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Pages 13 and 14 of the present calculation are in color.

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1. PURPOSE

In an attempt to predict the creep deformation of spent nuclear fuel cladding under the repository conditions, different correlations have been developed. One of them, which will be referred to as Murty's correlation in the following, and whose expression is given in Henningson (1998), was developed on the basis of experimental points related to unirradiated Zircaloy cladding (Henningson 1998, p. 56). The objective of this calculation is to adapt Murty's correlation to experimental points pertaining to irradiated Zircaloy cladding. The scope of the calculation is provided by the range of experimental parameters characterized by Zircaloy cladding temperature between 292°C and 420°C, hoop stress between 50 and 630 MPa, and test time extending to 8000 h. As for the burnup of the experimental samples, it ranges between 0.478 and 64 MWd/kgU (i.e., megawatt day per kilogram of uranium), but this is not a parameter of the adapted correlation.

This calculation is associated with engineering activity and has been developed in accordance with a technical work plan (CRWMS M&O 2000, main body of the document and pp. 23 to 26 of Addendum A), under Office of Civilian Radioactive Waste Management (OCRWM) procedure AP-3.12Q, Revision 0, ICN 3, *Calculations*.

2. METHOD

The correlation sought is heuristically developed as a power function of Murty's correlation, written in the following form:

$$\epsilon_{AM} = p \times \epsilon^m \quad (\text{Eq. 1})$$

where:

ϵ_{AM}	= creep strain of the adapted Murty's correlation (in percent)
ϵ	= creep strain calculated with Murty's correlation (in percent)
p	= unknown parameter
m	= unknown parameter

In order to facilitate the calculations, the base-10 logarithm is used, which yields the following equation:

$$\log(\epsilon_{AM}) = \log(p) + m \times \log(\epsilon) \quad (\text{Eq. 2})$$

Next, the values of $\log(p)$ and m that provide a fit of $\log(\epsilon_{AM})$ against the base-10 logarithm of the measured creep strains from a set of 223 experimental points are determined using the least-squares method.

As it will be shown in Section 6, though yielding a modified expression of Murty's correlation that adequately fits the experimental points, this method underestimates the creep strain in about 52 percent of the cases. That is why a greater value is used for $\log(p)$, so as to obtain more conservative results. The value used has been chosen so that the creep strain be overpredicted in about 75 percent of the cases, which is a reasonably conservative threshold.

In addition, the relative error, i.e., the absolute value of the difference between the calculated and measured creep strain divided by the measured creep strain: $\frac{|calculated - measured|}{measured}$, has been evaluated for each experimental point.

The control of the electronic management of data was accomplished in accordance with methods specified in the technical work plan (CRWMS M&O 2000, p. 30).

3. ASSUMPTIONS

- 3.1 It is assumed that the information listed in Table I-1 of Attachment I, whose main features are summarized in Section 5.1, adequately characterizes (for the purpose of this calculation) the cladding of the spent nuclear fuel that will be accepted for disposal in the repository. The rationale for this assumption is that the cladding characteristics were measured on cladding samples of actual spent nuclear fuel of various types currently in use or in storage at nuclear facilities, and that this information was generally produced under NRC-accepted or foreign-nuclear-agency-accepted nuclear quality assurance programs. This assumption is used in Section 5.1.
- 3.2 It is assumed that the uncertainty induced by reading values from plots (creep strain and time) is negligible. The rationale for this assumption is as follows. The scale of the figures from which experimental points have been read is such that the preponderant uncertainty is carried by the creep strain. It is possible to estimate the creep strain with a precision better than 0.02 percentage points, with creep strain generally ranging from 0.1 to 0.6 percent. This makes the uncertainty roughly bounded between $0.02/0.6 = 3$ percent and $0.02/0.1 = 20$ percent, which is an acceptable range. This assumption is used in Section 5.1.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE

No baselined software was used.

4.2 SOFTWARE ROUTINES

Microsoft Excel 97 SR (Software Release) -2 was used as a computational tool to perform the calculations. The formulas used in Microsoft Excel spreadsheets that invoke a combination of built-in functions linked together by user-defined operational instructions are considered routines per AP-SI.1Q, *Software Management*.

Documentation indicating that the software routines utilized provide correct results for the range of input parameters is given in Attachment II.

4.3 MODELS

None used.

5. CALCULATION

5.1 SET OF EXPERIMENTAL POINTS

The experiments were conducted on irradiated cladding specimens. They provide measured creep strain values along with temperature, hoop stress, burnup, and time. Though this information does not constitute qualified data, it is considered relevant to adequately represent the characteristics of the spent nuclear fuel that will be accepted for disposal in the repository (Assumption 3.1). The sources for that information are as follows:

- Kaspar et al. (1985): the test samples were from two different in-reactor creep test programs. The first concerned cladding samples preirradiated in the research reactor Geestnacht FRG-2. The fast neutron flux was around 3×10^{13} neutrons $\text{cm}^{-2} \text{s}^{-1}$, with irradiation periods of 540 or 1170 h (Kaspar et al. 1985, p. 52). This corresponds to an average fluence of $3 \times 10^{13} \times \frac{540 + 1170}{2} \times 3600 = 9.23 \times 10^{19}$ neutrons cm^{-2} . Based on the information given in Edsinger et al. (2000, p. 328), which shows that a fluence of 4.4×10^{25} neutrons m^{-2} roughly corresponds to a burnup of 22.8 GWd/tU (i.e., gigawatt day per metric ton of uranium), the average fluence of 9.23×10^{19} neutrons cm^{-2} is equivalent to a burnup of $9.23 \times 10^{19} \times 10^4 \times \frac{22.8}{4.4 \times 10^{25}} = 0.478 \text{ MWd/kgU}$. In addition, the hoop stress was 70 MPa (Kaspar et al. 1985, p. 52), and the temperature was 380°C for test times lower than 1000 h and 395°C for test times greater than 1000 h (Kaspar et al. 1985, p. 53). The measured creep strains at several time intervals were read from Figure 3 of Kaspar et al. (1985). The second creep test program involved preirradiated cladding samples from the Obrigheim power plant KWO. The fluence was between 5×10^{21} and 10^{22} neutrons cm^{-2} (Kaspar et al. 1985, p. 52). With the approach given above, this corresponds to a burnup which can roughly be estimated at: $\frac{5 \times 10^{21} + 10^{22}}{2} \times 10^4 \times \frac{22.8}{4.4 \times 10^{25}} = 38.9 \text{ MWd/kgU}$. In addition, the hoop stress was 50 MPa and the temperature was 350°C (Kaspar et al. 1985, p. 52). The measured creep strains at several time intervals were read from Figure 5 of Kaspar et al. (1985).
- Einziger and Kohli (1984): the test samples were from five rods irradiated in the Turkey Point pressurized water reactor. The burnups were 650 or 746 MWh/kgU (Einziger and Kohli 1984, p. 111), which corresponds to an average burnup of $(650 + 746)/(2 \times 24) = 29.1 \text{ MWd/kgU}$. The temperature, hoop stress, and measured creep strain at different time intervals were read from Table III of Einziger and Kohli (1984). It should be noted that the test sample for which a negative cladding creep was reported in Table III has not been taken into account in the present calculation.
- Chung et al. (1987): samples from two different commercial power reactors, Big Rock Point (boiling water reactor) and H.B. Robinson (pressurized water reactor), were examined. The information on temperature, hoop stress, burnup, and measured creep strain at different time intervals was gathered in Table 1 of Chung et al. (1987). It should be noted that two test

samples for which no creep strain was reported in Table 1 have not been taken into account in the present calculation.

- Bredel et al. (2000): the samples were from two similar rods irradiated for four cycles in a pressurized water reactor. The burnup was about 47200 MWd/tU (Bredel et al. 2000, p. 13), i.e., 47.2 MWd/kgU. The temperature, hoop stress, and measured creep strain at different time intervals were read from Figures 1 and 2 of Bredel et al. (2000, p. 14).
- Goll, Spilker and Toscano: the information related to the creep tests performed by these authors is to be published in the *Journal of Nuclear Materials*. A draft has been compiled in Macheret (2000, Attachment II). The test samples were prepared from two rods (designated as A and B) irradiated in a pressurized water reactor. The corresponding burnups were read from p. II-2 while the temperature, hoop stress, and measured creep strain at different time intervals were given in Figures 6 and 7 (Macheret 2000, pp. II-9 and II-10). It should be noted that the information related to the cladding samples designated as A_3a, A_1b, and B_3b has not been taken into account in the present calculation because the clamping of the samples used to conduct the experiments either failed or was unstable, which jeopardized the trustworthiness of the results. Besides, because the creep deformation of the sample designated as B_4a ranges between 4 and 6 percent, an average creep strain of 5 percent has been considered in the present calculation.

It is supposed that the uncertainty introduced by reading values from plots is negligible (Assumption 3.2).

