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기술보고서

# Computer Program of SIE ASME-NH Code

# ( Revision 1 )

## For Structural Integrity Evaluation of Next Generation Reactors Subjecting to Elevated Temperature Operations

**(SIE ASME-NH Code)**
A Computerized Implementation of
ASME Boiler and Pressure Vessel Code
Section III, Division 1-Subsection NH
Class 1 Components in Elevated Temperature Service
2004 Edition

# 제 출 문

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본 보고서를 "차세대 원자로 고온구조건전성 평가를 위한 SIE ASME-NH (Revision 1) 전산코드 개발,"에 대한 기술보고서로 제출합니다.

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# 요약문

본 보고서에서는 500°C 이상의 고온과 30 년 이상의 설계운전 수명을 목표로 하는 차세대 원자로 설계개발에 필수적인 고온 구조건전성 평가를 효율적이고 정확히 수행하기 위해 복잡한 ASME Code Section III, Subsection NH 의 적용 규정을 컴퓨터를 활용하여 수행할 수 있는 SIE ASME-NH (Structural Integrity Evaluations by ASME-NH) (Revision 1.0) 전산프로그램을 개발하고 이에 대한 사용자 설명서 및 예제들을 기술하였다.

# ABSTRACT

In this report, the SIE ASME (Structural Integrity Evaluations by ASME-NH) (Revision 1.0), which has a computerized implementation of ASME Pressure Vessels and Piping Code Section III Subsection NH rules, is developed to apply to the next generation reactor design subjecting to the elevated temperature operations over 500$^{o}$C and over 30 years design lifetime, and the user's manual for this program is described in detail.

# Contents of Revision

- □ **MAT-DB** 주 모듈 추가
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- □ ***SIE, *MATDB, *DB-TYPE** 명령어 추가
- □ 재료 **DB** 확장기능 **(60** 년 설계 **EXTRAPOLATION)**
- □ **“MAT-SRV-TIME-WELD”** 알고리즘 개선 **: “MAT-SRF” DB** 입력 배제
- □ 입력모듈**(INPUT-DATA)** 명령어 입력에러 메시지 기능추가
- □ 재료 **DB** 개선 **(Isochronous Curves for 316SS and 9Cr-1Mo-V Steel)**
- □ **MAT-SMT-WELD** 데이타베이스 추가
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- □ **Simplified Inelastic Strain Limits Rules of Test No. A-3** 적용성 검토
- □ **Add Application Temp Limits for Inelastic Strain Limits Rules of Test No. No. A-2**
- □ **Upgrade Load History Concept for a Simplified Inelastic Strain Limits Rules (*LOADHISTORY** 명령어 사용**)**
- □ **Revision of Safety Factors for Creep Damage Evaluations**
- □ **Total strain** 입력 값에 대한 크립평가 기능 추가
- □ 예제문제 개정 및 추가

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# 1. Introduction and Overview

In most LMR(Liquid Metal Reactor) design, the operating temperature is very high over 500°C and the design lifetime is much more than 30 years. Therefore, the time-dependent creep rupture, excessive creep deformation, cyclic creep ratcheting, creep-fatigue, creep crack growth and creep buckling become very important in reactor structural design. Unlike with conventional PWR, the normal operating conditions can be basically dominant design loading because the hold time at elevated temperature condition is enough long to result in severe creep damage during total service lifetime. For the purpose of the high temperature structural integrity evaluation in design of nuclear power plants, the worldwide design codes and assessment procedures such as ASME-NH(USA), RCC-MR(France), R5(UK), and DDS(Japan) are developed or under development status.

This report provides the user guidance for a high temperature structural integrity evaluation computer program(SIE ASME-NH Code), which has a computerized implementation of ASME Pressure Vessels and Piping Code Section III Subsection NH rules, for the time-dependent primary stress limits, total accumulated inelastic strain limits, and the creep-fatigue damage evaluations in structural mechanical design of nuclear power plants operating with high temperatures over creep temperature zone at normal operating conditions for both base metal and weldment. Actually it is very complicate to completely apply the ASME-NH design rules by hand calculation step by step to evaluate the high temperature structural integrity using the results of elastic analysis, especially when there are multi-transient cycle types for whole design lifetime. As an example for the creep ratcheting limit evaluations using simplified inelastic analysis rules the creep ratcheting strain should be calculated for each temperature-time block through the entire service life time. To do this the isochronous stress and strain curves entering at the initial strain accumulated throughout the prior load history have to be regenerated by appropriate curve fitting method corresponding to the time block period and temperature. SIE ASME-NH Code can provide the design by analysis tools to carry out the high-temperature structural integrity evaluation for the design of the next generation nuclear power plant.

This program is developed as modular type therefore it is very easy to expand and include another ASME Code rules. Especially the additional material database module can be developed and added into this program separately. Developed SIE ASME-NH Code can be used to evaluate multi-transient operating cycles and multi-evaluating points simultaneously with results of elastically or inelastically calculated stress and strain for each cycle type.

SIE ASME-NH (Revision 1.0) Computer Code consists of following main modular programs as;

- Main Program
- Input Data Control Program
- Primary Stress Limit Evaluation Program
- Total Inelastic Strain Limit Evaluation Program
- Creep-Fatigue Evaluation Program by Elastic Analysis Method
- Creep-Fatigue Evaluation Program by Inelastic Analysis Method
- Material Database Programs
- Material Data Evaluation Program

The main program controls the evaluating option and dynamic arrays for most variables required in structural integrity evaluation.

In input data control program, the input data such as elastic stress, strain, metal temperature, and so on, will be read and stored in array by control commands. The work process of SIE ASME-NH Code is a direct batch job and does not require an interactive procedure unlike CHECK-ASME. Therefore, users have to prepare the input file using with simple commands defined in this code.

Time-dependent primary load limits for design condition, service level A, B, C and D can be selectively checked by the primary stress limit evaluation program. This evaluation includes the primary membrane stress intensity limits, primary membrane plus bending stress intensity limits, primary membrane plus modified-bending stress intensity limits and the use-fraction sum corresponding to service levels.

The deformation and strain limits for structural integrity can be checked by using both the elastic analysis approach and the simplified inelastic analysis approach. The calculated effective creep ratcheting strains for each cycle types in this evaluation procedure will be used in next creep-fatigue evaluation.

The creep-fatigue damage evaluation can be carried out step by step in detail with compliance of ASME-NH rules. The total strain range including the elastic-plastic strain range and the creep strain increments will be calculated with the elastic analysis results and be used in fatigue damage evaluations. The fatigue damages at the evaluation points of structures are linearly summed for each cycle type as given in damage equation of ASME-NH. The creep damage evaluation during the steady state elevated temperature operation with multiple transient operating conditions having different peak metal temperature, duration, and primary loads can be performed by the method of stress/temperature time history envelop in ASME-NH non-mandatory appendix T rules. Actually the maximum dwell stress might occur during the transient duration and relax during the steady state normal operation. This stress levels, transient durations, and over temperatures larger than normal operation may seriously affect the creep damage. According to ASME-NH rules, the composite stress/temperature history will be divided into q time intervals and treated as a step-wise function of time. During each of these time intervals, the stress and temperature are assumed to be constant. Therefore, the user should be careful in selecting the time step size for the creep evaluation.

This report presents the user’s manual for the SIE ASME-NH (Revision 1.0) computer code and various examples of application.

## 2. Review of ASME-NH Design by Analysis Rules

At temperatures and loading conditions where creep effects are significant, the design by analysis shall consider the time-dependent material properties and structural behavior by guarding against the failure modes such as the ductile rupture from short-term loadings, the creep rupture from long-term loadings, the creep-fatigue damage, the gross distortion due to incremental collapse and ratcheting.

In evaluating the structural integrity for elevated temperature, it can be checked by four-quantities broadly such as 1) the load-controlled stress, 2) the total accumulated inelastic strain, 3) creep-fatigue damage, and 4) buckling instability.

In this chapter, the contents and the application procedures of the ASME-NH will be investigated to be implemented as the basis of the SIE ASME-NH program.

### 2.1 Limits for Load-Controlled Stresses

The primary stress intensity limits shall be satisfied for base metal and at weldments. To assure the high temperature structural integrity for the base metal, allowable stress limit values are defined: time-independent limit($S_m$), long-time service at elevated temperature($S_{mt}$), and a temperature and time-dependent limit obtained from long-term, constant load, and uniaxial tests($S_t$).

The priority work to carry out the structural integrity evaluation when using the elastic analysis is to derive the stress intensities from the results of the elastic stress analysis. This shall be calculated by the rules of ASME NH-3215(b), which requires the six scalar quantities of the stress components for each type of loading at critical locations cross the thickness of the structural section. The selection of the critical location and the cross section will mostly depend on the stress analysis results and the engineering experience. That means there are no precise rules in selecting the critical locations, therefore the designer should do it carefully with his own responsibility.

When the evaluation points are at weldments, $S_{mt}$ shall be taken as the lower of the $S_{mt}$ values or $0.8S_r$ x R, where $S_r$ is the value obtained from the expected minimum stress-to-rupture strength(Table I-14.6) and $R$ is the appropriate ratio of the weld metal creep rupture strength to the base metal creep rupture strength(Table I-14.10). The values of $S_t$ should be taken as the same way of $S_{mt}$.

Since ASME NH does not provide the inelastic analysis rules for satisfying the primary stress limits, these rules are basically carried out with the elastic analysis method.

#### 2.1.1 Design and Service Limits

The stress calculations required for the analysis of Design Loadings shall be based on a linearly elastic material model. The calculated stress intensity values shall satisfy the limits of following rules.

General Primary membrane Stress Intensity Limit:

$$P_m \le S_o \tag{1}$$

Where $S_o$ is the maximum allowable stress intensity value for design conditions.

Primary Membrane plus Bending Stress Intensity Limit:

$$P_L + P_b \le 1.5\,S_m \tag{2}$$

In calculating the left side of Eq. (2), it should be noted that $P_L$ and $P_b$ represent as many as six quantities and be separately summed to calculate the stress intensity.

### 2.1.2 Level A and B Service Limits

The stress calculations required for the analysis of Level A and B Service Loadings are based on a linearly-elastic material model.

The calculated stress intensity values obtained in range of elevated temperature shall satisfy the following conditions.

General Primary Membrane Stress Intensity Limit:

$$P_m \le S_{mt} \tag{3}$$

From Eq.(3), $S_{mt}$ is determined for the time, $t$, corresponding to the total duration of the particular loading during the entire service life, and for temperature, $T$, corresponding to the maximum wall-averaged temperature that occurs during the particular loading event.

Note that when the critical location are in the vicinity of a weld (defined by ±3 times the thickness to either side of the weld centerline), the limit $S_{mt}$ shall be taken as the lower of the $S_{mt}$ values or $0.8S_r$ x $R$.

Primary-Membrane plus Bending Stress Intensity Limit:

$$P_m + P_b \le K\,S_m \qquad (4)$$

$$P_m + P_b / K_t \le S_t \qquad (5)$$

$S_t$ is a temperature and time-dependent stress intensity limit. This limit is determined for the time corresponding to the total duration of the combined stress intensity and the maximum wall averaged temperature during the entire service life of the component.

The factor $K_t$ accounts for the reduction in extreme fiber bending stress due to the effect of creep. This factor is given by the following:

$$K_t = (K+1)/2\,, \qquad (6)$$

where the factor $K$ in above equation is the section factor for the cross section being considered. It is the ratio of the load set producing a fully plastic section to a load set producing initial yielding of the extreme fiber of the cross section. In evaluating across-the-wall bending of shell type structures, $K$=1.5 (for rectangular section) shall be used. Thus, for across-the-wall shell bending, $K_t$ is 1.25 in Eq.(6).

Note that the left-hand side of Eqs. (3), (4) and (5) shall be obtained with representation of the stress components as many as six quantities as described in NH-3215(b). When the critical location are the weldment, the limit $S_t$ shall be taken as the lower of the $S_t$ values or $0.8S_r$ x $R$.

### 2.1.3 Level C Service Limits

The stress calculations required for the analysis of Level C Service Loadings are based on a linearly-elastic material model.

The calculated stress intensity values obtained in range of elevated temperature shall satisfy the following conditions.

General Primary Membrane Stress Intensity Limit:

$$P_m \le \begin{cases} 1.2\,S_m \\ 1.0\,S_t \end{cases} \tag{7}$$

When the critical locations are the weldment, the limit $S_t$ shall be taken as the lower of the $S_t$ values or $0.8S_r$ x $R$.

Limit of Use-Fraction Sum Associated with $P_m$ :

$$\sum_i \left( \frac{t_i}{t_{im}} \right) \le B \ , \tag{8}$$

where $B$ is the use-fraction factor and is equal to 1.0 or less if so specified in the Design Specifications, $t_i$ is the total duration of a specific loading, $P_{mi}$, at elevated temperature during the entire service life of the component, and $t_{im}$ is the maximum allowed time obtained from $S_t$-vs-time data under the load stress intensity, $P_{mi}$.

The key consideration in this time fraction evaluation is the reduction in life due to different loads for different times as a short time transient load at higher temperatures than normal operating conditions. This condition is considered in SIE code by separating the total service life of components into two parts of total hours of the transient duration for each cycle with transient temperatures and the duration of the normal operation.

Primary Membrane plus Bending Stress Intensity Limit:

$$P_m + P_b \le 1.2\,K\,S_m \tag{9}$$

$$P_m + P_b / K_t \le S_t \tag{10}$$

When the critical locations are the weldment, the limit $S_t$ shall be taken as the lower of the $S_t$ values or $0.8S_r$ x $R$.

Limit of Use-Fraction Sum Associated with ($P_m + P_b/K_t$) :

$$\sum_i \left( \frac{t_i}{t_{ib}} \right) \leq 1.00 \ , \tag{11}$$

where $t_i$ is the total duration of a specific loading, ($P_{mi} + P_{bi}/K_t$), at elevated temperature during the entire service life of the component, and $t_{ib}$ is the maximum allowed time obtained from $S_t$-vs-time data under the load stress intensity, ($P_{mi} + P_{bi}/K_t$).

The total service life time including the time at higher temperatures than normal operating conditions is considered in SIE code same as calculated in Eq.(8).

### 2.1.4 Level D Service Limits

This rule shall be applied in all in cases as required by public health and safety considerations for specific components or systems. However, this load controlled condition D will be not considered in evaluating the strain based damage evaluations such as the ratcheting and the creep-fatigue described in Appendix T.

General primary membrane Stress Intensity Limit:

$$P_m \leq \begin{cases} Limit\ in\ Appendix\ F\ \ for\ P_m \\ 0.67\,S_r \\ 0.8\,R\,S_r \end{cases} , \tag{12}$$

where $R$ is the appropriate ratio of the weld metal creep fatigue strength to the base metal strength from Tables I-14.10 and $S_r$ is the expected minimum stress-to-rupture in time $t$ taken from Figs. I-14.6 in ASME-NH.

Limit of Use-Fraction Sum Associated with $P_m$:

$$\sum_i \left( \frac{t_i}{t_{ir}} \right) \le B_r$$

In above limit rule, $B_r$ is the use-fraction factor and is equal to 1.0. $t_i$ is the total duration of a specific loading, $P_{mi}$, at elevated temperature, $T_i$, during the entire service life of component. $t_{ir}$ is the maximum allowed time under the load stress intensity $1.5P_{mi}$ for base metal or, for weldments, the higher of $1.5P_{mi}$ and $(1.25/R)P_{mi}$.

Primary Membrane plus Bending Stress Intensity Limit:

$$P_m + P_b / K_t \le \begin{cases} 0.67\, S_r \\ 0.8\, R\, S_r \end{cases} \tag{13}$$

Limit of Use-Fraction Sum Associated with $(P_m + P_b/K_t)$ :

$$\sum_i \left( \frac{t_i}{t_{ibr}} \right) \le 1.0\,,$$

where $t_i$ is the total duration of loading at temperature, $t_i$, and $t_{ibr}$ is the maximum allowed time at a value of stress equal to $1.5(P_m + P_b/K_t)$ for base metal or higher of $1.5(P_m + P_b/K_t)$ and $1.25(P_m + P_b/K_t)/R$ for weldment.

When evaluating by Section III, Appendix F, the yield strength and tensile strength values shall be multiplied with the strength reduction factors, which are functions of the accumulated time-temperature history given in Table NH-3225.

## 2.2 Limits for Deformation and Strain

In this evaluation, the Design Loading and the Service Level D are exempted from deformation and strain limits but the Test Level shall be included in Level B Service

Loadings.

### 2.2.1 Limits for Inelastic Strains

In regions expecting elevated temperatures the maximum accumulated inelastic strain shall not exceed the following values.

(a) Strains averaged through the thickness, 1% : $Membrane\ \varepsilon_m \le 1.0\%$

(b) Strains at the surface, due to an equivalent linear distribution of strain through the thickness, 2% : $Bending\ \varepsilon_b \le 2.0\%$

(c) Local strains at any point, 5% : $Local\ \varepsilon_L \le 5.0\%$

Actually when creep effects are presumed significant, the above inelastic strain limits are required to be checked by the detail inelastic analysis. However, in order to reduce the number of evaluation points in a structure subjecting the elevated temperature, the elastic and simplified inelastic methods of analysis are provided in ASME NH Nonmandatory Appendix T with conservative bounds.

### 2.2.2 Elastic Analysis Method

The strain limits of T-1310 are considered to have been satisfied if the limits of any one of Test No. A-1, Test No. A-2, or Test No. A-3 are satisfied.

The metal temperatures used in this rule are the wall averaged temperatures, which can give more conservative results.

To establish the appropriate cycle to be evaluated in Test Nos. A-1 and A-2, an individual cycle, as defined in the DS(Design Specification) can not be split into subcycles to satisfy these requirements because the maximum range of the secondary stress intensity during the cycle may not be selected in the split subcycles. And at least one cycle must be defined that includes the maximum value of ($P_m + P_b/K_t$) which occur during all level A, B, and C Service Loadings.

The stress indices to be used in Test Nos. A-1 and A-2 are defined as follows:

$$X \equiv \left(P_m + P_b / K_t\right)_{\max} \div S_y, \qquad Y \equiv (Q_R)_{\max} \div S_y$$

Note that $S_y$ is the average of the $S_y$ values at the maximum and minimum wall-averaged temperatures during the cycle being evaluated. The value of $(Q_R)_{\max}$ is the maximum range of the secondary stress intensity during the cycle being considered.

The limit rules are as follows;

**Test No. A-1**

$$X + Y \le S_a / S_y \tag{T-1}$$

where $S_a = \text{Min}[1.25 S_t|_{t=10^4 \text{hrs}, T\max}, S_y]$.

**Test No. A-2**

$$X + Y \le 1 \tag{T-2}$$

**Test No. A-3**

For Test No. A-3, the limits of NB-3222.2 (Limits of primary plus secondary stress intensity), NB-3222.3(Limits of expansion stress intensity), and NB-3222.5(Limits of thermal stress ratchet) shall be met and, in addition, the requirements of the following rules shall be satisfied.

(a) Sum of the Use-Fractions

$$\sum_i t_i / t_{id} \le 0.1$$

where $t_i$ is the total duration of time during the service lifetime that the metal is at temperature, $T_i$ and $t_{id}$ is the maximum allowable time as determined by the stress-to-rupture value at temperature $T_i$ and a stress value of $1.5S_y|_{Ti}$.

(b) Creep Strains

$$\sum_i \varepsilon_i \leq 0.2\%$$

where $\varepsilon_i$ is the creep strain that would be expected from a stress level of $1.25S_y|_{Ti}$ applied for the total duration of time during the service lifetime that the metal is at $T_i$. The total times to enter the isochronous stress-strain curves shall sum to the total service lifetime.

(c) $3S_m$ Limits

In compliance with NB-3222.2 and NB-3222.3 of ASME Code Subsection NB, the maximum range of the linearised primary plus secondary stress shall be satisfied the rule as follows;

$$\Delta\left( P_L + P_b + Q \right) \leq 3\overline{S}_m$$

In above rule, the modified $3S_m$ values shall be determined as follow:

- When only one extreme of the stress difference occurs at the elevated temperature:

$$3\overline{S}_m = (1.5\,S_m + S_{rH})$$

- When both extremes of the stress difference occur at the elevated temperature:

$$3\overline{S}_m = (S_{rL} + S_{rH}),$$

where $S_{rH}$ and $S_{rL}$ are the relaxation strengths associated with the temperatures at the hot and cold extremes of the stress cycle. These relaxation strengths may be determined by performing a pure uniaxial relaxation analysis starting with a initial stress of $1.5S_m$ and holding the initial strain throughout the time interval equal to the time of service above 425°C for the austenitic stainless steel and 375° C for 2(1/4)Cr-1Mo and 9Cr-1Mo-V.

Appendix A is an example of a pure uniaxial relaxation analysis for 316 SS material by using the creep equation provided from ANSYS program.

### 2.2.3 Using Simplified Inelastic Analysis

The limits for inelastic strains are considered to have been satisfied if the limits of any one of the following Test No.B-1, Test No.B-2 or Test No.B-3 are satisfied.

The metal temperatures used in this rule are the hot and cold temperatures corresponding to the extremes of the stress cycle, which can reflect more realistic metal temperature conditions during the stress cycle.

Test No.B-1 can be used only for the axisymmetric structures subjected to axisymmetric loadings and away from local structural discontinuities, or general structures in which the peak through-the-wall thermal stress is negligible (i.e., the thermal stress distribution is linear through the wall). Test No.B-2, which is more conservative, is applicable to any structure and loadings. Test No.B-3 may be used for cycles in regimes $R_1$ and $R_2$ in Bree Diagram, which is applicable to axisymmetric shell structures subjected to internal pressure and thermal stresses caused by a linear through-thickness temperature gradient. This procedure may also be applied to cycles in the $S_1$, $S_2$, and $P$ regimes in order to minimize the conservatism in calculated strains when there are a few relatively severe cycles.

Note that in calculating the primary stress index $X$, the secondary stresses with elastic followup (i.e., pressure-induced membrane and bending stresses and thermal-induced membrane stresses) are classified as primary stresses for purposes of this evaluation. In calculating the stress indices of $X$ and $Y$, the $S_{yL}$ value shall be used instead of $S_y$ for Test Nos, B-1 and B-2.

One important thing kept in mind using this rule is that the time to enter the isochronous curves for individual time blocks shall always sum to the entire life regardless of whether all or only part of the cycles are evaluated under this rule. To do this the load history should be defined first for the entire design lifetime and they may be subdivided into the appropriate temperature-time blocks. The individual cycles or time blocks may differ from those for the creep-fatigue evaluations.

### Test No. B-1 and B-2

This rule can be available only when the average wall temperature at one of the stress extremes defining each secondary stress intensity range $Q_R$ is below the applicable temperature of Table 1.

The elastically calculated primary and secondary stress intensities are used to determine an effective creep stress,

$$\sigma_c = Z \cdot S_{yL}$$

which in turn is used to determine a total ratcheting creep strain. The dimensionless effective creep stress parameter $Z$ for any combination of loading, which is determined by the calculated stress indices of X and Y, is given in Fig. 1 for Test No B-1 and Test No B-3, and Fig. 2 for Test No B-2.

Table 1. Applicable Temperature

| **Material** | **Temperature, $^{o}$C** |
|---|---|
| Type 304 SS | 509 |
| Type 316 SS | 544 |
| Alloy 800H | 573 |
| 2(1/4)Cr-1Mo | 427 |
| 9Cr-1Mo-V | 504 |

In Fig. 1, the parameter $Z$ can be obtained as follows;

(a) in regimes $S_2$ and $P$ ;

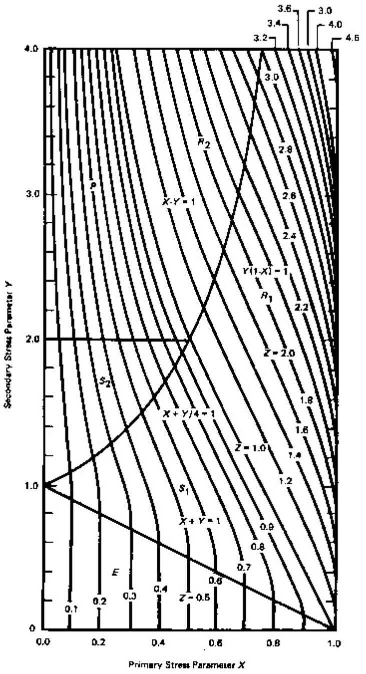
$$Z = X \cdot Y \tag{T-3}$$

(b) in regime $S_1$ ;

$$Z = Y + 1 - 2\sqrt{(1 - X)Y} \tag{T-4}$$

(c) in regime $E$ ;

$$Z = X$$



T-1332-1 EFFECTIVE CREEP STRESS PARAMETER *Z* FOR SIMPLIFIED INELASTIC ANALYSIS USING TEST NOS. B-1 AND B-3
[For Use Only When the Restrictions of T-1331(a) for Test No. B-1 Are Met]

Fig. 1 Bree Diagram for Effective Creep Stress Parameter Z for Test Nos. B-1 and B-3

The creep-ratcheting strain is determined by multiplying $\sigma_c$ by 1.25 and evaluating the creep strain associated with the $1.25\sigma_c$ stress held constant throughout the temperature-time history of the entire service life. The isochronous stress-strain curves shall be used to obtain the creep-ratcheting strain. The creep strain increment for each time block can be calculated separately with a general concept shown in Fig. 3. As shown in figure, the calculating procedure is very complicated. The different isochronous curves should be entered for each different temperature-time block and start at the initial strain accumulated throughout the prior load history. To do this a complicated interpolation techniques are required to find the appropriate isochronous curves from the given data of ASME-NH Appendix T. As mentioned previously the times used in selecting the isochronous curves shall sum to the total service life.

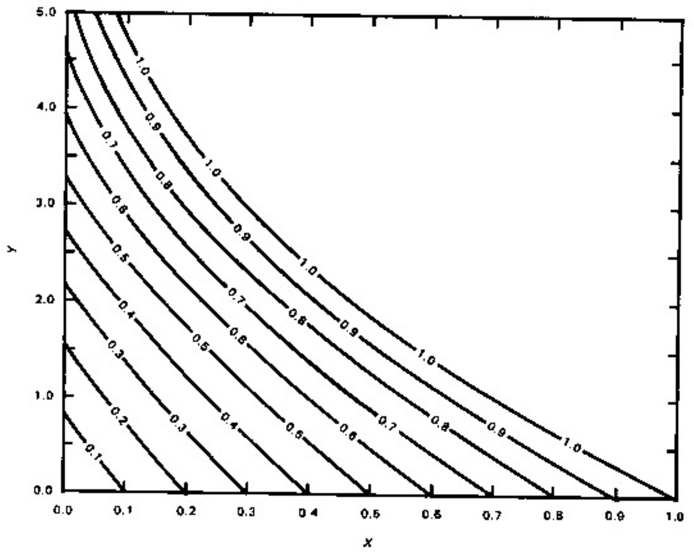


FIG. T-1332-2 EFFECTIVE CREEP STRESS PARAMETER *Z* FOR SIMPLIFIED INELASTIC ANALYSIS USING TEST NO. B-2
(Applicable to General Structures)

Fig. 2 Effective Creep Stress Parameter Z for Test No. B-2

The calculated each creep-ratcheting strain shall be summed and limited to 1% for parent metal and 1/2% for weld metal.

Note that Test No B-1 can only be applied when $\sigma_c$ is less than the yield stress of $S_{yH}$.

### Test No. B-3

When the calculated effective creep stress parameter Z is in regimes $R_1$ and $R_2$ where Test No B-1 is not applicable due to a few relatively severe time blocks, then the Test No B-3 can be used and the inelastic strains may be evaluated separately using the given equations. This method is applicable only to axisymmetric structures subjected to axisymmetric loadings and away from local structural discontinuities. Recently, studies are being carried out to apply this rule to the general structures extensively.

The total inelastic strains accumulated in the lifetime of the component are given by:

$$\sum \varepsilon_t = \sum \nu + \sum \eta + \sum \delta \tag{T-5}$$

Each component of Eq.(T-5) is obtained from the followings.

(a) $\sum \eta$ = the plastic ratchet strain increments occurring for only $[\sigma_{cL}] \geq S_{yH}$

$$\sum \eta = \frac{1}{E_H}\left[([\sigma_{cL}] - S_{yH}) + ([\sigma_{cH}] - S_{yL})\right] \quad \text{for } Z_L \leq 1.0 \qquad \text{(T-6)}$$

$$= \frac{1}{E_L}([\sigma_{cL}] - S_{yL}) + \frac{1}{E_H}([\sigma_{cH}] - S_{yH}) \quad \text{for } Z_L > 1.0 \qquad \text{(T-7)}$$

where $[\sigma_{cL}]$ and $[\sigma_{cH}]$ are the effective stresses for cold and hot extremes of the cycles as given by $[\sigma_{cL}] = Z_L S_{yL}$ and $[\sigma_{cH}] = Z_H S_{yH}$ respectively.

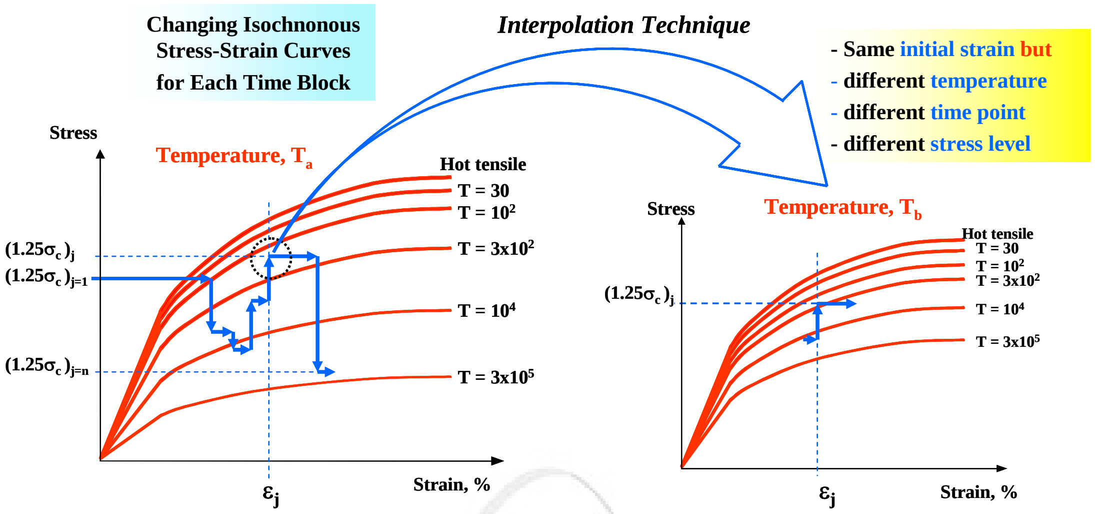
(b) $\sum \delta$ = the enhanced creep strain increments due to stress relaxation

$$\sum \delta = \frac{1}{E_H}\frac{S_{yH}^2 - \sigma_c^2}{\sigma_c} \quad \text{for cycles where } [\sigma_{cL}] \geq S_{yH} \qquad \text{(T-8)}$$

$$= \frac{1}{E_H}\frac{[\sigma_{cL}]^2 - \sigma_c^2}{\sigma_c} \quad \text{for cycles where } [\sigma_{cL}] < S_{yH} \qquad \text{(T-9)}$$

where $\sigma_c$ is the effective creep stress for the next time block. Unless sequence of loading is specified, the lowest $\sigma_c$ calculated in Test No B-1 or B-2 should be used. All values in equations of the enhanced creep strain are related to the load cycle ($n$). And only positive $\delta_{(n)}$ increments should be considered.

(c) $\sum \nu$ = the inelastic strains obtained from the isochronous curves in Test No. B-1



$$\sum_{j=1}^{n}(Time\ block\ duration)_j = Total\ life\ time$$

Fig. 3 General Concept of Creep Ratcheting Strain Calculations

### 2.2.4 Inelastic Analysis Method

The main intension of the ASME-NH is to restrict the maximum accumulated inelastic strain averaged across a wall thickness to 1% or less during whole service lifetime. When the elastic method can not satisfy the design rules, the inelastic analysis shall be used to demonstrate the deformation limits for functional requirements.

## 2.3 Limits for Creep-Fatigue Damage

The accumulated creep and fatigue damage shall satisfy the following relation for the combination of Levels A, B, and C Service Loadings.

$$\sum_{j=1}^{p}\left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q}\left(\frac{\Delta t}{T_d}\right)_k \le D \qquad \text{(T-10)}$$

where

$D$ = total creep-fatigue damage

$P$ = number of different cycle types

$(n)_j$ = number of applied repetitions of cycle type, $j$

$(N_d)_j$ = number of design allowable cycles for cycle type, $j$

$q$ = number of time intervals for the creep damage calculation

$(T_d)_k$ = allowable time duration determined from the stress-to-rupture curves

The total damage, $D$, shall not exceed the creep-fatigue damage envelope curves given in Fig. 4.

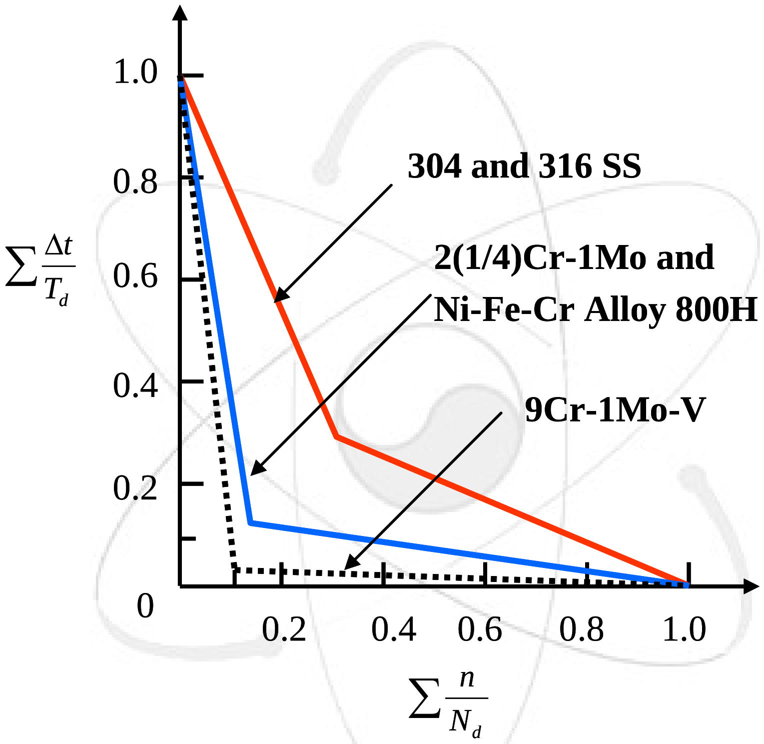


Fig. 4 Creep-Fatigue Damage Envelope

### 2.3.1 Fatigue Damage

An equivalent strain range is used to evaluate the fatigue damage sum for both elastic and inelastic analysis.

