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REGULATORY TESTING OF A MODERN MEDICAL ISOTOPE TRANSPORTATION PACKAGE

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ABSTRACT

Changes in the regulations governing certification of radioactive materials transportation packages have resulted in a number of packages losing their certificates. This is prompting a new generation of transportation packages for a variety of radioactive materials. Energy*Solutions* was tasked by the Dutch company Tyco Mallinckrodt (now Covidien) with developing a new Type B transportation package for a medical isotope to be used for international shipment. The design and licensing of this package was the responsibility of Energy*Solutions* Spent Fuel Division, Inc, and fabrication of the package was performed by Manufacturing Sciences Corporation, both subsidiaries of Energy*Solutions*. Because of the reputation for the U.S. licensing process, Tyco Mallinckrodt chose to have the package certified in the United States by the U.S. Nuclear Regulatory Commission, and to obtain Certificates of Competent Authority from other nations as required. Due to tight schedule constraints and a desire to deploy the new, higher capacity isotope transportation cask, expedited completion of the certification was needed. One of these tasks was to perform regulatory testing (10CFR71.73) on a full-scale package. Testing included performance of 9m drop tests, a 1m puncture drop, and thermal testing to simulate fire conditions. This paper discusses the testing basis, experience and results and describes how the results compared to the pre-test predictions. A discussion of the applicability of this approach to other new package designs is also provided.

INTRODUCTION

In 2005, Tyco Mallinckrodt awarded a contract to Energy*Solutions* to design, license, fabricate, and deliver several MIDUS transportation packages; a new modern Type B(U) transportation package for international shipments of Molybdenum-99 (^{99}Mo), a medical isotope used for medical imaging procedures. The MIDUS transportation package was needed by Tyco Mallinckrodt to replace an older transportation package design whose certification would soon expire and would not be renewed by the certificate holder. The MIDUS transportation package needed to be designed, licensed, fabricated, and delivered on an accelerated schedule in order to maintain the constant supply of ^{99}Mo to the United States and abroad.

Design-by-analysis was identified as the quickest design and licensing approach for the MIDUS package because computer models could be used to quickly iterate to the final package design. In order to expedite the NRC technical review, confirmatory testing was performed to confirm the adequacy of analytical tools and methods used to predict the package response to the regulatory free drop and thermal tests. Unlike a design qualification testing program, the confirmatory testing program did not address all NCT and HAC tests and initial conditions for which the package was designed. Instead, a limited number of confirmatory tests were performed to demonstrate the adequacy of the analytical methods used for the safety analyses. All confirmatory testing was performed using full-scale test specimens of the MIDUS package.

Pre-test prediction calculations were prepared for each confirmatory test using the same analytical tools and methods employed in the safety analyses. The response of the package to each confirmatory test was recorded and compared to the calculated predictions to demonstrate the adequacy of the analytical methods used for the safety analyses. The results of the confirmatory tests agreed well with the calculated predictions, thus validating the analytical methods used for the safety analyses accurately predicted the package response.

PACKAGE DESIGN DESCRIPTION

A section view of the MIDUS transportation package, with component call-outs pertaining to the following discussion, is shown in Figure 1. The MIDUS package has an outside diameter of 520 mm, an overall height of 551 mm, and a total weight of 330 kg. The MIDUS package is designed to transport a liquid solution of ^{99}Mo and its daughter products having a maximum activity of 4,400 Ci. The liquid payload is stored in a stainless steel product bottle (1) that is placed and contained inside the cask cavity. The MIDUS package consists of a cask assembly and an overpack assembly. The cask assembly, which is a stainless steel vessel with depleted uranium alloy shields, provides radiation shielding and containment of the radioactive payload. It is comprised of a cask body (2), a shield plug (3), a closure lid (4) that is secured to the cask body using eight high strength alloy steel bolts (8) and O-ring seals, and a shield lid (5). The cask assembly is secured inside of a two-piece overpack assembly for transport. The overpack base assembly (6) and lid assembly (7) are constructed from stainless steel shells filled with closed-cell polyurethane foam. The overpack lid is secured to the overpack base by eight high strength alloy steel bolts (9). The overpack base and lid assemblies include integral lugs for package lifting and tie down. The overpack assembly provides impact protection of the cask for the regulatory free drop tests and thermal protection of the cask for the regulatory thermal tests.