The complete list of experimental points is given in Table I-1 of Attachment I. Table 1 summarizes the main features of this experimental set. A total of 223 experimental points is considered.

Table 1. Main Features of the Set of Experimental Points

Source	Number of Points	Burnup (MWd/kg U)	Temperature Range (°C)		Hoop Stress Range (MPa)		Time range (h)		Measured Creep Strain (percent)	
Kaspar et al./FRG-2	59	0.478	380	395	70		1000	8000	0.005	0.268
Kaspar et al./KWO	60	38.9	350		50		1000	8000	0.013	0.115
Einziger and Kohli	4	29.1	323		146	157	231	2101	0.004	0.157
Chung et al./Big Rock Point	4	22.4	325		337	514	1	207.6	0.4	1.1
Chung et al./H.B. Robinson	4	27.7	292	325	469	552	108.2	236.7	1.4	11.7
Bredel et al.	74	47.2	380	420	150	200	10	930	0.01	7
Goll et al./Rod A	9	54	300	370	320	620	30	189	1	7.4
Goll et al./Rod B	9	64	300	370	400	630	13	143	1.1	5

5.2 MURTY'S CORRELATION

Murty's correlation (Henningson 1998, p. 57) gives total creep strain ϵ as:

$$\epsilon = \left(\dot{\epsilon}_{gl}t + \frac{\kappa \epsilon_T \dot{\epsilon}_{gl}t}{\epsilon_T + \kappa \dot{\epsilon}_{gl}t} \right) + (\dot{\epsilon}_{cb}t) \quad (\text{Eq. 3})$$

where $\kappa = 10$ and $\epsilon_T = 0.008$. $\dot{\epsilon}_{gl}$ represents the glide creep rate, and $\dot{\epsilon}_{cb}$ represents the Coble creep rate. These rates are calculated as follows:

$$\dot{\epsilon}_{gl} = 4.97 \times 10^6 e^{-31200/T} \frac{E}{T} \left[\sinh \left(807 \frac{\sigma}{E} \right) \right]^3 \quad (\text{Eq. 4})$$

$$\dot{\epsilon}_{cb} = 8.83 e^{-21000/T} \frac{\sigma}{T} \quad (\text{Eq. 5})$$

where

T = temperature, in Kelvin (K)

E = Young's modulus, in Pa, calculated as $E = (1.148 \times 10^5 - 59.9 \times T) \times 10^6$

σ = hoop stress, in Pa

t = time, in hours

For each experimental point, the total creep strain calculated via Murty's correlation is given in Table I-2 of Attachment I. Results are expressed in percentage, which means that the total creep strain calculated with the above expression has been multiplied by a factor of 100.

5.2 DETERMINATION OF THE ADAPTED MURTY'S CORRELATION

Given an experimental point i among a set of n points, characterized by four parameters: temperature, hoop stress, time and measured creep strain, call $x_i = \log(\epsilon_i)$ where ϵ_i represents the creep strain from Murty's correlation expressed in percentage, calculated using the information on temperature, hoop stress, and time, and call $y_i = \log(\epsilon_{measured\ i})$ where $\epsilon_{measured\ i}$ is the associated measured creep strain, expressed in percentage. Then assume a linear relationship between y_i and x_i , such that for every experimental point i : $y_i = a + b \times x_i + e_i$ where a and b are unknown constants and e_i is called a residual. The least-squares method makes it possible to determine the values of a and b that minimize the sum of the squares of the residuals.

Walpole et al. (1998, p. 362) give the analytical formulas for a and b . Calling $\bar{x}$ and $\bar{y}$ the mean values of the set of x_i and y_i respectively, the following relations can be written:

$$b = \frac{\sum_{i=1}^n (x_i - \bar{x}) \times (y_i - \bar{y})}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (\text{Eq. 6})$$

and:

$$a = \bar{y} - b \times \bar{x} \quad (\text{Eq. 7})$$

Applying the calculated values of parameters a and b to the parameters of Equation 2, i.e., $\log(p)$ and m respectively, yields estimates of p and m that provide a least-squares fit of the adapted Murty's correlation against measured creep strains. With these parameters, Equation 1 giving the preliminary adapted Murty's correlation can be rewritten:

$$\varepsilon_{AM} = 10^a \times \varepsilon^b \quad (\text{Eq. 8})$$

Next, the value of 10^a has been modified so as to ensure that about 75 percent of the measured creep strains of the set of experimental points would be overestimated by the adapted Murty's correlation. This has been done using trial and error. Calling q that new parameter, the final adapted Murty's correlation can be written:

$$\varepsilon_{AM} = q \times \varepsilon^b \quad (\text{Eq. 9})$$

Finally, the relative error associated with each experimental point, i.e., the absolute value of the difference between the calculated and measured value divided by the measured value:

$\frac{|calculated - measured|}{measured}$, has been evaluated.

6. RESULTS

Parameters b and a determined by Equations 6 and 7 are equal to about 0.492 and -0.863 respectively. With these values, Equation 8 becomes: $\epsilon_{AM} = 10^{-0.863} \times \epsilon^{0.492}$, which yields:

$$\epsilon_{AM} = 0.137 \times \epsilon^{0.492} \quad (\text{Eq. 10})$$

Table I-2 of Attachment I shows the creep strains calculated by Equation 10. Comparing the calculated creep strains to the measured creep strains of the experimental set shows that measured creep strains are underestimated in about 52 percent of the cases.

Following a conservative approach, a trial-and-error method aimed at reaching a threshold of 75 percent of overestimated creep strains, by modifying the value of a , leads to the following expression for Equation 9:

$$\epsilon_{AM} = 0.232 \times \epsilon^{0.492} \quad (\text{Eq. 11})$$

The corresponding calculated creep strain as well as the relative error associated with each experimental point are given in Table I-1 of Attachment I.

Figure 1 shows the plots of measured creep strains (base-10 logarithm in ordinate), against the creep strains calculated using Murty's correlation (base-10 logarithm in abscissa). Two straight lines are added, which represent the least-squares fit (Equation 10) and the final adapted correlation (Equation 11). Figure 2 gives the plot of the measured creep strain (base-10 logarithm in ordinate), against the creep strain estimated by Equation 11, yielding the final adapted Murty's correlation (base-10 logarithm in abscissa). The straight line whose equation is $y = x$ separates the points whose calculated creep strain overestimates the measured creep strain (points located under the line) from those whose creep strain is underestimated by the adapted Murty's correlation.

Figure 1. Plot of Measured Creep Strain versus Murty's Creep Strain, along with Trendlines from Equations 10 and 11

Figure 2. Plot of Measured Creep Strain versus Calculated Creep Strain from Equation 11

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7.2 PROCEDURES

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8. ATTACHMENTS

Attachment I (15 pages) gives in Table I-1 the set of experimental points and the creep strains calculated using the adapted Murty's correlation (Equation 11), along with the associated relative error. In addition, Table I-2 shows for each experimental point the creep strains predicted by Murty's correlation, as well as the strains predicted by Equations 10 and 11.

Attachment II (seven pages) supplies the documentation that the software routines provide correct results for the range of input parameters.

**I. TABLES OF EXPERIMENTAL POINTS, CALCULATED CREEP STRAINS, AND
RELATIVE ERRORS**

Table I-1. Experimental Points and Calculated Creep Strains from the Adapted Murty's Correlation, along with the Associated Relative Errors

