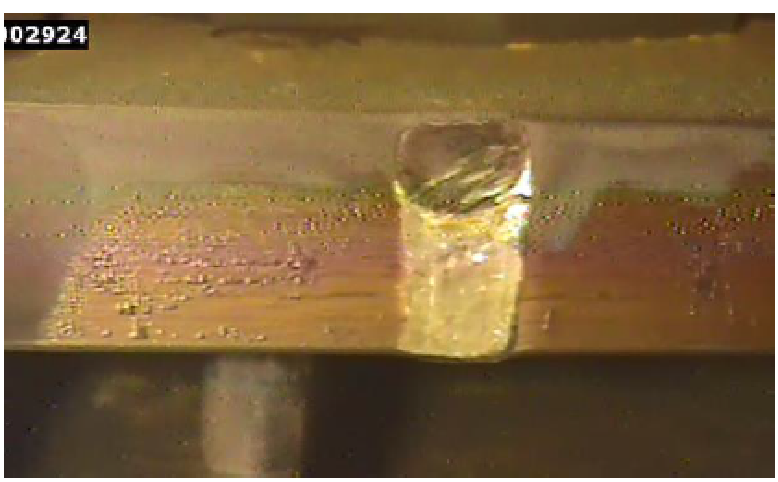

Figure 9 - Upper Core Plate Edge Showing Interference Damage from Protruding Thermal Shield Support Block Cap Screw

Since the as-built location of the end of the cap screw can vary within the holes due to shimming, any cap screw shank which is wholly contained within the hole cannot be confirmed as failed. Therefore, the acceptance criteria for the visual inspection should be considered as any cap screw shank for which the following observation can be made: the cap screw shank is neither flush with nor protrudes from the core barrel inner diameter (see Figure 8 as an example).

Westinghouse recommends that this visual general condition inspection be performed during the next refueling outage and all subsequent refueling outages. A separated cap screw shank will migrate towards the inside of the core barrel because of vibration in the reactor. Therefore, there is no certainty in the amount of time it takes for the shank to back-out after failure, or if it will ever back-out. Due to this, visual inspections may be insufficient to positively identify a failed cap screw, and therefore recurring inspections are recommended. Subsequent inspections may be omitted if action is taken to prevent the cap screw shank from backing its way towards the core barrel inner diameter or the status of the cap screw is determined through alternate means.

One proactive alternative to visual inspections is an ultrasonic testing (UT) examination performed from the inner diameter of the core barrel. This is a higher confidence inspection that does not rely on the displaced position of a failed cap screw for identification. A UT probe can be used to contact the end of the TSSB cap screw facing the core barrel inner diameter. A strong reflected signal at the depth of the head-to-shank transition is indicative of a fracture surface in the undercut section of the cap screw. This method was successfully applied at Salem Unit 1 to identify four such cap screws with strong reflections at depths less than expected from the design drawings. These cap screws were later removed and confirmed to be separated from the head-to-shank region. Intact cap screws should feature a deeper reflection due to the location and geometry of the head. Cap screw head geometry can vary by plant design and should be considered when determining the acceptance of any UT signals.

If TSSB cap screw access is available from the outer diameter, similar UT inspections may be performed in addition or as an alternative to UT inspections from the inner diameter. The rationale and conclusions applied to the inner diameter UT inspection, discussed previously, may be similarly applied.

Another option for an additional visual inspection is available during a refueling outage when the core barrel has been removed from the reactor vessel. This supplemental inspection views the thermal shield support blocks from the outer diameter to look for wear between the TSSB cap screw head and the lock bar. If any wear is present, or cracking found in the lock bar retention welds, then it can be determined that the cap screw head has separated from the shank. This condition was found at one of the Salem Unit 1 failed cap screw locations. Note that the other failed cap screws at Salem Unit 1 did not contain obvious lock bar wear.