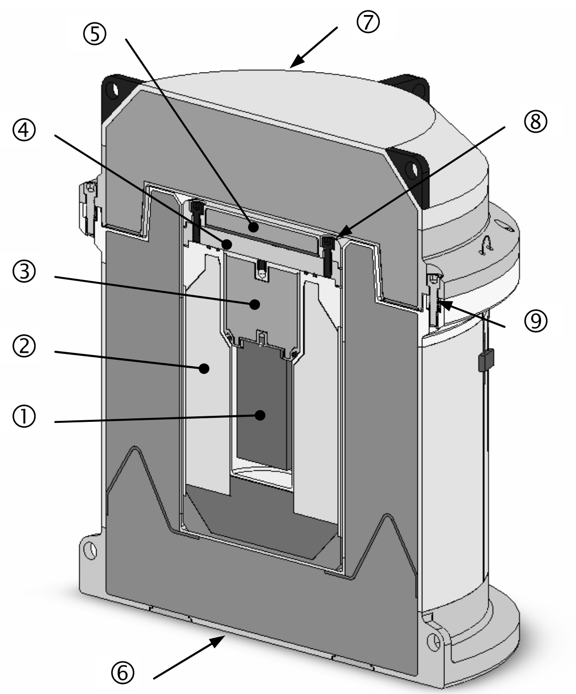


Figure 1 – MIDUS Package Cross-Section

TEST PROCEDURES

Energy*Solutions* conducted a total of seven different confirmatory tests. The first group of tests performed included four separate independent confirmatory drop tests, as illustrated in Figure 2; a 1.2m NCT bottom end free drop, a 9m HAC top end free drop, a 9m HAC top corner free drop, and a 1m HAC bottom end oblique puncture drop. Prior to each test, the test cask was assembled and containment system was leak tested to establish the initial condition of the package. The package was suspended in the required orientation and lifted to the specified height above the impact target. A functional verification of the required package instrumentation was performed, the data acquisition system was activated, and the package was released to free-fall onto the target. After each drop test, a leak test of the cask containment system was performed and post-test measurements were taken to determine the extent of damage to the package.

A second group of test was also performed that included a 9m HAC side drop, a 1m HAC oblique side puncture drop, and a 30-minute HAC thermal test, as illustrated in Figure 2. This group of tests was performed using a single test specimen for the entire test sequence, in accordance with the requirements of 10CFR71.73(c) [2]. The package was not disassembled during the test sequence for inspection and measurement of the package interior surfaces since cumulative damage was of primary interest and removing the overpack lid mid-sequence would have disturbed the package and possibly invalidated subsequent tests in the sequence. Dimensional inspections were performed before and after the test sequence to determine the cumulative package damage that resulted from the test sequence. In addition, a leak-test of the package containment system was performed before and after the test sequence to confirm the integrity of the cask containment o-ring seal. Accelerometers were used to record the cask acceleration time-history response to the 9m side drop test and thermocouples and temperature-indicating strips were used to record the cask temperatures during the thermal test.