Experimental Point Number	Source ^a	Temperature (C)	Stress (MPa)	Burnup (MWd/kgU)	Time (h)	Measured Creep Strain (percent)	Creep Strain (percent) from the Adapted Murty's Correlation (Equation 11)	Relative Error
1	Kaspar et al./FRG-2	380	70	0.478	1000	0.011	1.45E-01	1.22E+01
2	Kaspar et al./FRG-2	380	70	0.478	1000	0.011	1.45E-01	1.22E+01
3	Kaspar et al./FRG-2	380	70	0.478	1000	0.026	1.45E-01	4.59E+00
4	Kaspar et al./FRG-2	380	70	0.478	1000	0.03	1.45E-01	3.84E+00
5	Kaspar et al./FRG-2	395	70	0.478	2000	0.005	2.29E-01	4.49E+01
6	Kaspar et al./FRG-2	395	70	0.478	2000	0.005	2.29E-01	4.49E+01
7	Kaspar et al./FRG-2	395	70	0.478	2000	0.01	2.29E-01	2.19E+01
8	Kaspar et al./FRG-2	395	70	0.478	2000	0.015	2.29E-01	1.43E+01
9	Kaspar et al./FRG-2	395	70	0.478	2000	0.02	2.29E-01	1.05E+01
10	Kaspar et al./FRG-2	395	70	0.478	2000	0.02	2.29E-01	1.05E+01
11	Kaspar et al./FRG-2	395	70	0.478	2000	0.026	2.29E-01	7.82E+00
12	Kaspar et al./FRG-2	395	70	0.478	2000	0.026	2.29E-01	7.82E+00
13	Kaspar et al./FRG-2	395	70	0.478	2000	0.03	2.29E-01	6.65E+00
14	Kaspar et al./FRG-2	395	70	0.478	2000	0.099	2.29E-01	1.32E+00
15	Kaspar et al./FRG-2	395	70	0.478	2000	0.149	2.29E-01	5.40E-01
16	Kaspar et al./FRG-2	395	70	0.478	3000	0.03	2.53E-01	5.32E+00
17	Kaspar et al./FRG-2	395	70	0.478	3000	0.052	2.53E-01	3.86E+00
18	Kaspar et al./FRG-2	395	70	0.478	3000	0.08	2.53E-01	2.16E+00
19	Kaspar et al./FRG-2	395	70	0.478	3000	0.085	2.53E-01	1.97E+00
20	Kaspar et al./FRG-2	395	70	0.478	3000	0.085	2.53E-01	1.97E+00
21	Kaspar et al./FRG-2	395	70	0.478	3000	0.103	2.53E-01	1.45E+00
22	Kaspar et al./FRG-2	395	70	0.478	3000	0.109	2.53E-01	1.32E+00
23	Kaspar et al./FRG-2	395	70	0.478	3000	0.109	2.53E-01	1.32E+00
24	Kaspar et al./FRG-2	395	70	0.478	3000	0.135	2.53E-01	8.72E-01
25	Kaspar et al./FRG-2	395	70	0.478	3000	0.14	2.53E-01	8.05E-01
26	Kaspar et al./FRG-2	395	70	0.478	3000	0.14	2.53E-01	8.05E-01

Experimental Point Number	Source ^a	Temperature (C)	Stress (MPa)	Burnup (MWd/kgU)	Time (h)	Measured Creep Strain (percent)	Creep Strain (percent) from the Adapted Murty's Correlation (Equation 11)	Relative Error
27	Kaspar et al./FRG-2	395	70	0.478	3000	0.159	2.53E-01	5.89E-01
28	Kaspar et al./FRG-2	395	70	0.478	4000	0.07	2.72E-01	2.88E+00
29	Kaspar et al./FRG-2	395	70	0.478	4000	0.109	2.72E-01	1.49E+00
30	Kaspar et al./FRG-2	395	70	0.478	4000	0.125	2.72E-01	1.18E+00
31	Kaspar et al./FRG-2	395	70	0.478	4000	0.13	2.72E-01	1.09E+00
32	Kaspar et al./FRG-2	395	70	0.478	4000	0.135	2.72E-01	1.01E+00
33	Kaspar et al./FRG-2	395	70	0.478	4000	0.143	2.72E-01	9.02E-01
34	Kaspar et al./FRG-2	395	70	0.478	4000	0.149	2.72E-01	8.25E-01
35	Kaspar et al./FRG-2	395	70	0.478	4000	0.149	2.72E-01	8.25E-01
36	Kaspar et al./FRG-2	395	70	0.478	4000	0.151	2.72E-01	8.01E-01
37	Kaspar et al./FRG-2	395	70	0.478	4000	0.161	2.72E-01	6.89E-01
38	Kaspar et al./FRG-2	395	70	0.478	4000	0.169	2.72E-01	6.09E-01
39	Kaspar et al./FRG-2	395	70	0.478	4000	0.18	2.72E-01	5.11E-01
40	Kaspar et al./FRG-2	395	70	0.478	6000	0.13	3.05E-01	1.34E+00
41	Kaspar et al./FRG-2	395	70	0.478	6000	0.142	3.05E-01	1.15E+00
42	Kaspar et al./FRG-2	395	70	0.478	6000	0.169	3.05E-01	8.04E-01
43	Kaspar et al./FRG-2	395	70	0.478	6000	0.179	3.05E-01	7.03E-01
44	Kaspar et al./FRG-2	395	70	0.478	6000	0.189	3.05E-01	6.13E-01
45	Kaspar et al./FRG-2	395	70	0.478	6000	0.202	3.05E-01	5.09E-01
46	Kaspar et al./FRG-2	395	70	0.478	6000	0.208	3.05E-01	4.65E-01
47	Kaspar et al./FRG-2	395	70	0.478	6000	0.212	3.05E-01	4.38E-01
48	Kaspar et al./FRG-2	395	70	0.478	6000	0.219	3.05E-01	3.92E-01
49	Kaspar et al./FRG-2	395	70	0.478	6000	0.219	3.05E-01	3.92E-01
50	Kaspar et al./FRG-2	395	70	0.478	6000	0.219	3.05E-01	3.92E-01
51	Kaspar et al./FRG-2	395	70	0.478	6000	0.241	3.05E-01	2.65E-01
52	Kaspar et al./FRG-2	395	70	0.478	8000	0.212	3.33E-01	5.73E-01
53	Kaspar et al./FRG-2	395	70	0.478	8000	0.24	3.33E-01	3.89E-01
54	Kaspar et al./FRG-2	395	70	0.478	8000	0.248	3.33E-01	3.44E-01
55	Kaspar et al./FRG-2	395	70	0.478	8000	0.252	3.33E-01	3.23E-01

Experimental Point Number	Source ^a	Temperature (C)	Stress (MPa)	Burnup (MWd/kgU)	Time (h)	Measured Creep Strain (percent)	Creep Strain (percent) from the Adapted Murty's Correlation (Equation 11)	Relative Error
56	Kaspar et al./FRG-2	395	70	0.478	8000	0.259	3.33E-01	2.87E-01
57	Kaspar et al./FRG-2	395	70	0.478	8000	0.259	3.33E-01	2.87E-01
58	Kaspar et al./FRG-2	395	70	0.478	8000	0.259	3.33E-01	2.87E-01
59	Kaspar et al./FRG-2	395	70	0.478	8000	0.268	3.33E-01	2.44E-01
60	Kaspar et al./KWO	350	50	38.9	1000	0.013	3.33E-02	1.56E+00
61	Kaspar et al./KWO	350	50	38.9	1000	0.015	3.33E-02	1.22E+00
62	Kaspar et al./KWO	350	50	38.9	1000	0.017	3.33E-02	9.58E-01
63	Kaspar et al./KWO	350	50	38.9	1000	0.029	3.33E-02	1.48E-01
64	Kaspar et al./KWO	350	50	38.9	1000	0.029	3.33E-02	1.48E-01
65	Kaspar et al./KWO	350	50	38.9	1000	0.031	3.33E-02	7.38E-02
66	Kaspar et al./KWO	350	50	38.9	1000	0.032	3.33E-02	4.02E-02
67	Kaspar et al./KWO	350	50	38.9	1000	0.034	3.33E-02	2.09E-02
68	Kaspar et al./KWO	350	50	38.9	1000	0.038	3.33E-02	1.24E-01
69	Kaspar et al./KWO	350	50	38.9	1000	0.042	3.33E-02	2.07E-01
70	Kaspar et al./KWO	350	50	38.9	1000	0.045	3.33E-02	2.60E-01
71	Kaspar et al./KWO	350	50	38.9	1000	0.05	3.33E-02	3.34E-01
72	Kaspar et al./KWO	350	50	38.9	2000	0.023	4.64E-02	1.02E+00
73	Kaspar et al./KWO	350	50	38.9	2000	0.033	4.64E-02	4.05E-01
74	Kaspar et al./KWO	350	50	38.9	2000	0.036	4.64E-02	2.88E-01
75	Kaspar et al./KWO	350	50	38.9	2000	0.038	4.64E-02	2.20E-01
76	Kaspar et al./KWO	350	50	38.9	2000	0.042	4.64E-02	1.04E-01
77	Kaspar et al./KWO	350	50	38.9	2000	0.046	4.64E-02	8.11E-03
78	Kaspar et al./KWO	350	50	38.9	2000	0.053	4.64E-02	1.25E-01
79	Kaspar et al./KWO	350	50	38.9	2000	0.053	4.64E-02	1.25E-01
80	Kaspar et al./KWO	350	50	38.9	2000	0.056	4.64E-02	1.72E-01
81	Kaspar et al./KWO	350	50	38.9	2000	0.058	4.64E-02	2.00E-01
82	Kaspar et al./KWO	350	50	38.9	2000	0.058	4.64E-02	2.00E-01
83	Kaspar et al./KWO	350	50	38.9	2000	0.061	4.64E-02	2.40E-01
84	Kaspar et al./KWO	350	50	38.9	3000	0.041	5.61E-02	3.68E-01