The general procedures for the fatigue damage evaluation using the elastic analysis method are as follows;

● **Step 1 :** Calculate Elastic Strain Time History for Each Cycle Type, $j$

- **Step 2 :** Select One of Extreme Time Points for the Cycle (Set Subscript *o*)
- **Step 3 :** Calculate Strain Ranges for All Components at Each Time Point As

$$\Delta\varepsilon_{xi} = \varepsilon_{xi} - \varepsilon_{xo},\ \ \Delta\varepsilon_{yi} = \varepsilon_{yi} - \varepsilon_{yo},\ \ etc;$$

- **Step 4 :** Calculate the Equivalent Strain Range for Each Point in Time As

$$\Delta\varepsilon_{equi,i} = \frac{\sqrt{2}}{2(1+\nu^*)}\left[\left(\Delta\varepsilon_{xi} - \Delta\varepsilon_{yi}\right)^2 + \left(\Delta\varepsilon_{xi} - \Delta\varepsilon_{yi}\right)^2 + \left(\Delta\varepsilon_{xi} - \Delta\varepsilon_{yi}\right)^2 + \frac{3}{2}\left(\Delta\gamma_{xyi}^2 + \Delta\gamma_{yzi}^2 + \Delta\gamma_{zxi}^2\right)\right]^{1/2}$$

$$where\ \nu^* = 0.3\ \ for\ \ Elastic\ \ Analysis$$

$$\nu^* = 0.5\ \ for\ Inelastic\ \ Analysis$$

- **Step 5 :** Define $\Delta\varepsilon_{\max} = MAX\,(\Delta\varepsilon_{equiv,i})$
- **Step 6 :** Modify $\Delta\varepsilon_{\max}$ with Local Geometric Stress Concentration and Multiaxial Effects
- **Step 7 :** Calculate Total Strain Range As

$$\varepsilon_t = K_\nu \Delta\varepsilon_{\mathrm{mod}} + K\,\Delta\varepsilon_c$$

- **Step 8 :** Find Allowable Number of Cycles, $N_d$ from Design Fatigue Curves Corresponding to $\varepsilon_t$
- **Step 9 :** Calculate the Fatigue Damage by

$$\sum_j^p \left(\frac{n}{N_d}\right)_j$$

For the fatigue damage evaluation, it is required the maximum elastic strain range and the creep strain increment. The maximum elastic strain range can be obtained from the extreme time points in the elastic strain components calculated for each time point, *i*, for the complete cycle. After one of the extreme time points sets as a reference strain condition, the equivalent elastic strain range shall be calculated for each point, *i*, in time as:

$$\Delta\varepsilon_{equiv,i} = \frac{\sqrt{2}}{2(1+\nu^*)}[(\Delta\varepsilon_{xi} - \Delta\varepsilon_{yi})^2 + (\Delta\varepsilon_{yi} - \Delta\varepsilon_{zi})^2 + (\Delta\varepsilon_{zi} - \Delta\varepsilon_{xi})^2 + \frac{3}{2}(\Delta\gamma_{xyi}^2 + \Delta\gamma_{yzi}^2 + \Delta\gamma_{zxi}^2)]^{1/2} \qquad \text{(T-11)}$$

where $\nu^*$ = 0.3 when using the elastic analysis and $\nu^*$ = 0.5 when using the inelastic analysis.

The maximum elastic strain range, $\Delta\varepsilon_{\max}$, is defined as the maximum value of the above calculated equivalent strain ranges, $\Delta\varepsilon_{equiv,i}$.

Note that the strain components to be used in calculating $\Delta\varepsilon_{\max}$ do not include the local geometric stress concentration effects. Therefore, the modified maximum equivalent strain range $\Delta\varepsilon_{\mathrm{mod}}$ including this effect shall be calculated as using any one of Eq.(T-12), Eq.(T-13), or Eq.(T-14).

$$\Delta\varepsilon_{\mathrm{mod}} = \left(\frac{S^*}{\overline{S}}\right) K^2\, \Delta\varepsilon_{\max} \tag{T-12}$$

$$\Delta\varepsilon_{\mathrm{mod}} = \frac{K^2\, S^*\, \Delta\varepsilon_{\max}}{\Delta\sigma_{\mathrm{mod}}} \tag{T-13}$$

$$\Delta\varepsilon_{\mathrm{mod}} = K_e\, K\, \Delta\varepsilon_{\max} \tag{T-14}$$

where $S^*$ and $\overline{S}$ represent the stress indicators and $K$ is the equivalent stress concentration factor as determined by

$$K = \frac{(P+Q+F)_{eff}}{(P+Q)_{eff}}.$$

In Eq.(T-14), $K_e$ is defined as

$$K_e = 1 \qquad \text{for } K\Delta\varepsilon_{\max} \le 3\overline{S}_m / E$$

$$K_e = K\Delta\varepsilon_{\max} E / 3\overline{S}_m \quad \text{for } K\Delta\varepsilon_{\max} > 3\overline{S}_m / E$$

As shown in above equations from T-12 to T-14 , the Neuber's rule is introduced to consider the stress concentrations in local area, which were not considered in total elastic strain range calculations. Actually for elastic stress conditions, it is satisfied the relationship of $\sigma = K\sigma_f$ between the local stress, $\sigma$ and the far field stress, $\sigma_f$. The stress concentration factor has a relationship for elastic regions as $K = K_\sigma = K_\varepsilon$, where $K_\sigma$ is a stress concentration factor and $K_\varepsilon$ is a strain concentration factor. However, when yielding occurs, these three factors are not linearly related. In local area, the relationship between stress and strain can be represented by a Ramberg-Osgood relation of the form;

$$\varepsilon = \varepsilon_e + \varepsilon_p = \frac{\sigma}{E} + \left(\frac{\sigma}{A}\right)^{\frac{1}{n}},$$

which can use monotonic or cyclic stress-strain curve. For the plane stress situation, the Neuber relationship becomes;

$$K^2 = K_\sigma K_\varepsilon$$

Using the concentration factor, the modified stress and strain range in Fig. 5 can be written as;

$$\bar{S} = K_\sigma S^*$$

$$\Delta\varepsilon_{\text{mod}} = K_\varepsilon \Delta\varepsilon_{\max}$$

When introducing the Neuber's rule, $K^2 = K_\sigma K_\varepsilon$ for above equations, the relationship becomes;

$$\left(\frac{\bar{S}}{S^*}\right)\left(\frac{\Delta\varepsilon_{\text{mod}}}{\Delta\varepsilon_{\max}}\right) = K^2$$

From this relationship, the modified strain range, $\Delta\varepsilon_{\text{mod}}$ can be written as the same of above Eq.(T-12). Therefore, we can see that the Eq.(T-12) is more conservative than the Eq.(T-13) and the Eq.(T-14) gives the most conservative results.

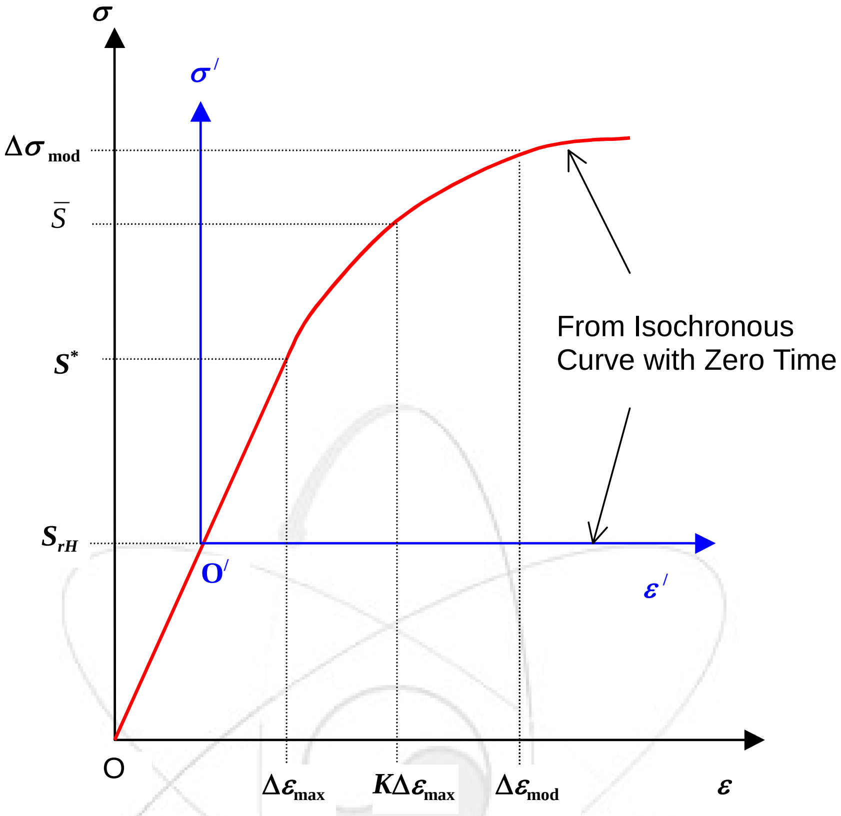


Fig. 5 Stress-Strain Relationship

The stress indicators in Eq.(T-12) and Eq.(T-13) can be determined by using the composite stress-strain curve constructed by adding the elastic stress-strain curve for the stress range, $S_{rH}$ obtained from the relaxation strength analysis, to the appropriate time-independent isochronous stress-strain curve as shown in Fig. 5.

To consider the multiaxial effects in total elastic-plastic strain range, the multiaxial plasticity and Poisson ratio adjustment factor, $K_\nu$ is introduced as

$$K_\nu = 1.0 + f\,(K'_\nu - 1.0) \qquad \text{(T-15)}$$

where $f$ is the factor determined by using the Triaxiality Factor, T.F., which is defined as

$$\text{T.F.} = \frac{|\sigma_1 + \sigma_2 + \sigma_3|}{\frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{1/2}}$$

and $K'_v$ is the plastic Poisson ratio adjustment factor by using the ratio of $K_e K \Delta\varepsilon_{\max} E / 3\overline{S}_m$ .

Finally, the total strain range, $\varepsilon_t$, that is used to enter one of the design fatigue curves of Fig. T-1420 in ASME-NH, is calculated as

$$\varepsilon_t = K_v \, \Delta\varepsilon_{\text{mod}} + K \, \Delta\varepsilon_c \qquad \text{(T-16)}$$

The creep strain increment $\Delta\varepsilon_c$, corresponding to the stress intensity equal to $1.25\sigma_c$ as defined in Test No. B-1, for the stress cycle due to load-controlled stresses can be determined from the isochronous stress-strain curve. In using the isochronous curve, the stress cycle time, including hold time between transients, shall be used instead of the entire service life. Therefore, the $\Delta\varepsilon_c$ equals the sum of the creep strain increment accumulated in one stress cycle time. Alternatively, the creep strain accumulated during the entire service life divided by the number of stress cycles during the entire service life may be used for the creep strain increment $\Delta\varepsilon_c$.

For the weldment evaluations, the obtained allowable number of design cycles $N_d$ shall be one-half the value permitted for the parent material.

### 2.3.2 Creep Damage

The creep damage term in Eq.(T-10) of the creep-fatigue damage equation is to be evaluated using the general procedure provided in ASME Code Section III, Subsection NH.

The general procedure can be described step by step as follows;

- **Step 1 :** Define total number of hours expended at elevated temperature, $t_H$
- **Step 2 :** Define the hold temperature, $T_{HT}$
- **Step 3 :** Define the average cycle time, $\bar{t}_j = t_H / n_j$

- **Step 4 :** Determine stress level, $S_j \mid \varepsilon_t$ from time-independent isochronous stress-strain curve corresponding to $T_{HT}$
- **Step 5 :** Obtain the stress relaxation time history curve at dwell stress $S_j$ and hold temperature, $T_{HT}$
- **Step 6 :** Modify the stress relaxation time history curve with considering the load-controlled transient effect
- **Step 7 :** Define the cycle transient temperature
- **Step 8 :** Repeat Step3 through Step 7 to make j=1 to P sets of the stress relaxation time histories and superpose these to result in the envelope stress-time history
- **Step 9 :** Determine integration time step size, $(\Delta t)_k$, the stress, $(S)_k / K'$, and temperature, $(T)_k$
- **Step 10 :** Obtain the allowable time duration, $(T_d)_k$ for each time interval from the expected minimum stress-to-rupture curve

To obtain the stress-time relaxation curve which enters to the minimum stress-to-rupture curve to determine the allowable time duration, the stress level, $S_j$ corresponding to $\varepsilon_t$ and $T_{HT}$ from the time-independent isochronous stress-strain curve shall be obtained at first. Account for stress relaxation during the average cycle time, the stress relaxation evaluation is to be performed at the constant temperature equal to $T_{HT}$. This relaxed stress level at time *t* adjusted for the multiaxial stress state can be calculated using

$$S_r = S_j - 0.8G(S_j - \overline{S}_r)$$

where $S_j$ is the initial stress level for cycle type *j* and $\overline{S}_r$ is the relaxed stress level at time *t* based on a uniaxial relaxation model as shown in Fig. 6. *G* is the multiaxiality factor defined as

$$\frac{[\sigma_1 - 0.5(\sigma_2 + \sigma_2)]}{[\sigma_1 - 0.3(\sigma_2 + \sigma_3)]}$$

where $\sigma_1$, $\sigma_2$, and $\sigma_3$ are principal stresses defined by $|\sigma_1| \geq |\sigma_2| \geq |\sigma_3|$ . The values of $G$ greater than 1.0 shall be taken as 1.0.

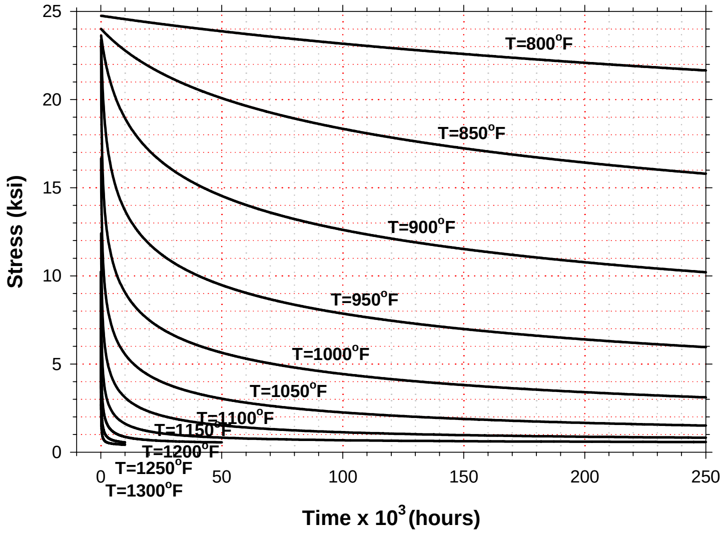


Fig. 6 Stress Relaxation History by Uniaxial Relaxation Analysis Model

The stress relaxation history may be determined alternatively by entering the appropriate isochronous stress-strain curves at strain level equal to $\varepsilon_t$ and determining corresponding stress levels at varying times as shown in Fig. 7.

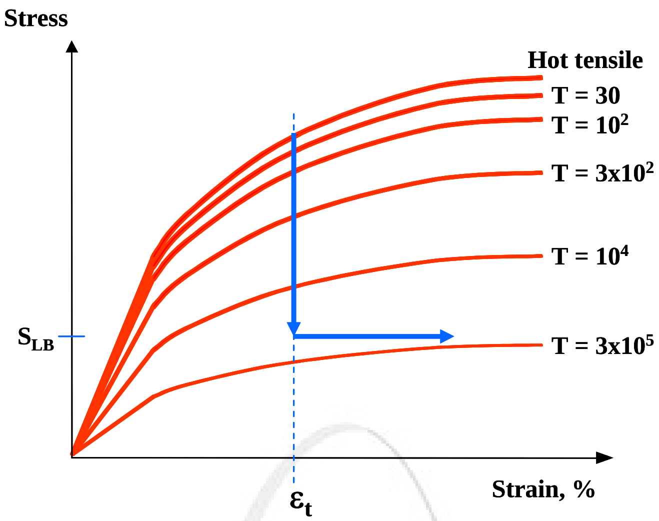


Fig. 7 Stress Relaxation from Isochronous Stress-Strain Curves

Fig. 8 shows the concept of the stress relaxation limits for creep damage evaluation. As shown in figure, the stress relaxation process shall not be permitted to proceed to a stress level less than $S_{LB}$. This lower bound stress level, $S_{LB}$, is defined to be equal to $1.25\sigma_c$ that exits during sustained normal operation.

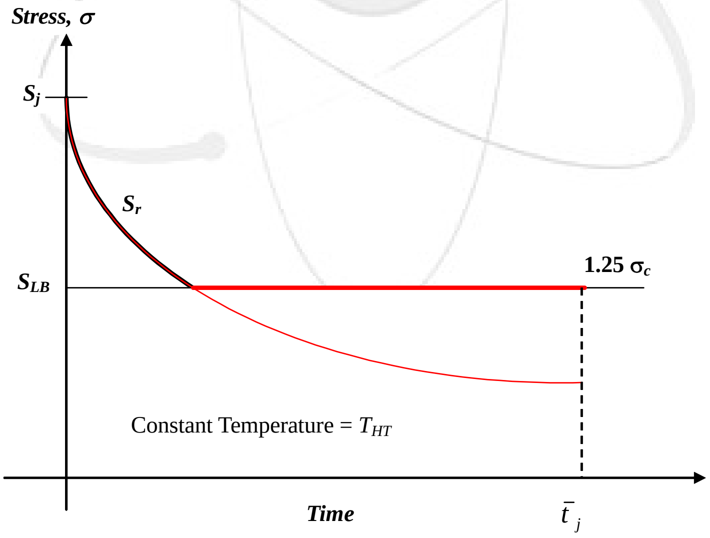


Fig. 8 Stress-Relaxation Limits for Creep Damage

When the maximum load controlled stresses exceed the stress-time history within the transient time duration, further modification of the stress-time history is required by simple translation in time as shown in Fig. 9.

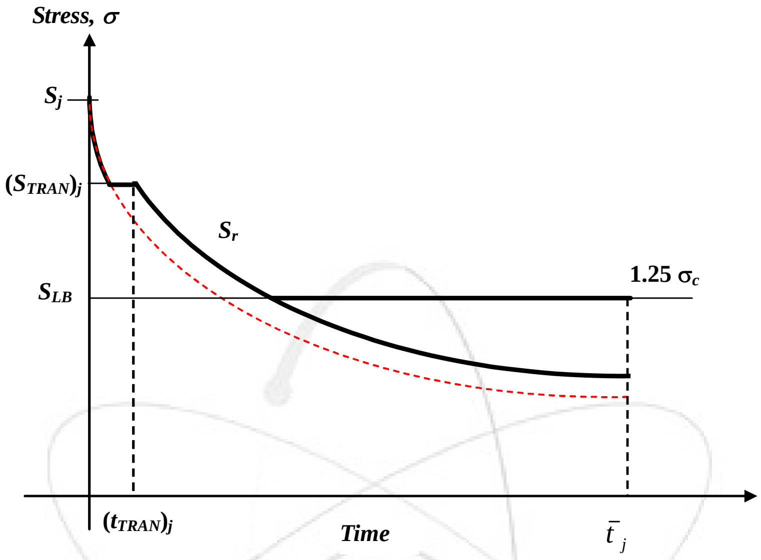


Fig. 9 Modification of Stress Relaxation Time History

Note that the maximum cycle transient temperature should be considered in the subsequent determination of the creep damage during the transient time duration.

For the multi-cycle types, the individual stress relaxation time histories should be generated and these are to be superimposed to make single representative enveloped history as shown in Fig. 10 and Fig. 11.

For evaluation of the creep damage, the allowable time duration $(T_d)_k$ is obtained from the expected minimum stress-to-rupture curve using the extrapolation. During each of time intervals, $(\Delta t)_k$, the stress, $(S)_k$, is assumed to be constant and is equal to the value at the start of that interval. The allowable time duration $(T_d)_k$, shall be obtained using the $(S)_k$ value divided by the stress factor $K^{/}$ in Table 2.

For the weldment evaluations, the allowable time duration $T_d$ shall be determined from a stress-to-rupture curve obtained by multiplying the parent material stress-to-rupture values by the weld strength reduction factors.

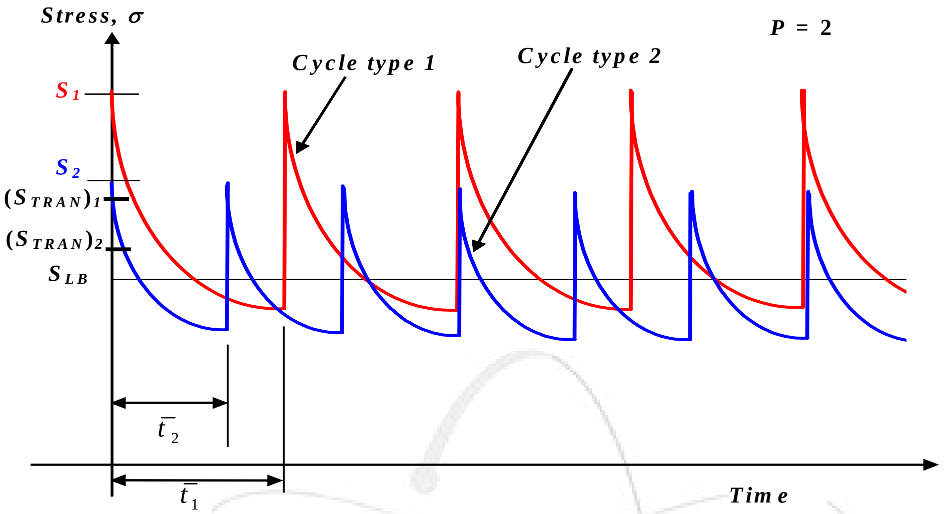


Fig. 10 Superimpose Stress-Time Histories

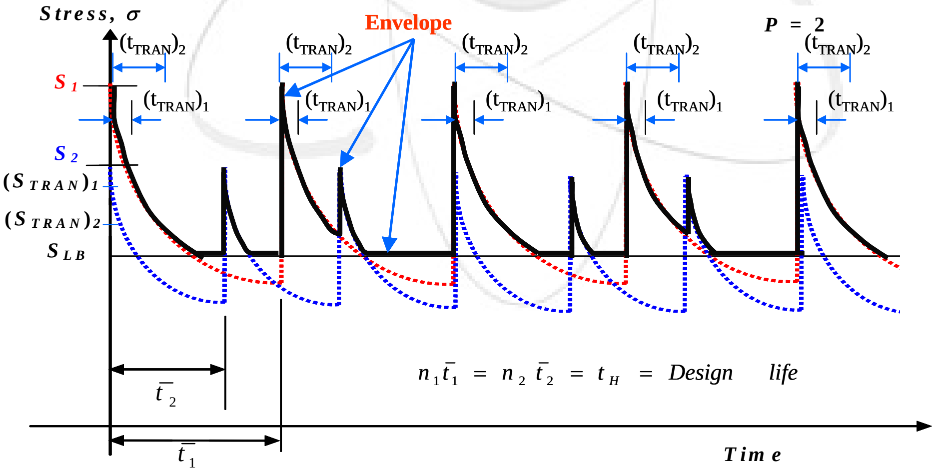


Fig. 11 Envelope Stress/Temperature-Time History for Creep Damage Assessment

### 2.3.3 Inelastic Analysis Method

The general procedures of the inelastic analysis method are basically same as the elastic analysis method, which is based on the well-defined cycle types. As the effects of local geometric stress concentration and the multiaxial behavior are included in the inelastic analysis, additional modification procedures of the maximum strain range, which are required in the elastic analysis method, are not necessary.

The fatigue damage can be directly evaluated by entering a design fatigue curve at the total strain range $\varepsilon_t$ which is defined as $\varepsilon_t = \Delta\varepsilon_{\max}$ obtained by the same procedures of the elastic method. The maximum metal temperature during the cycle shall be used in selecting the design fatigue curve.

The general procedures for the fatigue evaluation by the inelastic analysis method are as follows;

- **Step 1 :** Define **Complete Load Cycle Types**
- **Step 2 :** Perform Inelastic Analysis with Well-Proven **Constitutive Equations** for Each Cycle Type
- **Step 3 :** Find Maximum $\varepsilon_t = \Delta\varepsilon_{\max}$ Strain Range with **the Same Procedures** of Step 1 Through Step 5 in Elastic Analysis Method
- **Step 4 :** Find Allowable Number of Cycles, $N_d$ from Design Fatigue Curves Corresponding to $\varepsilon_t$ and the **Max Metal Temperature** during the Each Cycle
- **Step 5 :** Calculate Accumulated Fatigue Damage by

$$\sum_{j}^{p}\left(\frac{n}{N_d}\right)_j$$

To evaluate the creep damage term in Eq.(T-10), the stress-time history corresponding to the load history shall be calculated for a whole service lifetime by inelastic analysis with the well-proven constitutive equations.

The general procedures for the creep evaluation by the inelastic analysis method ar as follows;

- **Step 1 :** Define **Load History** for Entire Design Life Time
- **Step 2 :** Perform Inelastic Analysis with Well-Proven **Constitutive Equations**
- **Step 3 :** Calculate **Equivalent Stress-Time History** by the Given Equations:
- **Step 4 :** Obtain Allowable Time Durations for the Max Stress Divided by the Safety Factor, *K'* during Each Time Interval by Entering the Expected Minimum Stress-To-Rupture Curves
- **Step 5 :** Calculate Creep Damage by **Using the Integral** $\int_0^t \frac{dt}{T_d}$ **Form**:

For inelastic analysis, the following equivalent stress quantity should be used:

$$\sigma_e = \bar{\sigma} \exp\left[ C \left( \frac{J_1}{S_s} - 1 \right) \right],$$

where

$$J_1 = \sigma_1 + \sigma_2 + \sigma_3$$

$$S_s = \left[ \sigma_1^2 + \sigma_2^2 + \sigma_3^2 \right]^{1/2}$$

$$\bar{\sigma} = \frac{1}{\sqrt{2}} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{1/2}$$

and $\sigma_i$ are the principal stresses. The constant *C* is defined as follows:

- *C* = 0.24 for Types 304 and 316 SS
- *C* = 0.00 for Alloy 800H
- *C* = 0.16 for 2(1/4)Cr-1Mo and 9Cr-1Mo-V if $J_1/S_s \geq 1.0$
- *C* = 0.00 for 2(1/4)Cr-1Mo and 9Cr-1Mo-V if $J_1/S_s < 1.0$

As the same method of the elastic analysis, the equivalent stress time history shall be divided into *q* number of time intervals (each with a unique stress-temperature combination) and the allowable time duration $T_d$ is determined by entering the expected minimum stress-to-rupture curve at that stress value determined by dividing the maximum stress during each time interval $k$ by the safety factor of $K'$. The creep damage term of Eq.(T-10) may have the following integral form;

$$\int_o^t \frac{dt}{T_d}$$

Table 2. Safety Factor ( $K'$ ) for Creep Damage Evaluation

| **Material** | **Elastic Analysis** | **Inelastic Analysis** |
|---|---|---|
| Type 304 SS | 0.9 | 0.67 |
| Type 316 SS | 0.9 | 0.67 |
| Alloy 800H | 0.9 | 0.67 |
| 2(1/4)Cr-1Mo | 0.9 | 0.67 |
| 9Cr-1Mo-V | 0.9 | 0.67 |

# 3. User's Manual of SIE ASME-NH Code

## 3.1 Contents of Program

### 3.1.1 Lists of Main Evaluation Programs

- SIE-ASME-NH.f : Main program for overall procedures
- INPUT-DATA.f : Input data control module
- P-LIMITS.f : Primary stress limits evaluation module
- S-LIMITS.f : Inelastic strain limits evaluation module
- CF-LIMITS.f : Creep-fatigue evaluation module using elastic analysis
- CF-INELASTIC.f : Creep-fatigue evaluation using inelastic analysis
- MAT-DB.f : Material Database Evaluation module

### 3.1.2 Lists of Material Database Programs for SIE

- Mat-e.f : Elastic modulus ($E$)
- Mat-sy.f : Yield strength values ($S_y$)
- Mat-so.f : Allowable stress intensity for design condition ($S_o$)
- Mat-sm.f : Time-independent allowable stress intensity values ($S_{mt}$)
- Mat-st.f : Time-dependent allowable stress intensity values ($S_t$)
- Mat-smt.f : Lower of two stress intensity values, $S_m$ and $S_t$ ($S_{mt}$)
- Mat-st-time.f : Maximum allowable time by $S_t$-vs-time ($t_{im}$, $t_{ib}$, $t_{ir}$, $t_{ibr}$)
- Mat-srv.f : Expected minimum stress-to-rupture values ($S_r$)
- Mat-srv-time.f : Allowable time duration for creep by $S_r$-vs-time ($T_d$)
- Mat-srv-time-weld.f : Allowable time duration for creep at weldment
- Mat-srf.f : Weld strength reduction factor ($R$)
- Mat-srs.f : Stress relaxation strength by uniaxial analysis ($S_{rH}$ , $S_{rL}$)
- Mat-iso.f : Isochronous stress-strain database
- Mat-iso-strs.f : Isochronous stress-strain values for stress calculation

- Mat-iso-strn.f : Isochronous stress-strain values for strain calculation
- Mat-iso-time.f : Isochronous stress-strain for time point determination
- Mat-fatigue.f : Allowable number of cycle for fatigue ($N_d$)
- Mat-cf-fatigue.f : Fatigue Limit from Creep-fatigue damage envelope curves
- Mat-cf-creep.f : Creep Limit from Creep-fatigue damage envelope curves

### 3.1.3 Lists of Miscellaneous Programs for SIE

- Creep-strain.f : Creep strain increment for creep-fatigue evaluation
- Bree-b1b3.f : Bree diagram for effective creep stress parameter for Test Nos. B-1 and B-3 ($Z$)
- Bree-b2.f : Bree diagram for effective creep stress parameter for Test No. B-2 ($Z$)
- Amadj-kvd.f : Adjustment factors for inelastic biaxial Poisson's ratio ($K'v$)
- Amadj-tf.f : Inelastic multiaxial adjustment factors ($f$)
- Axi-tresca.f : Calculation of Tresca stress intensity for axisymmetric models
- Axi-principal.f : Calculation of principal stresses for axisymmetric models
- Gen-tresca.f : Calculation of principal stresses for general models

### 3.1.4 Lists of Complementary Programs

- Max-strn-range.f : Calculation of max-strain range from components time history
- Wall-temp : Calculation of max and min-wall averaged temperature

## 3.2 Lists of Input Commands

All commands supplied in SIE are using the * commands. Under these command lines the input values are required to be written sequentially.

In following command descriptions, the subscript symbol, "i" and "j" indicate the cycle types and the evaluation points respectively.

- ***SIE** : start of structural integrity evaluation
    1. ( INDEX, NCT )
    2. (INDEX, NEP)

    < DATA Line Meanings >
    INDEX = user defined arbitrary index
    NCT = total number of cycle types
    NEP = total number of evaluation points

When starting the structural integrity evaluation by SIE ASME-NH code, “*SIE” command should be announced at first in input deck with the data of the total number of cycle types and evaluation points.

If user want to perform the material data evaluation, the first command line should be start with “*MATDB” in the input deck (see *MATDB command).

- ***TITLE** : user-defined evaluation title
    1. ( TITLE )

The title description can be written up to 80 characters. The default title is “High-Temperature Structural Integrity Evaluation by ASME-NH”.

- ***MAT** : structural material option for base metal
    1. OPTION [ 304S, 316S, 800H, 2QCR1MO, 9CR1MOV ]

    < OPTION Meanings >
    304S = 304 stainless steel
    316S = 316 stainless steel (default)
    800H = Alloy 800H
    2QCR1MO = 2(1/4)Cr-1Mo steel
    9CR1MOV = 9Cr-1Mo-V steel

- ***WELDMENT** : welding option for weldment evaluation

  1. OPTION [ 0, A1,A2,A3,B1,B2,B3,C1,C2,D1,E1 ]

  < OPTION Meanings >

  0 = no weldment (default)
  A1, A2, A3 = Type 304 SS welded Table A1, A2, and A3 in ASME-NH Code
  B1, B2, B3 = Type 316 SS welded Table B1, B2, and B3 in ASME-NH Code
  C1, C2 = Alloy 800H welded Table C1 and C2 in ASME-NH Code
  D1 = 2(1/4)Cr-1Mo steel welded Table D1 in ASME-NH Code
  E1 = 9Cr-1Mo-V steel welded Table E1 in ASME-NH Code

- ***DB-TYPE** : material database evaluations

  1. OPTION [ MAT-E, MAT-SY, MAT-SO, MAT-SM, etc ]

  < OPTION Meanings >

  MAT-E = Elastic modulus (*E*)
  MAT-SY = Yield strength values (*Sy*)
  MAT-SO = Maximum allowable stress intensity for design condition
  MAT-SM = Time-independent allowable stress intensity values (*Smt*)
  MAT-ST = Time-dependent allowable stress intensity values (*St*)
  MAT-SMT = Lower of two stress intensity values, *Sm* and *St* (*Smt*)
  MAT-ST-TIME = Maximum allowable time by *St*-vs-time (*tim*, *tib*, *tir*, *tibr*)
  MAT-SRV = Expected minimum stress-to-rupture values (*Sr*)
  MAT-SRV-TIME = Allowable time duration for creep by *Sr*-vs-time (*Td*)
  MAT-SRV-TIME-WELD = Allowable time duration for creep at weldment
  MAT-SRF = Weld strength reduction factor (*R*)
  MAT-SRS = Stress relaxation strength values (*SrH* , *SrL*) by uniaxial analysis
  MAT-ISO-STRS = Isochronous stress-strain values for stress calculation
  MAT-ISO-STRN = Isochronous stress-strain values for strain calculation
  MAT-ISO-TIME = Isochronous stress-strain for time point determination
  MAT-FATIGUE = Allowable number of cycle for fatigue (*Nd*)

MAT-SMT-WELD = Min [ Smt , 0.8Sr X R ]
MAT-ST-WELD = Min [ St , 0.8Sr X R ]
MAT-SRELAX = Stress relaxation time history from isochronous curves

- ***UMAT** : material database evaluation by subroutine program

- ***P-CHECK** : option for primary stress intensity limits evaluation
  1. OPTION [ 0, 1 ]

  < OPTION Meanings >
  0 = no check (default)
  1 = check

- ***S-CHECK** : option for inelastic strain limits evaluation
  1. OPTION [ 0, 1 ]

  < OPTION Meanings >
  0 = no check (default)
  1 = check

- ***CF-CHECK** : option for creep-fatigue damage evaluation
  1. OPTION [ 0, 1, 2 ]

  < OPTION Meanings >
  0 = no check (default)
  1 = check with elastic analysis method
  2 = check with inelastic analysis method

  When OPTION = 2 is used with the inelastic analysis results, the data files of stress and temperature time histories shall be added in *CF-CHECK command as follows;

```
------------------------------------------------------------------
*CF-CHECK
2
File.*                          ! Stress-time data file name
File.*                          ! Temp-time data file name
OPTION [SEC, MIN, HR]   ! Unit of time data
------------------------------------------------------------------
```

In above input data, the file of the stress-time history shall contain the 4-column data set with a time and 3 components of principal stresses. The file of temperature-time shall contain the 2-column data set with a time and temperature. Note that the time interval points shall be the same in stress-time history and temperature-time history.

The unit of time data is to convert the time data of first row to the hour unit compatible to SIE Code. User can just put the data SEC, MIN and HR when the used unit is second, minute and hour respectively.

- ***MODEL** : option for structural model type

  1. OPTION [ 0, 1 ]

  < OPTION Meanings >

  0 = axisymmetric (default)

  1 = general

- ***PSTRESS** : elastic primary stress components corresponding to stress categories

  1. OPTION [ DESIGN, A, B, C, D ]
  2. ( INDEX )
  3. ( INDEX, PMX, PMY, PMZ, PMXY, PMYZ, PMZX ) $_{i,\,j}$
  4. ( INDEX, PBX, PBY, PBZ, PBXY, PBYZ, PBZX ) $_{i,\,j}$
  5. ( INDEX, PFX, PFY, PFZ, PFXY, PFYZ, PFZX ) $_{i,\,j}$

< OPTION meaning >

DESIGN = design condition
A = service level A
B = service level B
C = service level C
D = service level D

< DATA Line Meanings >

INDEX = user defined arbitrary index
PMX, - - - - - - = six-components of primary membrane stress (Pa)
PBX, - - - - - - = six-components of primary bending stress (Pa)
PFX, - - - - - - = six-components of primary peak stress (Pa)

INDEX in Data Line 2 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

INDEXs in DATA Line 3 to 5 can be also used to identify the stress categories. For examples are; “PM” for primary membrane, “PB” for primary bending, and “PF” for primary peak stress.

When MOPT=1 (Axisymmetric), X is the radial stress, Y is the axial stress, and Z is the hoop stress in the stress components input lines.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed. The data line 2 to data line 5 has to be repeated for each evaluation point, j and the cycle type, i sequentially.

For example in case of 2-cycle types and 2-evaluation points;

```
*PSTRESS
 A                                  ! service level A condition for cycle type 1
```

```
C1P1                      ! arbitrary INDEX ( cycle type 1, evaluation point 1)
 PM  0.56E7  - - - - -    ! arbitrary INDEX (PM) + membrane stress components
 PB   0.22E7  - - - - -   ! arbitrary INDEX (PB) + bending stress components
 PF  0.29E7  - - - - -    ! arbitrary INDEX (PF) + peak stress components
 C1P2                     ! arbitrary INDEX ( cycle type  1, evaluation point 2)
 PM  - - - - - -
 PB  - - - - - -
 PF - - - - - -
 2                         ! Service Level A & B for cycle type 2
C2P1                       ! arbitrary INDEX (cycle type  2, evaluation point 1)
 PM  - - - - - -
 PB  - - - - - -
 PF - - - - - -
C2P2                       ! arbitrary INDEX (cycle type  2, evaluation point 2)
 PM  - - - - - -
 PB  - - - - - -
 PF - - - - - -
```

- ***PDATA** : maximum temperature and total duration of specified primary load conditions

1. ( INDEX, PTEMP, PTIME ) $_{i,j}$

< DATA Line Meanings >
INDEX = user defined arbitrary index
PTEMP = maximum temperature for the specified cycle type ($^{o}$C)
PTIME = total duration (hour)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed.