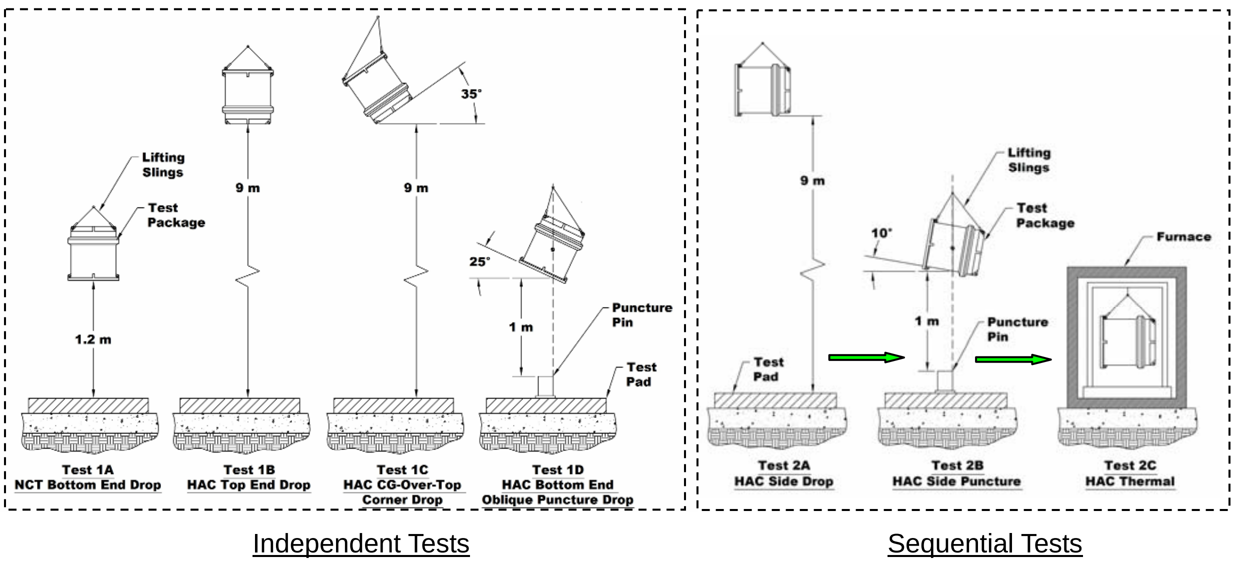


Figure 2 - Confirmatory Tests Performed

TEST FACILITIES

All confirmatory testing of the MIDUS package was performed at the Southwest Research Institute (SwRI) facilities in San Antonio, Texas. Free drop tests were conducted at the SwRI drop test facility. The drop test facility is equipped with an "essentially unyielding" drop test pad and puncture bar, video cameras and photographic back drops, and all lifting, rigging, and calibrated measuring equipment required for performing the drop tests. The drop test pad consists of a 10' x 10' x 6' thick reinforced concrete pad embedded in firm soil and having a 1-inch thick steel plate anchored to its top horizontal surface.

The thermal test of the MIDUS package was performed at the SwRI Fire Technology Department's facility using advanced fire science analysis equipment and a state-of-the-art full-scale furnace. The furnace, which measures 12' wide, 15' long, and 6' deep, is equipped with 14 premixed air/natural gas burners located near the base of the walls. The burners are controlled by a variable ratio gas/air regulator. The furnace exhaust duct is located at the top of the furnace. The furnace temperature and pressure are monitored during the thermal tests using Inconel-sheathed type "K" thermocouples and a Serta pressure transducer. In addition, the furnace is equipped with a camera to record the thermal test.

TEST PACKAGE

All confirmatory testing of the MIDUS transportation package was performed using full-scale test specimens of the MIDUS package. Figure 3 shows a disassembled full-scale test article, including an overpack base, overpack lid, cask body, cask shield plug, cask closure lid, cask shield lid, and all associated sealing devices and fasteners. The test articles were identical to the MIDUS package design with only minor modifications to accommodate instrumentation and rigging required for the confirmatory tests.

Figure 3 - Full-Scale Test Package Components

Four miniature tri-axial accelerometers were mounted on the outer surface of the cask body test articles inside small recessed pockets. In addition, each overpack base test article was equipped with accelerometer cables passing through the side wall with inner and outer bulkhead terminators to facilitate connection of the cask accelerometers to the data acquisition system. The overpack base test article included a small pocket to accommodate the accelerometer cables and connectors in the assembled test article. The test package used for the HAC thermal test was also instrumented with several thermocouples and non-reversible temperature-indicating strips to measure the temperature time-history response of the package. The approximate locations of accelerometers, thermocouples, and temperature indicating strips on the test package are shown in Figure 4.

TEST RESULTS

The results of the confirmatory tests demonstrate that the analytical methods used to calculate the structural and thermal response of the package to the NCT and HAC tests provide accurate simulations. As shown in Figure 5, the magnitude, shape, and duration of the acceleration time-history response of the package predicted using the LS-DYNA finite element program [3] all agree well with the measured acceleration time-history response for all free drop tests. The calculated peak accelerations are all within ±20% of the measured peak accelerations, and generally bound the measured values. In addition, the damage prediction of the MIDUS overpack for each drop test was shown to agree well with the test results. As predicted, neither the 1m bottom oblique puncture drop test (1D) nor the 1m side puncture drop test (2B) resulted in a breach or tear the overpack outer shell. In addition, the amount of deformation of the overpack shell resulting from the puncture drops was bounded by