Experimental Point Number	Source ^a	Temperature (C)	Stress (MPa)	Burnup (MWd/kgU)	Time (h)	Measured Creep Strain (percent)	Creep Strain (percent) from the Adapted Murty's Correlation (Equation 11)	Relative Error
85	Kaspar et al./KWO	350	50	38.9	3000	0.041	5.61E-02	3.68E-01
86	Kaspar et al./KWO	350	50	38.9	3000	0.047	5.61E-02	1.93E-01
87	Kaspar et al./KWO	350	50	38.9	3000	0.055	5.61E-02	1.98E-02
88	Kaspar et al./KWO	350	50	38.9	3000	0.055	5.61E-02	1.98E-02
89	Kaspar et al./KWO	350	50	38.9	3000	0.057	5.61E-02	1.60E-02
90	Kaspar et al./KWO	350	50	38.9	3000	0.062	5.61E-02	9.54E-02
91	Kaspar et al./KWO	350	50	38.9	3000	0.063	5.61E-02	1.10E-01
92	Kaspar et al./KWO	350	50	38.9	3000	0.066	5.61E-02	1.50E-01
93	Kaspar et al./KWO	350	50	38.9	3000	0.072	5.61E-02	2.21E-01
94	Kaspar et al./KWO	350	50	38.9	3000	0.079	5.61E-02	2.90E-01
95	Kaspar et al./KWO	350	50	38.9	3000	0.084	5.61E-02	3.32E-01
96	Kaspar et al./KWO	350	50	38.9	5000	0.045	7.08E-02	5.74E-01
97	Kaspar et al./KWO	350	50	38.9	5000	0.053	7.08E-02	3.36E-01
98	Kaspar et al./KWO	350	50	38.9	5000	0.062	7.08E-02	1.42E-01
99	Kaspar et al./KWO	350	50	38.9	5000	0.072	7.08E-02	1.62E-02
100	Kaspar et al./KWO	350	50	38.9	5000	0.075	7.08E-02	5.56E-02
101	Kaspar et al./KWO	350	50	38.9	5000	0.075	7.08E-02	5.56E-02
102	Kaspar et al./KWO	350	50	38.9	5000	0.075	7.08E-02	5.56E-02
103	Kaspar et al./KWO	350	50	38.9	5000	0.075	7.08E-02	5.56E-02
104	Kaspar et al./KWO	350	50	38.9	5000	0.078	7.08E-02	9.19E-02
105	Kaspar et al./KWO	350	50	38.9	5000	0.084	7.08E-02	1.57E-01
106	Kaspar et al./KWO	350	50	38.9	5000	0.085	7.08E-02	1.67E-01
107	Kaspar et al./KWO	350	50	38.9	5000	0.097	7.08E-02	2.70E-01
108	Kaspar et al./KWO	350	50	38.9	8000	0.065	8.70E-02	3.39E-01
109	Kaspar et al./KWO	350	50	38.9	8000	0.074	8.70E-02	1.76E-01
110	Kaspar et al./KWO	350	50	38.9	8000	0.076	8.70E-02	1.45E-01
111	Kaspar et al./KWO	350	50	38.9	8000	0.076	8.70E-02	1.45E-01
112	Kaspar et al./KWO	350	50	38.9	8000	0.08	8.70E-02	8.77E-02
113	Kaspar et al./KWO	350	50	38.9	8000	0.084	8.70E-02	3.59E-02

Experimental Point Number	Source ^a	Temperature (C)	Stress (MPa)	Burnup (MWd/kgU)	Time (h)	Measured Creep Strain (percent)	Creep Strain (percent) from the Adapted Murty's Correlation (Equation 11)	Relative Error
114	Kaspar et al./KWO	350	50	38.9	8000	0.086	8.70E-02	1.18E-02
115	Kaspar et al./KWO	350	50	38.9	8000	0.094	8.70E-02	7.43E-02
116	Kaspar et al./KWO	350	50	38.9	8000	0.096	8.70E-02	9.36E-02
117	Kaspar et al./KWO	350	50	38.9	8000	0.1	8.70E-02	1.30E-01
118	Kaspar et al./KWO	350	50	38.9	8000	0.1	8.70E-02	1.30E-01
119	Kaspar et al./KWO	350	50	38.9	8000	0.115	8.70E-02	2.43E-01
120	Einziger and Kohli	323	150	29.1	1769	0.004	1.05E-01	2.54E+01
121	Einziger and Kohli	323	152	29.1	231	0.053	4.40E-02	1.71E-01
122	Einziger and Kohli	323	146	29.1	2101	0.157	1.07E-01	3.18E-01
123	Einziger and Kohli	323	157	29.1	1769	0.02	1.15E-01	4.77E+00
124	Chung et al./Big Rock Point	325	384	22.4	1	1.1	1.06E-01	9.04E-01
125	Chung et al./Big Rock Point	325	344	22.4	25.1	0.8	1.97E-01	7.54E-01
126	Chung et al./Big Rock Point	325	337	22.4	207.6	0.4	3.17E-01	2.07E-01
127	Chung et al./Big Rock Point	325	514	22.4	7.9	1	7.44E-01	2.56E-01
128	Chung et al./H.B. Robinson	292	552	27.7	113.2	11.7	9.16E-01	9.22E-01
129	Chung et al./H.B. Robinson	292	545	27.7	108.2	2.5	8.13E-01	6.75E-01
130	Chung et al./H.B. Robinson	292	498	27.7	218.5	1.4	5.93E-01	5.76E-01
131	Chung et al./H.B. Robinson	325	469	27.7	236.7	2.4	1.95E+00	1.89E-01
132	Bredel et al.	380	150	47.2	10	0.01	8.52E-02	7.52E+00
133	Bredel et al.	380	150	47.2	20	0.01	1.13E-01	1.03E+01
134	Bredel et al.	380	150	47.2	120	0.05	1.95E-01	2.90E+00
135	Bredel et al.	380	150	47.2	180	0.06	2.14E-01	2.57E+00
136	Bredel et al.	380	150	47.2	240	0.08	2.29E-01	1.86E+00
137	Bredel et al.	380	150	47.2	300	0.09	2.41E-01	1.68E+00
138	Bredel et al.	380	150	47.2	360	0.09	2.52E-01	1.80E+00

Experimental Point Number	Source ^a	Temperature (C)	Stress (MPa)	Burnup (MWd/kgU)	Time (h)	Measured Creep Strain (percent)	Creep Strain (percent) from the Adapted Murty's Correlation (Equation 11)	Relative Error
139	Bredel et al.	380	150	47.2	480	0.09	2.71E-01	2.01E+00
140	Bredel et al.	380	150	47.2	600	0.11	2.88E-01	1.62E+00
141	Bredel et al.	380	150	47.2	720	0.12	3.04E-01	1.53E+00
142	Bredel et al.	380	150	47.2	840	0.13	3.18E-01	1.45E+00
143	Bredel et al.	380	150	47.2	930	0.14	3.29E-01	1.35E+00
144	Bredel et al.	400	150	47.2	10	0.03	1.47E-01	3.91E+00
145	Bredel et al.	400	150	47.2	20	0.05	1.80E-01	2.59E+00
146	Bredel et al.	400	150	47.2	120	0.12	2.76E-01	1.30E+00
147	Bredel et al.	400	150	47.2	180	0.15	3.10E-01	1.07E+00
148	Bredel et al.	400	150	47.2	240	0.17	3.40E-01	9.98E-01
149	Bredel et al.	400	150	47.2	300	0.2	3.66E-01	8.32E-01
150	Bredel et al.	400	150	47.2	360	0.21	3.91E-01	8.62E-01
151	Bredel et al.	400	150	47.2	480	0.21	4.36E-01	1.08E+00
152	Bredel et al.	400	150	47.2	600	0.24	4.76E-01	9.84E-01
153	Bredel et al.	400	150	47.2	720	0.24	5.13E-01	1.14E+00
154	Bredel et al.	400	150	47.2	780	0.25	5.31E-01	1.12E+00
155	Bredel et al.	420	150	47.2	10	0.07	2.12E-01	2.02E+00
156	Bredel et al.	420	150	47.2	20	0.1	2.49E-01	1.49E+00
157	Bredel et al.	420	150	47.2	120	0.22	4.35E-01	9.75E-01
158	Bredel et al.	420	150	47.2	180	0.26	5.12E-01	9.67E-01
159	Bredel et al.	420	150	47.2	240	0.29	5.78E-01	9.93E-01
160	Bredel et al.	420	150	47.2	300	0.31	6.37E-01	1.06E+00
161	Bredel et al.	420	150	47.2	360	0.33	6.91E-01	1.09E+00
162	Bredel et al.	420	150	47.2	480	0.38	7.88E-01	1.07E+00
163	Bredel et al.	420	150	47.2	600	0.42	8.74E-01	1.08E+00
164	Bredel et al.	420	150	47.2	720	0.44	9.51E-01	1.16E+00
165	Bredel et al.	420	150	47.2	780	0.47	9.88E-01	1.10E+00
166	Bredel et al.	380	200	47.2	10	0.02	1.58E-01	6.89E+00
167	Bredel et al.	380	200	47.2	20	0.04	1.90E-01	3.75E+00