- ***MINQSTRESS** : secondary stress components corresponding to stress categories at the minimum stress time point during the stress cycle

1. ( INDEX )
2. ( INDEX, QMX, QMY, QMZ, QMXY, QMYZ, QMZX )$_{i, j}$
3. ( INDEX, QBX, QBY, QBZ, QBXY, QBYZ, QBZX )$_{i, j}$
4. ( INDEX, QFX, QFY, QFZ, QFXY, QFYZ, QFZX )$_{i, j}$

< DATA Line Meanings >
INDEX = user defined arbitrary index
QMX, - - - = six-components of secondary membrane stress components (Pa)
QBX, - - - = six-components of secondary bending stress components (Pa)
QFX, - - - = six-components of secondary peak stress components (Pa)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

INDEXs in DATA Line 2 to 4 can be also used to identify the stress categories. For examples are; “QM” for secondary membrane, “QB” for secondary bending, and “QF” for secondary peak stress.

When MOPT=1 (Axisymmetric), X is the radial stress, Y is the axial stress, and Z is the hoop stress in the stress components input lines.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed. The data line 1 to data line 4 have to be repeated for each evaluation point, j and cycle type, i sequentially.

- ***MAXQSTRESS** : secondary stress components corresponding to stress categories at the maximum stress time point during the stress cycle

  1. ( INDEX )
  2. ( INDEX, QMX, QMY, QMZ, QMXY, QMYZ, QMZX )$_{i,j}$
  3. ( INDEX, QBX, QBY, QBZ, QBXY, QBYZ, QBZX )$_{i,j}$
  4. ( INDEX, QFX, QFY, QFZ, QFXY, QFYZ, QFZX )$_{i,j}$

  < DATA Line Meanings >
  INDEX = user defined arbitrary index
  QMX, - - - = six-components of secondary membrane stress components (Pa)
  QBX, - - - = six-components of secondary bending stress components (Pa)
  QFX, - - - = six-components of secondary peak stress components (Pa)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

INDEXs in DATA Line 2 to 4 can be also used to identify the stress categories. For examples are; “QM” for secondary membrane, “QB” for secondary bending, and “QF” for secondary peak stress.

When MOPT=1 (Axisymmetric), X is the radial stress, Y is the axial stress, and Z is the hoop stress in the stress components input lines.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed. The data line 1 to data line 4 have to be repeated for each evaluation point, j and cycle type, i sequentially.

- ***LOADHISTORY** : combination of the temperature-time blocks for a complete sequential load history generation based on the defined-cycle types **only for Creep Ratcheting Strain Evaluation by Simplified Inelastic Analysis**

1. (NSET)
2. ( INDEX, NTBT, NR )$_{i=NSET}$
3. ( INDEX, CTN, DUTATION )$_{i=NSET,\ j=NTBT}$

< DATA Line Meanings >

NSET = number of load sets
NTBT = number of temp-time block types for each set
NR = number of repetition for each set
CTN = cycle type number
DURATION = duration time (hour)

This command will be only used in the creep ratchet strain limit evaluation using the rule of the simplified inelastic analysis in ASME-NH Appendix T.

The load history generated in this command should be based on the combinations of each cycle type selected as the representative load cycles. Actually the determination of the time durations for each temperature-time block is just on responsibility of the designer but this can be done by distributing the all transient cycle types uniformly over the design life time of the plant as described in ASME-NH T-1331(b). Note that the times to be determined as temperature-time blocks shall always sum to the entire design life time regardless of whether all or only part of the cycles are evaluated.

- ***DESIGNLIFE** : the total design life time of class 1 components

1. ( TDL )

< DATA Line Meanings >

TDL = total design life time (hours)

- ***CYCLE** : number of cycles for each cycle type **for Creep-Fatigue Evaluations**

  1. ( INDEX, NCYC ) $_{i=NCT}$

  < DATA Line Meanings >

  INDEX = user defined arbitrary index

  NCYC = total cyclic number for each cycle type

- ***WATEMP** : the maximum and minimum wall averaged temperature

  1. ( INDEX, WATEMP-L, WATEMP-H ) $_{i, j}$

  < DATA Line Meanings >

  INDEX = user defined arbitrary index

  WATEMP-L = minimum wall averaged temperature ($^{o}$C)

  WATEMP-H = maximum wall averaged temperature ($^{o}$C)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed.

- ***HCTEMP** : hot and cold temperatures for the stress extremes

  1. ( INDEX, CTEMP, HTEMP ) $_{i, j}$

< DATA Line Meanings >
INDEX = user defined arbitrary index
CTEMP = cold temperature ($^o$C)
HTEMP = hot temperature ($^o$C)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed.

- ***EXTEMP** : the wall averaged temperatures for the stress extremes defining the maximum secondary stress range, $(Q_R)_{\max}$

1. ( INDEX, EXTEMP-L, EXTEMP-H ) $_{i,\,j}$

< DATA Line Meanings >
INDEX = user defined arbitrary index
EXTEMP-L = lower wall averaged temperature ($^o$C)
EXTEMP-H = higher wall averaged temperature ($^o$C)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed.

- ***MMTEMP** : the maximum metal temperature during the cycle

  1. ( INDEX, MMTEMP ) $_{i, j}$

  < DATA Line Meanings >

  INDEX = user defined arbitrary index

  MMTEMP = maximum metal temperature during the cycle ($^{o}$C)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed.

- ***HDTEMP** : hold temperature for the normal operation

  1. ( INDEX, HDTEMP ) $_{j}$

  < DATA Line Meanings >

  INDEX = user defined arbitrary index

  HDTEMP = hold temperature for the creep evaluation ($^{o}$C)

INDEX in Data Line 1 can be used to identify the evaluation points with arbitrary index by user. For example is; “P1” for the evaluation point 1.

Since the hold temperature is independent of cycle definition, it is necessary to define the hold temperature only for the evaluation points, j. Therefore, when evaluating the multi-evaluation points, input data should be sequentially prepared with the increasing order of specified evaluation points.

- ***STRAIN-C** : elastic strain components for calculating the maximum strain range

  1. ( INDEX )
  2. ( INDEX, SX1, SY1, SZ1, SXY1, SYZ1, SZX1 )$_{i,\,j}$
  3. ( INDEX, SX2, SY2, SZ2, SXY2, SYZ2, SZX2 )$_{i,\,j}$

  < DATA Line Meanings >
  INDEX = user defined arbitrary index
  SX1,- - - = six-strain components at minimum extreme time point during the cycle (m/m)
  SX2, - - - = six-strain components at maximum extreme time point during the cycle (m/m)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; "C1P1" for the cycle type 1 and the evaluation point 1.

INDEXs in DATA Line 2 and 3 can be also used to identify the extreme time points which can be the minimum or the maximum for the cycle. For examples are; "MIN" for the minimum extreme time point and "MAX" for the maximum extreme time point.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed. The data line 1 and 2 have to be repeated for each evaluation point, j and cycle type, i sequentially.

If the user can have the data of the maximum elastic strain ranges rather than the strain components, *STRAIN-R command can be used for the evaluation instead of *STRAIN-C command.

- ***STRAIN-R** : the maximum elastic strain range for creep-fatigue evaluation

  1. ( INDEX, SRANGE ) $_{i,\,j}$

  < DATA Line Meanings >

  INDEX = user defined arbitrary index

  SRANGE = maximum strain range for the cycle (m/m)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; “C1P1” for the cycle type 1 and the evaluation point 1.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed.

To prepare SRANGE data values, the complementary program of MAX-STRN-RANGE can be used. This program requires the strain time history data file containing each component which has the free format type such as (time strn-x strn-y strn-z strn-xy strn-yz strn-zx). Each data field shall be separated with the delimiter of space.

If the user can have the data of the strain components at the extreme time points rather than the maximum elastic strain range for the cycle, *STRAIN-C command can be used for the evaluation instead of *STRAIN-R command.

- ***STRAIN-T** : direct input of total strain range for creep-fatigue evaluation **with only cycle types**

  1. ( INDEX, SRANGE ) $_{i=NCT}$

  < DATA Line Meanings >

  INDEX = user defined arbitrary index

SRANGE = total strain range for each cycle type (m/m)

This command is only available to evaluate the creep-fatigue damage without modification of the maximum strain range with multiaxial effects and stress concentration effects.

- ***TRDATA** : the maximum transient temperature and duration

  1. ( INDEX, TRTEMP, TRTIME ) $_{i,\,j}$

  < DATA Line Meanings >

  INDEX = user defined arbitrary index

  TRTEMP = maximum metal temperature during transient operation ($^{o}$C)

  TRTIME = total hours of transient operation (hour)

INDEX in Data Line 1 can be used to identify the cycle types and the evaluation points with arbitrary index by user. For example is; "C1P1" for the cycle type 1 and the evaluation point 1.

When evaluating the multi-cycle types and, or the multi-evaluation points, input data should be repeatedly prepared with the increasing order of specified transient cycle types including all evaluation points corresponding to it. That means, for example, the data for the evaluation points j=1, 2, 3,…,n for cycle type 1 have to be written sequentially and the next data set for the evaluation points j=1, 2, 3,…,n for cycle type 2 have to be followed.

- ***DTCREEP** : time step size for integration of the creep damage

  1. ( TSC )

  < DATA Line Meanings >

  TSC = time step size (hour)

Note that the time step size can significantly affect the calculation results of the creep damage. Larger time step size may results in a very conservative evaluation and smaller makes the computing time much longer. However, since the creep damage value can be converged with proper smaller value, user might use the engineering experience in selecting the time step size. Recommended value is 1.0 hour or less.

- ***OUTRES** : control data for the stored output data points on output files

    1. ( NSC )

    < DATA Line Meanings >

    NSC = time step size (hour)

The output files affected by this command are “SRTH.OUT”, “ENVSTR.OUT”, and “CREEP.OUT”. The default value is 1. When using NSC=1 for all time step points, the output file size can be very large due to so long service lifetime over 200,000 hours in most high temperature reactor structures being developed now.

- ***END** : indicator of the end of input data (mandatory)

This command will complete the reading and storing the input data and make return to the main evaluation procedures.

## 3.3 Evaluation Procedures

### 3.3.1 Overall Procedures

The general procedures for high-temperature structural integrity evaluations using the SIE code are as follows;

- **Step 1 :** Determine the representative primary loads for the specified service levels
- **Step 2 :** Primary stress analyses
- **Step 3 :** Determine the representative thermal cycle types for the structural design

- **Step 4 :** Transient temperature distribution analyses for each specified cycle type
- **Step 5 :** Thermal stress analysis for each cycle type
- **Step 6 :** Determine the stress cycle indicating the extreme stress and strain time points during the cycle
- **Step 7 :** Determine the evaluation sections at time corresponding to the maximum stress time point
- **Step 8 :** Extract the input data required in the SIE code for the evaluation points at the time corresponding to the extreme stress and the strain time points from the analysis results
- **Step 9 :** Prepare the SIE input data file
- **Step 10 :** Run the SIE code
- **Step 11 :** Review the evaluation results in output files

In above step 7, the total stress intensity contour is very helpful to determine which locations can be taken as the critical evaluation sections. The recommendation notices to be considered in selecting the critical locations are as follows

* Weld zone
* Maximum stress level
* Maximum Stress range
* Maximum temperature level
* Hold time at maximum temperature level

In above step 8, the input data required in the SIE code are the stress components and the metal temperatures at the extreme stresses during the stress cycle, the maximum and the minimum wall averaged temperature, the strain components at the extreme strains during the strain cycle, and the maximum metal temperature during the cycle.

In most cases, to extract the maximum elastic strain range in above step 8, user can look for the strain cycle and determine the extreme strain time points. Using the elastic strain components at these two extreme time points the maximum strain range can be easily extracted instead of following the complex procedure of ASME-NH T-1413 Step 2 and Step 3.

Fig. 11 shows the overall application procedures of SIE ASME-NH Code.

### 3.3.2 Initial Input Data

The numbers of the cycle types and the evaluation points have to be included in the SIE input file in locations of first and second data lines respectively as follows;

*INDEX, number of cycle types
*INDEX, number of evaluation points

INDEX in data line can be used to identify the data type with arbitrary index by user. For example are; “NCYC” for the number of cycle types and “NPNT” for the number of the evaluation points.

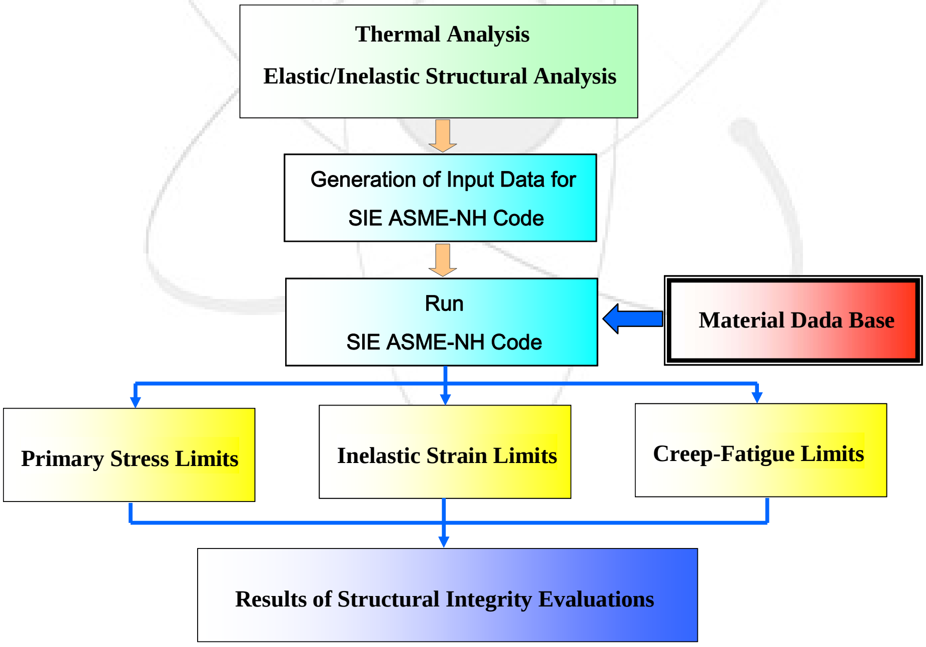


Fig. 11 General Procedures of SIE ASME-NH Code

### 3.3.3 Metal Temperature Data

For the evaluation of the high-temperature structural integrity by the rules of ASME-NH, several kinds of the metal temperature data at the evaluation points, obtained by the thermal analysis, are required as follows;

- Maximum and minimum wall averaged metal temperatures during the cycle (*WATEMP Command):

  These temperatures are used in the rules of the inelastic strain limit using **the elastic analysis method** with consideration of the conservatism such as the primary stress limits and the total inelastic strain limits using the elastic analysis approach. The values such as the yield strength($S_y$), time-independent and time-dependent allowable stress intensities($S_m$, $S_t$), stress-to-rupture time($S_r$-vs-time), and isochronous stress-strain curve are determined with these temperature data.

- Hot and Cold temperatures during the cycle (*HCTEMP Command):

  These temperatures are used to determine the stress relaxation strength ($S_{rH}$, $S_{rL}$). The hot and the cold temperature are defined as the temperatures corresponding to the two stress extremes in the stress cycle respectively. These are not wall averaged values but at local points, therefore different from below of the hot and cold end temperature(*EXTEMP).

- Wall averaged metal temperatures for the stress extremes defining the maximum secondary stress range, $(Q_R)_{\max}$ (*EXTEMP Command):

  These temperatures are used in the rules of the strain limits using **the simplified inelastic analysis method**. As the purpose of this rule is to reduce the conservatism of the code rules, more realistic temperature data are used. The yield strengths($S_{yL}$, $S_{yH}$) and elastic modulus($E_H$, $E_L$) are determined with these temperature data. These are called as the hot and the cold end temperature.

- Maximum metal temperature during the cycle (*MMTEMP Command):

  This temperature is used in the rule of the **fatigue damage** evaluation. The values such as the stress relaxation strengths($S_{rH}$), time-independent allowable stress intensities($S_m$), elastic modulus($E$), isochronous stress-strain, allowable number of cycle for fatigue are determined with these temperature data.

- Hold Temperature (*HDTEMP Command):
  This temperature is used in the rule of the **creep damage** evaluation.

- Transient Temperature (*TRDATA Command):
  This temperature is used in the rule of the **creep damage** calculation to consider the maximum transient metal temperature during the cycle. This value is to be equal to the maximum metal temperature during the cycle type(*MMTEMP).

These metal temperature data may significantly affect the evaluation results of all primary stress limits, inelastic stain limits, and creep-fatigue limits. Therefore, it is required to define the metal temperature data from the thermal analysis results in detail.

The general procedures to obtain the maximum and the minimum wall averaged temperature are as follows;

- **Step 1 :** Select Evaluation Section
- **Step 2 :** Obtain the Temperature Time History for Both Inner and Outer Surface Points
- **Step 3 :** Find Max & Min Temperature Time Points for Both Side
- **Step 4 :** Obtain Temperature Values Through Section for Max & Min Time Points as shown in Fig. 12
- **Step 5 :** Calculate Wall Averaged Temperatures by

$$T_{AVG} = \frac{\sum_{i}^{n-1} d_i \,(T_i + T_{i+1})}{2D}$$

- **Step 6 :** Minimum Wall Averaged Temp = Minimum Value of *TAVG*
  Maximum Wall Averaged Temp = Maximum Value of *TAVG*

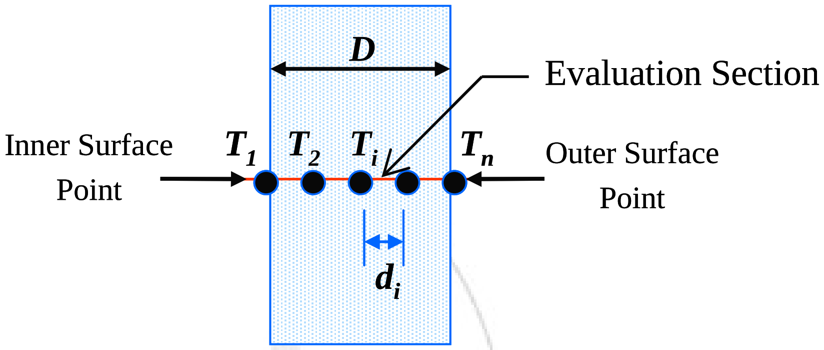


Fig. 12 Temperature Distribution Points through Evaluation Section

### 3.3.4 Load History Concepts

The complete load history of a component should be defined to evaluate the design integrity for a whole service lifetime. Actually the whole load history may be complicated and it can be difficult to delimit each operating cycle type. Therefore, it is required to simplify the load history to apply the structural integrity evaluations. To do this, user should resolve load history into well-defined cycle types as same way of R5 code before entering into the structural integrity evaluations. The representative cycle types with number of occurrence, which can cover all kinds of the design operating conditions for design life time, should be clearly defined.

Actually, the concepts of the load history required in the creep ratcheting stain limit evaluation and the creep-fatigue evaluation are basically different in ASME-NH code. In the strain limit evaluation, the temperature-time block concepts are introduced to be able to evaluate the cyclic creep ratcheting strain accumulation for each cycle of the time block. However, in creep-fatigue damage evaluations, the representative cycle types are required to calculate the maximum elastic-plastic strain ranges and the creep strain increments for each cycle type. The creep strain increment for each cycle type shall be obtained by the same rules used in the inelastic strain limit evaluation.

To avoid the confusion and keep the consistency with ASME-NH in using the defined load cycle types, the load history required in total inelastic strain limit evaluation can be constructed by the combination of the representative cycle types used in all SIE evaluations as shown in Fig. 13. To simplify the construction of a whole load history, the concept of the load sets which consist of several number of cycle types is introduced in SIE ASME-NH program.

For example, when there are 4 cycle types for whole design lifetime of 300,000 hours and assume that there are 2 sets, where the set 1 consists of 2 cycle type and repeat 10 times and the set 2 consists of 3 cycle types and repeat 5 times. Then, it can be constructed by the combination of load sets as follows;

```
-----------------------------------
*DESIGNLIFE
300000
*LOADHISTORY
2   (Total load sets)
SET1  2  10  (for set 1 including 2 cycle types with 10 times)
SET2  3   5   (for set 2 including 3 cycle types with 5 times)
S1C1  1  15000.   (cycle type 1 and 15000 h duration for set 1)
S1C2  2    5000.   (cycle type 2 and 5000 h duration for set 1)
S2C1  1  15000.   (cycle type 1 and 15000 h duration for set 2)
S2C3  3    2000.   (cycle type 3 and 2000 h duration for set 2)
S2C4  4    3000.   (cycle type 4 and 3000 h duration for set 2)
-----------------------------------
```

Note that the total time durations used in load history generation shall not be less than the design life time.

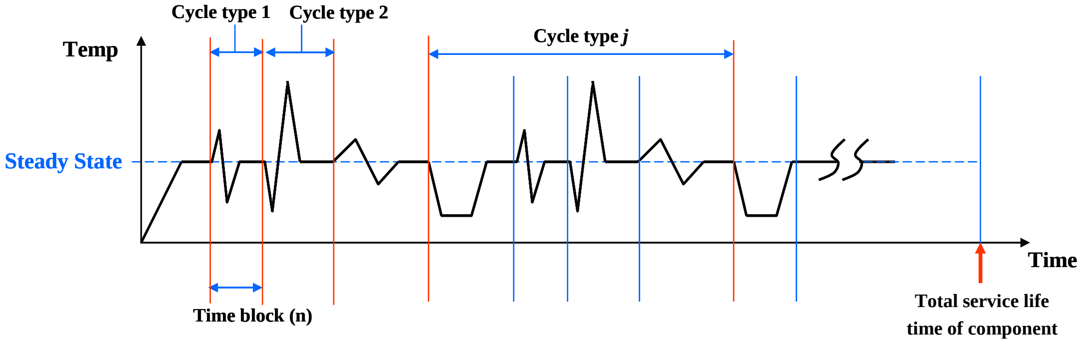


Fig. 13 Exampled Load History Constructed by Cycle Types

### 3.3.5 Weldments Evaluation

When the evaluation points are in the vicinity of a weld (defined by ± 3 times the thickness to either side of the weld centerline), the rules for weldment have to be applied. In SIE code, the command *WELDMENT is provided to support this rule.

For example of Type 316 SS welded with SFA-5.22 E 316T, the command line can be used as follows;

```
------------------------
*WELDMENT
B3
------------------------
```

For each base metal, the various weld metal options are provided as follows;

N = no weldment (default)
A1, A2, A3 = Type 304 SS welded Table A1, A2, and A3 in ASME-NH Code
B1, B2, B3 = Type 316 SS welded Table B1, B2, and B3 in ASME-NH Code
C1, C2 = Alloy 800H welded Table C1 and C2 in ASME-NH Code
D1 = 2(1/4)Cr-1Mo steel welded Table D1 in ASME-NH Code
E1 = 9Cr-1Mo-V steel welded Table E1 in ASME-NH Code

### 3.3.6 Inelastic Analysis Method for Creep-Fatigue

At first, for the fatigue damage evaluation using the inelastic analysis method, the input data of strain components at extreme time points(*STRN-C command) or the maximum equivalent strain ranges(*STRN-R command) are required for each cycle type as same of the elastic analysis method. To do this the inelastic analysis shall be performed with the well-proven constitutive equations. After calculating the strain-time history for the evaluation points, user can run the MAX-STRN-RANGE program to obtain the maximum equivalent strain range from the calculated strain-time history data files for each cycle type. This procedure will reduce the efforts to find the extreme time points of the maximum and minimum strain occurrence during the cycle and simplify the SIE input data file with *STRN-R command. The temperature entering into the allowable fatigue curve should be the maximum metal temperature(*MMTEMP) during the cycle.

The strain-time history data file has a free format with 7 data columns. Each field should be separated by the space delimiter. The first column shall be time data and the rests are strain components data as follows;

```
-----------------------------------------------------------------------------------------------
(Time) (STRN-X) (STRN-Y) (STRN-Z) (STRN-XY) (STRN-YZ) (STRN-ZX)
-----------------------------------------------------------------------------------------------
```

Second, for the creep damage evaluation by the inelastic analysis approach, the stress and the temperature-time history data files are required for a whole load history. To do this, the inelastic stress analysis should be performed with the well-proven constitutive equation for the specified load history. The data file of the stress-time history should have 4-columns data with a free format. The first column shall be time data and the rest 3 columns shall the principal stresses. The temperature data file has two columns. The first column shall be time data and the second column shall be temperature data. These information should be put with *CF-CHECK command as follows;

```
----------------------------------------------------
         *CF-CHECK
         2
         (Stress-time data file name)
```

(Temp-time data file name)

(Unit of time data) [SEC, MIN, HR]

---------------------------------------------------

### 3.3.7 Piping Evaluation

See Appendix B

## 3.4 Input Formats

### 3.4.1 Limits for Primary Stress Intensity

```
*SIE
NCT  -          ! number of cycle types
NEP  -          ! number of evaluation points
*TITLE
-               ! title of evaluation
*MAT
-               ! structural material name
*WELDMENT
-               ! weld metal table name
*MODEL
-               ! analysis model type
*P-CHECK
1               ! primary stress limit check on
*PSTRESS
-               ! service level for i-cycle type and j-point
-               ! user defined index for i-cycle type and j-point
PM - - - - - -  ! 6-primary membrane stress intensity components for i-
                  cycle type and j-point
PB - - - - - -  ! 6-primary bending stress intensity components for i-
                  cycle type and j-point
PF - - - - - -  ! 6-primary peak stress intensity components for i-
                  cycle type and j-point
*PDATA
- - -           ! index, max temp. and duration of elevated temp for i-
                  cycle type and j-point
*END
```

### 3.4.2 Limits for Inelastic Strain

```
*SIE
NCT  -          ! number of cycle types
NEP  -          ! number of evaluation points
*TITLE
-               ! title of evaluation
```

```
*MAT
-               ! structural material name
*WELDMENT
-               ! weld metal name
*MODEL
-               ! analysis model type
*S-CHECK
1               ! inelastic strain limits check on
*PSTRESS
-               ! service level
-               ! user defined arbitrary index
PM - - - - - -  ! 6-primary membrane stress intensity components
PB - - - - - -  ! 6-primary bending stress intensity components
PF - - - - - -  ! 6-primary peak stress intensity components
*MINQSTRESS
-               ! user defined index for i-cycle type and j-point
QM - - - - - -  ! 6-secondary membrane stress intensity components
QB - - - - - -  ! 6-secondary bending stress intensity components
QF - - - - - -  ! 6-secondary peak stress intensity components
*MAXQSTRESS
-               ! user defined index for i-cycle type and j-point
QM - - - - - -  ! 6-secondary membrane stress intensity components
QB - - - - - -  ! 6-secondary bending stress intensity components
QF - - - - - -  ! 6-secondary peak stress intensity components
*DESIGNLIFE
-               ! total service life time
*LOADHISTORY
-               ! number of sets
- - -           ! index, number of cycle types, number of repetitions
                  for k-set
- - -           ! index, cycle type number, duration corresponding to
                  each set type
*WATEMP
- - -           ! index, max and min wall averaged temp for i-cycle
                  type and j-point
*HCTEMP
- - -           ! index, hot and cold temp for i-cycle type and j-point
*EXTEMP
- - -           ! index, extreme temperatures for i-cycle type and j-
                  point
*MMTEMP
- -             ! index, max metal temperature for i-cycle type and j-
                  point
*HDTEMP
- -             ! index, Hold temperature for j-point
*TRDATA
- - -           ! index, Transient temp, and transient duration for i-
                  cycle type and j-point
*END
```

### 3.4.3 Creep-Fatigue Limit Evaluations by Elastic Analysis Method

```
*SIE
NCT  -          ! number of cycle types
NEP  -          ! number of evaluation points
```

```
*TITLE
-               ! title of evaluation
*MAT
-               ! structural material name
*WELDMENT
-               ! weld metal name
*MODEL
-               ! analysis model type
*CF-CHECK
1               ! creep-fatigue limit check on by elastic analysis
*PSTRESS
-               ! service level for i-cycle type and j-point
-               ! user defined index
PM - - - - - -  ! 6-primary membrane stress intensity components
PB - - - - - -  ! 6-primary bending stress intensity components
PF - - - - - -  ! 6-primary peak stress intensity components
*PDATA
- - -           ! index, max temp. and duration of elevated temp for i-
                  cycle type and j-point
*MINQSTRESS
-               ! user defined index for i-cycle type and j-point
QM - - - - - -  ! 6-secondary membrane stress intensity components
QB - - - - - -  ! 6-secondary bending stress intensity components
QF - - - - - -  ! 6-secondary peak stress intensity components
*MAXQSTRESS
-               ! user defined index for i-cycle type and j-point
QM - - - - - -  ! 6-secondary membrane stress intensity components
QB - - - - - -  ! 6-secondary bending stress intensity components
QF - - - - - -  ! 6-secondary peak stress intensity components
*DESIGNLIFE
-               ! total service life time
*CYCLE
- -             ! index and number of cycles for each i-cycle type
*WATEMP
- - -           ! index, max and min wall averaged temp for i-cycle
                  type and j-point
*HCTEMP
- - -           ! index, hot and cold temp for i-cycle type and j-point
*EXTEMP
- - -           ! index, extreme temperatures for i-cycle type and j-
                  point
*MMTEMP
- -             ! index, max metal temperature for i-cycle type and j-
                  point
*HDTEMP
- -             ! index, Hold temperature for j-point
*STRAIN-C
-               ! user defined index
MIN - - - - - - ! 6-strain components at one extreme time point for i-
                  cycle type and j-point
MAX - - - - - - ! 6-strain components at another extreme time point for
                  i-cycle type and j-point
*TRDATA
- - -           ! index, Transient temp, and transient duration for i-
                  cycle type and j-point
*DTCREEP
-               ! Time step size for creep calculation
```

```
*OUTRES
-               ! stored output results every defined step size
*END
```

### 3.4.4 Creep-Fatigue Limit Evaluations by Inelastic Analysis Method

```
*SIE
NCT  -          ! number of cycle types
NEP  -          ! number of evaluation points
*TITLE
-               ! title of evaluation
*MAT
-               ! structural material name
*WELDMENT
-               ! weld metal name
*MODEL
-               ! analysis model type
*CF-CHECK
2               ! creep-fatigue limit check on by inelastic analysis
-               ! stress data file name
-               ! Temp data file name
-               ! unit of time data
*DESIGNLIFE
-               ! total service life time
*CYCLE
- -             ! index and number of cycles for each i-cycle type
*MMTEMP
- -             ! index, max metal temperature for i-cycle type and j-
                  point
*HDTEMP
- -             ! index, Hold temperature for j-point
*STRAIN-C
-               ! user defined index
MIN - - - - - - ! 6-strain components at one extreme time point for i-
                  cycle type and j-point
MAX - - - - - - ! 6-strain components at another extreme time point for
                  i-cycle type and j-point
*DTCREEP
-               ! Time step size for creep calculation
*OUTRES
-               ! stored output results every defined step size
*END
```

### 3.4.5 Material DB Evaluations

```
*MATDB
*MAT
-               ! structural material name
*DB-TYPE
-               ! name of material DB
*END
```

The design material data provided in ASME-NH rules can be digitized and put into data file to evaluate the material database specified in *DB-TYPE command. When executing the input deck with the format of above procedures, the pop-up window will be appear on screen to request additional interactive input data. After completing trhe process, the results file with the file name of “MAT.out” will be generated in working directory. Various examples of application are presented in section 4.5.

# 4. Examples of Application

## 4.1 Elastic Structural Analyses

### 4.1.1 Analysis Model

As an example of application, the head-to-shell type structure with gross structural discontinuity is selected. Fig. 14 shows the analysis model, an axisymmetric cylindrical vessel having a geometric discontinuity at the bottom junction part. The radius of the filet size at the junction part is assumed to be the same as the vessel thickness. It is expected that the stress and the strain concentrations might occur at this part. The used structural material is a Type 316 austenitic stainless steel with a required design lifetime of 240,000 hours(about 28 years) at the elevated temperature operation.

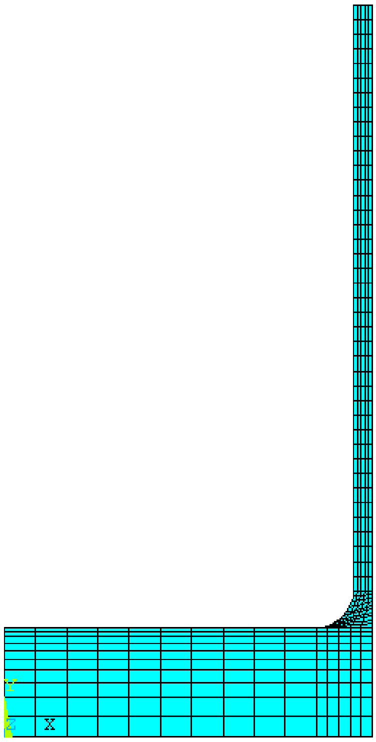


Fig.14 Axisymmetric Finite Analysis Model

The boundary conditions for the mechanical loads and thermal loads are shown in Fig. 15. The bulk temperature of the outer side of the cylindrical vessel is assumed to be maintained 300°C during all transient operating cycles. The inner surface of the cylindrical vessel is subjected to the transient bulk temperature and a constant pressure of 10 bar. For the stress analysis, the vertical displacement degree of freedom is only constrained at the upper end of the cylindrical vessel, therefore the structure can be freely expanded to the radial and vertical directions.

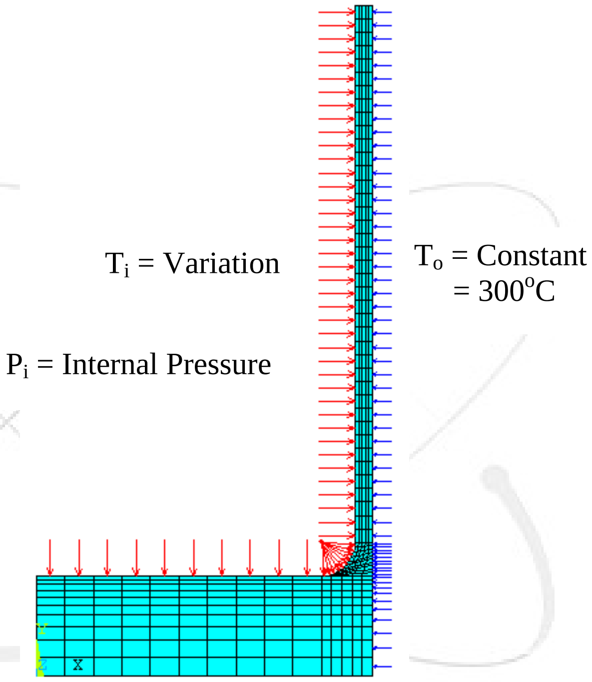


Fig. 15 Analysis Boundary Conditions

### 4.1.2 Thermal Transient Operating Cycles

The assumed representative thermal transient operating cycle type used in this example is shown in Fig. 16. The normal operating temperature $T_{ss}$ is assumed as 550°C. During the transient, the coolant temperature starts to decrease down to $T_1$ during $t_1$ time from the steady state normal temperature $T_{ss}$ and next gradually increase up to $T_2$ during $(t_2 - t_1)$ time and again decrease to the normal operating temperature during $(t_3 - t_2)$ time.

