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Material Qualification Program for Metamic-HT for Use in the HI-STAR 180 Fuel Basket

(USNRC Docket No. 71-9325)

A Presentation to the SFST

by
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Summary of June 27, 2008 Presentation

ESSENTIALS OF METAMIC-HT

- Metamic-HT consists of a metal matrix composite (MMC) of pure aluminum with its grain boundaries reinforced by dispersed nanoparticles of alumina and fine particles of boron carbide.
- Holtec utilizes Metamic-HT with a fixed B_4C concentration of 10% (nom.)
- Metals of Metamic-HT genré (i.e., uniformly distributed ceramic nanoparticles in aluminum MMC) have been known and studied for over 50 years. Metamic-HT is unique only in respect of the type of powder metallurgy process used to disperse the alumina spheroids in the aluminum matrix.

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Summary of June 27, 2008 Presentation

- Metamic-HT was selected as the structural material because of its considerable mechanical strength, including creep resistance in the operating temperature range of fuel baskets (ambient to 300°C), its excellent thermal conductivity, and the retention of its mechanical properties at low temperatures (-40°C) (in the manner of aluminum and aluminum alloys).
- Prior to the submittal of the HI-STAR 180 SAR, the properties of Metamic-HT were characterized by a controlled set of tests that were documented in a vendor report. In that report, the essential thermo-physical properties needed for the material to perform its safety function ("critical characteristics") were identified and quantified.
- Using the test data, the Minimum Guaranteed Values (MGVs) of all critical characteristics were defined.

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Summary of June 27, 2008 Presentation

Principal Characteristics of Metamic-HT
Required for Safety Evaluation

	Property	Symbol	Purpose
1.	Minimum Yield Strength	σ_y	To ensure adequate elastic strength for normal service conditions.
2.	Minimum Tensile Strength	σ_u	To ensure material integrity under accident conditions.
3.	Young's Modulus	Y	For input in structural analysis model
4.	Minimum elongation of δ_{max}, %	δ	To ensure adequate material ductility.
5.	Impact Resistance at ambient conditions	C_v	To ensure that Metamic-HT will not crack or break under impact.
6.	Maximum allowable creep rate	c	To prevent excessive deformation under steady state loading at elevated temperatures.
7.	Thermal conductivity (minimum averaged value in the range of ambient to max. service temperature, t_{max}	k	To ensure that the basket will conduct heat at the rate assumed in its thermal model.
8.	Minimum emissivity	ε	To ensure that the thermal calculations are performed conservatively.
9.	Specific Gravity	γ	To compute Weight of basket
10.	Thermal Expansion Coefficient	Γ	To compute the change in basket dimension due to temperature.

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Summary of June 27, 2008 Presentation

- On July 5, 2007, Holtec presented the data on the critical characteristics of Metamic-HT to SFST. SFST urged continued creep tests.
- The MGVs of the properties must be met in every lot of Metamic-HT for the lot to be acceptable. Any lot that has *a single* critical characteristic out of compliance will be rejected.

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Behavior of Metamic

Summary of the "HT's" Temperature State in HI-STAR 180†

Condition	Maximax Temperature, °C	
	Panel Closest to the Basket Centerline	Weld Line (At the basket periphery)
Normal condition of transport if transport occurred on the first day permitted by the CoC†	292	234
10CFR71 Fire Event †	332	275
Normal condition of storage** (on the first day of storage)	287	236

† Source: HI-STAR 180 SAR, Table 3.3.1

** HI-STAR 180 FSAR for action by the Swiss Regulatory Authority (HSK)

The maximum temperatures in the HI-STAR 180 fuel basket are quite modest and well below the material recrystallization temperature (530°C).

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Creep Tests (January 2007 to Now)

Coupons and their Parameters

Coupon	Condition	Temperature (ºC)	Stress (psi)	Creep Duration (hr)
E43807	Unirradiated	300	500	15956.6
E43808	Unirradiated	300	200	15972.9
E43809	Unirradiated	350	500	15971.0
E43810	Unirradiated	350	200	15968.7
E62545	Unirradiated	300	1000	14746.2
F60820	Irradiated	350	500	10374.2
F60821	Irradiated	400	500	10542.3

All coupons have been subjected to creep in excess of 10,000 hours, some in excess of 15,000 hrs.