Experimental Point Number	Source ^a	Temperature (C)	Stress (MPa)	Burnup (MWd/kgU)	Time (h)	Measured Creep Strain (percent)	Creep Strain (percent) from the Adapted Murty's Correlation (Equation 11)	Relative Error
168	Bredel et al.	380	200	47.2	120	0.1	2.94E-01	1.94E+00
169	Bredel et al.	380	200	47.2	180	0.12	3.33E-01	1.77E+00
170	Bredel et al.	380	200	47.2	240	0.15	3.66E-01	1.44E+00
171	Bredel et al.	380	200	47.2	300	0.16	3.97E-01	1.48E+00
172	Bredel et al.	380	200	47.2	360	0.17	4.25E-01	1.50E+00
173	Bredel et al.	380	200	47.2	480	0.2	4.76E-01	1.38E+00
174	Bredel et al.	380	200	47.2	600	0.24	5.22E-01	1.18E+00
175	Bredel et al.	380	200	47.2	720	0.27	5.64E-01	1.09E+00
176	Bredel et al.	380	200	47.2	840	0.3	6.03E-01	1.01E+00
177	Bredel et al.	400	200	47.2	10	0.06	2.28E-01	2.80E+00
178	Bredel et al.	400	200	47.2	20	0.1	2.70E-01	1.70E+00
179	Bredel et al.	400	200	47.2	120	0.26	4.95E-01	9.03E-01
180	Bredel et al.	400	200	47.2	180	0.32	5.87E-01	8.36E-01
181	Bredel et al.	400	200	47.2	240	0.36	6.67E-01	8.52E-01
182	Bredel et al.	400	200	47.2	300	0.4	7.38E-01	8.44E-01
183	Bredel et al.	400	200	47.2	360	0.42	8.02E-01	9.09E-01
184	Bredel et al.	400	200	47.2	480	0.5	9.16E-01	8.33E-01
185	Bredel et al.	400	200	47.2	600	0.54	1.02E+00	8.85E-01
186	Bredel et al.	400	200	47.2	720	0.58	1.11E+00	9.13E-01
187	Bredel et al.	400	200	47.2	780	0.6	1.15E+00	9.21E-01
188	Bredel et al.	400	200	47.2	10	0.08	2.28E-01	1.85E+00
189	Bredel et al.	400	200	47.2	20	0.13	2.70E-01	1.07E+00
190	Bredel et al.	400	200	47.2	120	0.31	4.95E-01	5.96E-01
191	Bredel et al.	400	200	47.2	180	0.37	5.87E-01	5.88E-01
192	Bredel et al.	400	200	47.2	240	0.43	6.67E-01	5.51E-01
193	Bredel et al.	400	200	47.2	300	0.46	7.38E-01	6.03E-01
194	Bredel et al.	400	200	47.2	360	0.5	8.02E-01	6.03E-01
195	Bredel et al.	400	200	47.2	480	0.58	9.16E-01	5.80E-01
196	Bredel et al.	400	200	47.2	600	0.62	1.02E+00	6.42E-01

Experimental Point Number	Source ^a	Temperature (C)	Stress (MPa)	Burnup (MWd/kgU)	Time (h)	Measured Creep Strain (percent)	Creep Strain (percent) from the Adapted Murty's Correlation (Equation 11)	Relative Error
197	Bredel et al.	400	200	47.2	720	0.66	1.11E+00	6.81E-01
198	Bredel et al.	400	200	47.2	780	0.69	1.15E+00	6.71E-01
199	Bredel et al.	420	200	47.2	10	0.14	3.32E-01	1.37E+00
200	Bredel et al.	420	200	47.2	20	0.22	4.24E-01	9.26E-01
201	Bredel et al.	420	200	47.2	30	0.33	4.98E-01	5.09E-01
202	Bredel et al.	420	200	47.2	120	0.92	9.23E-01	3.11E-03
203	Bredel et al.	420	200	47.2	180	1.13	1.12E+00	1.09E-02
204	Bredel et al.	420	200	47.2	840	5.1	2.35E+00	5.38E-01
205	Bredel et al.	420	200	47.2	930	7	2.47E+00	6.46E-01
206	Goll et al./Rod A	300	620	54	44	1	2.34E+00	1.34E+00
207	Goll et al./Rod A	300	620	54	189	2.4	4.78E+00	9.92E-01
208	Goll et al./Rod A	300	620	54	69	3.5	2.92E+00	1.67E-01
209	Goll et al./Rod A	370	320	54	72	4.5	7.97E-01	8.23E-01
210	Goll et al./Rod A	370	430	54	30	7.4	2.81E+00	6.21E-01
211	Goll et al./Rod A	370	430	54	54	4.2	3.74E+00	1.09E-01
212	Goll et al./Rod A	370	400	54	129	6	3.60E+00	4.01E-01
213	Goll et al./Rod A	370	410	54	74	2.3	3.20E+00	3.91E-01
214	Goll et al./Rod A	370	410	54	67	4.5	3.05E+00	3.23E-01
215	Goll et al./Rod B	300	620	64	143	1.9	4.17E+00	1.19E+00
216	Goll et al./Rod B	300	620	64	143	1.1	4.17E+00	2.79E+00
217	Goll et al./Rod B	300	630	64	13	2.5	1.50E+00	4.01E-01
218	Goll et al./Rod B	370	400	64	100	2.5	3.17E+00	2.69E-01
219	Goll et al./Rod B	370	400	64	124	3.1	3.53E+00	1.38E-01
220	Goll et al./Rod B	370	420	64	111	4.1	4.56E+00	1.12E-01
221	Goll et al./Rod B	370	410	64	137	5	4.33E+00	1.34E-01
222	Goll et al./Rod B	370	400	64	88	5	2.98E+00	4.04E-01
223	Goll et al./Rod B	370	410	64	55	3	2.77E+00	7.79E-02

^a NOTE: See Section 5.1 for details on the sources for experimental points

Table I-2. Comparison of Measured and Calculated Creep Strains

Experimental Point Number	Measured Creep Strain (percent)	Creep Strain from Murty's Correlation (percent)	Creep Strain from Equation 10 (percent)	Creep Strain from the Adapted Murty's Correlation (Equation 11) (percent)
1	1.10E-02	3.86E-01	8.58E-02	1.45E-01
2	1.10E-02	3.86E-01	8.58E-02	1.45E-01
3	2.60E-02	3.86E-01	8.58E-02	1.45E-01
4	3.00E-02	3.86E-01	8.58E-02	1.45E-01
5	5.00E-03	9.78E-01	1.35E-01	2.29E-01
6	5.00E-03	9.78E-01	1.35E-01	2.29E-01
7	1.00E-02	9.78E-01	1.35E-01	2.29E-01
8	1.50E-02	9.78E-01	1.35E-01	2.29E-01
9	2.00E-02	9.78E-01	1.35E-01	2.29E-01
10	2.00E-02	9.78E-01	1.35E-01	2.29E-01
11	2.60E-02	9.78E-01	1.35E-01	2.29E-01
12	2.60E-02	9.78E-01	1.35E-01	2.29E-01
13	3.00E-02	9.78E-01	1.35E-01	2.29E-01
14	9.90E-02	9.78E-01	1.35E-01	2.29E-01
15	1.49E-01	9.78E-01	1.35E-01	2.29E-01
16	4.00E-02	1.19E+00	1.49E-01	2.53E-01
17	5.20E-02	1.19E+00	1.49E-01	2.53E-01
18	8.00E-02	1.19E+00	1.49E-01	2.53E-01
19	8.50E-02	1.19E+00	1.49E-01	2.53E-01
20	8.50E-02	1.19E+00	1.49E-01	2.53E-01
21	1.03E-01	1.19E+00	1.49E-01	2.53E-01
22	1.09E-01	1.19E+00	1.49E-01	2.53E-01
23	1.09E-01	1.19E+00	1.49E-01	2.53E-01
24	1.35E-01	1.19E+00	1.49E-01	2.53E-01
25	1.40E-01	1.19E+00	1.49E-01	2.53E-01
26	1.40E-01	1.19E+00	1.49E-01	2.53E-01
27	1.59E-01	1.19E+00	1.49E-01	2.53E-01
28	7.00E-02	1.38E+00	1.61E-01	2.72E-01
29	1.09E-01	1.38E+00	1.61E-01	2.72E-01
30	1.25E-01	1.38E+00	1.61E-01	2.72E-01
31	1.30E-01	1.38E+00	1.61E-01	2.72E-01
32	1.35E-01	1.38E+00	1.61E-01	2.72E-01
33	1.43E-01	1.38E+00	1.61E-01	2.72E-01
34	1.49E-01	1.38E+00	1.61E-01	2.72E-01
35	1.49E-01	1.38E+00	1.61E-01	2.72E-01
36	1.51E-01	1.38E+00	1.61E-01	2.72E-01
37	1.61E-01	1.38E+00	1.61E-01	2.72E-01
38	1.69E-01	1.38E+00	1.61E-01	2.72E-01
39	1.80E-01	1.38E+00	1.61E-01	2.72E-01
40	1.30E-01	1.74E+00	1.80E-01	3.05E-01
41	1.42E-01	1.74E+00	1.80E-01	3.05E-01