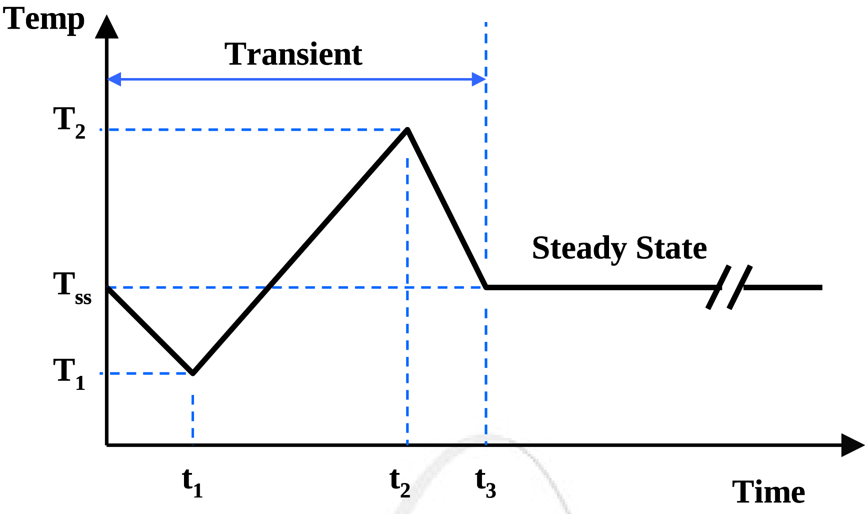
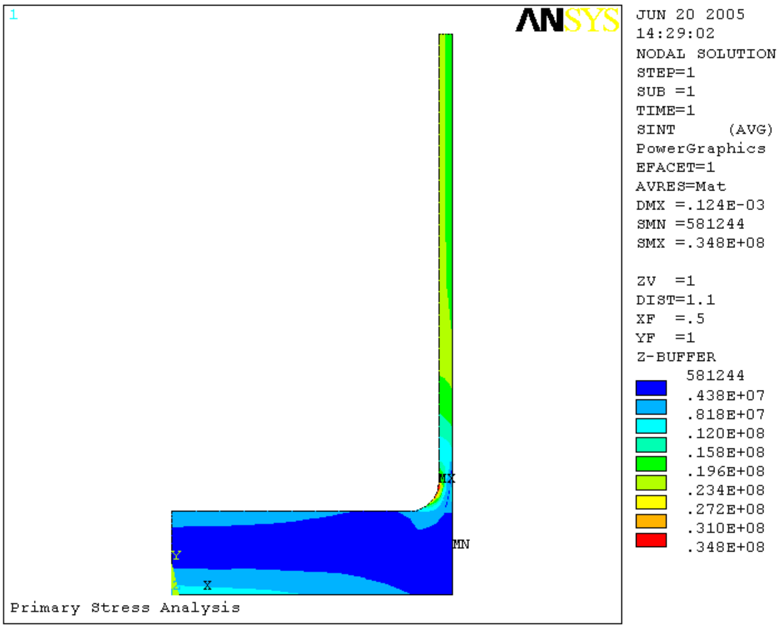


Fig. 16 Assumed Representative Thermal Transient Operating Cycle

### 4.1.3 Load Controlled Stress Analysis

For the design mechanical load, the maximum internal pressure is assumed as 10 bar for the total service life time.

Fig. 17 shows the calculated stress intensity contour. The maximum total stress intensity is 35 MPa and occurs at the inner surface of the junction part.



```
JUN 20 2005
14:29:02
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SINT      (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.124E-03
SMN =581244
SMX =.348E+08

ZV  =1
DIST=1.1
XF  =.5
YF  =1
Z-BUFFER
     581244
     .438E+07
     .818E+07
     .120E+08
     .158E+08
     .196E+08
     .234E+08
     .272E+08
     .310E+08
     .348E+08
```

Fig. 17 Stress Intensity Contour for Internal Pressure Load

## 4.2 Example 1: Single Operating Cycle Type

### 4.2.1 Temperature Distribution Analysis

The cycle type 1 used in this evaluation is shown in Fig. 16. In figure, the coolant temperature starts to decrease down to 500 °C from the normal operating temperature, 550°C for 5 hours and next gradually increase to 650°C for 5 hours and recovers again the normal operating temperature after 5 hours. Therefore, total transient duration is 15 hours.

The duration of the cycle type 1 is assumed as 20000 hours and the number of occurrence is 12 cycles, which is complied with the assumed total design lifetime, 240,000 hours.

Fig. 18 and Fig. 19 show the temperature distribution for the time points occurring the extreme thermal stresses respectively.

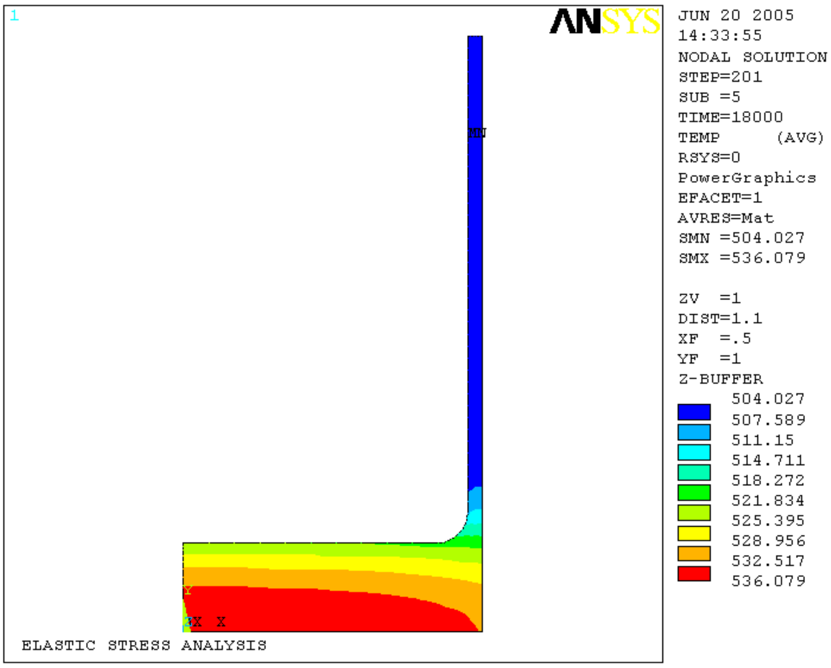


Fig. 18 Temperature Distributions at Time = 18000 Seconds

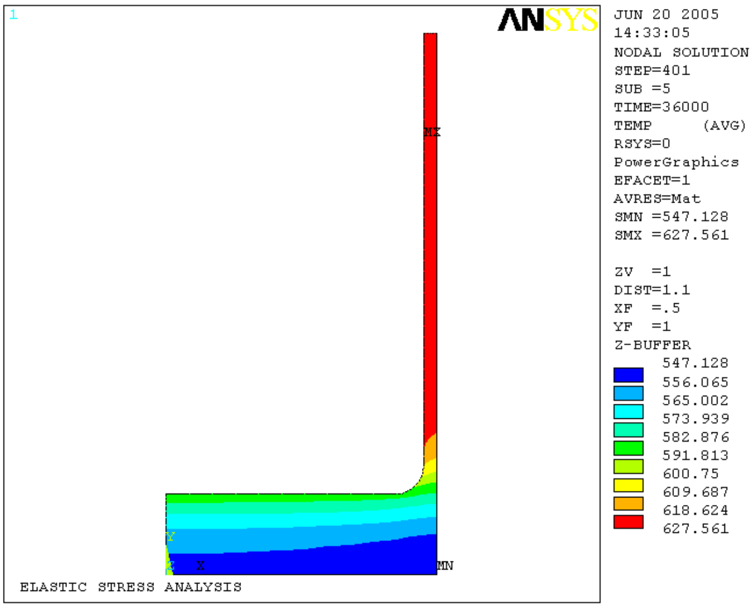


Fig. 19 Temperature Distributions at Time = 36000 Seconds

### 4.2.2 Thermal Stress Cycles

Fig. 20 shows the thermal stress time histories for each stress component at an arbitrary inner surface point of the junction part. As shown in the results, the axial component is dominant and the maximum and minimum extreme stresses occur in time points of 18000 seconds and 36000 seconds respectively. These extreme time points are almost same for any nodal points at the junction part. Therefore these time points will be used to calculate the maximum range of the secondary stress intensity at the evaluation points.

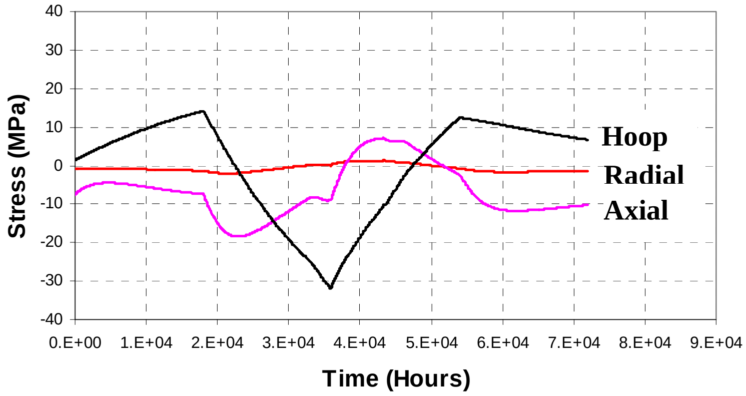


Fig. 20 Stress Time History for Each Component

### 4.2.3 Define Critical Locations

To determine the critical locations for the representative high temperature structural evaluations, the stress contours for the primary stress and the secondary stress intensity are investigated as shown in Fig. 17 and Fig. 21. From figures, the maximum primary stress occurs at the junction part and also the maximum secondary stress intensity occur almost the same location of that of the primary stress at the extreme time points. Therefore, the evaluation section is selected between the inner surface node number 200 and the outer surface node number 186, which is expected to give the maximum membrane stress intensity value.

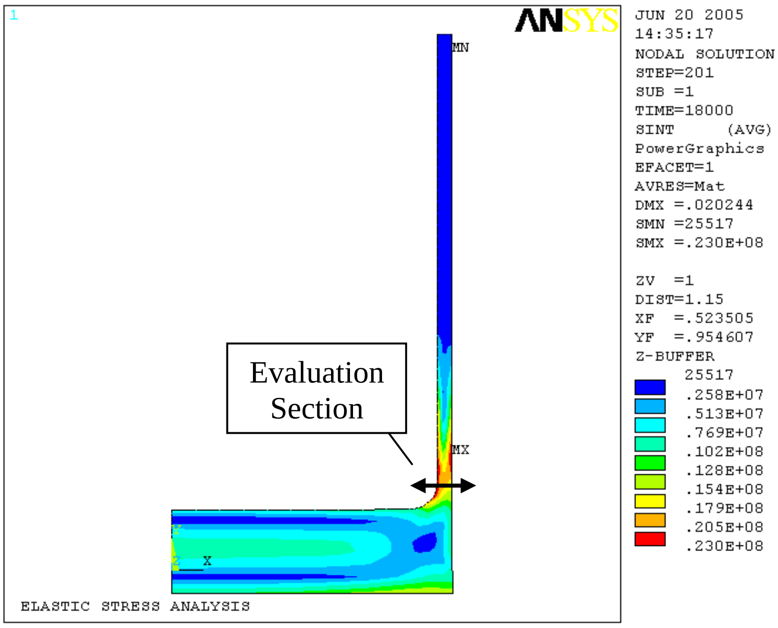


Fig. 21 Thermal Stress Intensity Contour and Evaluation Section

### 4.2.4 Input Data

In this example, the number of the cycle type is 1 and the number of evaluation points is 2, i.e., inner and outer points on the selected evaluation section.

The structural material is 316SS and the evaluation points are assumed to be far away from the welding zone.

The required metal temperature data determined at the evaluation points are as follows;

- At evaluation point 1 :
    - Maximum wall averaged temperature = 604.0$^{o}$C
    - Minimum wall averaged temperature = 512.3$^{o}$C
    - Hot extreme metal temperature = 605.5$^{o}$C
    - Cold extreme metal temperature = 512.1$^{o}$C
    - Maximum metal temperature during the cycle = 611.2$^{o}$C
    - Hold temperature = 546.8$^{o}$C

- At evaluation point 2 :
    - Maximum wall averaged temperature = 604.0$^{o}$C
    - Minimum wall averaged temperature = 512.3$^{o}$C
    - Hot extreme metal temperature = 602.4$^{o}$C
    - Cold extreme metal temperature = 512.5$^{o}$C
    - Maximum metal temperature during the cycle = 610.1$^{o}$C
    - Hold temperature = 546.1$^{o}$C

The transient duration is 15 hours and the time step size is selected as 1.0 hour to integrate the creep damage from the stress relaxation time history.

The prepared final SIE input data is shown in Table 1.

Table 1. Input Data Lists for Example 1

```
=======================================================================
*SIE
NCT  1          ! 1 cycle type
NEP  2          ! 2 evaluation points
*TITLE
EXAMPLE 1 for 1-Cycle Types and 2-Evaluation Points
*MAT
316S            ! Structural material = 316 austenitic stainless steel
*WELDMENT
N               ! For base metal
*MODEL
0               ! Axisymmetric model
*P-CHECK
1               ! Primary stress limit check
*S-CHECK
1               ! Inelastic strain limit check
```

```
*CF-CHECK
1               ! Creep-fatigue damage limit check
*PSTRESS
C               ! Service level C
C1P1
PM  0.8050E+06  0.9378E+07  0.1330E+07  0.2726E+07  0.000  0.000
PB  0.2867E+06  0.2046E+08  0.6240E+07  0.2466E+07  0.000  0.000
PF -0.5594E+06  0.3543E+07  0.9807E+06  0.5433E+06  0.000  0.000
C1P2
PM  0.8050E+06  0.9378E+07  0.1330E+07  0.2726E+07  0.000  0.000
PB -0.2867E+06 -0.2046E+08 -0.6240E+07 -0.2466E+07  0.000  0.000
PF -0.2182E+06  0.1084E+07  0.3168E+06  0.2989E+06  0.000  0.000
*PDATA
C1P1 611.2 240000.
C1P2 610.1 240000.
*MINQSTRESS
C1P1
QM -0.2266E+06  0.1390E+06 -0.2350E+08  0.3067E+07  0.000  0.000
QB -0.2767E+06 -0.2107E+08 -0.1297E+08 -0.9762E+06  0.000  0.000
QF  0.8746E+05 -0.7344E+06 -0.1998E+07 -0.2599E+07  0.000  0.000
C1P2
QM -0.2266E+06  0.1390E+06 -0.2350E+08  0.3067E+07  0.000  0.000
QB  0.2767E+06  0.2107E+08  0.1297E+08  0.9762E+06  0.000  0.000
QF -0.1943E+05  0.6906E+05 -0.1721E+07 -0.2192E+07  0.000  0.000
*MAXQSTRESS
C1P1
QM -0.3923E+06 -0.2548E+06  0.1558E+08 -0.2275E+07  0.000  0.000
QB -0.1584E+06 -0.1426E+07  0.1233E+07 -0.4098E+06  0.000  0.000
QF  0.1981E+06 -0.7047E+06  0.5818E+06  0.8781E+06  0.000  0.000
C1P2
QM -0.3923E+06 -0.2548E+06  0.1558E+08 -0.2275E+07  0.000  0.000
QB  0.1584E+06  0.1426E+07 -0.1233E+07  0.4098E+06  0.000  0.000
QF  0.1188E+06 -0.3200E+06  0.5541E+06  0.8426E+06  0.000  0.000
*DESIGNLIFE
240000.          ! total service life = 240000 hours
*LOADHISTORY     ! specify load history
1
SET1 1 12        ! number of cycle type=1, repeat=12 for set 1
S1C1 1 20000.    ! seq. no = 1, cycle type = 1, duration = 20000 hours
*CYCLE
C1 12            ! number of cycles
*WATEMP
C1P1 512.3 604.0 ! max and min wall averaged temperature at point 1
C1P2 512.3 604.0 ! max and min wall averaged temperature at point 2
*HCTEMP
C1P1 512.1 605.5 ! cold and hot temperatures at point 1
C1P2 512.5 602.4 ! cold and hot temperatures at point 1
*EXTEMP
C1P1 512.3 604.0 ! wall averaged extreme temperatures at point 1
C1P2 512.3 604.0 ! wall averaged extreme temperatures at point 2
*MMTEMP
C1P1 611.2       ! max metal temperature at point 1
C1P2 610.1       ! max metal temperature at point 2
*HDTEMP
P1 546.8         ! Hold temperature for point 1
P2 546.1         ! Hold temperature for point 2
*STRAIN-C
```

```
C1P1
MIN  0.11910E-03 -0.64670E-04 -0.21002E-03 -0.87877E-05  0.00  0.00
MAX -0.31131E-04 -0.47836E-04  0.11477E-03 -0.29705E-04  0.00  0.00
C1P2
MIN -0.18102E-04  0.16565E-03 -0.12426E-03  0.32013E-04  0.00  0.00
MAX -0.31070E-04 -0.23128E-04  0.92396E-04 -0.16819E-04  0.00  0.00
*TRDATA
C1P1 611.2 15.0  ! Transient temp= 624.5oC, transient duration=2 hours
C1P2 610.1 15.0  ! Transient temp= 624.3oC, transient duration=2 hours
*DTCREEP
1.               ! Time step size for creep calculation = 0.1 hour
*OUTRES
10               ! Stored output results every 10 steps
*END
======================================================================
```

### 4.2.5 Evaluation Results and Discussions

Appendix B shows the output results of the high-temperature structural integrity evaluations for the example 1 by the SIE code. In output lists, the bullet mark, "*" indicates the given input data, "-" indicates the calculated more important result value, no-bullet mark indicates calculated values, and [CHK] shows the checking results whether the code rules are satisfied or not for the base metal and the weldment.

#### 4.2.5.1 Primary Stress Limits

As assumed in the SIE input data, the used primary load is taken as the service level C condition.

At evaluation point 1, the calculated general primary membrane stress intensity, $P_m$ is 10.2 MPa, which satisfies the time-dependent allowable stress intensity limit $1.0S_t = 49.0$ MPa at the maximum metal temperature, 611.2$^{o}$C with enough design margin. The obtained use-fraction sum associated with the general primary membrane stress is almost 0.23, therefore, this rule satisfies the limit of B=1.0.

The calculated primary membrane plus bending stress intensity, $(P_m + P_b)$ is 30.6 MPa, which satisfies the time-independent allowable stress intensity limit multiplied with section factor, $1.2KS_m$=180.6 MPa. The calculated primary membrane plus bending stress intensity modified with the bending stress reduction factor due to the effects of creep, $(P_m + P_b/K_t)$ is = 26.4 MPa, which satisfies the time-dependent allowable stress intensity limit, $S_t$ = 49.0MPa. The obtained use-fraction sum associated with the stress level of $(P_m +$

$P_b/K_t$) = 26.4 MPa is 0.34. This value also satisfies the limit of 1.0 with enough design margin.

The calculated bending stress intensity at the evaluation point 2 is much smaller than that of the evaluation point 1. Therefore, all primary stress limits can be satisfied at this point with enough design margins as shown in Appendix B.

### 4.2.5.2 Total Inelastic Strain Limits

Actually total inelastic strain limit rule is intended to prevent the progressive ratcheting strain under consideration of the creep conditions. ASME-NH Appendix T provides two ways to evaluate this undesirable inelastic strain accumulation during total service life time of the components. One is the elastic analysis, which is simple but very conservative the other one is the simplified inelastic analysis, which is very complicated but less conservative.

When using the elastic analysis, the total inelastic strain limits, i.e., the creep ratcheting limits, will be satisfied if one of Test Nos, A-1, A-2, and A-3 is satisfied. For the evaluation points 1 and 2, the calculated primary stress parameter, $X$ is 0.229 and 0.067 and the secondary stress parameter, $Y$ is 0.472 and 0.404 respectively. The calculated parameter values are located in regime $E$ in the Bree diagram. Therefore, from the Test Nos. A-1 or A-2 no ratcheting is expected in this evaluation points.

For Test No. A-3, the limits of NB-3222-2(3Sm limit), NB-3222-3(Expansion stress intensity limit), and NB-3222.5(Thermal stress ratchet limit) were checked to be satisfied for both two points with the rules, therefore the additional requirements for Test No A-3 such as (1) the use-fraction sum, (2) the creep strain limit, and (3) 3Sm limits were checked out. In this evaluation, only 3Sm limits are satisfied at both evaluation points 1 and 2 but the limits of the use-fraction sum and the creep limits are not satisfied. In calculation of the use-fraction sum, the total duration is separated by the total transient time, 15 hours x 12 cycles = 180 hours, and the rest normal operation time, (240,000 hours – 180 hours) = 239820 hours. For the transient operation of Point 1, the maximum allowable time corresponding to the temperature T=610.4 $^{o}$C and a stress value of 1.5Sy|T (169.8 MPa) is obtained as 1216.4 hours from the expected minimum stress-to-rupture values of ASME-NH Table I-14.6A. Therefore, the use-fraction sum is calculated as 0.148 for the transient operation. However, for the normal operation, the maximum allowable time corresponding to the temperature 546.8$^{o}$C and a stress value of 1.5Sy|T (174.2 MPa) is 44647.1 hours. This results in a large use-fraction sum of 5.37 due to a long normal operation time of 239820 hours. Therefore, the total use-fraction sum becomes 5.52 and significantly exceeds the limit value of 0.1. Also for the creep strain limits, the required stress level of 1.25$S_y$|T is too much conservative. The stress level of 1.25$S_y$|T (142.5MPa) for normal operation with a total service lifetime of 239820 hours results in over creep strain value beyond the data range of the isochronous stress-strain curve provided in ASME-NH Appendix T. For the 3Sm limit rules, the calculated maximum range of (PL + Pb + Q) is 54.5 MPa, which satisfies the 3Sm = 216.6 MPa with enough margin.

In conclusion, it is not possible to satisfy the rule of Test No. A-3 in design of any high-temperature reactor structures having a long service life time over 30 years.

Next, when using simplified inelastic analysis, the total inelastic strain limits are satisfied if one of the limits of Test Nos, B-1 and B-2, and B-3 are satisfied. These rules are restricted in using only when the averaged wall temperature at one of the stress extremes defining each secondary stress range $Q_R$ is below the temperature ranges given at Table T-1323 in ASME-NH. In this example, these tests are available since the cold temperature in defining each secondary stress range $Q_R$ is 512.1$^{o}$C, which is below the applicable temperature, 544$^{o}$C for Type 316 SS, of Table T-1323 in ASME-NH.

Exampled analysis model is axisymmetric, therefore the Test Nos. B-1 or B-3 can be used. One of important rules in this evaluation is that the secondary stress with the thermal induced membrane stresses should be classified as primary stresses. And another one is that in calculating the stress parameters, $X$ and $Y$ the yield strength value $S_y$ has to be replaced by the $S_{yL}$ value which corresponding to the lower of the wall averaged temperatures for the stress extremes defining the secondary stress range, $Q_R$. Complying with this rule the primary stress parameter $X$ is calculated as 0.385 for the evaluation point 1 and 0.248 for the evaluation point 2 respectively and the secondary stress parameter $Y$ is 0.166 for both the evaluation point 1 and 2. In these calculations the primary stress index X at inner surface(point1) is higher than that at the outer surface(point 2). All calculated stress index values are located in regime *E* of the Bree diagram, therefore the creep stress parameter Z is the same as those of the X values, i.e. 0. 385 for point 1 and 0.248 for point 2. The yield strength value($S_{yL}$) at the cold temperature is 117.5 MPa. From the above determined values, the effective creep ratcheting stress 1.25Sc is calculated as 56.6 MPa at the evaluation point 1 and 36.5 MPa at the evaluation point 2 respectively. To calculate the total accumulated creep ratcheting strain, it is necessary to specify the load history for the whole design life time. In this evaluation, only one representative cycle type is assumed, therefore, no load history is defined. The calculated effective creep ratchet stress will be entered to the isochronous stress-strain curve with the total duration of 240,000 hours and the maximum wall averaged temperature of 604.0 $^{o}$C to calculate the total creep ratcheting strain. The determined total inelastic strain is 0.211 % at the evaluation point 1 and 0.0349 % at the evaluation point 2 respectively, which satisfy the total inelastic strain limits of 1.0 % for the base metal and 0.5 % for the weldment. Actually to reduce the conservatism, the metal temperatures entering the isochronous stress-strain curve shall be selected in the temperature-time history within each temperature-time block but in this report, the maximum wall averaged temperature during the cycle is used to consider the conservatism.

Additionally, when using the Test No B-3, which can separately evaluate the inelastic strains due to any number of selected operational cycles, the calculated enhanced creep strain increment and the plastic ratchet strain increment are all the same as those of Test No A-2 calculations as all zero as shown in the detailed output lists of Appendix C. Therefore, the total inelastic strains are the same as those calculated by Test B-1.

### 4.2.5.3 Creep-Fatigue Damages

In this evaluation, the maximum metal temperature occurring during the cycle shall be used in stead of the wall averaged temperature.

First, to evaluate the fatigue damage, the total numbers of cycle is assumed to be 12, which has the duration of 24000 hours for each cycle. The calculated elastic strain ranges are 0.0321 % for point 1 and 0.0273 % for point 2. These values are defined as the maximum elastic strain range $\Delta\varepsilon_{\max}$. The modified maximum equivalent strain range, $\Delta\varepsilon_{\mathrm{mod}}$, is obtained as by the Eq.(21), which is based on the Neuber's rule. The equivalent stress concentration factors defined as the effective(von Mises) primary plus secondary plus peak stress divided by the effective primary plus secondary stress are calculated as 1.12 for point 1 and 1.06 for point 2. This result means that the stress concentration is so small because the evaluation points are almost the end of the fillet region, however this is slightly larger at inner surface than at the outer surface due to a global geometric discontinuity region of inner surface. The modified strain ranges are 0.036 % for point 1 and 0.029 % for point 2. As shown in the output lists, the determined multiaxial adjustment factors are 1.0, then the multiaxial plasticity and the Poisson ratio do not affect the modified strain range. The creep strain increments multiplying with the equivalent stress concentration factor for single cycle duration are 0.0229 % for point 1 and 0.0037 % for point 2. Therefore the total strain ranges obtained for the fatigue damage are 0.0588 % for point 1 and 0.0325 % for point 2. These total strain ranges are very small under the data range of the fatigue damage-strain curves provided by ASME-NH code at given temperature. Therefore, the fatigue damages corresponding to the total strain range are 0.4E-5 for Point 1 and 0.3E-5 for Point 2 respectively.

For creep damage evaluation, the total hold time is defined as 240000 hours and the hold temperature is 546.8°C for point 1 and 546.1°C for point 2. The number of the cycle is assumed to be 12, then the averaged cycle time is 20000 hours. The stress level corresponding to the total strain range previously obtained is 81.4 MPa for point 1 and 44.6 MPa for point 2. By entering these stress levels as the initial values to the isochrounous stress-strain curves, the stress relaxation time history curves can be obtained as Fig. 22 and Fig. 23. The lower bound stresses $S_{LB}$ for each point are 56.6 MPa and 36.5 MPa respectively, which are much lower than the stress relaxation data curves. To obtain the creep damage corresponding to the stress relaxation time history from the expected minimum stress-to-rupture curves, the integration time step size is selected to be 1.0 hours. To consider the transient conditions in calculating the creep damage, the stress relaxation time history can be modified with the load controlled stresses. During the transient condition of 15.0 hours, the maximum primary stress intensity is 30.56 MPa for point 1 and 11.61 MPa for point 2, which are so lower than those of the stress relaxation time histories. Therefore, no further modification of the stress-time history is required. However, the maximum transient temperatures during the transient conditions have to be considered in calculating the creep damage. Finally the stress-time history data should be divided by the safety factor 0.9 for the austenitic stainless steel before entering to the expected minimum stress-to-rupture curve. Fig. 24 shows the cumulative creep damage curve for a cycle. The obtained total creep damages are 0.3188 for point 1 and 0.2345 for point 2, which satisfy the creep-fatigue interaction limit curves as shown in Fig. 25.

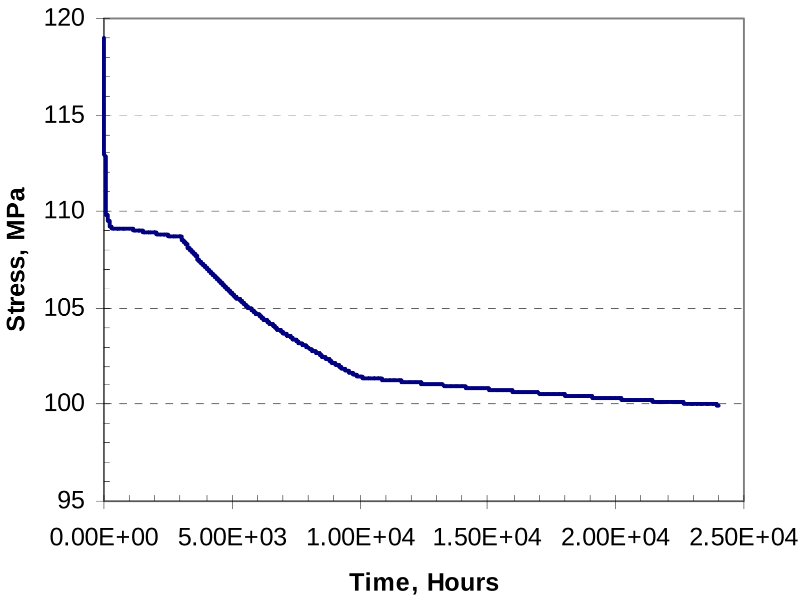


Fig. 22 Obtained Stress Relaxation Time History for Evaluation Point 1

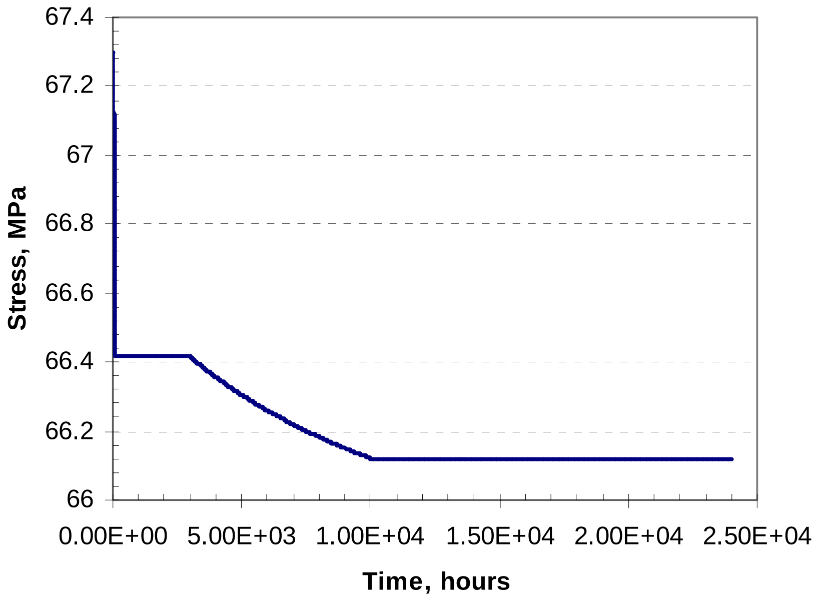


Fig. 23 Obtained Stress Relaxation Time History for Evaluation Point 2

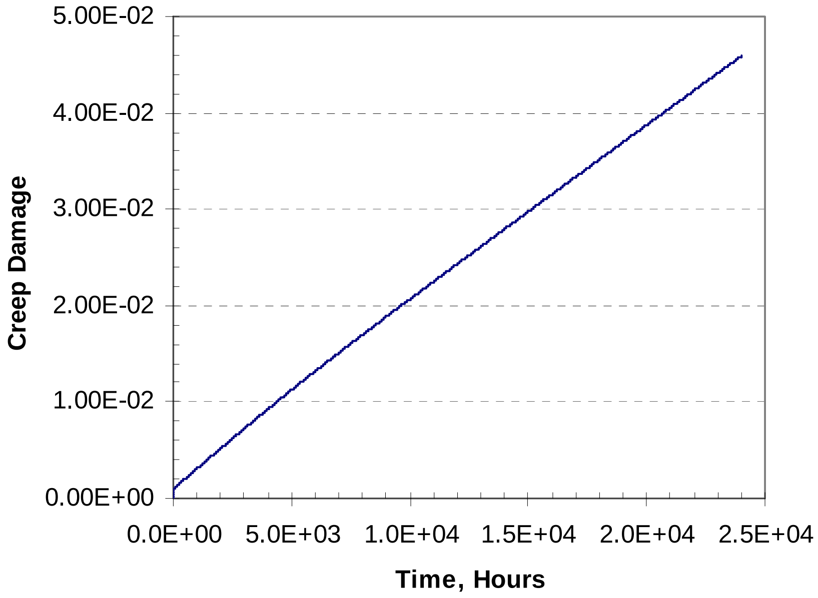


Fig. 24 Creep Damage Curve for a cycle at Point 1

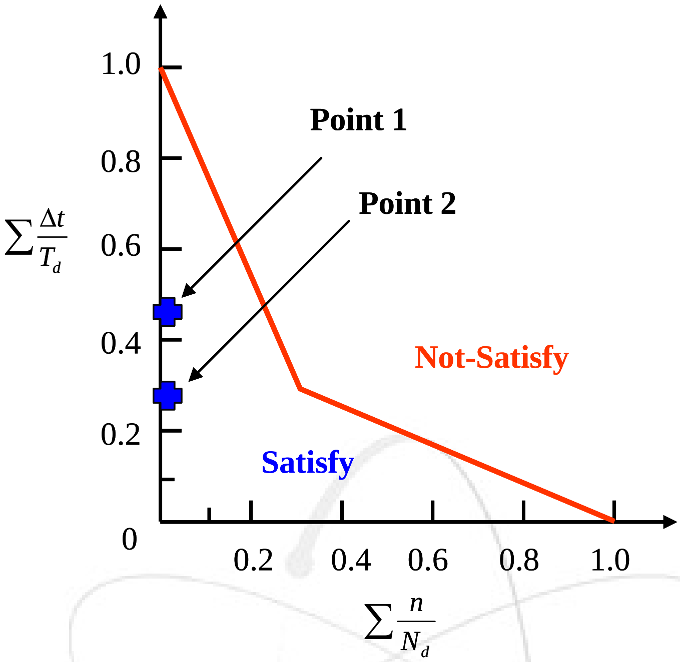


Fig. 25 Check of Creep-Fatigue Interaction Curve

Table 2 shows the summary of the structural integrity evaluations of point 1 for the example 1.

Table 2. Summary of Evaluation Results for the Example 1

| Evaluation Items | Calculated | Limit value | Check |
|---|---|---|---|
| ❑ **Primary Stress Limits (Level C)** | | | |
| $P_m$ | 10.16 MPa | 48.97 MPa | OK |
| $\sum(t / t_m)$ | 0.23 | 1.0 | OK |
| $P_L+P_B/t$ | 26.44 MPa | 48.97 MPa | OK |
| $\sum(t / t_B)$ | 0.34 | 1.0 | OK |
| ❑ **Inelastic Strain Limits** | | | |
| Elastic Approach | 0.7012 | 0.9005 | OK |
| Simplified Inelastic Approach | 0.211 % | 1.0 % | OK |
| ❑ **Creep-Fatigue Limits** | | | |
| Fatigue Damage | 0.4E-5 | 0.292 | OK |
| Creep Damage | 0.3188 | 1.0 | OK |

### 4.3 Example 2: Two Operating Cycle Types

The exampled structural model is the same as that of used in example 1.

#### 4.3.1 Defined Cycle Types

In this example, two representative cycle types are assumed during the life time. One is the same cycle type as used in example 1, the other one is that the coolant temperature starts to decrease down to 400 $^{o}$C from the normal operating temperature, 550$^{o}$C for 5 hours and next increase up to 600$^{o}$C for 5 hours and recovers again the normal operating temperature after 5 hours. The total transient duration is 15 hours as same as that of the cycle type 1.

To define the load history for the total creep ratcheting strain calculation, it is assumed that two cycle types are uniformly distributed over the design life time and have the same hold temperature, then a set with two cycles repeatedly occur 10 times with duration of 6000 hours for Cycle Type 1 and 18000 hours for Cycle Type 2 respectively. Therefore, the total temperature-time block used in the evaluation is sequential 20 time blocks and the total times used in selecting the isochronous curves exactly sum to the total service life.

The number of each cycle type for the creep-fatigue damage evaluations are defined to be 10 times for the cycle type 1 and 10 times for the cycle type 2.

The primary cycle types are assumed as the same in both cycle types with the internal pressure of 10 bars.

#### 4.3.2 Input Data List

The critical points for the evaluation are the same used in example 1. The input data used in evaluation is shown in Table 2.