Thermal Shield Flexure Inspection Basis

Currently, inspections of the thermal shield flexures are included in MRP-227-A [2] and MRP-227, Rev. 1 [3] as a primary component. As such, the flexures are managed for cracking or wear as part of most utilities' aging management plans. The recommended examination method is a qualified visual inspection (VT-3) which shall occur no later than two refueling outages from the beginning of a license renewal period with subsequent inspections at ten-year intervals. The inspection is to cover 100% of the flexures (see Figure 10). The acceptance criteria for the flexures are focused on identifying a lack of excessive wear, fracture, or complete separation. It has been identified that the required coverage of 100% of the flexures can be ambiguous and should be clarified to ensure that the highest susceptible locations are viewed in the inspection. Therefore, this TB includes a recommendation to clarify the detail of this inspection.

In addition to clarification of inspection coverage for the thermal shield flexures when performing MRP-227 inspections, identification of degraded thermal shield bolts and any associated disposition or repair of this condition requires a clear understanding of the condition of the remaining supports and flexures. The thermal shield support blocks and flexures work together as a system to provide support and maintain rigidity of the thermal shield. Degradation of any support or flexure has the potential for dynamic load communication to the other supports or flexures. As a result, recommendations are included herein related to inspections of the remaining support block hardware and flexures in the event of a discovery of degradation of either the thermal shield support block hardware or flexure.

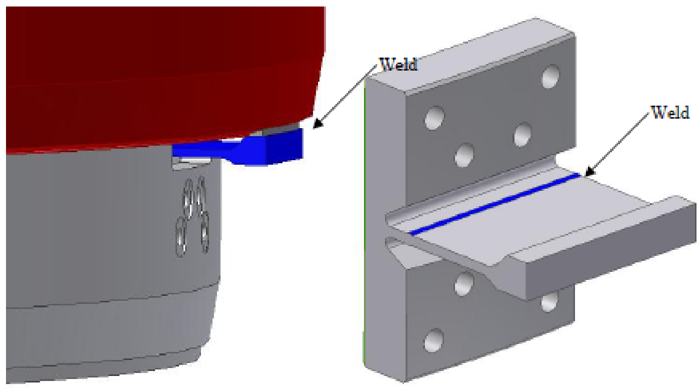

Figure 10 - Thermal Shield Flexure

Asset Management Risk

The degradation of the thermal shield supports does not have an impact on the safe operation of the reactor, the ability to cool the core, or to RCCA insertion. However, the potential for a separated TSSB cap screw to impede the removal of the upper internals is an identified asset management issue for all Westinghouse-designed PWRs with thermal shields. As experienced at Salem Unit 1, difficulty removing the upper internals may cause delays in planned outage schedules or even potentially compromise lift rig capacity.

Beyond reactor disassembly, if left unchecked, TSSB cap screw separation can lead to progressive degradation of the thermal shield. This degradation results in further asset risks. Replacement of thermal shield support block cap screws is difficult and expensive, particularly when unplanned. Advanced support degradation has the potential to require repair of the thermal shield flexures as well, which is more difficult due to their location and configuration. In the most extreme scenarios, thermal shield removal or core barrel crack mitigation may be required. Identifying this condition early, in accordance with the recommendations provided in this TB, significantly reduces the risk of needing to perform the more difficult repairs. Westinghouse is providing the following inspection recommendations to identify potential thermal shield degradation.

RECOMMENDED ACTIONS

The following inspection recommendations are presented as potential asset management risk mitigations. The utility should determine their individual asset management risk tolerance to determine the appropriate course of action.

Thermal Shield Support Block Cap Screw:

- **MINIMUM INSPECTION RECOMMENDATION**. During the next refueling outage and each subsequent refueling outage, with the upper internals removed, perform a general condition visual inspection of the inside diameter of the core barrel at the elevation of the upper core plate.
  - Separated TSSB cap screws can potentially protrude from their threaded holes into the core barrel inner diameter.
  - These locations are visible at regular spacing around the core barrel.
  - Any TSSB cap screw shank that is flush with, or protrudes beyond the surface of the core barrel, has separated from the head.
  - Examples of acceptable and unacceptable TSSB cap screw conditions are shown in Figure 11.
  - Should visual inspections of the TSSB cap screws reveal degradation, it is recommended that UT be performed, per Supplementary Inspection Recommendation #1, to confirm the condition of the visually degraded bolt, as well as all other support bolts.