Experimental Point Number	Measured Creep Strain (percent)	Creep Strain from Murty's Correlation (percent)	Creep Strain from Equation 10 (percent)	Creep Strain from the Adapted Murty's Correlation (Equation 11) (percent)
42	1.69E-01	1.74E+00	1.80E-01	3.05E-01
43	1.79E-01	1.74E+00	1.80E-01	3.05E-01
44	1.89E-01	1.74E+00	1.80E-01	3.05E-01
45	2.02E-01	1.74E+00	1.80E-01	3.05E-01
46	2.08E-01	1.74E+00	1.80E-01	3.05E-01
47	2.12E-01	1.74E+00	1.80E-01	3.05E-01
48	2.19E-01	1.74E+00	1.80E-01	3.05E-01
49	2.19E-01	1.74E+00	1.80E-01	3.05E-01
50	2.19E-01	1.74E+00	1.80E-01	3.05E-01
51	2.41E-01	1.74E+00	1.80E-01	3.05E-01
52	2.12E-01	2.09E+00	1.97E-01	3.33E-01
53	2.40E-01	2.09E+00	1.97E-01	3.33E-01
54	2.48E-01	2.09E+00	1.97E-01	3.33E-01
55	2.52E-01	2.09E+00	1.97E-01	3.33E-01
56	2.59E-01	2.09E+00	1.97E-01	3.33E-01
57	2.59E-01	2.09E+00	1.97E-01	3.33E-01
58	2.59E-01	2.09E+00	1.97E-01	3.33E-01
59	2.68E-01	2.09E+00	1.97E-01	3.33E-01
60	1.30E-02	1.93E-02	1.97E-02	3.33E-02
61	1.50E-02	1.93E-02	1.97E-02	3.33E-02
62	1.70E-02	1.93E-02	1.97E-02	3.33E-02
63	2.90E-02	1.93E-02	1.97E-02	3.33E-02
64	2.90E-02	1.93E-02	1.97E-02	3.33E-02
65	3.10E-02	1.93E-02	1.97E-02	3.33E-02
66	3.20E-02	1.93E-02	1.97E-02	3.33E-02
67	3.40E-02	1.93E-02	1.97E-02	3.33E-02
68	3.80E-02	1.93E-02	1.97E-02	3.33E-02
69	4.20E-02	1.93E-02	1.97E-02	3.33E-02
70	4.50E-02	1.93E-02	1.97E-02	3.33E-02
71	5.00E-02	1.93E-02	1.97E-02	3.33E-02
72	2.30E-02	3.79E-02	2.74E-02	4.64E-02
73	3.30E-02	3.79E-02	2.74E-02	4.64E-02
74	3.60E-02	3.79E-02	2.74E-02	4.64E-02
75	3.80E-02	3.79E-02	2.74E-02	4.64E-02
76	4.20E-02	3.79E-02	2.74E-02	4.64E-02
77	4.60E-02	3.79E-02	2.74E-02	4.64E-02
78	5.30E-02	3.79E-02	2.74E-02	4.64E-02
79	5.30E-02	3.79E-02	2.74E-02	4.64E-02
80	5.60E-02	3.79E-02	2.74E-02	4.64E-02
81	5.80E-02	3.79E-02	2.74E-02	4.64E-02
82	5.80E-02	3.79E-02	2.74E-02	4.64E-02
83	6.10E-02	3.79E-02	2.74E-02	4.64E-02

Experimental Point Number	Measured Creep Strain (percent)	Creep Strain from Murty's Correlation (percent)	Creep Strain from Equation 10 (percent)	Creep Strain from the Adapted Murty's Correlation (Equation 11) (percent)
84	4.10E-02	5.58E-02	3.31E-02	5.61E-02
85	4.10E-02	5.58E-02	3.31E-02	5.61E-02
86	4.70E-02	5.58E-02	3.31E-02	5.61E-02
87	5.50E-02	5.58E-02	3.31E-02	5.61E-02
88	5.50E-02	5.58E-02	3.31E-02	5.61E-02
89	5.70E-02	5.58E-02	3.31E-02	5.61E-02
90	6.20E-02	5.58E-02	3.31E-02	5.61E-02
91	6.30E-02	5.58E-02	3.31E-02	5.61E-02
92	6.60E-02	5.58E-02	3.31E-02	5.61E-02
93	7.20E-02	5.58E-02	3.31E-02	5.61E-02
94	7.90E-02	5.58E-02	3.31E-02	5.61E-02
95	8.40E-02	5.58E-02	3.31E-02	5.61E-02
96	4.50E-02	8.97E-02	4.18E-02	7.08E-02
97	5.30E-02	8.97E-02	4.18E-02	7.08E-02
98	6.20E-02	8.97E-02	4.18E-02	7.08E-02
99	7.20E-02	8.97E-02	4.18E-02	7.08E-02
100	7.50E-02	8.97E-02	4.18E-02	7.08E-02
101	7.50E-02	8.97E-02	4.18E-02	7.08E-02
102	7.50E-02	8.97E-02	4.18E-02	7.08E-02
103	7.50E-02	8.97E-02	4.18E-02	7.08E-02
104	7.80E-02	8.97E-02	4.18E-02	7.08E-02
105	8.40E-02	8.97E-02	4.18E-02	7.08E-02
106	8.50E-02	8.97E-02	4.18E-02	7.08E-02
107	9.70E-02	8.97E-02	4.18E-02	7.08E-02
108	6.50E-02	1.36E-01	5.14E-02	8.70E-02
109	7.40E-02	1.36E-01	5.14E-02	8.70E-02
110	7.60E-02	1.36E-01	5.14E-02	8.70E-02
111	7.60E-02	1.36E-01	5.14E-02	8.70E-02
112	8.00E-02	1.36E-01	5.14E-02	8.70E-02
113	8.40E-02	1.36E-01	5.14E-02	8.70E-02
114	8.60E-02	1.36E-01	5.14E-02	8.70E-02
115	9.40E-02	1.36E-01	5.14E-02	8.70E-02
116	9.60E-02	1.36E-01	5.14E-02	8.70E-02
117	1.00E-01	1.36E-01	5.14E-02	8.70E-02
118	1.00E-01	1.36E-01	5.14E-02	8.70E-02
119	1.15E-01	1.36E-01	5.14E-02	8.70E-02
120	4.00E-03	2.01E-01	6.23E-02	1.05E-01
121	5.30E-02	3.40E-02	2.60E-02	4.40E-02
122	1.57E-01	2.07E-01	6.32E-02	1.07E-01
123	2.00E-02	2.42E-01	6.81E-02	1.15E-01
124	1.10E+00	2.04E-01	6.26E-02	1.06E-01
125	8.00E-01	7.16E-01	1.16E-01	1.97E-01