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Creep Tests (continued)

- Creep tests on all 7 test coupons (five unirradiated and two coupons irradiated in the University of Maryland Reactor to simulate ≈ 56.1 years of exposure to fuel in HI-STAR 180) began in late 2006 and continue to this day. The histograms below compare the measured creep with the creep predicted by the Creep Equation, for some typical coupons.

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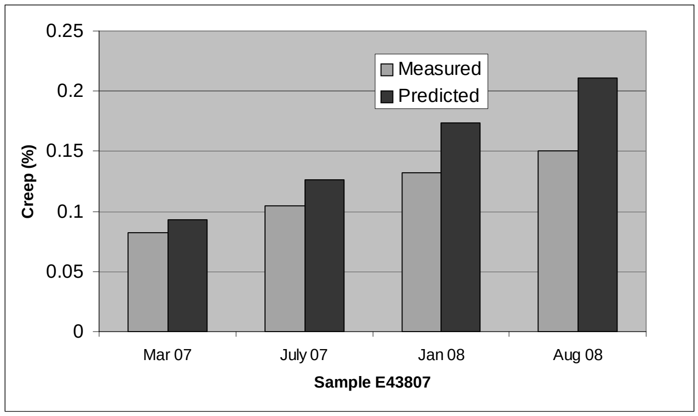
Creep Tests (continued)



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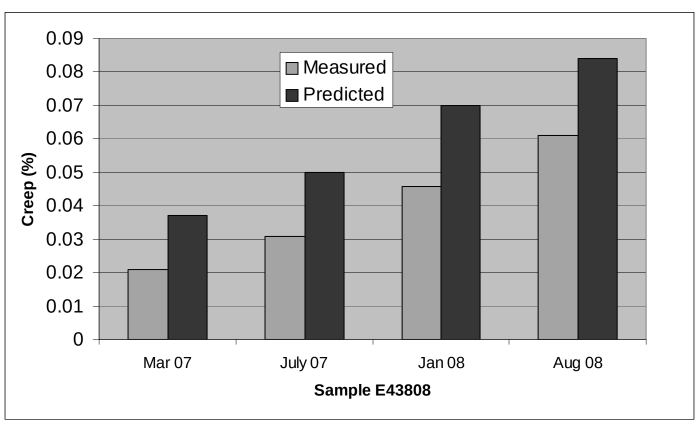
Creep Tests (continued)



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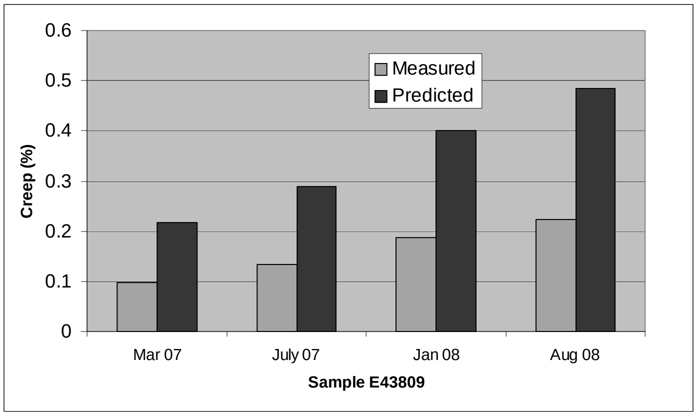
Creep Tests (continued)



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Creep Tests (continued)

- The test data confirm that the Creep Equation is uniformly conservative.
- Using the Creep Equation, the maximum strain in the basket panel after 5 years of continuous transport service (i.e., horizontal basket configuration) is computed to be 0.104%, which is about 25% of the Japanese limit of 0.4%.
- Calculation of projected creep in 60 years of transport in the horizontal configuration meets the Japanese limit of 0.4%.
- The latest creep data is documented in Holtec Report HI-2084122, “Qualification Tests on Metamic-HT for Structural Properties and Reactivity Control”, successor to the vendor’s Report No. HTA-0911.