Table 2. Input Data Lists for Example 2

```
========================================================================

*SIE
NCT  2
NEP  2
*TITLE
```

```
EXAMPLE 2 for 2-Cycle Types and 2-Evaluation Points
*MAT
316S
*WELDMENT
N
*MODEL
0
*P-CHECK
1
*S-CHECK
1
*CF-CHECK
1
*PSTRESS
C
C1P1
PM  0.8050E+06  0.9378E+07  0.1330E+07  0.2726E+07   0.000  0.000
PB  0.2867E+06  0.2046E+08  0.6240E+07  0.2466E+07   0.000  0.000
PF -0.5594E+06  0.3543E+07  0.9807E+06  0.5433E+06   0.000  0.000
C1P2
PM  0.8050E+06  0.9378E+07  0.1330E+07  0.2726E+07   0.000  0.000
PB -0.2867E+06 -0.2046E+08 -0.6240E+07 -0.2466E+07   0.000  0.000
PF -0.2182E+06  0.1084E+07  0.3168E+06  0.2989E+06   0.000  0.000
2
C2P1
PM  0.8050E+06  0.9378E+07  0.1330E+07  0.2726E+07   0.000  0.000
PB  0.2867E+06  0.2046E+08  0.6240E+07  0.2466E+07   0.000  0.000
PF -0.5594E+06  0.3543E+07  0.9807E+06  0.5433E+06   0.000  0.000
C2P2
PM  0.8050E+06  0.9378E+07  0.1330E+07  0.2726E+07   0.000  0.000
PB -0.2867E+06 -0.2046E+08 -0.6240E+07 -0.2466E+07   0.000  0.000
PF -0.2182E+06  0.1084E+07  0.3168E+06  0.2989E+06   0.000  0.000
*PDATA
C1P1 611.2 240000.
C1P2 610.1 240000.
C2P1 563.6 240000.
C2P2 562.7 240000.
*MINQSTRESS
C1P1
QM -0.2266E+06  0.1390E+06 -0.2350E+08  0.3067E+07   0.000  0.000
QB -0.2767E+06 -0.2107E+08 -0.1297E+08 -0.9762E+06   0.000  0.000
QF  0.8746E+05 -0.7344E+06 -0.1998E+07 -0.2599E+07   0.000  0.000
C1P2
QM -0.2266E+06  0.1390E+06 -0.2350E+08  0.3067E+07   0.000  0.000
QB  0.2767E+06  0.2107E+08  0.1297E+08  0.9762E+06   0.000  0.000
QF -0.1943E+05  0.6906E+05 -0.1721E+07 -0.2192E+07   0.000  0.000
C2P1
QM -0.2813E+06  0.1607E+06 -0.2327E+08  0.3355E+07   0.000  0.000
QB -0.3455E+06 -0.2238E+08 -0.1499E+08 -0.1272E+07   0.000  0.000
QF  0.6825E+05 -0.1709E+07 -0.2912E+07 -0.2866E+07   0.000  0.000
C2P2
QM -0.2813E+06  0.1607E+06 -0.2327E+08  0.3355E+07   0.000  0.000
QB  0.3455E+06  0.2238E+08  0.1499E+08  0.1272E+07   0.000  0.000
QF -0.9134E+05 -0.5160E+06 -0.2332E+07 -0.2442E+07   0.000  0.000
*MAXQSTRESS
C1P1
QM -0.3923E+06 -0.2548E+06  0.1558E+08 -0.2275E+07   0.000  0.000
```

```
QB -0.1584E+06 -0.1426E+07  0.1233E+07 -0.4098E+06   0.000  0.000
QF  0.1981E+06 -0.7047E+06  0.5818E+06  0.8781E+06   0.000  0.000
C1P2
QM -0.3923E+06 -0.2548E+06  0.1558E+08 -0.2275E+07   0.000  0.000
QB  0.1584E+06  0.1426E+07 -0.1233E+07  0.4098E+06   0.000  0.000
QF  0.1188E+06 -0.3200E+06  0.5541E+06  0.8426E+06   0.000  0.000
C2P1
QM -0.4519E+06 -0.4949E+06  0.3849E+08 -0.5582E+07   0.000  0.000
QB -0.5051E+05  0.1127E+08  0.1055E+08  0.1012E+06   0.000  0.000
QF  0.2675E+06 -0.2791E+06  0.2436E+07  0.3083E+07   0.000  0.000
C2P2
QM -0.4519E+06 -0.4949E+06  0.3849E+08 -0.5582E+07   0.000  0.000
QB  0.5051E+05 -0.1127E+08 -0.1055E+08 -0.1012E+06   0.000  0.000
QF  0.2304E+06 -0.3572E+06  0.2079E+07  0.2778E+07   0.000  0.000
*DESIGNLIFE
240000.
*LOADHISTORY
1
SET1 2 10
S1C1 1 6000.
S1C2 2 18000.
*NCYC
C1 10
C2 10
*WATEMP
C1P1 512.3 604.0
C1P2 512.3 604.0
C2P1 443.3 549.3
C2P2 443.3 549.3
*HCTEMP
C1P1 512.1 605.5
C1P2 512.5 602.4
C2P1 442.1 551.1
C2P2 444.5 547.4
*EXTEMP
C1P1 512.3 604.0
C1P2 512.3 604.0
C2P1 443.3 549.3
C2P2 443.3 549.3
*MMTEMP
C1P1 611.2
C1P2 610.1
C2P1 563.6
C2P2 562.7
*HDTEMP
P1 546.8
P2 546.1
*STRAIN-C
C1P1
MIN  0.11910E-03 -0.64670E-04 -0.21002E-03 -0.87877E-05  0.00  0.00
MAX -0.31131E-04 -0.47836E-04  0.11477E-03 -0.29705E-04  0.00  0.00
C1P2
MIN -0.18102E-04  0.16565E-03 -0.12426E-03  0.32013E-04  0.00  0.00
MAX -0.31070E-04 -0.23128E-04  0.92396E-04 -0.16819E-04  0.00  0.00
C2P1
MIN  0.12456E-03 -0.71803E-04 -0.21666E-03 -0.13167E-04  0.00  0.00
MAX -0.11621E-03 -0.31387E-04  0.29258E-03 -0.37911E-04  0.00  0.00
```

```
C2P2
MIN -0.22601E-04  0.16232E-03 -0.11135E-03  0.36632E-04  0.00  0.00
MAX -0.34228E-04 -0.12880E-03  0.20472E-03 -0.45988E-04  0.00  0.00
*TRDATA
C1P1 611.2 15.0
C1P2 610.1 15.0
C2P1 563.6 15.0
C2P2 562.7 15.0
*DTCREEP
1.
*OUTRES
10
*END
=======================================================================
```

### 4.3.1 Creep Ratcheting Evaluations

The overall output lists of the evaluation results are shown in Appendix D.

When using the elastic analysis rules, the calculated sum of the stress parameters (X + Y) at evaluation point 1 is 0.6997 for the cycle type 1 and 0.9715 for the cycle type 2. These satisfy the limit value of Sa/Sy = 0.9512 for the cycle type 1 and Sa/Sy = 1.0 for the cycle type 2 in Test No A-1. The evaluation point 2 also satisfies the creep ratcheting limit rules with enough margins.

When using the simplified inelastic analysis rules, the obtained effective creep ratchet stresses for each evaluation point and cycle type are assumed to be remained constant throughout each block service time defined in the evaluation. These are listed as follows;

Point No = 1, Cycle Type = 1: 1.25Sc = 56.59(MPa)
Point No = 1, Cycle Type = 2: 1.25Sc = 56.52(MPa)
Point No = 2, Cycle Type = 1: 1.25Sc = 36.45(MPa)
Point No = 2, Cycle Type = 2: 1.25Sc = 55.82(MPa)

The above effective creep ratchet stresses are so small that the shake down might be expected. As shown in the output lists, the inelastic strains occur during first a few time blocks but no more after that. The calculated total creep ratchet strains are 0.1281 % for point 1 and 0.0382 % for point 2, which are very small quantities compared with the inelastic strain limits for the base metal 1.0 % or 0.5 % for the weldment.

When using the Test No B-3 for individual strain calculations, the total enhanced creep strain increments occur during the time blocks corresponding to the cycle type 1, which has higher metal temperature over 605°C, but is very small as 8.053e-6 for each time block and can hardly affect the total inelastic strains.

### 4.3.2 Creep-Fatigue Evaluations

The calculated fatigue damages are negligible for both cycle types at each evaluation point as shown in the output lists of Appendix D. The obtained total strain ranges are too small to invoke the fatigue damages. Therefore, the fatigue damages are negligible at both evaluation points.

To evaluate the creep damages, the enveloped stress relaxation time history should be generated for the cycle type 1 (10 cycle times) and cycle type 2 (15 cycle times) during an entire life time. Fig. 26 shows the obtained envelope stress relaxation time history at evaluation point 1 including the safety factor K'=0.9.

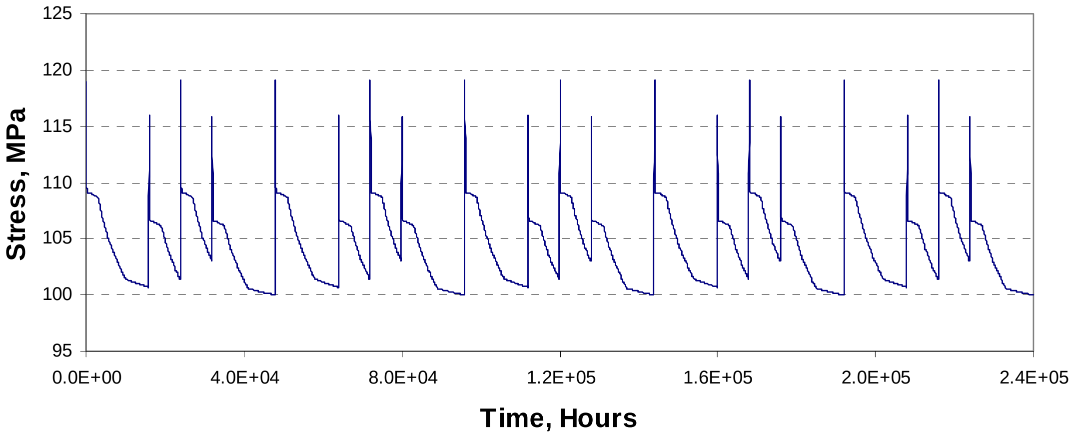


Fig. 26 Envelope Stress Relaxation Time History

As shown in figure, the obtained the envelope stress relaxation time history is very complicated and during the stress relaxation time of the cycle type 1 the stress level of the cycle type 2 makes the stress level increase enough to affect the creep damage occurrence. This stress envelop procedure of ASME-NH enables the designer to treat any kind of temperature and stress increments occurring intermediate operating time following the severe transient operation on the creep damage evaluations. In figure, no further modification of the stress time history is done on the stress time history curve during the transient time of 15.0 hours due to less primary stress than those in stress curve, but the maximum transient metal temperature is included in compliance with the ASME-NH rules. As shown in the enveloped stress relaxation time history curve, the stresses are significantly relaxed at the beginning time of the dwell stress. This phenomenon will keep the creep damage from severely increasing during the maximum transient temperature operation. This is due to the low dwell stress level. However, when the initial stress level is much higher, then the trend of significant reductions of the initial stress at the beginning stage will be reduced. Actually as we investigate the characteristics of the isochronous curves in detail, we can see that the slopes of the hot tensile stress-strain curves less than the strains of 0.2% and the stress less than 138 MPa are so steep for most temperature ranges. This means that the dwell stresses can be significantly reduced at the beginning stage of the relaxation for these stress and strain ranges. All stress levels in the obtained stress time history are higher than that of the lower bound level, 56.6 MPa for point 1 and 55.8 MPa for point 2.

The calculated creep damages are 0.3168 for point 1 and 0.2704 for point 2. Instead of the enveloped stress method provided in ASME-NH, if we calculate the creep damage individually for both cycle types and linearly sum these with assumption that each cycle type is repeated throughout the entire design life time, then the creep damages at point 1 will be 0.3188 for the cycle type 1 and 0.3098 for the cycle type 2, which results in total creep damage, 0.6286. This estimation method is simple but results in greatly overestimated creep damage. Therefore, it should be careful to define the cycle types and their time durations, which sum to the entire design life time.

Table 3 shows the summary of the structural integrity evaluations of point 1 for the example 2.

Table 3. Summary of Evaluation Results for Example-2

| Evaluation Items | Calculated | Limit value | Check |
|---|---|---|---|
| ❑ **Primary Stress Limits (Level C)** | | | |
| $P_m$ | 10.16 MPa | 48.97 MPa | OK |
| $\sum(t / t_m)$ | 0.23 | 1.0 | OK |
| $P_L+P_B/t$ | 26.44 MPa | 48.97 MPa | OK |
| $\sum(t / t_B)$ | 0.34 | 1.0 | OK |
| ❑ **Inelastic Strain Limits** | | | |
| Elastic Approach | 0.6997 | 0.9512 | OK |
| Simplified Inelastic Approach | 0.2181 % | 1.0 % | OK |
| ❑ **Creep-Fatigue Limits** | | | |
| Fatigue Damage | 0.9E-5 | 0.2928 | OK |
| Creep Damage | 0.3168 | 1.0 | OK |

### 4.4 Parametric Studies Using SIE ASME-NH Code

All data such as the model and the operating cycle types used in these evaluations are based on a previous example 2.

#### 4.4.1 Evaluations for Weldment

When assuming the evaluation points are the part welded with SFA-5.22 E 316T, then the input data corresponding to the command *WELDMENT can be used to evaluate the high temperature structural integrity evaluations. The calculated creep ratcheting strain 0.1544% satisfies the limit value of 0.5% and the fatigue damages are still negligible. However, the creep damages are calculated to be 2.8467 for point 1 and 1.1535 for point 2, which are greatly over the limit value of 1.0. Compared these results with those of the base metal case, the creep values significantly increase due to the stress rupture factors given in Table I-14.10 of ASME-NH.

### 4.4.2 Effects of Time Step Size for Creep Calculation

In calculating the creep damage from the stress relaxation time history, it is important to select the time step size which will be used to integral the time fraction. According to the ASME-NH, the stress $(S)_k$ and Temperature $(T)_k$ are assumed to be constant during each of time interval $(\Delta t)_k$.

Fig. 27 shows the effect of the time step size on the creep damage calculation in the previous example 2. As shown in result, the calculated creep damages increase from when the time step size is larger than 10 hours. This is due to the assumption of the maximum stress value to be constant during the time step size. Especially when considering the transient time of 15 hours, which has higher temperature conditions, the larger time step size may result in much conservative or overestimated creep damage values in this time interval. Therefore, to minimize the conservatism in calculating the creep damage, it is recommended that the time step size should be less than the transient time interval at least.

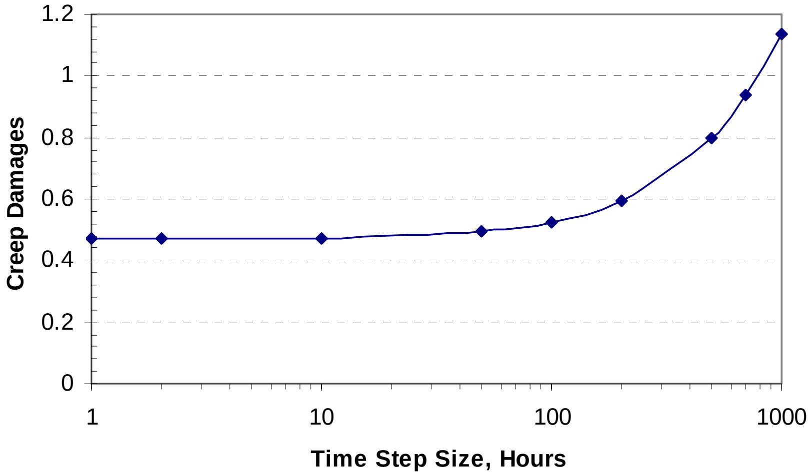


Fig. 27 Time Step Size Effects on Creep Calculation

### 4.4.3 Effects of Primary Load on Creep Damage

Actually the creep damage is primarily invoked by the load-controlled stresses under high temperature conditions. Fig. 28 shows the effect of the load-controlled stresses, which are calculated for the variation of the internal pressure in previous example 2, on the creep damages using the ASME-NH rules. As shown in figure, the creep damages start to increase significantly when the internal pressure reach to a certain level. From these results, we can see that even slightly increasing the primary loads at a certain level subjected with the elevated temperature may result in unexpected severe creep damage rather than any other design factors.

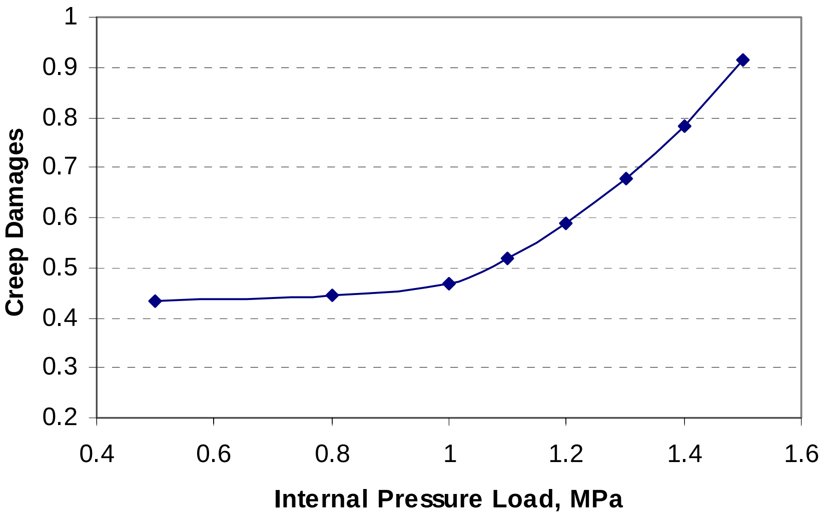


Fig. 28. Primary Load Effects on Creep Damage

### 4.4.4 Number of Cycle Effect on Creep Damage

When there are several kinds of the representative cycle types, the enveloped stress relaxation time history can be complicated and the occurrence number of the short period transient operations during the longer transient operating cycles can affect the total accumulated creep-fatigue damages. In this investigation, it is assumed that the cycle type 1 is a long period transient cycle occurring 10 times and the cycle type 2 is a short period transient cycle with varying cycle numbers but the individual operating cycle shall sum to the total design life time of 240000 hours. Fig. 29 shows the results of the calculated creep damages versus the numbers of the cycle type 2. As shown in figure, as numbers of the cycle type 2 increase the creep damages become larger. This means that as many as high transient temperature occurrences and enhancement of the stress level by the following transient cycle types can significantly affect the creep damages.

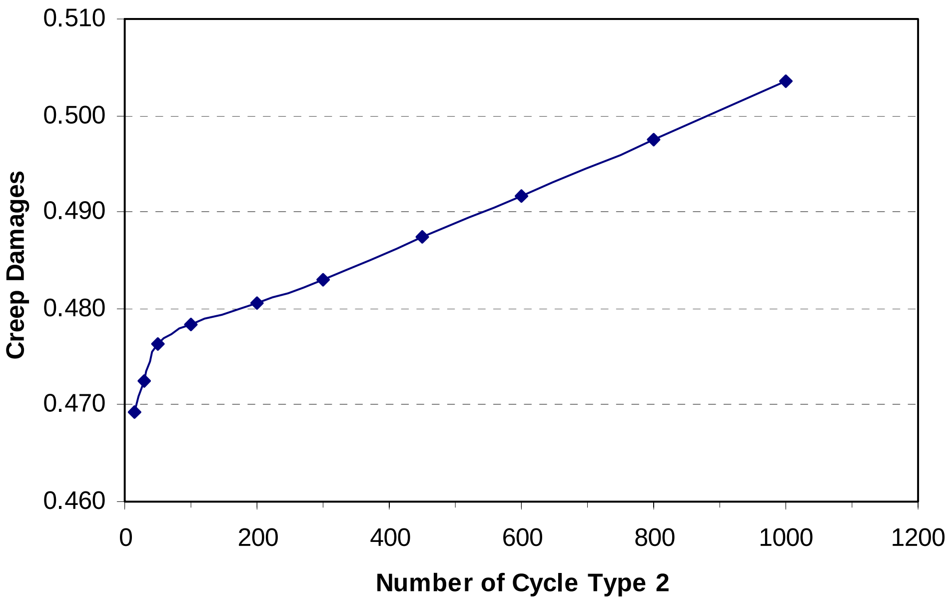


Fig. 29 Effects of Number of Cycles on Creep Damage

### 4.4.5 Load History Effects on Creep Ratchet Strains

To investigate the load history effects on creep ratchet strain, it is assumed that the cycle type 1 and the cycle type 2 repeatedly occur with the same time intervals. For example of two time blocks, the cycle type 1 occurs 1 cycle with 120000 hours and the cycle type 2 with 120000 hours occurs 1 cycle with following the cycle type 1. The each time block sum to the total design service life time of 240000 hours.

Fig. 30 shows the results of this evaluation. As shown in figure, the total accumulated creep ratchet strain decrease as the numbers of time block increase. This result gives the rational of the general requirements of the rule T-1331 (b) where the individual cycles or time blocks defined in the design specification can not be split into sub-cycles.

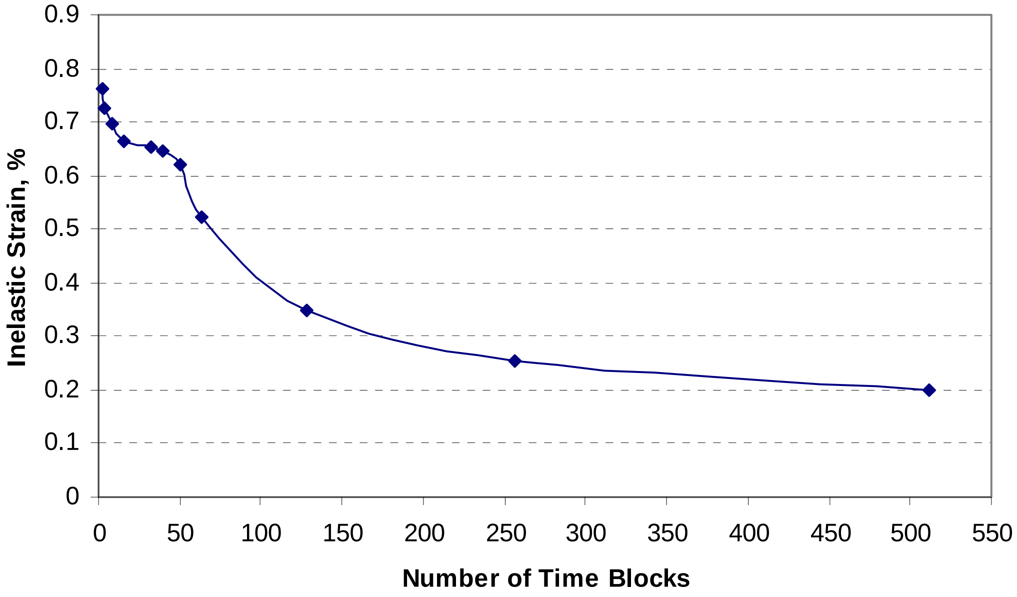


Fig. 30 Load History Effects on Accumulated Total Inelastic Strain

### 4.4.6 Normal Temperature Effects

### 4.4.7 Effect of Structural Discontinuity

### 4.4.8 Effects of Short Time Primary Loads

### 4.4.9 Creep-Fatigue Evaluations Using Total Strain Input Data

## 4.5 Examples of Material DB Evaluations

### 4.5.1 Yield Strength

Input Deck Lists (file name = MAT.TXT)

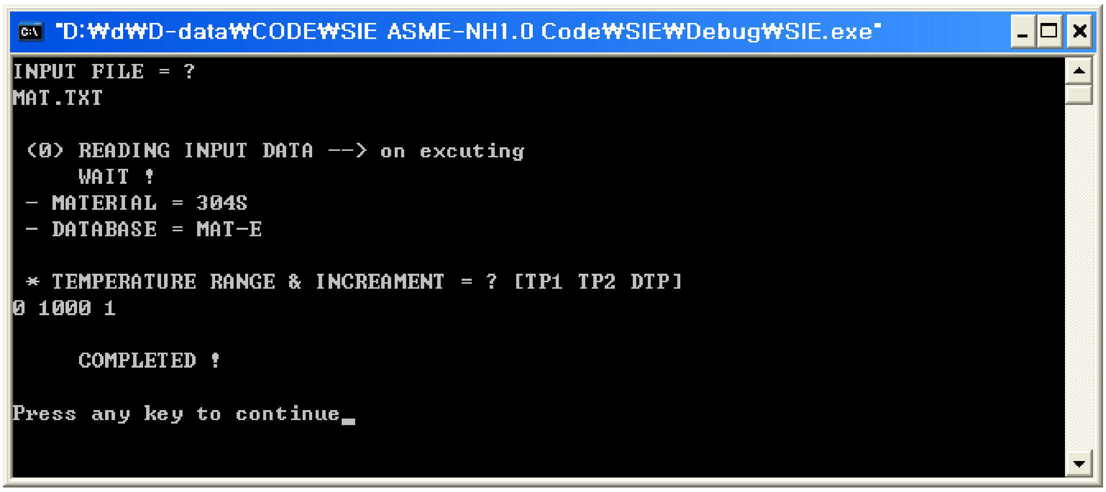
```
*MATDB
*MAT
304S
```

*DB-TYPE

MAT-SY

*END

Interactive Process



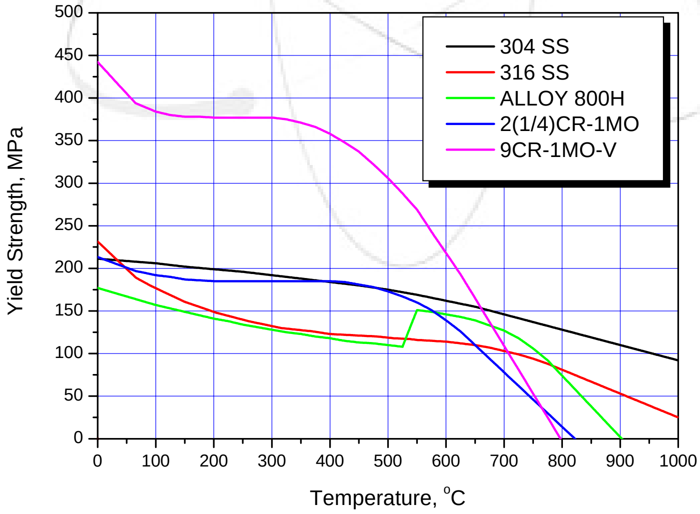
```
INPUT FILE = ?
MAT.TXT

 (0) READING INPUT DATA --> on excuting
     WAIT !
 - MATERIAL = 304S
 - DATABASE = MAT-E

 * TEMPERATURE RANGE & INCREAMENT = ? [TP1 TP2 DTP]
0 1000 1

     COMPLETED !

Press any key to continue
```



### 4.5.2 Design Stress Intensity

<u>Input Deck Lists (file name = MAT.TXT)</u>

*MATDB

*MAT

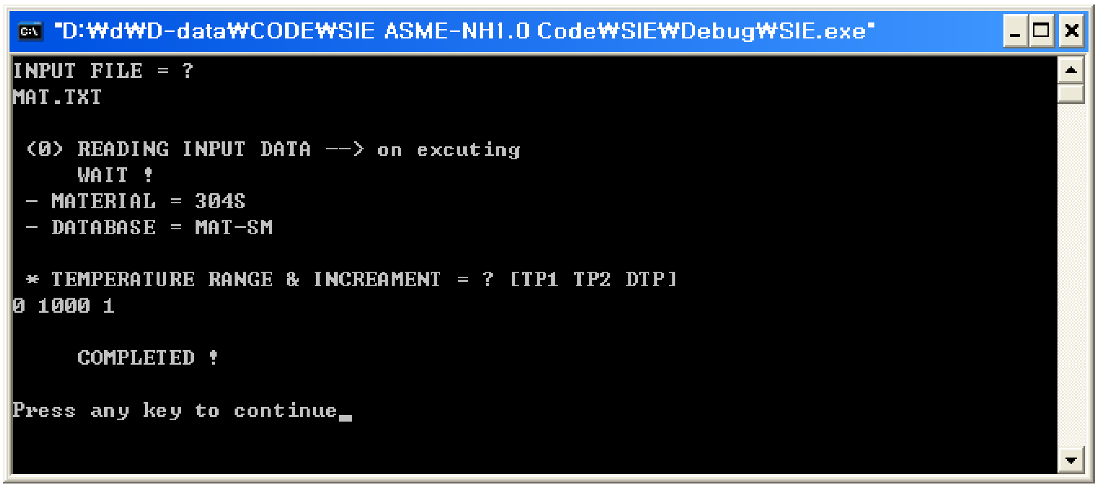
304S

*DB-TYPE

MAT-SM

*END

<u>Interactive Process</u>



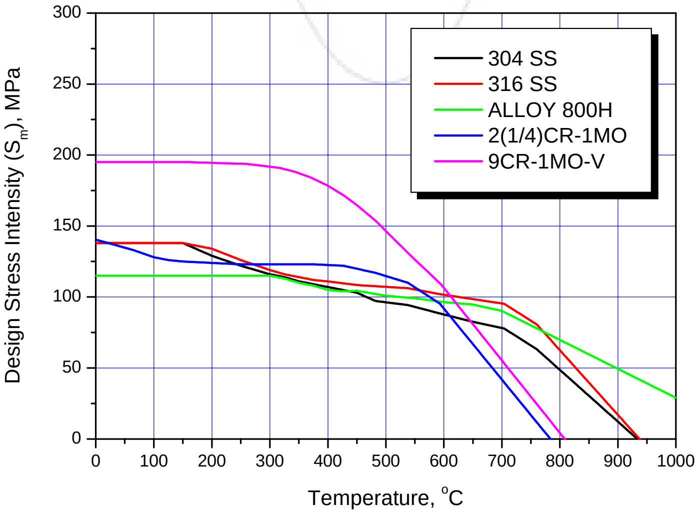
```
INPUT FILE = ?
MAT.TXT

 <0> READING INPUT DATA --> on excuting
     WAIT !
 - MATERIAL = 304S
 - DATABASE = MAT-SM

 * TEMPERATURE RANGE & INCREAMENT = ? [TP1 TP2 DTP]
0 1000 1

     COMPLETED !

Press any key to continue_
```

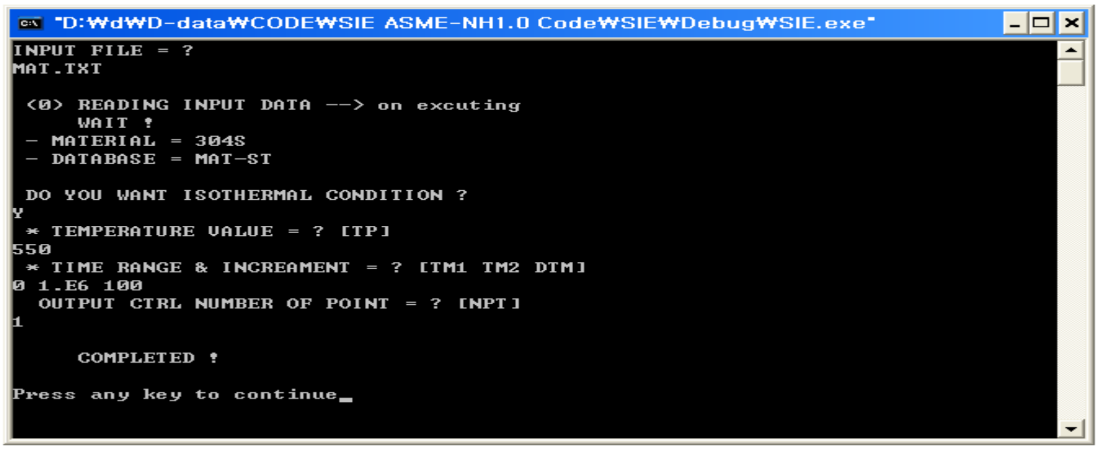


### 4.5.3 Time Dependent Stress Intensity Limit

<u>Input Deck Lists (file name = MAT.TXT)</u>

```
*MATDB
*MAT
304S
*DB-TYPE
MAT-ST
*END
```

<u>Interactive Process</u>



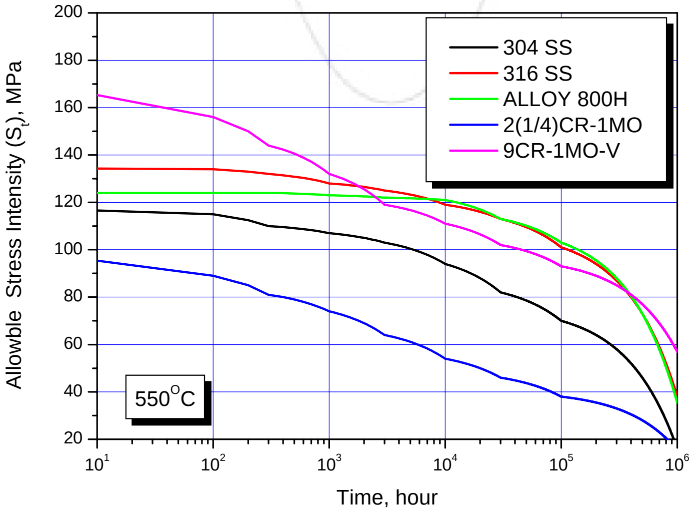
```
INPUT FILE = ?
MAT.TXT

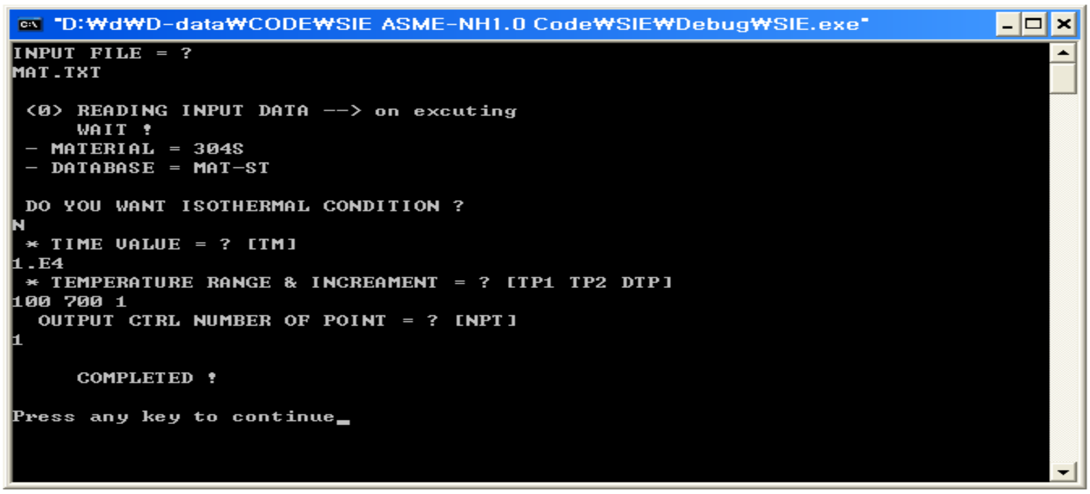
 <0> READING INPUT DATA --> on excuting
     WAIT !
 - MATERIAL = 304S
 - DATABASE = MAT-ST

 DO YOU WANT ISOTHERMAL CONDITION ?
Y
 * TEMPERATURE VALUE = ? [TP]
550
 * TIME RANGE & INCREAMENT = ? [TM1 TM2 DTM]
0 1.E6 100
  OUTPUT CTRL NUMBER OF POINT = ? [NPT]
1

     COMPLETED !

Press any key to continue_
```





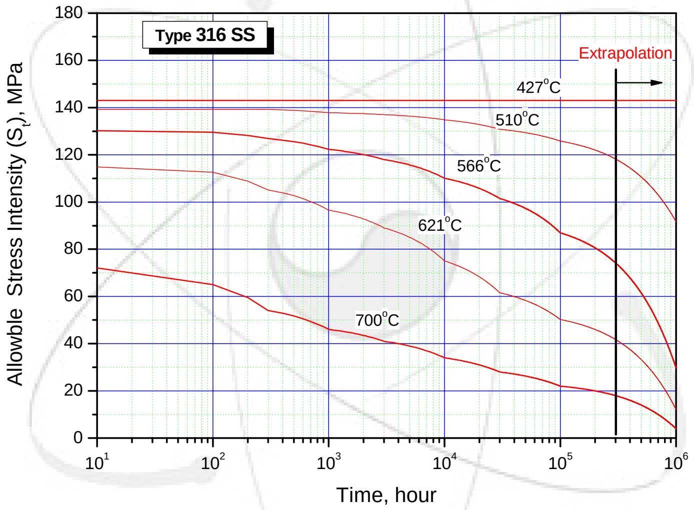
```
INPUT FILE = ?
MAT.TXT

 <0> READING INPUT DATA --> on excuting
     WAIT !
 - MATERIAL = 304S
 - DATABASE = MAT-ST

 DO YOU WANT ISOTHERMAL CONDITION ?
N
 * TIME VALUE = ? [TM]
1.E4
 * TEMPERATURE RANGE & INCREAMENT = ? [TP1 TP2 DTP]
100 700 1
  OUTPUT CTRL NUMBER OF POINT = ? [NPT]
1

     COMPLETED !

Press any key to continue_
```