Experimental Point Number	Measured Creep Strain (percent)	Creep Strain from Murty's Correlation (percent)	Creep Strain from Equation 10 (percent)	Creep Strain from the Adapted Murty's Correlation (Equation 11) (percent)
126	4.00E-01	1.89E+00	1.87E-01	3.17E-01
127	1.00E+00	1.07E+01	4.40E-01	7.44E-01
128	1.17E+01	1.63E+01	5.41E-01	9.16E-01
129	2.50E+00	1.28E+01	4.80E-01	8.13E-01
130	1.40E+00	6.74E+00	3.50E-01	5.93E-01
131	2.40E+00	7.54E+01	1.15E+00	1.95E+00
132	1.00E-02	1.31E-01	5.03E-02	8.52E-02
133	1.00E-02	2.31E-01	6.67E-02	1.13E-01
134	5.00E-02	7.03E-01	1.15E-01	1.95E-01
135	6.00E-02	8.51E-01	1.27E-01	2.14E-01
136	8.00E-02	9.73E-01	1.35E-01	2.29E-01
137	9.00E-02	1.08E+00	1.42E-01	2.41E-01
138	9.00E-02	1.18E+00	1.49E-01	2.52E-01
139	9.00E-02	1.37E+00	1.60E-01	2.71E-01
140	1.10E-01	1.55E+00	1.70E-01	2.88E-01
141	1.20E-01	1.73E+00	1.79E-01	3.04E-01
142	1.30E-01	1.90E+00	1.88E-01	3.18E-01
143	1.40E-01	2.03E+00	1.94E-01	3.29E-01
144	3.00E-02	3.98E-01	8.70E-02	1.47E-01
145	5.00E-02	5.94E-01	1.06E-01	1.80E-01
146	1.20E-01	1.42E+00	1.63E-01	2.76E-01
147	1.50E-01	1.80E+00	1.83E-01	3.10E-01
148	1.70E-01	2.17E+00	2.01E-01	3.40E-01
149	2.00E-01	2.53E+00	2.16E-01	3.66E-01
150	2.10E-01	2.89E+00	2.31E-01	3.91E-01
151	2.10E-01	3.60E+00	2.57E-01	4.36E-01
152	2.40E-01	4.31E+00	2.81E-01	4.76E-01
153	2.40E-01	5.02E+00	3.03E-01	5.13E-01
154	2.50E-01	5.38E+00	3.13E-01	5.31E-01
155	7.00E-02	8.29E-01	1.25E-01	2.12E-01
156	1.00E-01	1.15E+00	1.47E-01	2.49E-01
157	2.20E-01	3.58E+00	2.57E-01	4.35E-01
158	2.60E-01	4.99E+00	3.02E-01	5.12E-01
159	2.90E-01	6.39E+00	3.41E-01	5.78E-01
160	3.10E-01	7.80E+00	3.76E-01	6.37E-01
161	3.30E-01	9.20E+00	4.08E-01	6.91E-01
162	3.80E-01	1.20E+01	4.65E-01	7.88E-01
163	4.20E-01	1.48E+01	5.16E-01	8.74E-01
164	4.40E-01	1.76E+01	5.62E-01	9.51E-01
165	4.70E-01	1.90E+01	5.83E-01	9.88E-01
166	2.00E-02	4.57E-01	9.32E-02	1.58E-01
167	4.00E-02	6.66E-01	1.12E-01	1.90E-01

Experimental Point Number	Measured Creep Strain (percent)	Creep Strain from Murty's Correlation (percent)	Creep Strain from Equation 10 (percent)	Creep Strain from the Adapted Murty's Correlation (Equation 11) (percent)
168	1.00E-01	1.62E+00	1.74E-01	2.94E-01
169	1.20E-01	2.08E+00	1.96E-01	3.33E-01
170	1.50E-01	2.53E+00	2.16E-01	3.66E-01
171	1.60E-01	2.98E+00	2.34E-01	3.97E-01
172	1.70E-01	3.43E+00	2.51E-01	4.25E-01
173	2.00E-01	4.32E+00	2.81E-01	4.76E-01
174	2.40E-01	5.20E+00	3.08E-01	5.22E-01
175	2.70E-01	6.09E+00	3.33E-01	5.64E-01
176	3.00E-01	6.98E+00	3.56E-01	6.03E-01
177	6.00E-02	9.65E-01	1.35E-01	2.28E-01
178	1.00E-01	1.36E+00	1.59E-01	2.70E-01
179	2.60E-01	4.66E+00	2.92E-01	4.95E-01
180	3.20E-01	6.61E+00	3.47E-01	5.87E-01
181	3.60E-01	8.55E+00	3.94E-01	6.67E-01
182	4.00E-01	1.05E+01	4.36E-01	7.38E-01
183	4.20E-01	1.24E+01	4.73E-01	8.02E-01
184	5.00E-01	1.63E+01	5.41E-01	9.16E-01
185	5.40E-01	2.02E+01	6.01E-01	1.02E+00
186	5.80E-01	2.41E+01	6.55E-01	1.11E+00
187	6.00E-01	2.60E+01	6.81E-01	1.15E+00
188	8.00E-02	9.65E-01	1.35E-01	2.28E-01
189	1.30E-01	1.36E+00	1.59E-01	2.70E-01
190	3.10E-01	4.66E+00	2.92E-01	4.95E-01
191	3.70E-01	6.61E+00	3.47E-01	5.87E-01
192	4.30E-01	8.55E+00	3.94E-01	6.67E-01
193	4.60E-01	1.05E+01	4.36E-01	7.38E-01
194	5.00E-01	1.24E+01	4.73E-01	8.02E-01
195	5.80E-01	1.63E+01	5.41E-01	9.16E-01
196	6.20E-01	2.02E+01	6.01E-01	1.02E+00
197	6.60E-01	2.41E+01	6.55E-01	1.11E+00
198	6.90E-01	2.60E+01	6.81E-01	1.15E+00
199	1.40E-01	2.07E+00	1.96E-01	3.32E-01
200	2.20E-01	3.40E+00	2.50E-01	4.24E-01
201	3.30E-01	4.72E+00	2.94E-01	4.98E-01
202	9.20E-01	1.65E+01	5.45E-01	9.23E-01
203	1.13E+00	2.44E+01	6.60E-01	1.12E+00
204	5.10E+00	1.11E+02	1.39E+00	2.35E+00
205	7.00E+00	1.23E+02	1.46E+00	2.47E+00
206	1.00E+00	1.10E+02	1.38E+00	2.34E+00
207	2.40E+00	4.69E+02	2.82E+00	4.78E+00
208	3.50E+00	1.72E+02	1.72E+00	2.92E+00
209	4.50E+00	1.23E+01	4.71E-01	7.97E-01

Experimental Point Number	Measured Creep Strain (percent)	Creep Strain from Murty's Correlation (percent)	Creep Strain from Equation 10 (percent)	Creep Strain from the Adapted Murty's Correlation (Equation 11) (percent)
210	7.40E+00	1.59E+02	1.66E+00	2.81E+00
211	4.20E+00	2.85E+02	2.21E+00	3.74E+00
212	6.00E+00	2.63E+02	2.12E+00	3.60E+00
213	2.30E+00	2.07E+02	1.89E+00	3.20E+00
214	4.50E+00	1.88E+02	1.80E+00	3.05E+00
215	1.90E+00	3.55E+02	2.46E+00	4.17E+00
216	1.10E+00	3.55E+02	2.46E+00	4.17E+00
217	2.50E+00	4.43E+01	8.84E-01	1.50E+00
218	2.50E+00	2.04E+02	1.87E+00	3.17E+00
219	3.10E+00	2.52E+02	2.08E+00	3.53E+00
220	4.10E+00	4.26E+02	2.69E+00	4.56E+00
221	5.00E+00	3.83E+02	2.56E+00	4.33E+00
222	5.00E+00	1.79E+02	1.76E+00	2.98E+00
223	3.00E+00	1.54E+02	1.63E+00	2.77E+00

II. DOCUMENTATION THAT THE SOFTWARE ROUTINES PROVIDE CORRECT RESULTS FOR THE RANGE OF INPUT PARAMETERS

The Excel formulas that invoke a combination of built-in functions are considered routines per AP-SI.1Q, *Software Management*. The purpose of this attachment is to verify that such Excel formulas provide correct results over the range of input parameters. The input parameters (such as temperature, hoop stress, and time) have been considered independently so that the calculations performed do not represent actual results. The formulas concerned are the following:

- Calculation of Young's modulus
- Calculation of glide creep rate (see Equation 4)
- Calculation of Coble creep rate (see Equation 5)
- Calculation of Murty's correlation (see Equation 3)
- Calculation of Equation 10
- Calculation of the adapted Murty's correlation (see Equation 11)
- Calculation of the relative error.

It should be noted that the other formulas of the present calculation, such as those giving the parameters of the least-squares method (see Equations 6 and 7) have been directly evaluated by a built-in function of Excel.

Calculation of Young's modulus E (in Pa) as a function of temperature T (in K)

Version of the software routine: None.

Equation: $E = (1.148 \times 10^5 - 59.9 \times T) \times 10^6$

Input range: Temperature T ranges from 565 K to 693 K.

Routine programmed in Excel spreadsheet: With a temperature (in K) in Cell G2, the programmed routine for calculating Young's modulus (in Pa) in Cell I2 is: $I2 = (114800 - 59.9 * G2) * 1000000$. In order to obtain the Young's modulus associated with the other parameter values, this formula has been pasted over the rest of Column I.

Computer generated results for the range of input parameters:

- For $T = 565$ K, Young's modulus calculated by Excel is 8.10×10^{10} Pa.
- For $T = 693$ K, Young's modulus calculated by Excel is 7.33×10^{10} Pa.

Comparison with independent calculation performed on a hand calculator: the results are identical. Consequently, the routine provides correct results over the range of input parameters considered.

Calculation of Murty's glide creep rate as a function of temperature (in K) and hoop stress (in MPa)

Version of the software routine: None.

Equation: see Equation 4. However, this equation uses hoop stress expressed in Pa, while this parameter is given in MPa in the Excel spreadsheet. To account for that, Murty's glide creep rate can be rewritten in an equivalent manner as follows:

$$\dot{\epsilon}_{gl} = 4.97 \times 10^6 \times e^{-31200/T} \frac{E}{T} \left[\sinh \left(807 \frac{\sigma \times 10^6}{E} \right) \right]^3$$

where T is the temperature in K, σ is the hoop stress in MPa, and E is Young's modulus in Pa.