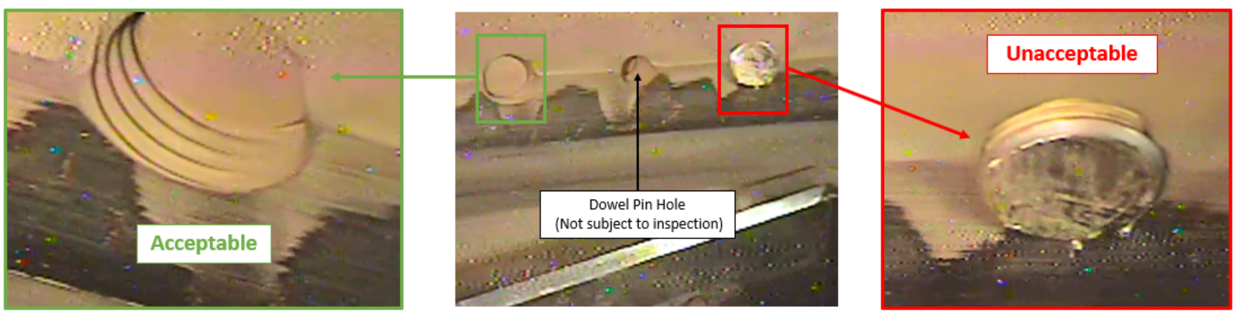

Figure 11 - Examples of Acceptability of TSSB Cap Screw Condition

- **SUPPLEMENTARY INSPECTION RECOMMENDATION #1**. At an initial inspection date and frequency determined by the utility based on asset management risk tolerance, UT examination of the TSSB cap screws can identify separation with more confidence, without relying on shank migration.
  - UT examination is performed after removal of the upper internals.
  - UT probes can access the inner diameter facing end of the TSSB cap screw shank through its threaded hole or the bolt head if the core barrel outer diameter is accessible.
  - TSSB cap screw separation is expected to occur at the head-to-shank transition.
  - UT examinations, which produce a strong signal reflection at a distance shorter than expected from the head geometry, may be indicative of a separated shank (this distance varies by plant design).

- **SUPPLEMENTARY INSPECTION RECOMMENDATION #2**. During refueling or maintenance outages with planned core barrel removal, a utility may perform general condition visual inspections of the TSSB cap screw retention lock bars, ledge, and dowel pin on the core barrel outer diameter.
  - Cracking or wear of the TSSB cap screw head, lock bar, or retention welds are potentially indicative of a degraded TSSB cap screw.

- Signs of cracking of the dowel pin retaining weld or wear at either the dowel pin or thermal shield support block ledge are potentially an indication of relative movement between the thermal shield and core barrel which may indicate a degraded TSSB cap screw.
- Lack of cracking or wear of these components should be regarded as inconclusive.

Thermal Shield Flexure

- **INSPECTION RECOMMENDATION (ONLY APPLIES IF ONE OR MORE TSSB CAP SCREWS ARE DETERMINED TO BE FAILED).** Perform visual inspections of the thermal shield flexures in accordance with MRP-227 guidance.
  - Intended to be performed during the same outage as the discovered TSSB cap screw failure to validate the extent of degradation considered when dispositioning the degraded TSSB cap screw.
  - Alternatively, a plant-specific evaluation may be able to be performed to justify deferral of this inspection to an outage more aligned with the utilities' plans to pull the core barrel. The ability to perform this evaluation in lieu of inspection would be dependent on the level of TSSB cap screw degradation observed, alternative methods used to understand or monitor the condition of the thermal shield, as well as the utilities' individual asset management risk tolerance.

- **RECOMMENDATION FOR CLARIFIED COVERAGE REQUIREMENT WHEN PERFORMING VISUAL EXAMINATION PER MRP-227-A [2] OR MRP-227, REV. 1 [3].** Examination coverage is 100% of the *accessible surfaces* of 100% of the thermal shield flexures (i.e., all accessible surfaces on each flexure). Minimum coverage shall include the top and bottom accessible surfaces of the inner flexure weld (closest to the attachment to the core barrel) and the outer surface of the thermal shield to flexure weld, including the transition radii of this weld. These weld locations, particularly the inner weld, see the highest levels of fatigue stress and are expected to be the most susceptible to failure. See Figure 12 for an example of these weld locations.