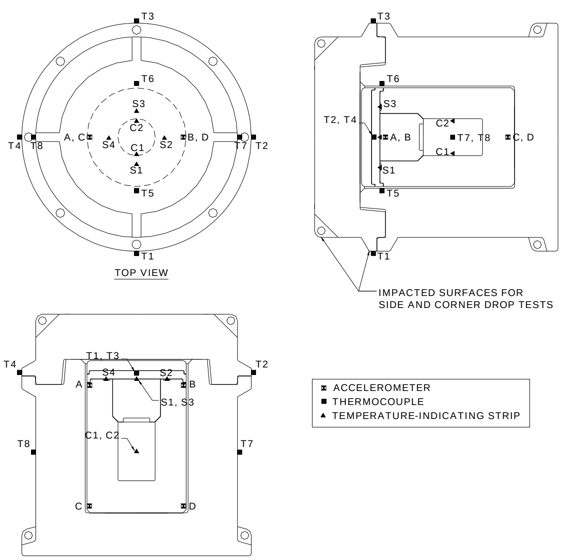


Figure 4 –Instrumentation Locations

the predictions. Figure 6 shows a comparison of the predicted and actual damage to the overpack for the 9m top corner drop test.

Test 1C was a 30-minute furnace test of the same package subjected to the HAC side drop test (2A) and HAC side puncture test (2B) to simulate the effects of the HAC thermal test required by 10CFR71.73(c)(4). The instrumented test package was moved into a furnace that was pre-heated to a temperature of 800°C. The package remained in the furnace for a period of 30 minutes after the furnace thermocouples recovered to a temperature of 800°C. Shortly after placing the package in the furnace, flame jets were observed at the overpack thermal relief ports, as expected. The flame jets continued to burn throughout the remainder of the 30-minute soak. After completion of the 30-minute soak time, the package was removed from the furnace and placed in an area where it was not exposed to artificial cooling and combustion of packaging materials was allowed to extinguish naturally. The test continued until the temperature reading of the inner-most thermocouples continuously decreased for a period of at least 2-hours.

A comparison of the predicted and measured thermal response of the package to the HAC thermal test at the key thermocouple locations is presented in Figure 8. As shown in the upper plot of Figure 8, the measured peak temperatures on the outer shell of the overpack (TC 7 and 8) were slightly higher than the predicted temperature due to extra heat from the furnace and combustion of the overpack foam. The measured temperature time-histories at the bottom (TC 5) and top (TC 6) of the overpack inner shell are shown in the lower plot of Figure 8, along with the corresponding predictions. While the temperature on the bottom of the overpack inner shell (TC 5) agreed well with the prediction, the temperature on the top of the overpack inner shell (TC 6) was higher than predicted. This resulted from the combustion of the foam material that extruded out of the overpack base assembly through both of its top-dead-center instrumentation cable bulkheads (see Figure 7). Since this was a local effect, it had no significant impact on the overall thermal response of the package during the HAC thermal test. After the HAC thermal test, the test cask passed the leak test. Examination of the containment O-ring showed no evidence of damage.

CONCLUSIONS

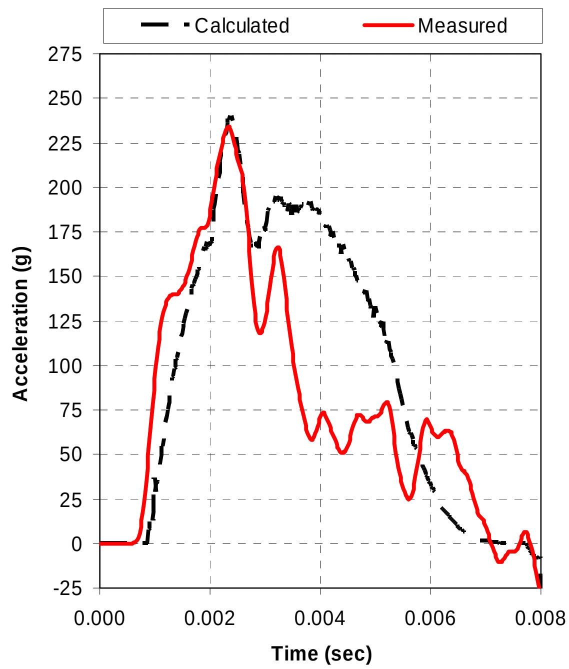
The results of the confirmatory tests demonstrate that the analytical methods used to predict the package response to the 10 CFR Part 71 NCT and HAC tests provide accurate results. The completion of the confirmatory testing program proved to be an important factor on the timely certification of the MIDUS package. The combination of design-by-analysis and confirmatory testing completed prior to, and included in the SAR submittal to NRC, proved to be the quickest approach to complete the design and licensing of the MIDUS package. Computer simulations minimized the time required to develop the MIDUS package design and confirmatory testing provided assurance that the computer simulations provided accurate results. Use of such an approach can be useful to minimize the design and licensing time for other new packages.