It should be noted that, because Young's modulus is calculated as a function of temperature, it does not constitute an input parameter. The actual input parameters are temperature and hoop stress.

Input range: The temperature ranges from 565 K to 693 K, and the hoop stress ranges from 50 MPa to 630 MPa.

Routine programmed in Excel spreadsheet: With a temperature (in K) in Cell G2, a Young's modulus (in Pa) in Cell I2, a hoop stress (in MPa) in Cell C2, the programmed routine for calculating Murty's glide creep rate (in h^{-1}) in Cell J2 is:

$$J2 = 4970000 * \text{EXP}(-31200/G2) * I2/G2 * \text{POWER}(\text{SINH}(807 * C2 * 1000000/I2), 3)$$

In order to obtain Murty's glide creep rate associated with the other parameter values, this formula has been pasted over the rest of Column J.

Computer generated results for the range of input parameters:

- For a temperature of 565 K and a hoop stress of 50 MPa, Murty's glide creep rate calculated by Excel is: $1.04 \times 10^{-10} \text{ h}^{-1}$.
- For a temperature of 693 K and a hoop stress of 630 MPa, Murty's glide creep rate calculated by Excel is: $2.01 \times 10^3 \text{ h}^{-1}$.

Comparison with independent calculation performed on a hand calculator: the results are identical. Consequently, the routine provides correct results over the range of input parameters considered.

Calculation of Murty's Coble creep rate as a function of temperature (in K) and hoop stress (in MPa)

Version of the software routine: None.

Equation: see Equation 5. However, this equation uses hoop stress expressed in Pa, while this parameter is given in MPa in Excel spreadsheet. To account for hoop stress expressed in MPa, Murty's Coble creep rate can be rewritten in an equivalent manner as follows:

$$\dot{\epsilon}_{cb} = 8.83 e^{-21000/T} \frac{\sigma \times 10^6}{T}$$

where T is the temperature in K, and σ is the hoop stress in MPa.

Input range: The temperature ranges from 565 K to 693 K, and the hoop stress ranges from 50 MPa to 630 MPa.

Routine programmed in Excel spreadsheet: With a temperature (in K) in Cell G2, and a hoop stress (in MPa) in Cell C2, the programmed routine for calculating Murty's Coble creep rate (in h^{-1}) in Cell K2 is:

$$K2 = 8.83 * \text{EXP}(-21000/G2) * C2 * 1000000/G2$$

In order to obtain Murty's Coble creep associated with the other parameter values, this formula has been pasted over the rest of Column K.

Computer generated results for the range of input parameters:

- For a temperature of 565 K and a hoop stress of 50 MPa, Murty's Coble creep rate calculated by Excel is: $5.64 \times 10^{-11} \text{ h}^{-1}$.
- For a temperature of 693 K and a hoop stress of 630 MPa, Murty's Coble creep rate calculated by Excel is: $5.55 \times 10^{-7} \text{ h}^{-1}$.

Comparison with independent calculation performed on a hand calculator: the results are identical. Consequently, the routine provides correct results over the range of input parameters considered.

Calculation of Murty's total creep strain as a function of temperature (in K), hoop stress (in MPa), and time (in h)

Version of the software routine: None.

Equation: see Equation 3. It should be noted that Murty's total creep strain is calculated on the basis of Murty's glide creep rate, Murty's Coble creep rate, and time. Because Murty's glide creep rate and Coble creep rate are calculated as a function of temperature and hoop stress, the actual input parameters for Murty's total creep strain are temperature, hoop stress, and time.

Input range: The temperature ranges from 565 K to 693 K, the hoop stress ranges from 50 MPa to 630 MPa, and the time ranges from 1 h to 8000 h.

Routine programmed in Excel spreadsheet: With a time (in h) in Cell E2, Murty's glide creep rate (in h^{-1}) in Cell J2, Murty's Coble creep rate (in h^{-1}) in Cell K2, the programmed routine for calculating Murty's total creep strain (in percent) in Cell L2 is:

$$L2 = (J2 * E2 + 0.008 * 10 * J2 * E2 / (0.008 + 10 * J2 * E2) + K2 * E2) * 100$$

In order to obtain Murty's total creep strain associated with the other parameter values, this formula has been pasted over the rest of Column L.

Computer generated results for the range of input parameters:

- For a temperature of 565 K, a hoop stress of 50 MPa, and a time of 1 h, Murty's total creep strain calculated by Excel is: 1.20×10^{-7} percent.
- For a temperature of 693 K, a hoop stress of 630 MPa, and a time of 8000 h, Murty's total creep strain calculated by Excel is: 1.61×10^9 percent.

Comparison with independent calculation performed on a hand calculator: the results are identical. Consequently, the routine provides correct results over the range of input parameters considered.

Calculation of Equation 10 as a function of temperature (in K), hoop stress (in MPa), and time (in h)

Version of the software routine: None.

Equation: see Equation 10. It should be noted that this equation which invokes Murty's creep strain, is essentially function of temperature, hoop stress, and time.

Input range: The temperature ranges from 565 K to 693 K, the hoop stress ranges from 50 MPa to 630 MPa, and the time ranges from 1 h to 8000 h.

Routine programmed in Excel spreadsheet: With Murty's total creep strain (in percent) in Cell L2, the programmed routine for calculating the value of Equation 10 in Cell P2 is:

$$P2 = \text{POWER}(L2, 0.492) * 0.137$$

In order to obtain the creep strain associated with the other parameter values, this formula has been pasted over the rest of Column P.

Computer generated results for the range of input parameters:

- For a temperature of 565 K, a hoop stress of 50 MPa, and a time of 1 h, Equation 10 yields: 5.39×10^{-5} percent.

- For a temperature of 693 K, a hoop stress of 630 MPa, and a time of 8000 h, Equation 10 yields: 4.64×10^3 percent.

Comparison with independent calculation performed on a hand calculator: the results are identical. Consequently, the routine provides correct results over the range of input parameters considered.

Calculation of the adapted Murty's correlation (see Equation 11) as a function of temperature (in K), hoop stress (in MPa), and time (in h)

Version of the software routine: None.

Equation: see Equation 11. It should be noted that this equation which invokes Murty's creep strain, is essentially function of temperature, hoop stress, and time.

Input range: The temperature ranges from 565 K to 693 K, the hoop stress ranges from 50 MPa to 630 MPa, and the time ranges from 1 h to 8000 h.

Routine programmed in Excel spreadsheet: With Murty's total creep strain (in percent) in Cell L2, the programmed routine for calculating the value of Equation 11 in Cell S2 is:

$$S2 = \text{POWER}(L2, 0.492) * 0.232$$

In order to obtain the creep strain associated with the other parameter values, this formula has been pasted over the rest of Column S.

Computer generated results for the range of input parameters:

- For a temperature of 565 K, a hoop stress of 50 MPa, and a time of 1 h, Equation 11 yields: 9.13×10^{-5} percent.
- For a temperature of 693 K, a hoop stress of 630 MPa, and a time of 8000 h, Equation 11 yields: 7.85×10^3 percent.

Comparison with independent calculation performed on a hand calculator: the results are identical. Consequently, the routine provides correct results over the range of input parameters considered.

Calculation of the relative error associated with the adapted Murty's correlation as a function of temperature (in K), hoop stress (in MPa), time (in h), and measured creep strain (in percent)

Version of the software routine: None.

Equation: $\frac{|\text{calculated strain} - \text{measured strain}|}{\text{measured strain}}$. It should be noted that this equation which invokes the adapted Murty's creep strain and the measured creep strain, is essentially function of temperature, hoop stress, time, and the measured creep strain.

Input range: Because the calculated strain is to reflect an actual measured strain, two experimental points representative of the range of input parameters have been selected to perform the verification: the first one (Number 120 in Table I-1) is characterized by a temperature of 596 K, a hoop stress of 150 MPa, a measured creep strain of 0.004 percent at a time of 1769 h; the second one (Number 128 in Table I-1) is characterized by a temperature of 565 K, a hoop stress of 552 MPa, a measured creep strain of 11.7 percent at a time of 113.2 h.

Routine programmed in Excel spreadsheet: With adapted Murty's total creep strain (in percent) in Cell S2, and the measured creep strain in Cell F2 (in percent), the programmed routine for calculating the relative error in Cell V2 is:

$$V2 = \text{ABS}(S2-F2)/F2$$

In order to obtain the creep strain associated with the other parameter values, this formula has been pasted over the rest of Column S.

Computer generated results for the range of input parameters:

- For the first selected point, the relative error is calculated as 25.4.
- For the second selected point, the relative error is calculated as 0.92.

Comparison with independent calculation performed on a hand calculator: the results are identical. Consequently, the routine provides correct results over the range of input parameters considered.