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Final Report to B&W Y-12 for MPO4300089700 Rev. 1

Gerald C. Mok

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Lawrence Livermore National Security LLC
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Written By:
Gerald C. Mok, Mechanical Engineer
Signature Gerald Chi-Hung Mok Date 10/23/13

Approved By:
Brian L. Anderson, Associate Program Leader
Signature B L Anderson Date 10/28/13

Transportation and Packaging Program
Lawrence Livermore National Laboratory

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Submitted by Vendor Number: 900142. Lawrence Livermore National Security, LLC
Responsible Engineer: Gerald (Gerry) C. Mok, 925-422-8859, mok1@llnl.gov
Responsible Financial Administrator: Kia Johnson, 925-423-3155, kia@llnl.gov
Responsible Program Leader: Brian L. Anderson, 925-422-2685, anderson1@**llnl.gov**

Summary

This report highlights the engineering information and findings that the Transportation and Packaging Program of Lawrence Livermore National Laboratory (LLNL) reviewed and evaluated for B&W Y-12. The reviewer finds the DPP-2 packaging to be adequately designed. Its containment vessel (CV) closure bolts are expected to satisfy all NUREG/CR-6007 bolt stress requirements under the Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC) specified in US Regulation 10CFR71. Using the cutting-edge FEA program LS-DYNA, B&W Y-12 has demonstrated the compliance of DPP-2 with all but one of the NUREG/CR-6007 stress criteria. Recommendations are made here to select the proper stresses and locations to demonstrate the compliance of the last criteria, which is a relatively more restrictive requirement under NCT. Suggestions are also made to seek additional validation of the bolt stress analysis results.

Introduction

The primary objective of this technical assistance contract as described in the original proposal, which is attached to the end of this report, is to review details of the current design and analysis of the DPP-2 bolted CV closure. If necessary, the LLNL responsible engineer would suggest appropriate changes to the design and analysis to bring DPP-2 into compliance with the bolt-stress acceptance criteria defined in NUREG/CR 6007. Thus, the work also involves occasional interpretation of the acceptance criteria. The following discussion of the results is divided into four categories: Documents, Design, Analysis, and Compliance.

Documents

Eighteen M2E80150 series drawings were provided and reviewed. Of the eighteen, fifteen (sub #8A001 through 8A014 and sub #8A020) describe the design of the DPP-2 packaging; and the three Sub #8A080, #8A083, and #8A086 describe, respectively, the Side-Corner, Side, and Top Test Weights, which are surrogate contents used for ORNL tests. The Test-Weight drawings do not provide complete engineering information, and there was no drawing for the Inner Convenience Can (ICC) and 2R Containers included in the FEA models. However, the Y-12 draft analysis report provides sufficient information for this review.

Two ORNL test reports (ORNL-NTRC-008 V1 and V3) were provided and referred to for NCT and HAC test conditions and results. Volume 2 of the report containing photographs was not available. In general, the test results of post-HAC CV leak rate and breakaway bolt torque support the positive conclusions of the draft Y-12 analysis report concerning the CV closure bolts.

Y-12 draft report DAC M801508-0003 000 00, Rev. 0, *DPP-2 Impact Analysis*, was reviewed for all information related to the impact analysis project. The lengthy (more-than-600 pages) report, however, contains only brief description of the methodology and results of all the impact analyses performed. A table highlighting the purpose, special features, and results of each analysis case would have facilitated the use of the reported information. The focus of the present review is on the CV closure bolts. Special requests for supplemental analyses and results were made. Drew Winder of B&W Y-12 responded patiently and timely to all the requests. The additional information from Y-12 is not currently documented. Only some of the information is included here to support the reviewer's opinion.

Design

The drawings identified in the Document section show that the DPP-2 packaging is essentially a circular cylindrical containment vessel (CV) protected by a surrounding layer (an overpack) of confined Kaolite material. The Kaolite is about 5 inches thick at the top and about 4 inches around the side and bottom of the CV. The overpack apparently provides adequate protection to the CV, because the NCT and HAC test series conducted at ORNL showed no significant change in leak rate and breakaway bolt torque. In addition, the Y-12 analysis shows no significant change of the CV performance with a change of the Kaolite stiffness from the lower bound (LB) value to the upper bound (UB) value. The only possible weakness in the Kaolite defense is at the top corner of the overpack where the continuity of the Kaolite is broken by the steel inner liners of the Kaolite plug and container. However, the CV of TU-2 (ORNL Test Unit – 2) went through all CGOTC (CG Over Top Corner) drops and crush tests without showing a significant change in leak rate after the test. Thus, the Kaolite overpack appears to provide adequate protection to the CV.

The Y-12 drawings also suggest that the CV is properly designed. The CV has a circular cylindrical vessel body which is 0.156 inches thick, about 11.16 inches high, and 12.75 inches in outer diameter. The body is significantly thinner than the vessel bottom pan, domed lid, upper and lower bolted flanges, which have the thickness of 0.66 inches, 0.46 inches, 0.79 inches, and 0.7 inches, respectively. The significantly-thin-walled body should reduce the influence of the lower-vessel deformation on the bolted flanges. In addition, the interaction between the CV and the Test Weights probably occurs close to the circumference of the CV cavity. Thus, bending and prying of the bolted joint is not expected to be significant, and the bolted joint performance is mainly determined by the bolt preload and applied bolt axial force (impact). Assuming a Nut Factor of 0.2, the Y-12 specified bolt preload torque of 18 + or -1 ft-lb should produce a preload of 2,880 lb per bolt and a total of 46,080 lb for all 16 bolts of the CV. The ORNL tests showed that the preload is sufficient to keep the DPP-2 bolted joint a tight one after all the NCT and HAC tests.