REFERENCES

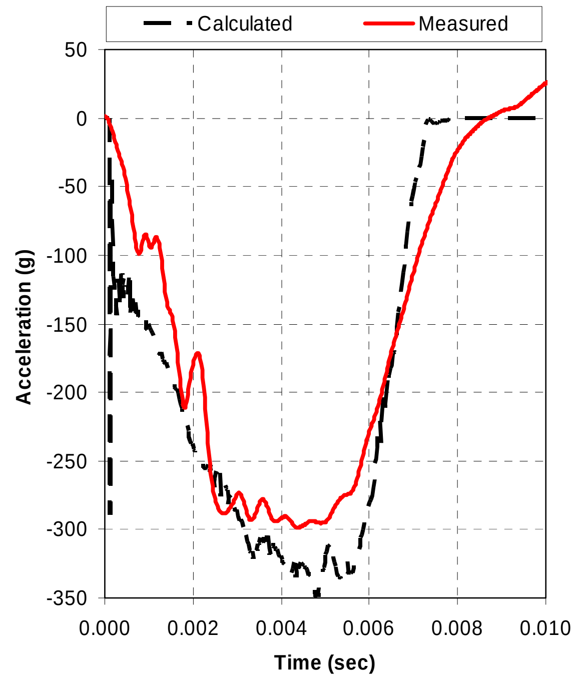
1. NUREG-1617, *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel*, U.S. Nuclear Regulatory Commission, March 2000.

2. Title 10, Code of Federal Regulations, Part 71, *Packaging and Transportation of Radioactive Material*, Nuclear Regulatory Commission, October 2004.

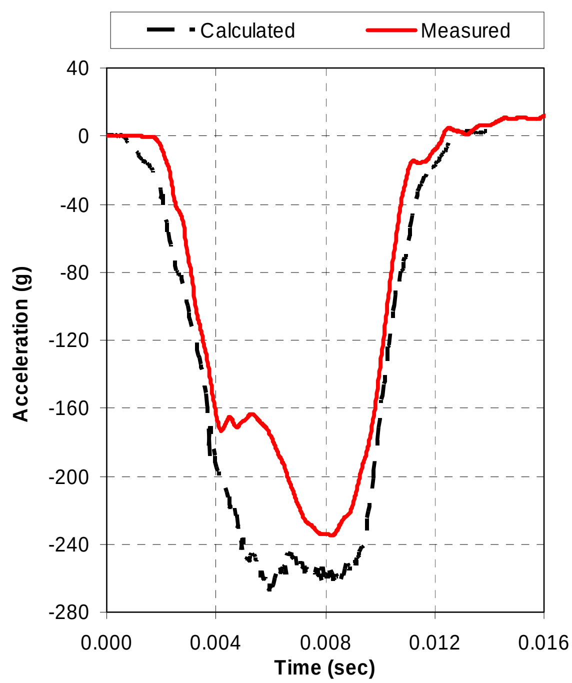
3. ANSYS LS-DYNA PC, Release 10.0, ANSYS Inc., Canonsburg, PA.



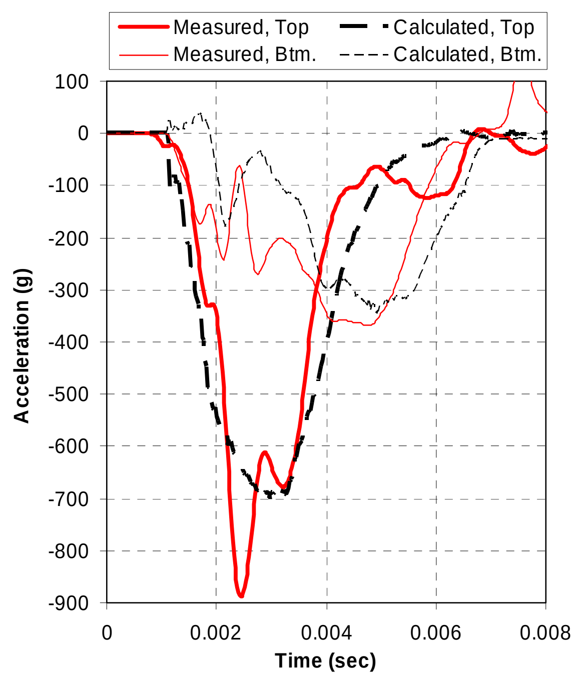
Test 1A – 1.2m Bottom End Drop
(Longitudinal)