### 4.5.4 Expected Minimum Stress-to-Rupture Value

Input Deck Lists (file name = MAT.TXT)

*MATDB

*MAT

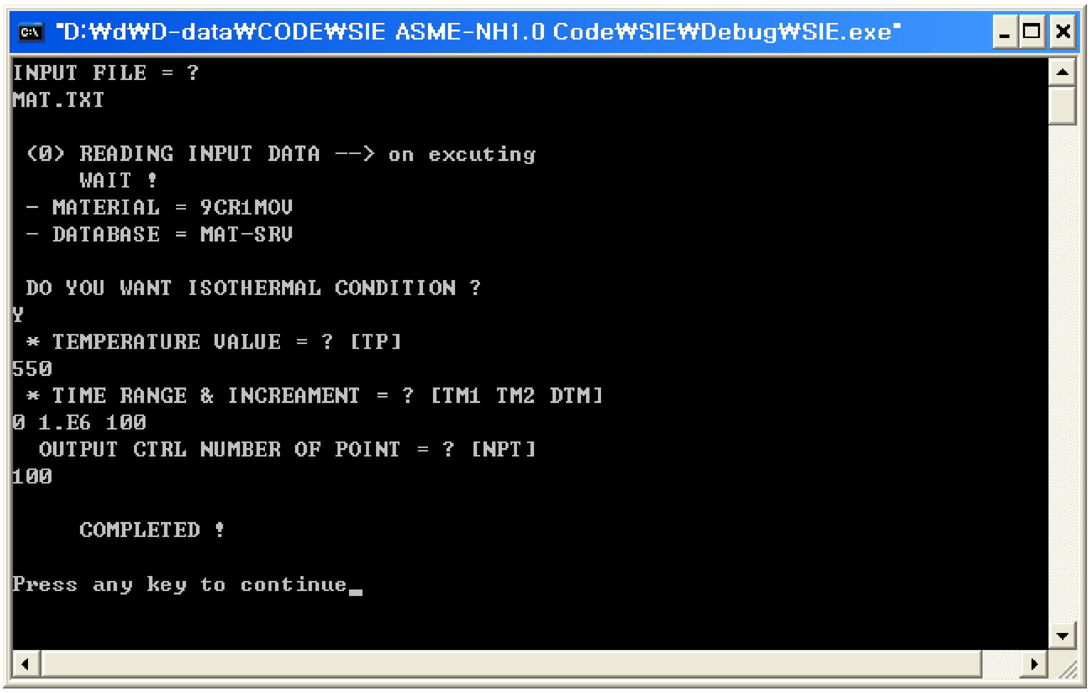
304S

*DB-TYPE

MAT-SRV

*END

Interactive Process



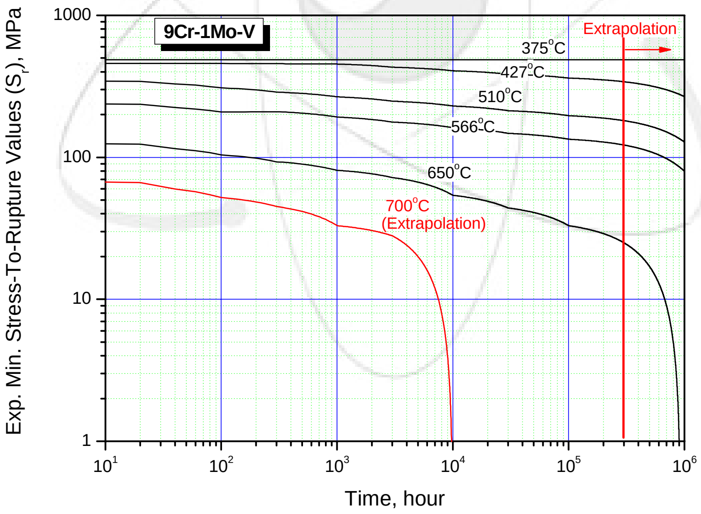
```
INPUT FILE = ?
MAT.TXT

 (0) READING INPUT DATA --> on excuting
     WAIT !
 - MATERIAL = 9CR1MOV
 - DATABASE = MAT-SRV

 DO YOU WANT ISOTHERMAL CONDITION ?
Y
 * TEMPERATURE VALUE = ? [TP]
550
 * TIME RANGE & INCREAMENT = ? [TM1 TM2 DTM]
0 1.E6 100
  OUTPUT CTRL NUMBER OF POINT = ? [NPT]
100

     COMPLETED !

Press any key to continue_
```



## 4.5.5 Allowable Creep Time for Weldment

Input Deck Lists (file name = MAT.TXT)

*MATDB

*MAT

316

*WELDMENT

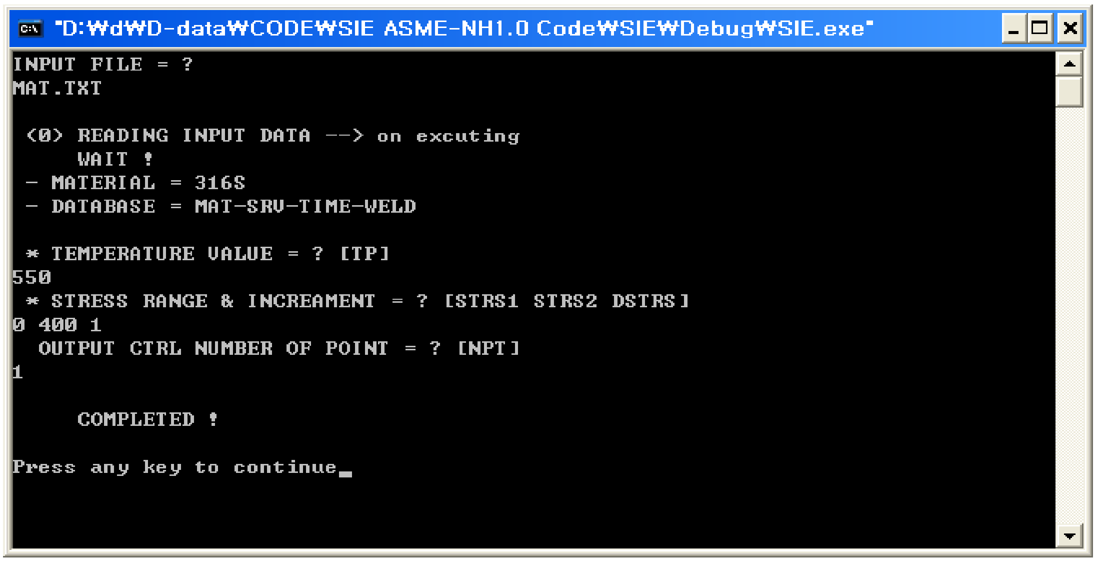
B1

*DB-TYPE

MAT-SRV-TIME-WELD

*END

Interactive Process



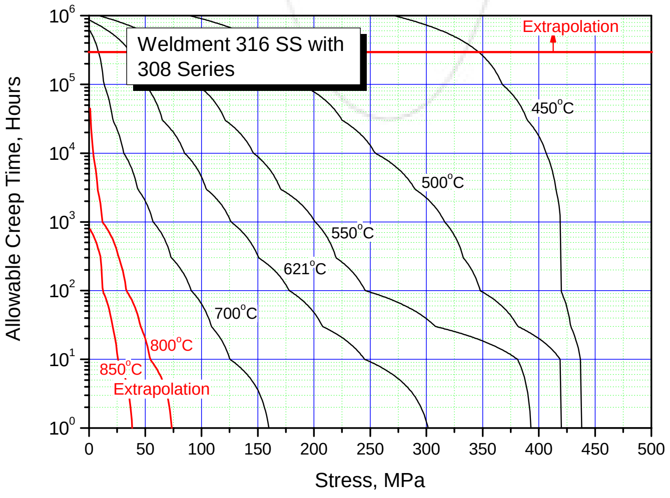
```
INPUT FILE = ?
MAT.TXT

 <0> READING INPUT DATA --> on excuting
     WAIT !
 - MATERIAL = 316S
 - DATABASE = MAT-SRV-TIME-WELD

 * TEMPERATURE VALUE = ? [TP]
550
 * STRESS RANGE & INCREAMENT = ? [STRS1 STRS2 DSTRS]
0 400 1
  OUTPUT CTRL NUMBER OF POINT = ? [NPT]
1

     COMPLETED !

Press any key to continue_
```



### 4.5.6 Stress Relaxation Strength

Input Deck Lists (file name = MAT.TXT)

*MATDB

*MAT

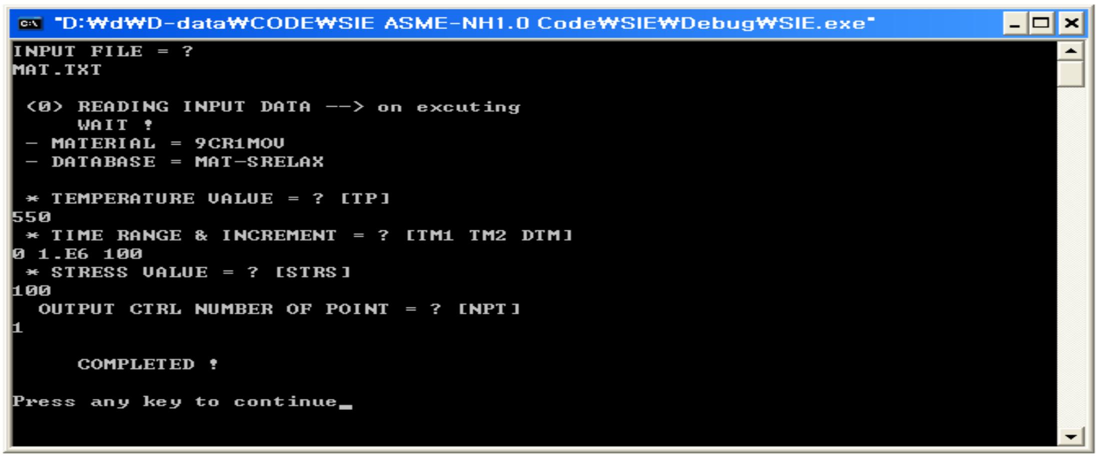
9CR1MOV

*DB-TYPE

MAT-SRELAX

*END

Interactive Process



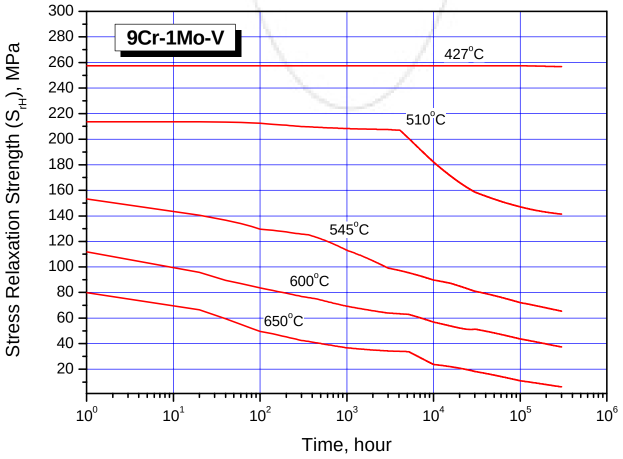
```
INPUT FILE = ?
MAT.TXT

 <0> READING INPUT DATA --> on excuting
     WAIT !
 - MATERIAL = 9CR1MOV
 - DATABASE = MAT-SRELAX

 * TEMPERATURE VALUE = ? [TP]
550
 * TIME RANGE & INCREMENT = ? [TM1 TM2 DTM]
0 1.E6 100
 * STRESS VALUE = ? [STRS]
100
  OUTPUT CTRL NUMBER OF POINT = ? [NPT]
1

     COMPLETED !

Press any key to continue_
```

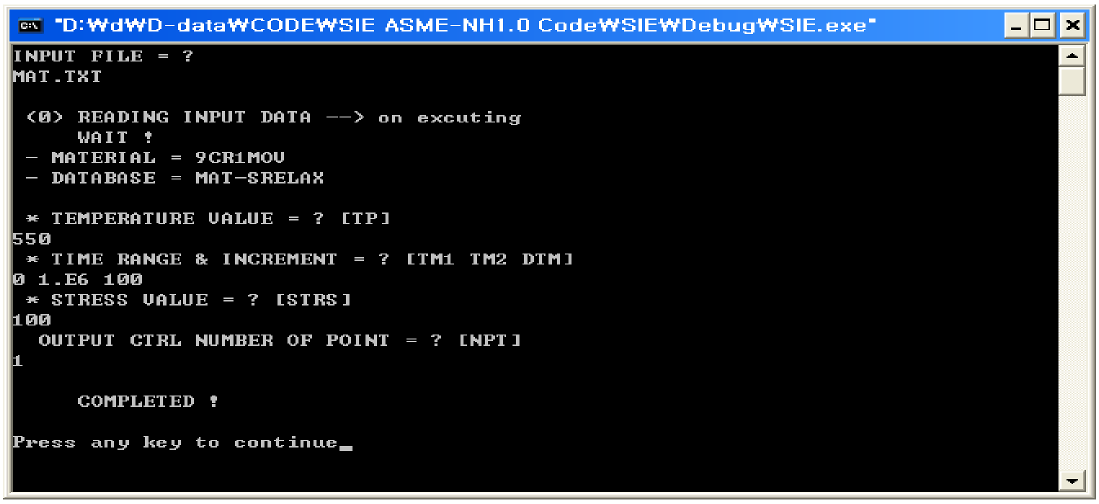


### 4.5.7 Fatigue Curve

Input Deck Lists (file name = MAT.TXT)

```
*MATDB
*MAT
316S
*DB-TYPE
MAT-FATIGUE
*END
```

Interactive Process



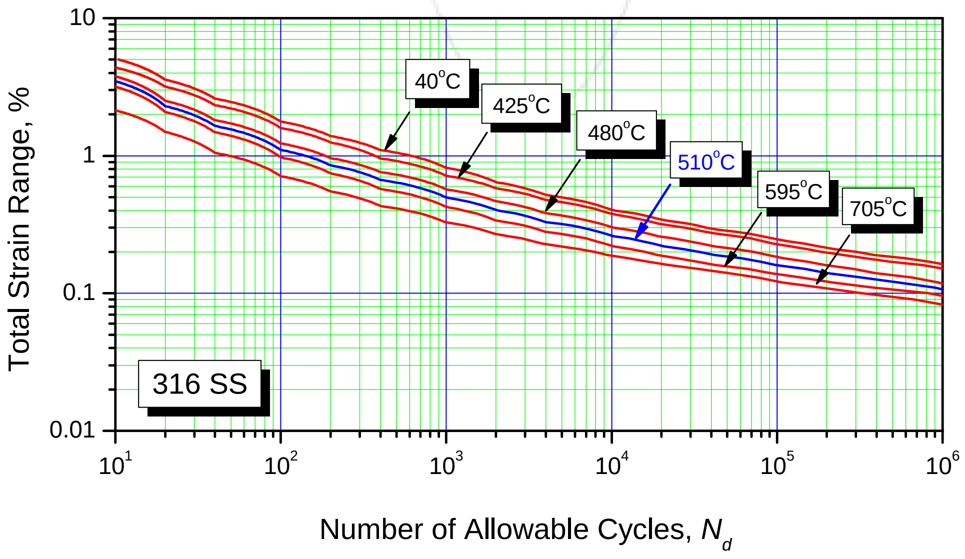
```
INPUT FILE = ?
MAT.TXT

 <0> READING INPUT DATA --> on excuting
      WAIT !
 - MATERIAL = 9CR1MOV
 - DATABASE = MAT-SRELAX

 * TEMPERATURE VALUE = ? [TP]
550
 * TIME RANGE & INCREMENT = ? [TM1 TM2 DTM]
0 1.E6 100
 * STRESS VALUE = ? [STRS]
100
  OUTPUT CTRL NUMBER OF POINT = ? [NPT]
1

      COMPLETED !

Press any key to continue_
```

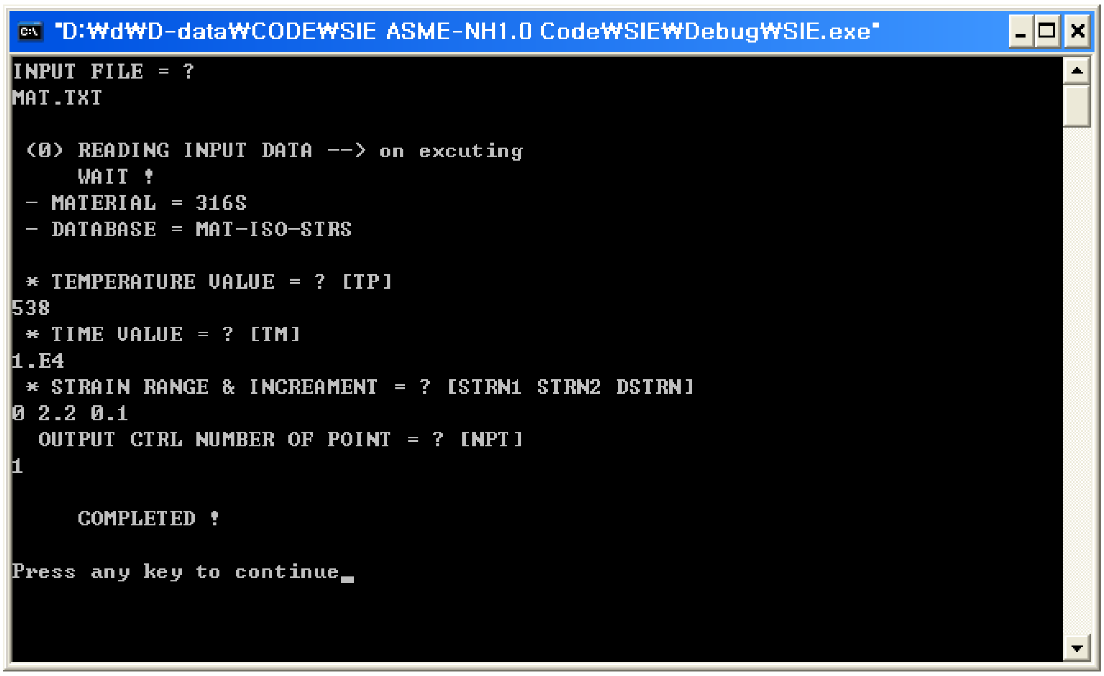


### 4.5.8 Isochronous Stress-Strain Curve

<u>Input Deck Lists (file name = MAT.TXT)</u>

```
*MATDB
*MAT
316S
*DB-TYPE
MAT-FATIGUE
*END
```

<u>Interactive Process</u>



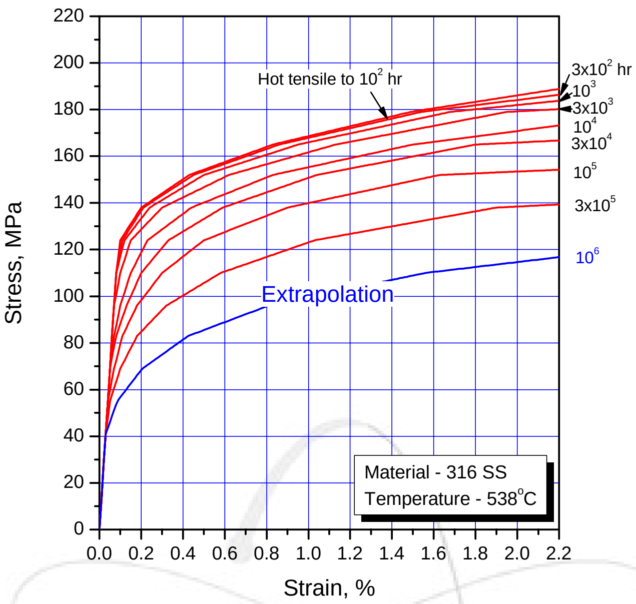
```
INPUT FILE = ?
MAT.TXT

 (0) READING INPUT DATA --> on excuting
     WAIT !
 - MATERIAL = 316S
 - DATABASE = MAT-ISO-STRS

 * TEMPERATURE VALUE = ? [TP]
538
 * TIME VALUE = ? [TM]
1.E4
 * STRAIN RANGE & INCREAMENT = ? [STRN1 STRN2 DSTRN]
0 2.2 0.1
  OUTPUT CTRL NUMBER OF POINT = ? [NPT]
1

     COMPLETED !

Press any key to continue_
```



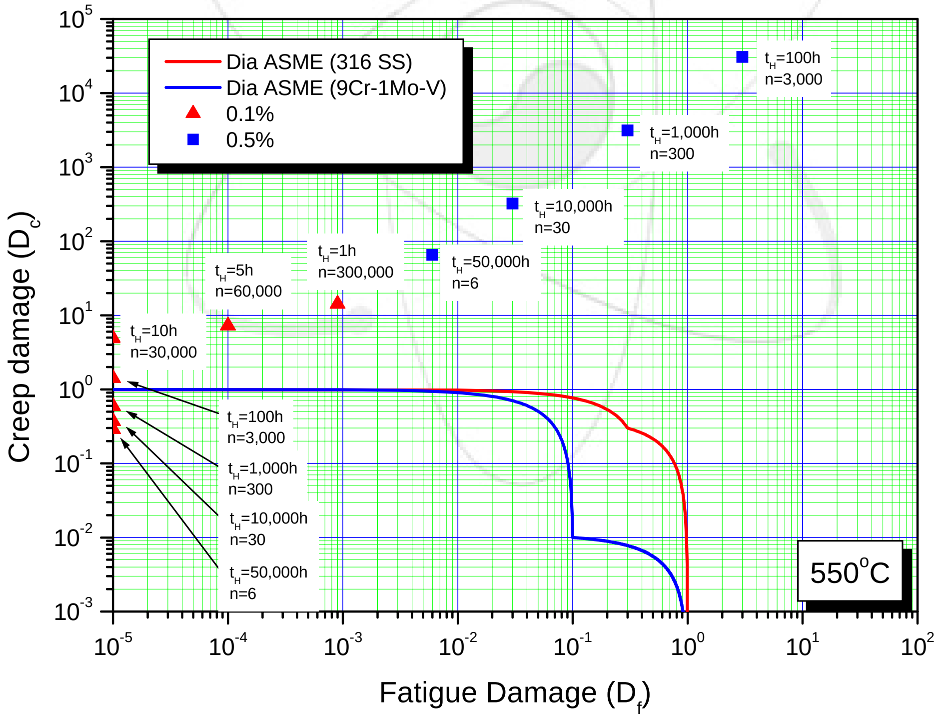
## 4.6 Creep-Fatigue Evaluation for Long-Term Fuel Cycle Reactor

To investigate the creep-fatigue interaction effects on long-term fuel cycle reactor, the damage evaluations are carried out with the command of *STRAIN-T. The used total strain ranges are 1% and 5% for the structural material of 9Cr-1Mo-V steel. The total service lifetime is 300,000 hours and the hold temperature is 510°C. In this evaluation, the multiaxial effect, stress concentration effect, and safety factors are not considered.

<u>Input Deck Lists (file name = MAT.TXT)</u>

```
*SIE
NCT  1
NEP  1
*TITLE
EXAMPLE OF CREEP-FATIGUE EVALUATION
*MODEL
1
*MAT
9CR1MOV
*CF-CHECK
1
*DESIGNLIFE
```

```
300000.
*CYCLE
C1  100
*MMTEMP
C1 510.
*HDTEMP
C1 510.
*STRAIN-T
C1 0.01
*TRDATA
C1 510. 0.001
*DTCREEP
1.
*OUTRES
1
*END
```



# 5. Conclusions

This report is rewritten for revision of the KAERI/TR-3161/2006 document to provide the user's manual of SIE ASME-NH (Revision 1.0) computer code. In this revision, the load history concept for the simplified inelastic analysis method and the creep-fatigue evaluation are mainly upgraded. And the material DB and evaluation functions are newly added. Much more examples of application are also included in report for user's manual.

**Acknowledgment**

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**References**

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# Appendix A : Creep Equations for a Pure Stress Relaxation Strength Analysis for 316SS

The two relaxation strengths, $S_{rH}$ and $S_{rL}$, may be determined by performing a pure uniaxial relaxation analysis starting with an initial stress of $1.5S_m$ and holding the initial strain throughout the time interval equal to the time of service above $427^{o}$C. In symbols, the subscripts *H* and *L* represent the temperatures at the hot and cold extremes of the stress cycle respectively.

The constitutive equation for the primary creep of 316SS is used as follows:

$$\Delta\varepsilon_{cr} = C_1 \left( \frac{\partial \varepsilon_c}{\partial t} \right) \Delta t$$

where

$$\varepsilon_c = \dot{\varepsilon}_m + \frac{C \cdot P \cdot t}{(1 + P\,t)}$$

$\ln C = -1.35 - 5620/T - 50.6\text{x}10^{-6}\sigma + 1.918 \ln(\sigma/1000)$

$\ln P = 31.0 - 67310/T + 330.6\text{x}10^{-6}\sigma - 885.0\text{x}10^{-12}\ \sigma^2$

$\ln \dot{\varepsilon}_m = 43.69 - 106400/T + 294.0\text{x}10^{-6}\sigma + 2.596 \ln(\sigma/1000)$

The units in above equation should be only absolute temperature, hours, pounds and inches. The valid temperature ranges for above equation are from $800^{o}$F to $1300^{o}$F and the valid stress range is 0.0 psi $\leq \sigma \leq$ 45 ksi. If the temperature *T* is less than $800^{o}$F, then no creep is expected.

The secondary creep equation of 316SS is given as

$$\Delta\varepsilon_{cr} = C_7\, e^{\sigma / C_8}\, e^{-C_{10} / T}\, \Delta t$$

where $\sigma$ is the equivalent stress.

# Appendix B : Summary of Piping Design

☐ **NH-3610 GENERAL REQUIREMENTS**

☐ NH-3611 Acceptability

- 만일 NH-3100(General Requirements for Design), NH-3200 (Design by Analysis), 그리고 NH-3600(Piping Design)이 서로 상충되는 면이 있을 경우에는 NH-3600 을 따름.

- Pipe Fitting 에 대한 Dimensional Standards 는 최소 두께만 제어하고 심각한 열과도가 고려되어야 할 경우에는 설계자가 최대 두께를 결정해야 함.

☐ NH-3612 Pressure-Temperature Ratings for Piping Components

- 밸브가 있을 경우에 밸브설계는 높은 쪽 압력과 온도요건에 대해 설계함. 그렇지 않을 경우에는 저압시스템을 보호하기 위한 Relief device 나 Safety valve 를 밸브근방에 설치해야 함.

- 펌프토출 배관은 펌프에 의해 가해지는 최대압력을 견디도록 설계되어야 함.

☐ **NH-3620 DESIGN CONSIDERATION**

☐ NH-3622 Dynamic Effects

- Impact, Earthquake, Vibration

☐ NH-3623 Weight Effects

☐ NH-3624 Loadings, Displacements, and Restraints

☐ NH-3636 Special Drainage Problems

- Drain 이 요구되는 배관계는 고온계통에 있는 배관지지물들 사이에 크립기인 처짐(Sag)현상을 고려해야 함.

- 중간 또는 고온에서 Drain 하는 배관계에 대해서는 이 조건과 관련된 Load Cycles 을 설계에 고려해야 함.

☐ NH-3627 Considerations for Liquid Metal Piping

☐ NH-3627.1 Location

- 증기나 물배관 주위에 설치 금지

☐ NH-3627.2 Heat Tracing

- 액체금속배관은 용융상태로의 액체금속을 유지할 수 있는 Heat Tracing 을 설치해야 함.

- 이때 Heat tracing 을 위해 증기나 물 사용은 금지.

- Heat Tracing 은 용융팽창으로 인한 과압방지 장치가 필요 없도록 서서히 해야 하고 설계 온도변화율이나 온도제한지를 초과하지 않도록 해야 함.

□ NH-3627.3 Filling and Draining

- 모든 액체금속배관들은 Drain Reservoirs 에 중력으로 완전 배출될 수 있도록 경사설계를 해야 하며 보조 배출관의 사용을 금함.

□ **NH-3640 PRESSURE DESIGN OF COMPONENTS**

□ NH-3641.1 Straight Pipe

- 최소 배관두께 > tm (= NH-3222.1 Design Limit 에 따라서 결정)

- Note: NB-3641.1 은 공식에 따른 설계두께

□ NH-3642 Curved Segments of Pipe

□ NH-3642.1 Pipe Bends

- Pipe Bend 설계는 NH-3200 해석요건을 만족해야 함.

- Bend 의 기본치수(직경, 두께, 굽힘반경)외에 설계자는 굽힘 공정시에 존재하는 이차변형과 Irregularity 을 고려해야 하고 해석을 통해 이에 대한 여유도를 정의해야 함.

- 특히 굽힘배관 설계에 고려해야 할 사항들은

  (a) 굽힘공정후 배관두께가 직관 두께보다 작지 말 것.

  (b) Wall Thinning and Thickening (Table NH-3642.1-1)

  (c) Ovality

  (d) Wrinkling ≤ 3%

  (e) Surface irregularities

( Note: Elbows 에 대한 규정이 없음.)

□ NH-3642 Intersection

- NH-3642 규정은 전적으로 NH-3200 요건에 부응하는 해석이나 실험을 또는 두 가지 방법 모두를 사용할 수 있도록 허용함.

□ NH-3643.1 General Requirements

(a) Opening은 원형, 타원형 또는 원판 또는 실린더형상을 갖는 타원실린더의 교점으로 기인한 어떤 형상이어야 함.

(b) 이 규정은 부식허용에 더해지는 재료를 재외하고는 모두 완성치수에 적용됨.

(c) Opening은 Welded joint에 위치 할 수 있음.

(d) NB-3643.3(Reinforcement for Openings)의 요건들이 NH-3643.2(b), (c), (d)에 열거된 Branch Connections에 대해 만족해야 함. 단, 이때는 Sm 대신 So를 사용해야 함.

□ NH-3643. 2 Branch Connections

- 배관설계에서 Branch Connections 다음중의 하나로 만들 수 있음

(a) Flanged, Butt Weld, 또는 Socket Weld (ANSYS Standards: Table NB-3132-1)

(b) Contour outlet fittings having integral reinforcement and attached by butt welding, or Flanged ends for attachment to the branch pipe

(c) An extruded outlet at right angles to the run pipe (크립을 무시할 수 있을 경우)

□ NH-3644 Miters

□ NH-3645 Attachments

□ NH-3646 Closures

□ NH-3647 Flanged Joints

□ NH-3648 Reducer

□ NH-3649 Pressure Design of Other Pressure Retaining Components

- Table NB-3132-1 (Dimensional Standards)에 포함되지 않은 압력부품들도 NH-3200의 요건을 만족하면 사용할 수 있음.

- Note: NB에서 Expansion Joints을 배관설계에 적용하기 위한 규정이 현재 개발중임. 그러나 NH에서는 아직 규정 마련에 대한 언급이 없음.

**□ NH-3650 ANALYSIS OF PIPING COMPONENTS**

□ NH-3651 General Requirements

배관 전용 설계규정이 마련될 때 까지 다음과 같은 해석요건들을 제공됨.

(a) 구조해석은 NH-3200 요건에 전적으로 부합해야 함 (해석, 실험, 또는 모두)

(b) NB-3600 에 주어진 응력지수 (B, C)는 NH-3220(일차응력제한)과 T-1320(변형율제한)에 사용가능하고, 응력지수법(NB-3684, NB-3685, NB-3338)으로 구한 응력 성분들은 탄성 또는 단순비탄성해석을 사용한 변형율 및 크립-피로 제한규정(T-1320, T-1330, T-1430)에 사용가능

(c) 상세 유한요소해석법

□ **NH-3660 DESIGN OF WELDS**

- 일반적으로 Socket weld 와 Seal welded threads 는 고온운전에 허용 안됨. Socket weld 인 경우에 NB 에서 2 inch 이하 배관에만 허용됨.
- 그러나 각 Junction 에 대해 해석요건들을 만족하고 각각의 적용이 Design Spec. (NCA-3250)의 일부로 특별히 기술된 경우에는 허용됨. 이 경우 허용 Joint 의 직경은 1 inch 이하임.

□ **NH-3670 SPECIAL PIPING Requirements**

□ NH-3671 Nonwelded Piping Joints

□ NH-3672 Expansion and Flexibility

- NB 와 동일. 그러나 고온운전조건에 대해 크립, 크립완화가 배관해석 및 정상상태 배관 Configuration 설계에 고려되어야 함.

□ NH-3674 Design of Piping Supports

- 배관지지물 설계는 NF 에 따라서 하지만 응력해석은 NH-3200 에 따라서 해야 함.