Analysis

The Y-12 draft report DAC M801508-0003 000 00, Rev. 0, *DPP-2 Impact Analysis*, provides the following information about the analysis:

- The LS-DYNA explicit computer program is used. LS-DYNA is a popular internationally-known, cutting-edge computer program for impact and crash analyses. However, proceedings of past international user conferences have provided no published application to PV (pressure vessel) or CV closure bolt mechanical analysis.

- Meshes of the CV FE model, but not those of the Test Weights, are shown in the Y-12 draft report.

- The model comprises of (default) constant stress solid elements and Belytschko-Tsay shell elements. For a few trial cases, the solid elements representing the CV bolt shanks have been replaced with Hughes-Liu beam elements.

- All elements using reduced number of integration points are stabilized using hourglass control.

- The CV bolt preload is applied as initial stress and the CV pressure load is increased slowly from zero to the intended value as a quasi-static load prior to the impacts. LS-DYNA probably treats the application of the two static loads similarly by a dynamic relaxation process. However, as indicated in the theory manual, some static loads are relatively more sensitive to numerical noise in this process. In the Y-12 analysis, the shear force shows significantly greater noise than that of the preload tensile force. Thus the noisy shear force should be properly filtered.

- In the Y-12 analysis, the closure bolts are represented by elastic solid elements for both NCT and HAC impacts, but the CV and flanges are allowed to deform plastically during HAC. Following the rule of Regulatory Guide (RG) 7.6, NUREG/CR-6007 requires the CV to be fully elastic under all conditions. However, since a large safety margin appears to exist in the present HAC bolt analysis, the change from elastic-plastic to fully elastic CV may not make a difference.

- The Kaolite is modeled with three stiffness values: the Lower Bound (LB), the Nominal, and the Upper Bound (UB). The Y-12 analysis does not show significant change in the bolt results. This fact suggests that the Kaolite overpack probably provides adequate protection to the bolted CV joint.

- Similarly, the CV bolt tensile force from the Y-12 analysis indicates that the bolt preload is adequate. Only a few HAC impacts, and almost no NCT impact, produce a bolt axial stress exceeding the bolt pre-stress.

Compliance with NUREG/CR-6007 Acceptance Criteria

The Y-12 draft report DAC M801508-0003 000 00, Rev. 0, *DPP-2 Impact Analysis*, show the bolt stress results from the LS-DYNA analysis satisfy all the NUREG/CR-6007 criteria for average individual and combined tensile and shear bolt stresses under NCT impact conditions and HAC impact and puncture conditions. The only unsatisfied criteria is the combined tension, residual torsion, shear, and bending stress criteria, which is intended to prevent permanent deformation of the bolt shank under NCT conditions. However, the apparently sound DPP-2 bolted CV closure design give us hope that the remaining criteria will also be met. The following section recommends actions to attain this goal.

Recommendations

- Additional validations of the Y-12 bolt impact stress analysis methodology should continue. The Y-12 draft report currently describes four validations. The first three compare the Y-12 analysis models with corresponding ORNL test articles in the exterior appearance, in the dimensional change, and in the whole body accelerations. These comparisons should be expanded inwards, if possible, to include the CV bolt stresses and deformations. However, the fourth comparison with NUREG/CR-6007 should be eliminated, because the DPP-2 CV and the NUREG/CR-6007 example CV are not similar. In addition, the Y-12 description there indicates an inadequate understanding of bolt behavior and prying action.

- The practice of using beam elements to model a bolt should continue, because no post processing software will be needed. The good agreements obtained in the present project between the beam-element bolt model and solid-element bolt model may be due to the area-only-based post-processor of the solid-element results. The area-only processor essentially forces the solid-element bolt model to behave as a beam, which has constant axial and shear forces along the bolt length.

- The LS-DYNA bolt shear output for all solution times should be sampled and filtered using a low-pass filter at a cut-off frequency, which is low enough to eliminate most of the random oscillations in the shear stress time histories.

- In addition, the bolt shear force should be assumed to occur near the root or fixed end of each bolt so that the bolt shear force induces no bolt bending moment. This assumption is necessary and reasonable in view of the random nature of the bolt clearance and alignment between the bolt shank and the bolt hole. The effect of uncertain shear location is covered by the safety margin of the acceptance criteria. The current Y-12 LS-DYNA model for impact analysis somehow places the bolt shear at or near the bolt head and causes significant bending of the bolt. This bending due to the bolt shear should be excluded from the NUREG/CR-6007 bolt stress acceptance criteria. Without the shear bending, the entire bolt shank will be governed by the same acceptance criteria.

- In conclusion, the filtering of the bolt shear result and the elimination of the bolt bending due to shear will bring DPP-2 bolt stresses into full compliance with NUREG/CR-6007 bolt stress acceptance criteria.

Acknowledgements

B&W engineer, Lance Lowe wrote the initial statement of work (SOW) and the request for proposal (RFP) for the project. Another engineer, Drew Winder provided timely supply of computational results and supporting information. Gerry Mok of LLNL enjoys and appreciates their collaboration.