Test 1B – 9m Top End Drop
(Longitudinal)

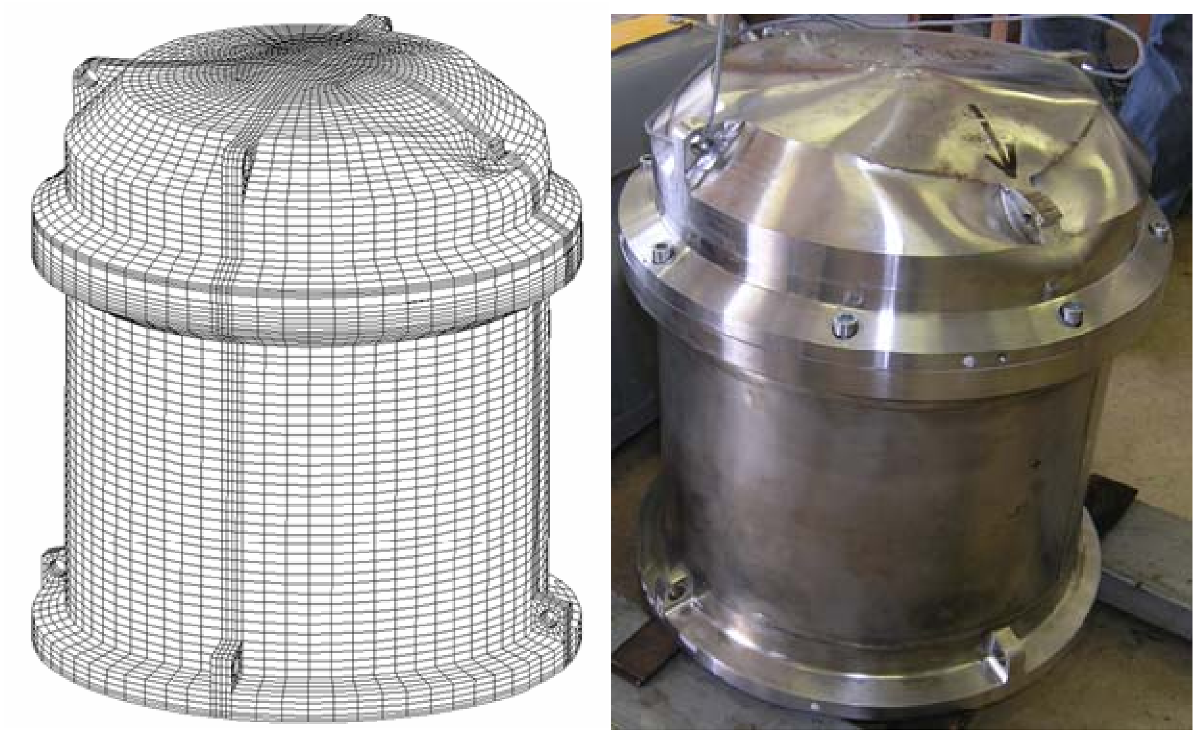


Test 1C – 9m Top Corner Drop
(Longitudinal)



Test 2A – 9m Side Drop
(Transverse)