## Appendix C : Output Lists of Example 1

```
****************************************************
 ****************************************************

                SIE ASME-NH 1.0 CODE

                  (DEC. 01, 2007)

  High Temperature Structural Integrity Evaluations
                    According to
      The ASME Boiler and Pressure Vessel Code
       Section III, Division 1 -Subsection NH
  Class 1 Components in Elevated Temperature Service
                    2004 Edition

 ****************************************************
 ****************************************************

  * TITLE = EXAMPLE 1 for 1-Cycle Types and 2-Evaluation Points

 * ANALYSIS MODEL= AXISYMMETRIC

 * BASE MATERIAL = 316S

 * APPLICATION   = BASE METAL

* TOTAL CYCLE TYPES       =  1
* TOTAL EVALUATION POINTS =  2

* TOTAL SERVICE LIFE TIME = 240000.0000(HOURS)


 ====================================================
 =                                                  =
 =   EVALUATION OF PRIMARY STRESS INTENSITY LIMITS  =
 =                                                  =
 =        NH-3220 Design Rules and Limits for       =
 =      Load Controlled Stresses in Structures      =
 =                Other Than Bolts                  =
 =                                                  =
 ====================================================

 * SERVICE LEVEL - C
 ===================

* CYCLE TYPE =  1
* POINT NO   =  1

 * MAX TEMP       =    611.200000000000     C
 * TOTAL DURATION =    240000.000000000     HOURS
```

```
 EQ(7) GENERAL PRIMARY MEMBRANE SI LIMITS
 ----------------------------------------

[CHK] Pm = 0.10160E+02 < 1.0St = 0.48969E+02 : OK  for BASE METAL


 EQ(8) USE-FRACTION SUM ASSOCIATED WITH EQ(7)
 --------------------------------------------

Total Duration of a Loading,       ti = 0.24000E+06
Maximum Allowed Time(Fig.I-14.4), tim = 0.10438E+07

[CHK] UFS(ti/tim) = 0.22992E+00 < B = 1.0    : OK


 EQ(9)(10) PRIMARY MEMBRANE+BENDING SI LIMITS
 --------------------------------------------

Section Factor,                     K = 0.15000E+01
Bending Stress Reduction Factor, Kt = 0.12500E+01

[CHK] (PL + Pb) =0.30564E+02 < 1.2KSm = 0.18159E+03  : OK

[CHK] (PL+Pb/Kt) = 0.26438E+02 < St = 0.48969E+02   : OK for BASE
METAL

 EQ(11) USE-FRACTION SUM ASSOCIATED WITH EQ(10)
 ----------------------------------------------

Total Duration of a Loading ,      ti = 0.24000E+06
Maximum Allowed Time(Fig.I-14.4), tib = 0.70666E+06

[CHK] UFS(ti/tib) = 0.33962E+00 < 1.0                : OK

* CYCLE TYPE =  1
* POINT NO   =  2

 * MAX TEMP       =    610.100000000000     C
 * TOTAL DURATION =    240000.000000000     HOURS

 EQ(7) GENERAL PRIMARY MEMBRANE SI LIMITS
 ----------------------------------------

[CHK] Pm = 0.10160E+02 < 1.0St = 0.49492E+02 : OK  for BASE METAL

 EQ(8) USE-FRACTION SUM ASSOCIATED WITH EQ(7)
 --------------------------------------------

Total Duration of a Loading,       ti = 0.24000E+06
Maximum Allowed Time(Fig.I-14.4), tim = 0.10437E+07
```

```
[CHK] UFS(ti/tim) = 0.22995E+00 < B = 1.0             : OK

 EQ(9)(10) PRIMARY MEMBRANE+BENDING SI LIMITS
 --------------------------------------------

Section Factor,                   K = 0.15000E+01
Bending Stress Reduction Factor, Kt = 0.12500E+01

[CHK] (PL + Pb) = 0.11612E+02 < 1.2KSm = 0.18171E+03  : OK

[CHK] (PL+Pb/Kt) = 0.77142E+01 < St = 0.49492E+02    : OK  for
BASE METAL

 EQ(11) USE-FRACTION SUM ASSOCIATED WITH EQ(10)
 ----------------------------------------------

Total Duration of a Loading ,      ti = 0.24000E+06
Maximum Allowed Time(Fig.I-14.4), tib = 0.10937E+07

[CHK] UFS(ti/tib) = 0.21945E+00 < 1.0                 : OK

 ====================================================
 =                                                  =
 =           DEFORMATION AND STRAIN LIMITS          =
 =                                                  =
 =       T-1300 Deformation and Strain Limits       =
 =              for Structural Integrity            =
 =                                                  =
 ====================================================

 (1) USING ELASTIC ANALYSIS
 ==========================

* CYCLE TYPE =  1
* POINT NO   =  1

 * MIN WALL AVG. TEMP =    511.800000000000     C
 * MAX WALL AVG. TEMP =    610.400000000000     C

 * COLD TEMPERATUE    =    512.100000000000     C
 * HOT TEMPERATURE    =    605.500000000000     C

Yield stress at min wall averaged temp, SyL =    117.5280 MPa
Yield stress at max wall averaged temp, SyH =    113.1680 MPa
Averaged yield stress,                   Sy =    115.3480 MPa
Max primary stress intensity, (Pm+Pb/Kt)max =     26.4382 MPa
Max range of secondary SI,          (QR)max =     54.4476 MPa

 Primary Stress Parameter,   X =   0.229204065955426
 Secondary Stress Parameter, Y =   0.472028564066886

 (T-1322) TEST NO. A-1
```

```
 ---------------------

[CHK] (X + Y) = 0.7012 < Sa/Sy= 0.9005  : OK

 (T-1323) TEST NO. A-2
 ---------------------

[CHK] (X + Y) = 0.7012 < 1.0            : OK

* CYCLE TYPE =  1
* POINT NO   =  2

 * MIN WALL AVG. TEMP =    511.800000000000     C
 * MAX WALL AVG. TEMP =    610.400000000000     C

 * COLD TEMPERATUE    =    512.500000000000     C
 * HOT TEMPERATURE    =    602.400000000000     C

Yield stress at min wall averaged temp, SyL =    117.5280 MPa
Yield stress at max wall averaged temp, SyH =    113.1680 MPa
Averaged yield stress,                   Sy =    115.3480 MPa
Max primary stress intensity, (Pm+Pb/Kt)max =      7.7142 MPa
Max range of secondary SI,          (QR)max =     46.5471 MPa

 Primary Stress Parameter,   X =   6.687721113776959E-002
 Secondary Stress Parameter, Y =   0.403536503903491

 (T-1322) TEST NO. A-1
 ---------------------

[CHK] (X + Y) = 0.4704 < Sa/Sy= 0.9005  : OK

 (T-1323) TEST NO. A-2
 ---------------------

[CHK] (X + Y) = 0.4704 < 1.0            : OK

 (T-1324) TEST NO. A-3
 ---------------------
 (1) LIMIT OF NB-3222.2 FOR 3Sm CHECK
POINT NO:  1,  CYCLE TYPE:  1:  (P+Q) RANGE =     54.4476 MPa
* MAX(P+Q)RANGE =  54.4476  >  3Sm = 302.8022 MPa  : OK

POINT NO:  2,  CYCLE TYPE:  1:  (P+Q) RANGE =     46.5471 MPa
* MAX(P+Q)RANGE =  46.5471  >  3Sm = 302.8022 MPa  : OK

 (2) LIMIT OF NB-3222.3 EXPANSION STRESS INTENSITY
 (NOTE ! This rule is not applicable to vessels: Pe in Fig.NB-
3222-1)

 (3) LIMIT OF NB-3222-5 THERMAL STRESS RATCHET
POINT NO:  1,  CYCLE TYPE:  1:
```

```
X = 0.0881  ,Y =11.3534
*  THERMAL  STRESS  RANGE  =   55.8869   >   ALLOBLE  RANGE  =1309.5946
MPa  : OK

POINT NO:  2,  CYCLE TYPE:  1:
X = 0.0881  ,Y =11.3534
*  THERMAL  STRESS  RANGE  =   47.9783   >   ALLOBLE  RANGE  =1309.5946
MPa  : OK

 (4) ADDITIONAL REQUIREMENTS OF (A) THROUGH (D)

* POINT NO =  1
 ================

 (A) USE-FRACTION SUM

 - FOR TOTAL TRNASIENT OPERATION

* CYCLE NO =  1
Max Wall Average Temperature, Ti =     610.4000 C
Stress Level,           1.5Sy|Ti =     169.7520 MPa
Number of Hours (Transient time) =     180.0000 HOURS
Allowable Hours (TABLE I-14.6)   =    1216.3852 HOURS

 - FOR TOTAL STEADY STATE OPERATION

Normal Metal Temperature      Ti =     546.8000 C
Stress Level,           1.5Sy|Ti =     174.1920 MPa
Number of Hours (Normal Time)    =  239820.0000 HOURS
Allowable Hours (TABLE I-14.6)   =   44647.0588 HOURS

[CHK] UFS(ti/tid) = 5.5194 > 0.1    : NOT OK

  (B) CREEP STRAIN LIMITS

 - FOR TOTAL TRNASIENT OPERATION

* CYCLE TYPE =  1
Max Wall Average Temperature, Ti =     610.4000 C
Stress Level,          1.25Sy|Ti =     141.4600 MPa
Number of Hours (Transient Time) =     180.0000 HOURS
Creep Strain (FIG. T-1800)       =       0.6636 %

 - FOR TOTAL STEADY STATE OPERATION

Normal Metal Temperature,     Ti =     546.8000 C
Stress Level,          1.25Sy|Ti =     145.1600 MPa
Number of Hours (Normal Time)    =  239820.0000 HOURS
Creep Strain (FIG. T-1800)       =       3.1746 %

[CHK] TOTAL CREEP STRAIN FOR 1.25Sy|Ti = 3.8382 % > 0.2  : NOT OK
```

```
 (C) 3Sm LIMITS

* CYCLE TYPE =  1

Cold Temp at Extreme Stress Cycle, Tcold =     512.1000 C
Hot Temp at Extreme Stress Cycle,   Thot =     605.5000 C
Stress Relax. Strength at Cold Temp, SrL =     139.9133 MPa
Stress Relax. Strength at Hot Temp,  SrH =      76.6328 MPa
Modified-3Sm = SrL + SrH =    216.5461
3Sm =    303.7027

[CHK] MAX RANGE OF (PL + Pb + Q) =  54.448 < 3Sm = 216.546  : OK

* POINT NO =  2
 ================

 (A) USE-FRACTION SUM

 - FOR TOTAL TRNASIENT OPERATION

* CYCLE NO =  1
Max Wall Average Temperature, Ti =     610.4000 C
Stress Level,           1.5Sy|Ti =     169.7520 MPa
Number of Hours (Transient time) =     180.0000 HOURS
Allowable Hours (TABLE I-14.6)   =    1216.3852 HOURS

 - FOR TOTAL STEADY STATE OPERATION

Normal Metal Temperature      Ti =     546.1000 C
Stress Level,           1.5Sy|Ti =     174.2340 MPa
Number of Hours (Normal Time)    =  239820.0000 HOURS
Allowable Hours (TABLE I-14.6)   =   48033.6538 HOURS

[CHK] UFS(ti/tid) = 5.1407 > 0.1    : NOT OK

  (B) CREEP STRAIN LIMITS

 - FOR TOTAL TRNASIENT OPERATION

* CYCLE TYPE =  1
Max Wall Average Temperature, Ti =     610.4000 C
Stress Level,          1.25Sy|Ti =     141.4600 MPa
Number of Hours (Transient Time) =     180.0000 HOURS
Creep Strain (FIG. T-1800)       =       0.6636 %

 - FOR TOTAL STEADY STATE OPERATION

Normal Metal Temperature,     Ti =     546.1000 C
Stress Level,          1.25Sy|Ti =     145.1950 MPa
Number of Hours (Normal Time)    =  239820.0000 HOURS
Creep Strain (FIG. T-1800)       =       3.1247 %
```

```
[CHK] TOTAL CREEP STRAIN FOR 1.25Sy|Ti = 3.7883 % > 0.2  : NOT OK

  (C) 3Sm LIMITS

* CYCLE TYPE =  1

Cold Temp at Extreme Stress Cycle, Tcold =     512.5000 C
Hot Temp at Extreme Stress Cycle,   Thot =     602.4000 C
Stress Relax. Strength at Cold Temp, SrL =     139.5438 MPa
Stress Relax. Strength at Hot Temp,  SrH =      79.6641 MPa
Modified-3Sm = SrL + SrH =    219.2078
3Sm =    304.2724

[CHK] MAX RANGE OF (PL + Pb + Q) =  46.547 < 3Sm = 219.208  : OK

  (2) USING SIMPLIFIED INELASTIC ANALYSIS
 =======================================

 (T-1332) TEST NOS. B-1 and B-2
 ------------------------------

* POINT NO   =  1
* CYCLE TYPE =  1

 * MIN WALL AVG. TEMP =    511.800000000000     C
 * MAX WALL AVG. TEMP =    610.400000000000     C

 * LOWER EXTREME TEMPERATURE  =    512.100000000000     C
 * HIGHER EXTREME TEMPERATURE =    605.500000000000     C


 Primary SI,  (Pm + Pb/Kt) + Qm =   45.2730965931277     (MPa)
 Secondary SI Range,         QR =   19.5585325709778     (MPa)

 Yield Stress at Cold Temp, SyL =   117.516000000000     (MPa)

 Primary Stress Parameter,    X =   0.385250490087543
 Secondary Stress Parameter,  Y =   0.166432933140830

 Creep Stress Parameter,      Z =   0.385250490087543

 Effective Creep Stress,     Sc =    45.2730965931277     (MPa)

* POINT NO   =  2
* CYCLE TYPE =  1

 * MIN WALL AVG. TEMP =    511.800000000000     C
 * MAX WALL AVG. TEMP =    610.400000000000     C

 * LOWER EXTREME TEMPERATURE  =    512.500000000000     C
 * HIGHER EXTREME TEMPERATURE =    602.400000000000     C
```

```
 Primary SI,  (Pm + Pb/Kt) + Qm =   29.1602172758127     (MPa)
 Secondary SI Range,          QR =   19.5585325709778     (MPa)

 Yield Stress at Cold Temp, SyL =   117.500000000000     (MPa)

 Primary Stress Parameter,    X =   0.248172061921811
 Secondary Stress Parameter,  Y =   0.166455596348747

 Creep Stress Parameter,      Z =   0.248172061921811

 Effective Creep Stress,     Sc =    29.1602172758127     (MPa)

 - EFFECTIVE CREEP RATCHET STRESSES :

POINT NO =   1,  CYCLE TYPE =   1:   1.25Sc =  56.591(MPa)
POINT NO =   2,  CYCLE TYPE =   1:   1.25Sc =  36.450(MPa)

 * LISTS OF SEQUENCE OF LOAD HISTORIES

 SEQUENCE NO.  CYCLE TYPES      DURATION OF TEMP-TIME BLOCKS
 ------------------------------------------------------------
      1            1                      20000.0000
      2            1                      20000.0000
      3            1                      20000.0000
      4            1                      20000.0000
      5            1                      20000.0000
      6            1                      20000.0000
      7            1                      20000.0000
      8            1                      20000.0000
      9            1                      20000.0000
     10            1                      20000.0000
     11            1                      20000.0000
     12            1                      20000.0000

TOTAL  SUM  OF  TIME  BLOCKS  =  240000.0000    >    DESIGN  LIFE=
240000.0000 : OK

 - CALCULATED CREEP STRAIN INC FOR EACH TIME BLOCK

* POINT NO   =  1
 (SEQ NO)  (CREEP STRN INC)   (TEMP)
 ------------------------------------
      1       0.102028       605.500
      2       0.009905       605.500
      3       0.009905       605.500
      4       0.009905       605.500
      5       0.009905       605.500
      6       0.009905       605.500
      7       0.009905       605.500
      8       0.009905       605.500
      9       0.009905       605.500
     10       0.009905       605.500
```

```
     11       0.009905        605.500
     12       0.009905        605.500

[CHK] TOTAL CREEP RATCHETING STRAIN = 0.2110 % < 1.0 %  : OK  for
BASE METAL


* POINT NO   =  2
 (SEQ NO)  (CREEP STRN INC)   (TEMP)
 ------------------------------------
      1       0.028704        602.400
      2       0.002024        602.400
      3       0.001641        602.400
      4       0.000276        602.400
      5       0.000276        602.400
      6       0.000276        602.400
      7       0.000276        602.400
      8       0.000276        602.400
      9       0.000276        602.400
     10       0.000276        602.400
     11       0.000276        602.400
     12       0.000276        602.400

[CHK] TOTAL CREEP RATCHETING STRAIN = 0.0349 % < 1.0 %  : OK  for
BASE METAL

 (T-1333) TEST NO. B-3
 ---------------------

* POINT NO =  1

* TEMP-TIME BLOCK NO =  1

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,      SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   0.102027509727608      %

* TEMP-TIME BLOCK NO =  2

 XL =   0.385250490087543     ,    XH =   0.398671157037053
```

```
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860127385E-003 %

* TEMP-TIME BLOCK NO =  3

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860127441E-003 %

* TEMP-TIME BLOCK NO =  4

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860127385E-003 %

* TEMP-TIME BLOCK NO =  5
```

```
 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860126941E-003 %

* TEMP-TIME BLOCK NO =  6

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860128718E-003 %

* TEMP-TIME BLOCK NO =  7

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860121612E-003 %
```

```
* TEMP-TIME BLOCK NO =  8

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860036347E-003 %

* TEMP-TIME BLOCK NO =  9

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860377408E-003 %

* TEMP-TIME BLOCK NO = 10

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,     SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
```

```
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732860377408E-003 %

* TEMP-TIME BLOCK NO = 11

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,      SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732862196397E-003 %

* TEMP-TIME BLOCK NO = 12

 XL =   0.385250490087543     ,    XH =   0.398671157037053
 YL =   0.166432933140830     ,    YH =   0.172230825739502

 ZL =   0.385250490087543
 ZH =   0.398671157037053

 Yield Stress at Cold End,      SyL =   117.516000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.560000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.904732840368524E-003 %

 - TOTAL ENHANCED CREEP STRAIN INCREMENT   =   0.0E+000 %
 - TOTAL PLASTIC RATCHET STRAIN INCREMENT  =   0.0E+000 %
 - TOTAL INELASTIC CREEP STRAIN =   0.210979571171724      %

[CHK] TOTAL INELASTIC STRAIN = 0.2110 % < 1.0 %  : OK  for BASE
METAL

* POINT NO =  2

* TEMP-TIME BLOCK NO =  1

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158
```

```
 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.870351363226709E-002 %

* TEMP-TIME BLOCK NO =  2

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.023621686852085E-003 %

* TEMP-TIME BLOCK NO =  3

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.641176691453958E-003 %

* TEMP-TIME BLOCK NO =  4
```

```
 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.764678083229805E-004 %

* TEMP-TIME BLOCK NO =  5

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.764678083229666E-004 %

* TEMP-TIME BLOCK NO =  6

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.764678083229388E-004 %
```

```
* TEMP-TIME BLOCK NO =  7

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.764678083229666E-004 %

* TEMP-TIME BLOCK NO =  8

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.764678083229111E-004 %

* TEMP-TIME BLOCK NO =  9

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
```

```
 -INELASTIC CREEP STRAIN           =   2.764678083231331E-004 %

* TEMP-TIME BLOCK NO = 10

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.764678083249095E-004 %

* TEMP-TIME BLOCK NO = 11

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.764678083195804E-004 %

* TEMP-TIME BLOCK NO = 12

 XL =   0.248172061921811     ,    XH =   0.256222912939448
 YL =   0.166455596348747     ,    YH =   0.171855516053158

 ZL =   0.248172061921811
 ZH =   0.256222912939448

 Yield Stress at Cold End,     SyL =   117.500000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.808000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)
```

```
 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.764678083195804E-004 %

 - TOTAL ENHANCED CREEP STRAIN INCREMENT   =   0.0E+000 %
 - TOTAL PLASTIC RATCHET STRAIN INCREMENT  =   0.0E+000 %
 - TOTAL INELASTIC CREEP STRAIN            =   3.4856E-002 %

[CHK] TOTAL INELASTIC STRAIN = 0.0349 % < 1.0 %  : OK  for BASE
METAL

 ====================================================
 =                                                  =
 =        T-1400 CREEP-FATIGUE EVALUATION           =
 =                                                  =
 ====================================================

* POINT NO =   1
 ================

 (1) FATIGUE DAMAGE EVALUATION
 -----------------------------

* CYCLE NO =  1

 * MAX METAL TEMP   =    611.200000000000     C

 * CYCLE DURATION   =    20000.0000000000     HOURS
 * NUMBER OF CYCLES =           12

Max Elastic Strain  Range,       Emax =      0.0321 %

Equi. Stress Concentration Factor,  K =      1.1189

Stress Indicator,                  S* =     48.1647 MPa
Stress Indicator,               S_bar =     53.8929 MPa

Modified Strain Range,           Emod =      0.0360 %

Triaxiality Factor,              T.F.=      1.9413
Factor by Triaxiality Factor,       f =      0.8978
Modified 3Sm Value       Modified-3Sm =    216.5461 MPa

KEmax =0.0004 < Modified-3Sm/E =0.0014

Stress Ratio Factor at Yield,      Ke =      1.0000
Factor, (Ke)(K)(Emax)(E)/Modified-3SM =      0.2489
Plastic Poisson Ratio Adj Factor, Kv* =      1.0000

Mutiaxial Adjustment Factor,       Kv =      1.0000

- ELASTIC-PLASTIC STRAIN RANGE,   Eep =      0.0360 %
```

```
- CREEP STRAIN INCREMENT,          Ec =      0.0229 %

- TOTAL STRAIN RANGE,              Et =      0.0588 %

Design Number of cycle,             n =         12.
Allowable Number of cycle,         Nd =    2770211.

- FATIGUE DAMAGE =   0.000004   for CYCLE NO =   1

- TOTAL FATIGUE DAMAGE, Df = 0.000004  for BASE METAL

 (2) CREEP DAMAGE EVALUATION
 ---------------------------

* CYCLE NO =  1

(STEP 1) DEFINE TOTAL HOLD TIME,     tH = 240000.0000 H

(STEP 2) DEFINE HOLD TEMPERATURE,   THT =    546.8000 C

(STEP 3) DEFINE AVERAGE CYCLE TIME,  tj =  20000.0000 H

         DEFINE NUMBER OF CYCLE,     nj =     12

(STEP 4) STRESS LEVEL,               Sj =     81.3627 MPa
         TOTAL STRAIN,               Et =      0.0588 %

(STEP 5) STRESS RELAXATION TIME HISTORY GENERATION

         LOWER BOUND STRESS,        SLB =     56.5914 MPa
         TIME STEP SIZE FOR CREEP,   DT =      1.0000 H

         OUTPUT FILE = SRTH.OUT

(STEP 6) NOT-MODIFIED WITH TRANSIENT PRIMARY STRESS

         AT TRANSIENT TIME =    15.00 HOURS
         (PMB= 30.56 MPa   SR= 80.26 MPa)

(STEP 7) DEFINE CYCLE TRANSIENT TEMPERATURE

         TRNASIENT DURATION,   (tTRAN)j =     15.0000 H
         TRNASIENT TEMPERATURE,(TTRAN)j =    611.2000 C

(STEP 8) REPETITION OF STEP 3 THROUGH 7 FOR J=  1 TO  1

         DWELL STRESS,             Sj/K* =     90.4031 MPa
         SAFETY FACTOR,               K* =      0.9000

[CHK] FATIGUE(CREEP)=      0.0000 < FATIGUE-LIMIT=      0.2920   :
OK  for BASE METAL
```

```
[CHK] CREEP(FATIGUE)=      0.3188 < CREEP-LIMIT=        1.0000   :
OK  for BASE METAL

* POINT NO =   2
 ================

 (1) FATIGUE DAMAGE EVALUATION
 -----------------------------

* CYCLE NO =  1

 * MAX METAL TEMP   =    610.100000000000     C

 * CYCLE DURATION   =    20000.0000000000     HOURS
 * NUMBER OF CYCLES =           12

Max Elastic Strain  Range,       Emax =      0.0273 %

Equi. Stress Concentration Factor,  K =      1.0561

Stress Indicator,                  S* =     40.9214 MPa
Stress Indicator,               S_bar =     43.2165 MPa

Modified Strain Range,           Emod =      0.0288 %

Triaxiality Factor,              T.F.=      0.2101
Factor by Triaxiality Factor,       f =      0.0546
Modified 3Sm Value       Modified-3Sm =    219.2078 MPa

KEmax =0.0003 < Modified-3Sm/E =0.0015

Stress Ratio Factor at Yield,      Ke =      1.0000
Factor, (Ke)(K)(Emax)(E)/Modified-3SM =      0.1971
Plastic Poisson Ratio Adj Factor, Kv* =      1.0000

Mutiaxial Adjustment Factor,       Kv =      1.0000

- ELASTIC-PLASTIC STRAIN RANGE,   Eep =      0.0288 %
- CREEP STRAIN INCREMENT,          Ec =      0.0037 %

- TOTAL STRAIN RANGE,              Et =      0.0325 %

Design Number of cycle,             n =         12.
Allowable Number of cycle,         Nd =    4011837.

- FATIGUE DAMAGE =   0.000003   for CYCLE NO =   1

- TOTAL FATIGUE DAMAGE, Df = 0.000003  for BASE METAL

 (2) CREEP DAMAGE EVALUATION
 ---------------------------
```

```
* CYCLE NO =  1

(STEP 1) DEFINE TOTAL HOLD TIME,     tH = 240000.0000 H

(STEP 2) DEFINE HOLD TEMPERATURE,   THT =    546.1000 C

(STEP 3) DEFINE AVERAGE CYCLE TIME,  tj =  20000.0000 H

         DEFINE NUMBER OF CYCLE,     nj =     12

(STEP 4) STRESS LEVEL,               Sj =     44.5692 MPa
         TOTAL STRAIN,               Et =      0.0325 %

(STEP 5) STRESS RELAXATION TIME HISTORY GENERATION

         LOWER BOUND STRESS,        SLB =     36.4503 MPa
         TIME STEP SIZE FOR CREEP,   DT =      1.0000 H

         OUTPUT FILE = SRTH.OUT

(STEP 6) NOT-MODIFIED WITH TRANSIENT PRIMARY STRESS

         AT TRANSIENT TIME =    15.00 HOURS
         (PMB= 11.61 MPa   SR= 44.57 MPa)

(STEP 7) DEFINE CYCLE TRANSIENT TEMPERATURE

         TRNASIENT DURATION,   (tTRAN)j =     15.0000 H
         TRNASIENT TEMPERATURE,(TTRAN)j =    610.1000 C

(STEP 8) REPETITION OF STEP 3 THROUGH 7 FOR J=  1 TO  1

         DWELL STRESS,             Sj/K* =     49.5214 MPa
         SAFETY FACTOR,               K* =      0.9000

[CHK] FATIGUE(CREEP)=      0.0000 < FATIGUE-LIMIT=      0.4528   :
OK  for BASE METAL

[CHK] CREEP(FATIGUE)=      0.2345 < CREEP-LIMIT=        1.0000   :
OK  for BASE METAL
```