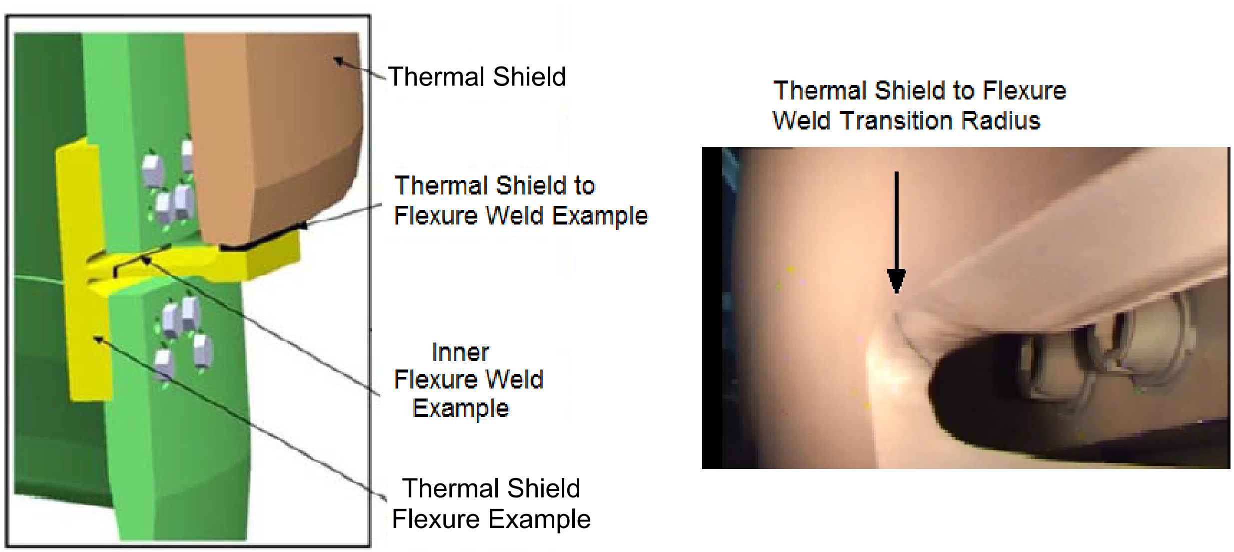

Figure 12 - Thermal Shield Flexure Showing Weld Locations

AFFECTED PLANTS

Table 1 lists all Westinghouse-designed plants with thermal shields that are affected by this OE.

Table 1 - List of Affected Westinghouse-Designed Plants

Angra 1	Point Beach 1 & 2
Beaver Valley 1	Prairie Island 1 & 2
Beznau 1 & 2	R.E. Ginna
Diablo Canyon 1	Ringhals 2
Doel 1 & 2	Salem 1 & 2
Donald C. Cook 1 & 2	Sequoyah 1 & 2
H.B. Robinson 2	Surry 1 & 2
Indian Point 2 & 3	Takahama 1
Krško	Tihange 1
North Anna 1 & 2	Turkey Point 3 & 4

REFERENCES

1. Electric Power Research Institute Materials Reliability Program Letter, MRP-2019-17, "Notification of Recent PWR Thermal Shield Attachment Bolting Failures and Flexure Cracking Operating Experience and Recommended Plant Actions," May 31, 2019.
2. *Materials Reliability Program: Pressurized Water Reactor Internals Inspection and Evaluation Guidelines (MRP-227-A)*, December 23, 2011, Product Id. 1022863, EPRI, Palo Alto, CA.
3. *Materials Reliability Program: Pressurized Water Reactor Internals Inspection and Evaluation Guidelines (MRP-227)*, Revision 1, October 29, 2015, Product Id. 3002005349, EPRI, Palo Alto, CA.