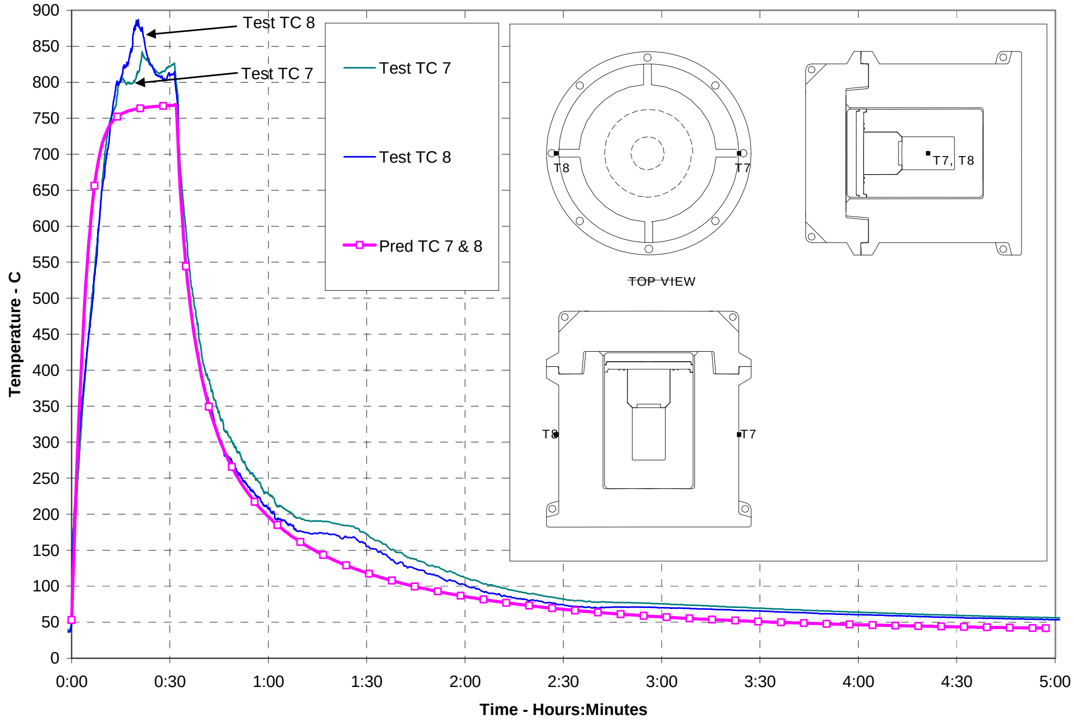
Figure 5 - Free Drop Test Acceleration Time-Histories



Predicted Test Result

Figure 6 - Overpack Deformation - HAC Top Corner Drop

Figure 7 - Package Condition After HAC Thermal Test



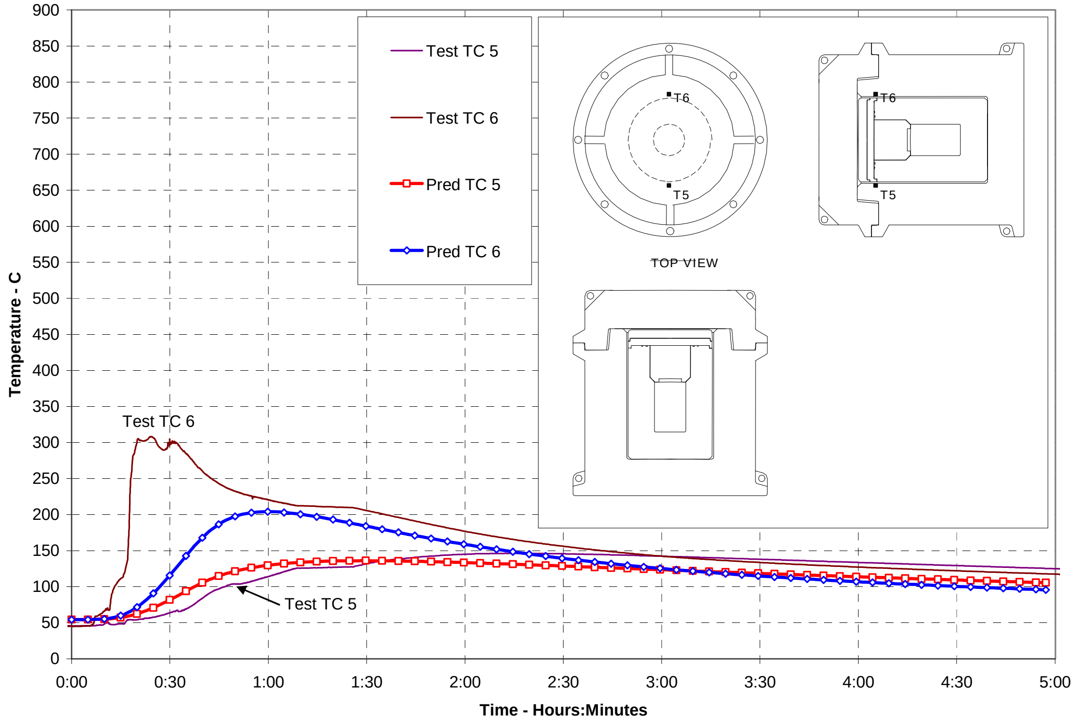


Figure 8 - HAC Thermal Test Temperature Time-History Results