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Creep Tests (continued)

- Report HI-2084122 also contains test data on corrosion resistance and post-irradiation neutron absorption capability.

Conclusion: Creep resistance of Metamic-HT has been proved. Discontinue creep tests.

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Test Plan

- After the June 27, 2008 meeting with SFST, Holtec launched a comprehensive test program to emulate an ASTM qualification of the material to acquire conclusive data to respond to the SFST's queries. Among the questions explored are:
  - Isotropy
  - Effect of low temperature on mechanical properties
  - Effect of irradiation on mechanical properties
  - Effect of a long-term thermal environment (say 300°C for the entire service life of the basket).

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Test Plan (continued)

- Coupons of Metamic-HT were manufactured in accordance with the *Metamic-HT Purchase Specification* and the *Metamic-HT Manufacturing Manual* (available for visual perusal in the meeting).
- The number of coupons for each property characterization was guided by applicable industry standards (MIL-STD105 and ASTM E105-04) and statistical analysis in accordance with ASTM E 122-07.
- Property measurements are performed on as-manufactured coupons as well as peer coupons that have been thermally conditioned at elevated temperature (“thermally aged coupons”) and additional coupons that have been thermally aged plus irradiated to an equivalent greater than 40 years of fluence in the HI-STAR 180 cask.
- The strength tests on all coupons are carried out in accordance with applicable ASTM Test Specifications.
- The tests on the as manufactured coupons serve as the benchmark property data. The tests on thermally aged and irradiated coupons provide the confirmation that the basket panels will not degrade under the concurrent effect of operating temperatures and exposure to neutron and gamma radiation.

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Test Plan (continued)

- Charpy impact tests on a sufficient population of coupons under cold (-40°C) condition to demonstrate that Metamic-HT maintains it’s fracture toughness characteristics.
- Tests on weld coupons are performed in accordance with the provisions of ASME Section IX to establish upperbound % strength reduction in the weld region.
- A special testing technique, ASTM E9-89a compression testing is deployed, to evaluate isotropy in the three principal directions, longitudinal, long transverse and short transverse directions.

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Test Plan (continued)

Procedure to Compute Minimum Property Values from Test Data

n = Number of coupons tested

σ: standard deviation in the measured data

M: mean value of measured data

In accordance with ASTM E122-07 the uncertainty, μ in the sample mean M is characterized by:

$$\mu = 3\sigma/\mathrm{SQRT}(n)$$

The minimum value of the property @95% confidence level, M_{95} is given by

$$M_{95} = M — \mu - 2\sigma$$

M_{95} must be greater than MGV of the property committed in the SAR

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Test Plan (continued)

Type of Coupons

i. As extruded Metamic-HT coupons
ii. Thermally aged Metamic-HT coupons
iii. Thermally aged and irradiated Metamic-HT coupons

The following tests are performed on each coupon to ascertain the principal characteristics of Metamic-HT:

a. Tensile Testing (Yield, Ultimate, Elongation and Young’s Modulus)
b. Isotropy Testing
c. Charpy Testing
d. Conductivity Measurement
e. Coefficient of Thermal Expansion Measurement

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Test Plan (continued)

ASTM Procedures Used for Mechanical and Thermal Property Measurement		
Item No.	Property	ASTM Procedure
1	Isotropy	E9-89a (Reapproved 2000)
2	Yield Strength	E8-04, E21-05
3	Elongation	E8-04, E21-05
4	Tensile Strength	E8-04, E21-05
5	Young's Modulus	E111-04, E1876-07
6	Impact Strength	E23-07
7	Coefficient of Thermal Expansion	E228-06
8	Thermal Conductivity	E1225-04

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Test Plan (continued)

Weld Coupon Testing

- The principal objective of weld coupon testing is to measure the percentage strength reduction in the weld zone. For this purpose coupons machined from welded Metamic-HT plates are subjected to thermal aging and irradiation and tensile properties measured. The test coupon layout is defined in the following pages.