## Appendix D : Output Lists of Example 2

```
 ****************************************************
 ****************************************************

                SIE ASME-NH 1.0 CODE

                  (DEC 01, 2007)

  High Temperature Structural Integrity Evaluations
                    According to
      The ASME Boiler and Pressure Vessel Code
       Section III, Division 1 -Subsection NH
  Class 1 Components in Elevated Temperature Service
                    2004 Edition

 ****************************************************
 ****************************************************

 * TITLE = EXAMPLE 2 for 2-Cycle Types and 2-Evaluation Points

 * ANALYSIS MODEL= AXISYMMETRIC

 * BASE MATERIAL = 316S

 * APPLICATION   = BASE METAL

* TOTAL CYCLE TYPES       =  2
* TOTAL EVALUATION POINTS =  2

* TOTAL SERVICE LIFE TIME = 240000.0000(HOURS)

 ====================================================
 =                                                  =
 =   EVALUATION OF PRIMARY STRESS INTENSITY LIMITS  =
 =                                                  =
 =        NH-3220 Design Rules and Limits for       =
 =      Load Controlled Stresses in Structures      =
 =                Other Than Bolts                  =
 =                                                  =
 ====================================================

 * SERVICE LEVEL - C
 ===================

* CYCLE TYPE =  1
* POINT NO   =  1

 * MAX TEMP       =    611.200000000000     C
 * TOTAL DURATION =    240000.000000000     HOURS
```

```
 EQ(7) GENERAL PRIMARY MEMBRANE SI LIMITS
 ----------------------------------------

[CHK] Pm = 0.10160E+02 < 1.0St = 0.48969E+02 : OK  for BASE METAL

 EQ(8) USE-FRACTION SUM ASSOCIATED WITH EQ(7)
 --------------------------------------------

Total Duration of a Loading,       ti = 0.24000E+06
Maximum Allowed Time(Fig.I-14.4), tim = 0.10438E+07

[CHK] UFS(ti/tim) = 0.22992E+00 < B = 1.0             : OK

 EQ(9)(10) PRIMARY MEMBRANE+BENDING SI LIMITS
 --------------------------------------------

Section Factor,                   K = 0.15000E+01
Bending Stress Reduction Factor, Kt = 0.12500E+01

[CHK] (PL + Pb) = 0.30564E+02 < 1.2KSm = 0.18159E+03  : OK

[CHK] (PL+Pb/Kt) = 0.26438E+02 < St = 0.48969E+02      : OK   for
BASE METAL

 EQ(11) USE-FRACTION SUM ASSOCIATED WITH EQ(10)
 ----------------------------------------------

Total Duration of a Loading ,      ti = 0.24000E+06
Maximum Allowed Time(Fig.I-14.4), tib = 0.70666E+06

[CHK] UFS(ti/tib) = 0.33962E+00 < 1.0                 : OK

* CYCLE TYPE =  1
* POINT NO   =  2

 * MAX TEMP       =    610.100000000000     C
 * TOTAL DURATION =    240000.000000000     HOURS

 EQ(7) GENERAL PRIMARY MEMBRANE SI LIMITS
 ----------------------------------------

[CHK] Pm = 0.10160E+02 < 1.0St = 0.49492E+02 : OK  for BASE METAL

 EQ(8) USE-FRACTION SUM ASSOCIATED WITH EQ(7)
 --------------------------------------------

Total Duration of a Loading,       ti = 0.24000E+06
Maximum Allowed Time(Fig.I-14.4), tim = 0.10437E+07


[CHK] UFS(ti/tim) = 0.22995E+00 < B = 1.0             : OK
```

```
 EQ(9)(10) PRIMARY MEMBRANE+BENDING SI LIMITS
 --------------------------------------------

Section Factor,                   K = 0.15000E+01
Bending Stress Reduction Factor, Kt = 0.12500E+01

[CHK] (PL + Pb) = 0.11612E+02 < 1.2KSm = 0.18171E+03  : OK

[CHK] (PL+Pb/Kt) = 0.77142E+01 < St = 0.49492E+02      : OK  for
BASE METAL

 EQ(11) USE-FRACTION SUM ASSOCIATED WITH EQ(10)
 ----------------------------------------------

Total Duration of a Loading ,      ti = 0.24000E+06
Maximum Allowed Time(Fig.I-14.4), tib = 0.10937E+07

[CHK] UFS(ti/tib) = 0.21945E+00 < 1.0                 : OK

 * SERVICE LEVEL - A & B (NH-3223)
 =================================

* CYCLE TYPE =  2
* POINT NO   =  1

 * MAX TEMP       =    563.600000000000     C
 * TOTAL DURATION =    240000.000000000     HOURS

 EQ(3) GENERAL PRIMARY MEMBRANE SI LIMITS
 ----------------------------------------

[CHK] Pm = 0.10160E+02 < Smt = 0.79994E+02   : OK  for BASE METAL

 EQ(4)(5) PRIMARY-MEMBRANE+BENDING SI LIMITS
 -------------------------------------------

Section Factor,                   K = 0.15000E+01
Bending Stress Reduction Factor, Kt = 0.12500E+01

[CHK] (PL+Pb) = 0.30564E+02 < KSm = 0.15642E+03    : OK

[CHK] (PL+Pb/Kt) = 0.26438E+02 < St = 0.79994E+02  : OK  for BASE
METAL

* CYCLE TYPE =  2
* POINT NO   =  2

 * MAX TEMP       =    562.700000000000     C
 * TOTAL DURATION =    240000.000000000     HOURS

 EQ(3) GENERAL PRIMARY MEMBRANE SI LIMITS
```

```
 ----------------------------------------

[CHK] Pm = 0.10160E+02 < Smt = 0.80735E+02   : OK  for BASE METAL

 EQ(4)(5) PRIMARY-MEMBRANE+BENDING SI LIMITS
 -------------------------------------------

Section Factor,                   K = 0.15000E+01
Bending Stress Reduction Factor, Kt = 0.12500E+01

[CHK] (PL+Pb) = 0.11612E+02 < KSm = 0.15652E+03    : OK

[CHK] (PL+Pb/Kt) = 0.77142E+01 < St = 0.80735E+02  : OK  for BASE
METAL

 ====================================================
 =                                                  =
 =           DEFORMATION AND STRAIN LIMITS          =
 =                                                  =
 =       T-1300 Deformation and Strain Limits       =
 =              for Structural Integrity            =
 =                                                  =
 ====================================================

 (1) USING ELASTIC ANALYSIS
 ==========================

* CYCLE TYPE =  1
* POINT NO   =  1

 * MIN WALL AVG. TEMP =    512.300000000000     C
 * MAX WALL AVG. TEMP =    604.000000000000     C

 * COLD TEMPERATUE    =    512.100000000000     C
 * HOT TEMPERATURE    =    605.500000000000     C

Yield stress at min wall averaged temp, SyL =    117.5080 MPa
Yield stress at max wall averaged temp, SyH =    113.6800 MPa
Averaged yield stress,                   Sy =    115.5940 MPa
Max primary stress intensity, (Pm+Pb/Kt)max =     26.4382 MPa
Max range of secondary SI,          (QR)max =     54.4476 MPa

 Primary Stress Parameter,   X =   0.228716288041131
 Secondary Stress Parameter, Y =   0.471024022077160

 (T-1322) TEST NO. A-1
 ---------------------

[CHK] (X + Y) = 0.6997 < Sa/Sy= 0.9512  : OK

 (T-1323) TEST NO. A-2
 ---------------------
```

```
[CHK] (X + Y) = 0.6997 < 1.0            : OK


* CYCLE TYPE =  1
* POINT NO   =  2

 * MIN WALL AVG. TEMP =    512.300000000000     C
 * MAX WALL AVG. TEMP =    604.000000000000     C

 * COLD TEMPERATUE    =    512.500000000000     C
 * HOT TEMPERATURE    =    602.400000000000     C

Yield stress at min wall averaged temp, SyL =    117.5080 MPa
Yield stress at max wall averaged temp, SyH =    113.6800 MPa
Averaged yield stress,                   Sy =    115.5940 MPa
Max primary stress intensity, (Pm+Pb/Kt)max =      7.7142 MPa
Max range of secondary SI,          (QR)max =     46.5471 MPa

 Primary Stress Parameter,   X =   6.673488719414025E-002
 Secondary Stress Parameter, Y =   0.402677722479193

 (T-1322) TEST NO. A-1
 ---------------------

[CHK] (X + Y) = 0.4694 < Sa/Sy= 0.9512  : OK

 (T-1323) TEST NO. A-2
 ---------------------

[CHK] (X + Y) = 0.4694 < 1.0            : OK

* CYCLE TYPE =  2
* POINT NO   =  1

 * MIN WALL AVG. TEMP =    443.300000000000     C
 * MAX WALL AVG. TEMP =    549.300000000000     C

 * COLD TEMPERATUE    =    442.100000000000     C
 * HOT TEMPERATURE    =    551.100000000000     C

Yield stress at min wall averaged temp, SyL =    121.2680 MPa
Yield stress at max wall averaged temp, SyH =    116.0280 MPa
Averaged yield stress,                   Sy =    118.6480 MPa
Max primary stress intensity, (Pm+Pb/Kt)max =     26.4382 MPa
Max range of secondary SI,          (QR)max =     88.8326 MPa

 Primary Stress Parameter,   X =   0.222829129861662
 Secondary Stress Parameter, Y =   0.748707141154094

 (T-1322) TEST NO. A-1
 ---------------------
```

```
[CHK] (X + Y) = 0.9715 < Sa/Sy= 1.0000  : OK

 (T-1323) TEST NO. A-2
 ---------------------

[CHK] (X + Y) = 0.9715 < 1.0            : OK

* CYCLE TYPE =  2
* POINT NO   =  2

 * MIN WALL AVG. TEMP =    443.300000000000     C
 * MAX WALL AVG. TEMP =    549.300000000000     C

 * COLD TEMPERATUE    =    444.500000000000     C
 * HOT TEMPERATURE    =    547.400000000000     C

Yield stress at min wall averaged temp, SyL =    121.2680 MPa
Yield stress at max wall averaged temp, SyH =    116.0280 MPa
Averaged yield stress,                   Sy =    118.6480 MPa
Max primary stress intensity, (Pm+Pb/Kt)max =      7.7142 MPa
Max range of secondary SI,          (QR)max =     73.4194 MPa

 Primary Stress Parameter,   X =   6.501713092778173E-002
 Secondary Stress Parameter, Y =   0.618800132314499

 (T-1322) TEST NO. A-1
 ---------------------

[CHK] (X + Y) = 0.6838 < Sa/Sy= 1.0000  : OK


 (T-1323) TEST NO. A-2
 ---------------------

[CHK] (X + Y) = 0.6838 < 1.0            : OK

 (T-1324) TEST NO. A-3
 ---------------------
 (1) LIMIT OF NB-3222.2 FOR 3Sm CHECK
POINT NO:  1,  CYCLE TYPE:  1:  (P+Q) RANGE =     54.4476 MPa
POINT NO:  1,  CYCLE TYPE:  2:  (P+Q) RANGE =     88.8326 MPa
* MAX(P+Q)RANGE =  88.8326  >  3Sm = 316.0575 MPa  : OK

POINT NO:  2,  CYCLE TYPE:  1:  (P+Q) RANGE =     46.5471 MPa
POINT NO:  2,  CYCLE TYPE:  2:  (P+Q) RANGE =     73.4194 MPa
* MAX(P+Q)RANGE =  73.4194  >  3Sm = 316.0575 MPa  : OK

 (2) LIMIT OF NB-3222.3 EXPANSION STRESS INTENSITY
 (NOTE ! This rule is not applicable to vessels: Pe in Fig.NB-
3222-1)
```

```
 (3) LIMIT OF NB-3222-5 THERMAL STRESS RATCHET
POINT NO:  1,  CYCLE TYPE:  1:
X = 0.0879  ,Y =11.3776
*  THERMAL  STRESS  RANGE =   55.8869   >   ALLOBLE  RANGE =1315.1864
MPa  : OK

POINT NO:  1,  CYCLE TYPE:  2:
X = 0.0856  ,Y =11.6782
*  THERMAL  STRESS  RANGE =   92.4007   >   ALLOBLE  RANGE =1385.5991
MPa  : OK

POINT NO:  2,  CYCLE TYPE:  1:
X = 0.0879  ,Y =11.3776
*  THERMAL  STRESS  RANGE =   47.9783   >   ALLOBLE  RANGE =1315.1864
MPa  : OK

POINT NO:  2,  CYCLE TYPE:  2:
X = 0.0856  ,Y =11.6782
*  THERMAL  STRESS  RANGE =   75.5234   >   ALLOBLE  RANGE =1385.5991
MPa  : OK


 (4) ADDITIONAL REQUIREMENTS OF (A) THROUGH (D)

* POINT NO =  1
 ================

 (A) USE-FRACTION SUM

 - FOR TOTAL TRNASIENT OPERATION

* CYCLE NO =  1
Max Wall Average Temperature, Ti =     604.0000 C
Stress Level,           1.5Sy|Ti =     170.5200 MPa
Number of Hours (Transient time) =     150.0000 HOURS
Allowable Hours (TABLE I-14.6)   =    1749.2260 HOURS

* CYCLE NO =  2
Max Wall Average Temperature, Ti =     549.3000 C
Stress Level,           1.5Sy|Ti =     174.0420 MPa
Number of Hours (Transient time) =     225.0000 HOURS
Allowable Hours (TABLE I-14.6)   =   31386.2952 HOURS

 - FOR TOTAL STEADY STATE OPERATION

Normal Metal Temperature      Ti =     546.8000 C
Stress Level,           1.5Sy|Ti =     174.1920 MPa
Number of Hours (Normal Time)    =  239625.0000 HOURS
Allowable Hours (TABLE I-14.6)   =   44647.0588 HOURS

[CHK] UFS(ti/tid) = 5.4600 > 0.1    : NOT OK
```

```
 (B) CREEP STRAIN LIMITS

 - FOR TOTAL TRNASIENT OPERATION

* CYCLE TYPE =  1
Max Wall Average Temperature, Ti =     604.0000 C
Stress Level,          1.25Sy|Ti =     142.1000 MPa
Number of Hours (Transient Time) =     150.0000 HOURS
Creep Strain (FIG. T-1800)       =       0.5464 %

* CYCLE TYPE =  2
Max Wall Average Temperature, Ti =     549.3000 C
Stress Level,          1.25Sy|Ti =     145.0350 MPa
Number of Hours (Transient Time) =     225.0000 HOURS
Creep Strain (FIG. T-1800)       =       0.1131 %

 - FOR TOTAL STEADY STATE OPERATION

Normal Metal Temperature,     Ti =     546.8000 C
Stress Level,          1.25Sy|Ti =     145.1600 MPa
Number of Hours (Normal Time)    =  239625.0000 HOURS
Creep Strain (FIG. T-1800)       =       3.1731 %

[CHK] TOTAL CREEP STRAIN FOR 1.25Sy|Ti = 3.8326 % > 0.2  : NOT OK

 (C) 3Sm LIMITS

* CYCLE TYPE =  1

Cold Temp at Extreme Stress Cycle, Tcold =     512.1000 C
Hot Temp at Extreme Stress Cycle,   Thot =     605.5000 C
Stress Relax. Strength at Cold Temp, SrL =     139.9133 MPa
Stress Relax. Strength at Hot Temp,  SrH =      76.6328 MPa
Modified-3Sm = SrL + SrH =    216.5461
3Sm =    303.7027

[CHK] MAX RANGE OF (PL + Pb + Q) =  54.448 < 3Sm = 216.546  : OK

* CYCLE TYPE =  2

Cold Temp at Extreme Stress Cycle, Tcold =     442.1000 C
Hot Temp at Extreme Stress Cycle,   Thot =     551.1000 C
Stress Relax. Strength at Cold Temp, SrL =     162.6214 MPa
Stress Relax. Strength at Hot Temp,  SrH =     106.7365 MPa
Modified-3Sm = SrL + SrH =    269.3578
3Sm =    315.6525

[CHK] MAX RANGE OF (PL + Pb + Q) =  88.833 < 3Sm = 269.358  : OK

* POINT NO =  2
 ================
```

```
 (A) USE-FRACTION SUM

 - FOR TOTAL TRNASIENT OPERATION

* CYCLE NO =  1
Max Wall Average Temperature, Ti =     604.0000 C
Stress Level,           1.5Sy|Ti =     170.5200 MPa
Number of Hours (Transient time) =     150.0000 HOURS
Allowable Hours (TABLE I-14.6)   =    1749.2260 HOURS

* CYCLE NO =  2
Max Wall Average Temperature, Ti =     549.3000 C
Stress Level,           1.5Sy|Ti =     174.0420 MPa
Number of Hours (Transient time) =     225.0000 HOURS
Allowable Hours (TABLE I-14.6)   =   31386.2952 HOURS

 - FOR TOTAL STEADY STATE OPERATION

Normal Metal Temperature      Ti =     546.1000 C
Stress Level,           1.5Sy|Ti =     174.2340 MPa
Number of Hours (Normal Time)    =  239625.0000 HOURS
Allowable Hours (TABLE I-14.6)   =   48033.6538 HOURS

[CHK] UFS(ti/tid) = 5.0816 > 0.1    : NOT OK

 (B) CREEP STRAIN LIMITS

 - FOR TOTAL TRNASIENT OPERATION

* CYCLE TYPE =  1
Max Wall Average Temperature, Ti =     604.0000 C
Stress Level,          1.25Sy|Ti =     142.1000 MPa
Number of Hours (Transient Time) =     150.0000 HOURS
Creep Strain (FIG. T-1800)       =       0.5464 %

* CYCLE TYPE =  2
Max Wall Average Temperature, Ti =     549.3000 C
Stress Level,          1.25Sy|Ti =     145.0350 MPa
Number of Hours (Transient Time) =     225.0000 HOURS
Creep Strain (FIG. T-1800)       =       0.1131 %

 - FOR TOTAL STEADY STATE OPERATION

Normal Metal Temperature,     Ti =     546.1000 C
Stress Level,          1.25Sy|Ti =     145.1950 MPa
Number of Hours (Normal Time)    =  239625.0000 HOURS
Creep Strain (FIG. T-1800)       =       3.1232 %

[CHK] TOTAL CREEP STRAIN FOR 1.25Sy|Ti = 3.7827 % > 0.2  : NOT OK

 (C) 3Sm LIMITS
```

```
* CYCLE TYPE =  1

Cold Temp at Extreme Stress Cycle, Tcold =     512.5000 C
Hot Temp at Extreme Stress Cycle,   Thot =     602.4000 C
Stress Relax. Strength at Cold Temp, SrL =     139.5438 MPa
Stress Relax. Strength at Hot Temp,  SrH =      79.6641 MPa
Modified-3Sm = SrL + SrH =    219.2078
3Sm =    304.2724

[CHK] MAX RANGE OF (PL + Pb + Q) =  46.547 < 3Sm = 219.208  : OK

* CYCLE TYPE =  2

Cold Temp at Extreme Stress Cycle, Tcold =     444.5000 C
Hot Temp at Extreme Stress Cycle,   Thot =     547.4000 C
Stress Relax. Strength at Cold Temp, SrL =     162.2538 MPa
Stress Relax. Strength at Hot Temp,  SrH =     109.3651 MPa
Modified-3Sm = SrL + SrH =    271.6189
3Sm =    316.4850

[CHK] MAX RANGE OF (PL + Pb + Q) =  73.419 < 3Sm = 271.619  : OK

 (2) USING SIMPLIFIED INELASTIC ANALYSIS
 =======================================

 (T-1332) TEST NOS. B-1 and B-2
 ------------------------------

* POINT NO   =  1
* CYCLE TYPE =  1

 * MIN WALL AVG. TEMP =    512.300000000000     C
 * MAX WALL AVG. TEMP =    604.000000000000     C

 * LOWER EXTREME TEMPERATURE  =    512.300000000000     C
 * HIGHER EXTREME TEMPERATURE =    604.000000000000     C


 Primary SI,  (Pm + Pb/Kt) + Qm =   45.2730965931277     (MPa)
 Secondary SI Range,          QR =   19.5585325709778     (MPa)

 Yield Stress at Cold Temp, SyL =   117.508000000000     (MPa)

 Primary Stress Parameter,     X =   0.385276718122406
 Secondary Stress Parameter,  Y =   0.166444263973328

 Creep Stress Parameter,       Z =   0.385276718122406

 Effective Creep Stress,      Sc =    45.2730965931277     (MPa)

* POINT NO   =  1
* CYCLE TYPE =  2
```

```
 * MIN WALL AVG. TEMP =    443.300000000000     C
 * MAX WALL AVG. TEMP =    549.300000000000     C

 * LOWER EXTREME TEMPERATURE  =    443.300000000000     C
 * HIGHER EXTREME TEMPERATURE =    549.300000000000     C

 Primary SI,  (Pm + Pb/Kt) + Qm =   45.2124069678152     (MPa)
 Secondary SI Range,         QR =   33.4678861755579     (MPa)

 Yield Stress at Cold Temp, SyL =   121.268000000000     (MPa)

 Primary Stress Parameter,    X =   0.372830482631982
 Secondary Stress Parameter,  Y =   0.275982832862403

 Creep Stress Parameter,      Z =   0.372830482631982

 Effective Creep Stress,     Sc =    45.2124069678152     (MPa)

* POINT NO   =  2
* CYCLE TYPE =  1

 * MIN WALL AVG. TEMP =    512.300000000000     C
 * MAX WALL AVG. TEMP =    604.000000000000     C

 * LOWER EXTREME TEMPERATURE  =    512.300000000000     C
 * HIGHER EXTREME TEMPERATURE =    604.000000000000     C

 Primary SI,  (Pm + Pb/Kt) + Qm =   29.1602172758127     (MPa)
 Secondary SI Range,         QR =   19.5585325709778     (MPa)

 Yield Stress at Cold Temp, SyL =   117.508000000000     (MPa)

 Primary Stress Parameter,    X =   0.248155166250917
 Secondary Stress Parameter,  Y =   0.166444263973328

 Creep Stress Parameter,      Z =   0.248155166250917

 Effective Creep Stress,     Sc =    29.1602172758127     (MPa)

* POINT NO   =  2
* CYCLE TYPE =  2

 * MIN WALL AVG. TEMP =    443.300000000000     C
 * MAX WALL AVG. TEMP =    549.300000000000     C

 * LOWER EXTREME TEMPERATURE  =    443.300000000000     C
 * HIGHER EXTREME TEMPERATURE =    549.300000000000     C

 Primary SI,  (Pm + Pb/Kt) + Qm =   44.6559501777589     (MPa)
 Secondary SI Range,         QR =   33.4678861755579     (MPa)
```

```
 Yield Stress at Cold Temp, SyL =   121.268000000000     (MPa)

 Primary Stress Parameter,    X =   0.368241829483120
 Secondary Stress Parameter,  Y =   0.275982832862403

 Creep Stress Parameter,      Z =   0.368241829483120

 Effective Creep Stress,     Sc =    44.6559501777589     (MPa)

 - EFFECTIVE CREEP RATCHET STRESSES :

POINT NO =   1,  CYCLE TYPE =   1:   1.25Sc =  56.591(MPa)
POINT NO =   1,  CYCLE TYPE =   2:   1.25Sc =  56.516(MPa)
POINT NO =   2,  CYCLE TYPE =   1:   1.25Sc =  36.450(MPa)
POINT NO =   2,  CYCLE TYPE =   2:   1.25Sc =  55.820(MPa)

 * LISTS OF SEQUENCE OF LOAD HISTORIES

 SEQUENCE NO.  CYCLE TYPES      DURATION OF TEMP-TIME BLOCKS
 ------------------------------------------------------------
      1            1                            6000.0000
      2            2                           18000.0000
      3            1                            6000.0000
      4            2                           18000.0000
      5            1                            6000.0000
      6            2                           18000.0000
      7            1                            6000.0000
      8            2                           18000.0000
      9            1                            6000.0000
     10            2                           18000.0000
     11            1                            6000.0000
     12            2                           18000.0000
     13            1                            6000.0000
     14            2                           18000.0000
     15            1                            6000.0000
     16            2                           18000.0000
     17            1                            6000.0000
     18            2                           18000.0000
     19            1                            6000.0000
     20            2                           18000.0000

TOTAL  SUM  OF  TIME  BLOCKS  =  240000.0000    >    DESIGN  LIFE=
240000.0000 : OK

 - CALCULATED CREEP STRAIN INC FOR EACH TIME BLOCK

* POINT NO   =  1
 (SEQ NO)  (CREEP STRN INC)   (TEMP)
 ------------------------------------
      1       0.089943        604.000
      2       0.001095        549.300
      3       0.005893        604.000
```

```
      4       0.001095        549.300
      5       0.002663        604.000
      6       0.001095        549.300
      7       0.002663        604.000
      8       0.001095        549.300
      9       0.002663        604.000
     10       0.001095        549.300
     11       0.002663        604.000
     12       0.001095        549.300
     13       0.002663        604.000
     14       0.001095        549.300
     15       0.002663        604.000
     16       0.001095        549.300
     17       0.002663        604.000
     18       0.001095        549.300
     19       0.002663        604.000
     20       0.001095        549.300

[CHK] TOTAL CREEP RATCHETING STRAIN = 0.1281 % < 1.0 %  : OK  for
BASE METAL

* POINT NO   =  2
 (SEQ NO)  (CREEP STRN INC)   (TEMP)
 ------------------------------------
      1       0.027315        604.000
      2       0.001005        549.300
      3       0.000093        604.000
      4       0.001005        549.300
      5       0.000093        604.000
      6       0.001005        549.300
      7       0.000093        604.000
      8       0.001005        549.300
      9       0.000093        604.000
     10       0.001005        549.300
     11       0.000093        604.000
     12       0.001005        549.300
     13       0.000093        604.000
     14       0.001005        549.300
     15       0.000093        604.000
     16       0.001005        549.300
     17       0.000093        604.000
     18       0.001005        549.300
     19       0.000093        604.000
     20       0.001005        549.300

[CHK] TOTAL CREEP RATCHETING STRAIN = 0.0382 % < 1.0 %  : OK  for
BASE METAL

 (T-1333) TEST NO. B-3
 ---------------------

* POINT NO =  1
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* TEMP-TIME BLOCK NO =  1

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   8.994260524062253E-002 %

* TEMP-TIME BLOCK NO =  2

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,      SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,       SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142332959E-003 %

* TEMP-TIME BLOCK NO =  3

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
```

```
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   5.893012599207326E-003 %

* TEMP-TIME BLOCK NO =  4

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142332959E-003 %

* TEMP-TIME BLOCK NO =  5

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.663125777352254E-003 %

* TEMP-TIME BLOCK NO =  6

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)
```

```
 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142332987E-003 %

* TEMP-TIME BLOCK NO =  7

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.663125777352282E-003 %

* TEMP-TIME BLOCK NO =  8

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,      SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,       SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142332987E-003 %

* TEMP-TIME BLOCK NO =  9

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
```

```
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.663125777352171E-003 %

* TEMP-TIME BLOCK NO = 10

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142332987E-003 %

* TEMP-TIME BLOCK NO = 11

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.663125777352171E-003 %

* TEMP-TIME BLOCK NO = 12

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
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```
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142332764E-003 %

* TEMP-TIME BLOCK NO = 13

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.663125777349507E-003 %

* TEMP-TIME BLOCK NO = 14

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142333653E-003 %

* TEMP-TIME BLOCK NO = 15


 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
```

```
 ZH =   0.398250321895916

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.663125777360165E-003 %

* TEMP-TIME BLOCK NO = 16

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142340758E-003 %

* TEMP-TIME BLOCK NO = 17

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.663125777417008E-003 %

* TEMP-TIME BLOCK NO = 18

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272
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```
 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,      SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,       SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142340758E-003 %

* TEMP-TIME BLOCK NO = 19

 XL =   0.385276718122406     ,    XH =   0.398250321895916
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.385276718122406
 ZH =   0.398250321895916

 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2730965931277     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2730965931277     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2124069678152     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   8.065120562196273E-007 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.663125777644382E-003 %

* TEMP-TIME BLOCK NO = 20

 XL =   0.372830482631982     ,    XH =   0.389668071222595
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.372830482631982
 ZH =   0.389668071222595

 Yield Stress at Cold End,      SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,       SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   45.2124069678152     (MPa)
 Eff Creep Stress at Hot End,  ScH =   45.2124069678152     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   45.2730965931277     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.094851142170228E-003 %

 -   TOTAL   ENHANCED   CREEP   STRAIN   INCREMENT          =
8.065120562196274E-006 %
```

```
 - TOTAL PLASTIC RATCHET STRAIN INCREMENT  =   0.0E+000 %
 - TOTAL INELASTIC CREEP STRAIN            =   0.128      %

[CHK] TOTAL INELASTIC STRAIN = 0.1281 % < 1.0 %  : OK  for BASE
METAL

* POINT NO =  2

* TEMP-TIME BLOCK NO =  1

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   2.731452612338172E-002 %

* TEMP-TIME BLOCK NO =  2

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582064556E-003 %

* TEMP-TIME BLOCK NO =  3

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080
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```
 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.348359229589820E-005 %

* TEMP-TIME BLOCK NO =  4

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,      SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,       SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582064556E-003 %

* TEMP-TIME BLOCK NO =  5

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.348359229589820E-005 %

* TEMP-TIME BLOCK NO =  6

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
```

```
 ZH =   0.384872187556098

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582064556E-003 %

* TEMP-TIME BLOCK NO =  7

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.348359229588432E-005 %

* TEMP-TIME BLOCK NO =  8

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582064570E-003 %

* TEMP-TIME BLOCK NO =  9

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001
```

```
 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End,  ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,   ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,   Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.348359229588432E-005 %

* TEMP-TIME BLOCK NO = 10

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,      SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,       SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End,  ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,   ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,   Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582064487E-003 %

* TEMP-TIME BLOCK NO = 11

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,      SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,       SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End,  ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,   ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,   Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.348359229588432E-005 %

* TEMP-TIME BLOCK NO = 12
```

```
 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582064542E-003 %

* TEMP-TIME BLOCK NO = 13

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.348359229566228E-005 %

* TEMP-TIME BLOCK NO = 14

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582063987E-003 %
```

```
* TEMP-TIME BLOCK NO = 15

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.348359229655046E-005 %

* TEMP-TIME BLOCK NO = 16

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582064431E-003 %

* TEMP-TIME BLOCK NO = 17

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
```

```
 -INELASTIC CREEP STRAIN           =   9.348359229832681E-005 %

* TEMP-TIME BLOCK NO = 18

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582064431E-003 %

* TEMP-TIME BLOCK NO = 19

 XL =   0.248155166250917     ,    XH =   0.256511411645080
 YL =   0.166444263973328     ,    YH =   0.172049019801001

 ZL =   0.248155166250917
 ZH =   0.256511411645080

 Yield Stress at Cold End,     SyL =   117.508000000000     (MPa)
 Yield Stress at Hot End,      SyH =   113.680000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   29.1602172758127     (MPa)
 Eff Creep Stress at Hot End,  ScH =   29.1602172758127     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   44.6559501777589     (MPa)

 -ENHANCED CREEP STRAIN INCREMENT  =   0.000000000000000E+000 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   9.348359230898495E-005 %

* TEMP-TIME BLOCK NO = 20

 XL =   0.368241829483120     ,    XH =   0.384872187556098
 YL =   0.275982832862403     ,    YH =   0.288446635084272

 ZL =   0.368241829483120
 ZH =   0.384872187556098

 Yield Stress at Cold End,     SyL =   121.268000000000     (MPa)
 Yield Stress at Hot End,      SyH =   116.028000000000     (MPa)
 Eff Creep Stress at Cold End, ScL =   44.6559501777589     (MPa)
 Eff Creep Stress at Hot End,  ScH =   44.6559501777589     (MPa)
 Eff Creep STR for Next Cycle,  Sc =   29.1602172758127     (MPa)
```

```
 -ENHANCED CREEP STRAIN INCREMENT  =   2.513578124701602E-004 %
 -PLASTIC RATCHET STRAIN INCREMENT =   0.000000000000000E+000 %
 -INELASTIC CREEP STRAIN           =   1.005420582067984E-003 %

 - TOTAL ENHANCED CREEP STRAIN INCREMENT   =   2.513E-003 %
 - TOTAL PLASTIC RATCHET STRAIN INCREMENT  =   0.000E+000 %
 - TOTAL INELASTIC CREEP STRAIN            =   3.821E-002 %

[CHK] TOTAL INELASTIC STRAIN = 0.0407 % < 1.0 %  : OK  for BASE
METAL

 ====================================================
 =                                                  =
 =        T-1400 CREEP-FATIGUE EVALUATION           =
 =                                                  =
 ====================================================

* POINT NO =   1
 ================

 (1) FATIGUE DAMAGE EVALUATION
 -----------------------------

* CYCLE NO =  1

 * MAX METAL TEMP   =    611.200000000000     C

 * CYCLE DURATION   =    24000.0000000000     HOURS
 * NUMBER OF CYCLES =          10

Max Elastic Strain  Range,       Emax =      0.0321 %

Equi. Stress Concentration Factor,  K =      1.1189

Stress Indicator,                  S* =     48.1647 MPa
Stress Indicator,               S_bar =     53.8929 MPa

Modified Strain Range,           Emod =      0.0360 %

Triaxiality Factor,              T.F.=      1.9413
Factor by Triaxiality Factor,       f =      0.8978
Modified 3Sm Value       Modified-3Sm =    216.5461 MPa

KEmax =0.0004 < Modified-3Sm/E =0.0014

Stress Ratio Factor at Yield,      Ke =      1.0000
Factor, (Ke)(K)(Emax)(E)/Modified-3SM =      0.2489
Plastic Poisson Ratio Adj Factor, Kv* =      1.0000

Mutiaxial Adjustment Factor,       Kv =      1.0000

- ELASTIC-PLASTIC STRAIN RANGE,   Eep =      0.0360 %
```

```
- CREEP STRAIN INCREMENT,          Ec =      0.0217 %

- TOTAL STRAIN RANGE,              Et =      0.0577 %

Design Number of cycle,             n =         10.
Allowable Number of cycle,         Nd =    2824543.

- FATIGUE DAMAGE =   0.000004   for CYCLE NO =   1

* CYCLE NO =  2

 * MAX METAL TEMP   =    563.600000000000     C

 * CYCLE DURATION   =    16000.0000000000     HOURS
 * NUMBER OF CYCLES =           15

Max Elastic Strain  Range,       Emax =      0.0505 %

Equi. Stress Concentration Factor,  K =      1.0769

Stress Indicator,                  S* =     78.1073 MPa
Stress Indicator,               S_bar =     84.1120 MPa

Modified Strain Range,           Emod =      0.0544 %

Triaxiality Factor,               T.F.=      1.9359
Factor by Triaxiality Factor,       f =      0.8884
Modified 3Sm Value       Modified-3Sm =    269.3578 MPa

KEmax =0.0005 < Modified-3Sm/E =0.0017

Stress Ratio Factor at Yield,      Ke =      1.0000
Factor, (Ke)(K)(Emax)(E)/Modified-3SM =      0.3123
Plastic Poisson Ratio Adj Factor, Kv* =      1.0000

Mutiaxial Adjustment Factor,       Kv =      1.0000

- ELASTIC-PLASTIC STRAIN RANGE,   Eep =      0.0544 %
- CREEP STRAIN INCREMENT,          Ec =      0.0017 %

- TOTAL STRAIN RANGE,              Et =      0.0561 %

Design Number of cycle,             n =         15.
Allowable Number of cycle,         Nd =    2898164.

- FATIGUE DAMAGE =   0.000005   for CYCLE NO =   2

- TOTAL FATIGUE DAMAGE, Df = 0.000009  for BASE METAL

 (2) CREEP DAMAGE EVALUATION
 ---------------------------
```

```
* CYCLE NO =  1

(STEP 1) DEFINE TOTAL HOLD TIME,      tH = 240000.0000 H

(STEP 2) DEFINE HOLD TEMPERATURE,    THT =    546.8000 C

(STEP 3) DEFINE AVERAGE CYCLE TIME,   tj =  24000.0000 H

         DEFINE NUMBER OF CYCLE,      nj =     10

(STEP 4) STRESS LEVEL,                Sj =     79.7527 MPa
         TOTAL STRAIN,                Et =      0.0577 %

(STEP 5) STRESS RELAXATION TIME HISTORY GENERATION

         LOWER BOUND STRESS,         SLB =     56.5914 MPa
         TIME STEP SIZE FOR CREEP,    DT =      1.0000 H

         OUTPUT FILE = SRTH.OUT


(STEP 6) NOT-MODIFIED WITH TRANSIENT PRIMARY STRESS

         AT TRANSIENT TIME =    15.00 HOURS
         (PMB= 30.56 MPa   SR= 78.65 MPa)

(STEP 7) DEFINE CYCLE TRANSIENT TEMPERATURE

         TRNASIENT DURATION,    (tTRAN)j =     15.0000 H
         TRNASIENT TEMPERATURE,(TTRAN)j =    611.2000 C

(STEP 8) REPETITION OF STEP 3 THROUGH 7 FOR J=  1 TO  2

         DWELL STRESS,              Sj/K* =     88.6141 MPa
         SAFETY FACTOR,                K* =      0.9000

* CYCLE NO =  2

(STEP 1) DEFINE TOTAL HOLD TIME,      tH = 240000.0000 H

(STEP 2) DEFINE HOLD TEMPERATURE,    THT =    546.8000 C

(STEP 3) DEFINE AVERAGE CYCLE TIME,   tj =  16000.0000 H

         DEFINE NUMBER OF CYCLE,      nj =     15

(STEP 4) STRESS LEVEL,                Sj =     77.5711 MPa
         TOTAL STRAIN,                Et =      0.0561 %

(STEP 5) STRESS RELAXATION TIME HISTORY GENERATION

         LOWER BOUND STRESS,         SLB =     56.5914 MPa
```

```
         TIME STEP SIZE FOR CREEP,   DT =      1.0000 H

         OUTPUT FILE = SRTH.OUT

(STEP 6) NOT-MODIFIED WITH TRANSIENT PRIMARY STRESS

         AT TRANSIENT TIME =    15.00 HOURS
         (PMB= 30.56 MPa   SR= 76.47 MPa)

(STEP 7) DEFINE CYCLE TRANSIENT TEMPERATURE

         TRNASIENT DURATION,   (tTRAN)j =     15.0000 H
         TRNASIENT TEMPERATURE,(TTRAN)j =    563.6000 C

(STEP 8) REPETITION OF STEP 3 THROUGH 7 FOR J=  2 TO  2

         DWELL STRESS,            Sj/K* =     86.1901 MPa
         SAFETY FACTOR,              K* =      0.9000

(STEP 9) ENVELOPE STRESS RELAXATION TIME HISTORIES

         OUTPUT FILE = ENVSTR.OUT

(STEP 10) TOTAL CREEP DAMAGE,  Dc = 0.3168 for POINT NO =   1

[CHK] FATIGUE(CREEP)=     0.0000 < FATIGUE-LIMIT=      0.2928   :
OK  for BASE METAL

[CHK] CREEP(FATIGUE)=     0.3168 < CREEP-LIMIT=        1.0000   :
OK  for BASE METAL

* POINT NO =   2
 ================

 (1) FATIGUE DAMAGE EVALUATION
 -----------------------------

* CYCLE NO =  1

 * MAX METAL TEMP   =    610.100000000000     C

 * CYCLE DURATION   =    24000.0000000000     HOURS
 * NUMBER OF CYCLES =           10

Max Elastic Strain  Range,       Emax =      0.0273 %

Equi. Stress Concentration Factor,  K =      1.0561

Stress Indicator,                 S* =     40.9214 MPa
Stress Indicator,              S_bar =     43.2165 MPa

Modified Strain Range,           Emod =      0.0288 %
```

```
Triaxiality Factor,               T.F.=      0.2101
Factor by Triaxiality Factor,       f =      0.0546
Modified 3Sm Value       Modified-3Sm =    219.2078 MPa

KEmax =0.0003 < Modified-3Sm/E =0.0015

Stress Ratio Factor at Yield,      Ke =      1.0000
Factor, (Ke)(K)(Emax)(E)/Modified-3SM =      0.1971
Plastic Poisson Ratio Adj Factor, Kv* =      1.0000

Mutiaxial Adjustment Factor,       Kv =      1.0000

- ELASTIC-PLASTIC STRAIN RANGE,   Eep =      0.0288 %
- CREEP STRAIN INCREMENT,          Ec =      0.0041 %

- TOTAL STRAIN RANGE,              Et =      0.0329 %

Design Number of cycle,             n =         10.
Allowable Number of cycle,         Nd =    3994271.

- FATIGUE DAMAGE =   0.000003   for CYCLE NO =   1

* CYCLE NO =  2

 * MAX METAL TEMP   =    562.700000000000     C

 * CYCLE DURATION   =    16000.0000000000     HOURS
 * NUMBER OF CYCLES =           15

Max Elastic Strain  Range,       Emax =      0.0409 %

Equi. Stress Concentration Factor,  K =      1.0487

Stress Indicator,                  S* =     63.2292 MPa
Stress Indicator,               S_bar =     66.3086 MPa

Modified Strain Range,           Emod =      0.0429 %

Triaxiality Factor,               T.F.=      0.1204
Factor by Triaxiality Factor,       f =      0.0313
Modified 3Sm Value       Modified-3Sm =    271.6189 MPa

KEmax =0.0004 < Modified-3Sm/E =0.0018

Stress Ratio Factor at Yield,      Ke =      1.0000
Factor, (Ke)(K)(Emax)(E)/Modified-3SM =      0.2441
Plastic Poisson Ratio Adj Factor, Kv* =      1.0000

Mutiaxial Adjustment Factor,       Kv =      1.0000

- ELASTIC-PLASTIC STRAIN RANGE,   Eep =      0.0429 %
```

```
- CREEP STRAIN INCREMENT,          Ec =      0.0015 %

- TOTAL STRAIN RANGE,              Et =      0.0444 %

Design Number of cycle,             n =         15.
Allowable Number of cycle,         Nd =    3452960.

- FATIGUE DAMAGE =   0.000004   for CYCLE NO =   2


- TOTAL FATIGUE DAMAGE, Df = 0.000007  for BASE METAL

 (2) CREEP DAMAGE EVALUATION
 ---------------------------

* CYCLE NO =  1

(STEP 1) DEFINE TOTAL HOLD TIME,     tH = 240000.0000 H

(STEP 2) DEFINE HOLD TEMPERATURE,   THT =    546.1000 C

(STEP 3) DEFINE AVERAGE CYCLE TIME,  tj =  24000.0000 H

         DEFINE NUMBER OF CYCLE,     nj =     10

(STEP 4) STRESS LEVEL,               Sj =     45.0898 MPa
         TOTAL STRAIN,               Et =      0.0329 %

(STEP 5) STRESS RELAXATION TIME HISTORY GENERATION

         LOWER BOUND STRESS,        SLB =     55.8199 MPa
         TIME STEP SIZE FOR CREEP,   DT =      1.0000 H

         OUTPUT FILE = SRTH.OUT

(STEP 6) NOT-MODIFIED WITH TRANSIENT PRIMARY STRESS

         AT TRANSIENT TIME =    15.00 HOURS
         (PMB= 11.61 MPa   SR= 45.09 MPa)

(STEP 7) DEFINE CYCLE TRANSIENT TEMPERATURE

         TRNASIENT DURATION,   (tTRAN)j =     15.0000 H
         TRNASIENT TEMPERATURE,(TTRAN)j =    610.1000 C

(STEP 8) REPETITION OF STEP 3 THROUGH 7 FOR J=  1 TO  2

         DWELL STRESS,            Sj/K* =     62.0222 MPa
         SAFETY FACTOR,              K* =      0.9000

* CYCLE NO =  2
```

```
(STEP 1) DEFINE TOTAL HOLD TIME,      tH = 240000.0000 H

(STEP 2) DEFINE HOLD TEMPERATURE,    THT =    546.1000 C

(STEP 3) DEFINE AVERAGE CYCLE TIME,   tj =  16000.0000 H

         DEFINE NUMBER OF CYCLE,      nj =     15

(STEP 4) STRESS LEVEL,                Sj =     61.1306 MPa
         TOTAL STRAIN,                Et =      0.0444 %


(STEP 5) STRESS RELAXATION TIME HISTORY GENERATION

         LOWER BOUND STRESS,         SLB =     55.8199 MPa
         TIME STEP SIZE FOR CREEP,    DT =      1.0000 H

         OUTPUT FILE = SRTH.OUT

(STEP 6) NOT-MODIFIED WITH TRANSIENT PRIMARY STRESS

         AT TRANSIENT TIME =    15.00 HOURS
         (PMB= 11.61 MPa   SR= 60.78 MPa)

(STEP 7) DEFINE CYCLE TRANSIENT TEMPERATURE

         TRNASIENT DURATION,   (tTRAN)j =     15.0000 H
         TRNASIENT TEMPERATURE,(TTRAN)j =    562.7000 C

(STEP 8) REPETITION OF STEP 3 THROUGH 7 FOR J=  2 TO  2

         DWELL STRESS,              Sj/K* =     67.9229 MPa
         SAFETY FACTOR,                K* =      0.9000

(STEP 9) ENVELOPE STRESS RELAXATION TIME HISTORIES

         OUTPUT FILE = ENVSTR.OUT

(STEP 10) TOTAL CREEP DAMAGE,  Dc = 0.2704 for POINT NO =   2

[CHK] FATIGUE(CREEP)=      0.0000 < FATIGUE-LIMIT=      0.3691   :
OK  for BASE METAL

[CHK] CREEP(FATIGUE)=      0.2704 < CREEP-LIMIT=        1.0000   :
OK  for BASE METAL
```

## BIBLIOGRAPHIC INFORMATION SHEET

| **Performing Org. Report No.** | **Sponsoring Org. Report No.** | **Standard Report No.** | **INIS Subject Code** |
|---|---|---|---|
| KAERI/TR-3526/2008 | | | |

**Title / Subtitle**

Computer Program of SIE ASME-NH (Revision 1.0) Code For Structural Integrity Evaluation of Next Generation Reactors Subjecting to Elevated Temperature Operations

| | |
|---|---|
| **Project Manager and Dept. (Main Author)** | Gyeong-Hoi Koo / Development of LMR Design Technology |

**Researcher and Dept.**

J.H. Lee / Development of LMR Design Technology

| | | | | | |
|---|---|---|---|---|---|
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| **Note** | | | | | |
| **Classified** | Open(o), Outside( ), __Class | | **Report Type** | | |
| **Sponsoring Org.** | | | **Contract No.** | | |

**Abstract (About 300 Words)**

In this report, the SIE ASME (Structural Integrity Evaluations by ASME-NH) (Revision 1.0), which has a computerized implementation of ASME Pressure Vessels and Piping Code Section III Subsection NH rules, is developed to apply to the next generation reactor design subjecting to the elevated temperature operations over 500$^{o}$C and over 30 years design lifetime, and the user's manual for this program is described in detail.

**Subject Keywords (About 10 Words)**

ASME-NH, SIE ASME-NH, Structural Integrity, Liquid Metal Reactor, Inelastic Strain, Ratcheting, Creep-Fatigue

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<tr><td>수행기관<br>보고서번호</td><td colspan="2">위탁기관<br>보고서번호</td><td>표준보고서번호</td><td colspan="2">INIS 주제코드</td></tr>
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<tr><td colspan="6">차세대 원자로 고온구조건전성 평가를 위한 SIE ASME-NH (Revision 1.0)<br>프로그램 개발 및 사용자 설명서</td></tr>
<tr><td>연구책임자 및<br>부서명<br>(TR 일 경우<br>주저자)</td><td colspan="5">구 경 회 / 액체금속로 기계설계기술개발</td></tr>
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<tr><td>발 행 지</td><td>한국, 대전</td><td>발행기관</td><td>한국원자력(연)</td><td>발행일</td><td>2008. 1</td></tr>
<tr><td>페 이 지</td><td>171 P</td><td>도 표</td><td>유(o), 무( )</td><td>크 기</td><td>26 cm</td></tr>
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<tr><td colspan="6">초록 (300 단어 내외)</td></tr>
<tr><td colspan="6">본 보고서에서는 500°C 이상의 고온과 30 년 이상의 설계운전 수명을 목표로 하는 차세대 원자로 설계개발에 필수적인 고온 구조건전성 평가를 효율적이고 정확히 수행하기 위해 복잡한 ASME Code Section III, Subsection NH 의 적용 규정을 컴퓨터를 활용하여 수행할 수 있는 SIE ASME-NH (Structural Integrity Evaluations by ASME-NH) (Revision 1.0) 전산프로그램을 개발하고 이에 대한 사용자 설명서 및 예제들을 기술하였다.</td></tr>
<tr><td colspan="6">주제명 키워드 (10 단어 내외)</td></tr>
<tr><td colspan="6">ASME-NH, SIE ASME-NH 전산코드, 구조건전성, 소듐냉각고속로,<br>비탄성변형률, 라체팅, 크립-피로</td></tr>
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