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Test Plan (continued)

Minimum Number of Tensile Test Coupons			
Temperature (°C)	As Extruded	Thermally Aged	Aged and Irradiated
-40	12	12	12
20	12	12	12
200	12	12	12
300	12	12	12
350	12	12	12

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Test Plan (continued)

Isotropy Test Coupons	
Direction	Minimum Number of Coupons
Longitudinal	8
Long Transverse	8
Short Transverse	8
Notes: As-extruded Metamic-HT samples are tested for isotropy by measuring the room temperature (20°C) compressive yield strength and Young's Modulus in three principal directions.	

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Test Plan (continued)

Minimum Number of Charpy Test Coupons			
Temperature (°C)	As Extruded	Thermally Aged	Aged and Irradiated
-40	12	12	12
20	12	12	12
200	12	12	12
300	12	12	12
350	12	12	12

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Test Plan (continued)

Conductivity and Thermal Expansion Test Coupons		
Property	Minimum Number of Coupons	Test Temperatures
Conductivity	6	-40°C, 20°C, 200°C, 300°C, and 350°C
Coefficient of Thermal Expansion	6	-40°C, 20°C, 200°C, 300°C, and 350°C

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Test Plan (continued)

Weld Coupon Testing	
Condition	Minimum Number of Coupons
As Extruded	12
Thermally Aged	12
Irradiated	12
Note: Weld coupons are tested for percentage strength reduction by conducting room temperature (20°C) tensile tests.	

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Test Plan (continued

- Miscellaneous Testing
  - Microstructure
    - Metamic-HT and weld coupons microstructure examinations are included.
  - Micro-hardness
    - Metamic-HT and weld coupons micro-hardness measurements are included.
  - Weld Non-Isotropy
    - If parent material is determined to be isotropic, then, weld testing will not be required.

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Thermal Conditioning

- Accelerated testing is used to simulate thermal conditions of Metamic-HT under the upper bound operating temperature (300°C) for the service life of the basket.
- The Larson-Miller correlation* for aluminum is used to compute the required duration τ at temperature T corresponding to the service condition temperature T_o (=300°C) for an assumed service life τ_o of 40 years. The Larson-Miller formulation (1953) relates T, τ, T_o, and τ_o by the following equation:

  $T_o (20 + \log \tau_o) = T (20 + \log \tau)$

* Application of Time – Temperature - Stress Parameters to High Temperature Performance of Aluminum Alloys, J.G. Haufman et al., Minerals, Metals & Materials Society, 2007.

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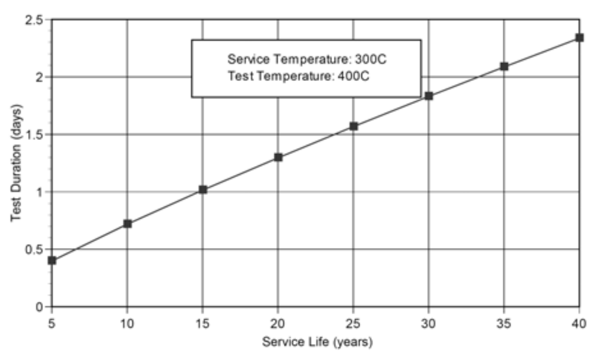
Thermal Conditioning (continued)



The test plan calls for thermal conditioning @400ºC for 14 days which equals 328 years of exposure @300ºC.

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Concluding Remarks

- The Comprehensive Test Plan being carried out by Holtec is intended to answer all queries raised by the SFST in June 2008.
- Early test results corroborate the veracity of MGV values used in the SAR based on the first test program (ca. 2005-2007).
- The tests are ongoing. SFST is welcome to inspect the Q.A. compliance of the test program.

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Concluding Remarks (continued)

We plan the revised Licensing submittal in October 2008

with the following supporting Metamic-HT documentation:

1. Metamic-HT Purchasing Specification
2. Metamic-HT Manufacturing Manual
3. Holtec Report HI-2084112 (successor to vendor's report on Metamic-HT tests)
4. A new Holtec report documenting the ongoing test program

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