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MICROS-2 : A COMPUTER PROGRAM FOR PREDICTING THE MECHANICAL BEHAVIORS OF COATED FUEL PARTICLES DURING IRRADIATION (Revised)

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MICROS-2: A Computer Program for Predicting the Mechanical Behaviors of Coated Fuel Particles during Irradiation (Revised)

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The computer program MICROS-2, revised from the original MICROS, is described; which calculates the stress and strain variations in a coated fuel particle and predicts the lifetime of the particle under neutron irradiation. It employs some improved models for physical phenomena occurring during irradiation. Of these, the ones for material behaviors are based on the recent experimental results. The mathematical models for stress-strain calculations are then improved to allow for layer debonding and coating fractures in one or more layers.

The revised program is written in FORTRAN-IV for computer FACOM 230/60. The machine time is about 100 sec for the analysis of a TRISO-2 type coated fuel particle irradiated to a fast fluence of 8×10^{21} n/cm^2.

JAERI－M 5848

被覆燃料粒子の応力解析
（改良計算コード MICROS－2）

日本原子力研究所・動力炉開発管理室
荒 井 長 利

（1974年8月27日 受理）

被覆燃料粒子の応力・ひずみ変化を計算し，このことによって照射下での粒子の寿命を予測するための計算コードMICROS－2 が開発された。このコードは原コードMICROSを改良したもので，照射下で発生する幾つかの現象に対して改良モデルを使用している。これらのうち，材料挙動には最近の実験結果を取り入れ，また，応力計算式には被覆層の分離や破壊を考慮できるようにしている。

この計算コードはFORTRAN Ⅳ で記述されている。また，高速中性子照射量8×10^{21} n／㎠ まで照射されたTRISO－2型被覆燃料粒子の解析には，約100秒の計算時間を要する。

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1. Introduction

Coated fuel particles are widely used in high temperature gas cooled reactors in which fuel burnup reaches as high as about 70% FIMA and fast neutron fluence as high as 8×10^{21} n/cm^2 (E>0.18 Mev) at temperatures in excess of 1,300°C. Coatings of the coated fuel particles are usually made of pyrocarbons (PyC) and silicon carbide (SiC), and occasionally only of pyrocarbons.

Among them, a few such as the BISO (PyC) and the TRISO type (PyC/SiC/PyC) are used in current medium and large HTGRs for electric power generation, since these coated fuel particles proved to be so resistant to neutron irradiation and high temperatures that the release of the radioactive fission products is very low, within allowable level.

Several types of particle failures have, however, been observed in some irradiation experiments. These are known as spearhead attack, pressure failure, fast neutron induced PyC cracking and amoeba failure. The spearhead attack to a layer in contact with the fuel kernel is caused by fission fragment bombardment and is found to be overcome by incorporating a buffer layer with proper thickness between the fuel kernel and high density layers. The amoeba failure, resulting from unidirectional migration of kernel material into the coating layers under extreme temperatures and severe temperature gradients, may also be eliminated by proper design of the particle and by adaquate thermal design.

In contrast with the above two, pressure failure and fast neutron induced PyC cracking are both referred to as mechanical failures because they are caused by high stresses or large strains exceeding the particular values of a material. These problems can be treated by conventional stress analysis. Much work has been made on the prediction of mechanical behaviors of coated fuel particles under irradiation since Prados and Scott developed a computer program for this purpose[(1)-(7)].

Along with remarkable progress in material researches, including fabrication, irradiation experiment and post-irradiation examination, the theoretical models have been improved and are now becoming a powerful tool for designing the coated fuel particles.

Recently, some important material behaviors have been observed in overseas countries, which may be taken into consideration in the stress analysis models. This is the reason why the code MICROS, developed in JAERI two years ago, has been revised.

The revised version MICROS-2 now enables calculation of the stress and strain variations in the coating layers with consideration of such material behaviors as below.

1) The fractional release of gaseous fission products from the fuel kernel into the internal pore volume within the particle is not necessarily constant such as at 100% or less. Occasionally, however, in the irradiation experiments of accelerated fuel burnup it is dependent on the fuel burnup, especially in the uranium dioxide kernel.
2) The amount of carbon oxides (CO, CO_2) formed in the oxide fuel particles has been measured more quantitatively and more accurately than ever. It is clarified that the content of carbon oxides is much less than that calculated by a conventional theoretical models, and it depends largely on the formation of plutonium isotopes.
3) The fraction of open-pore volume accessible to the gases is not so large in porous pyrocarbons as measured in the past. It in-

creases with fast neutron fluence from an initial value of about 20% to a saturated value.

4) Separation or debonding between coating layers of different materials was not well known in the past. But it is mentioned that it has been frequently observed in a pyrocarbon and silicon carbide coated fuel particle.

5) Failure criteria have been studied, of which the results are applied successfully to some as-coated pyrocarbons or silicon carbides before and after irradiation. A limiting hoop stress criterion may be suitable for the silicon carbide coatings, while either a limiting hoop stress criterion or a limiting creep strain criterion may be so for the pyrocarbon coatings.
In addition, the sequence of coating failures has been identified by various irradiation experiments, which largely contributes to the verification of the stress analysis models.

This report describes the computer program MICROS-2 which calculates stresses and strains of the coated fuel particles during irradiation, and predicts the lifetime of the particles in the reactor.

2. Mathematical models

2.1 Basic assumptions

1) The coated fuel particle consists of three parts; a spherical fuel kernel, a porous buffer layer and high density layers. These buffer and high density layers are assumed to be spherically symmetry with respect to the fuel kernel.

2) In the fuel kernel thermal expansion and fission induced swelling take place under service conditions. The pore volume in the fuel kernel, which completely accomodates the gaseous fission products, remains unchanged in volume throughout the lifetime. Gaseous fission products and carbon oxides are released or formed, respectively, of which the fraction depends on the fuel burnup.

3) The buffer layer is made of so porous pyrocarbon that it can accomodate the fuel swelling and provides another pore volume accessible to the gases. But it does not possess any mechanical strength. The pore volume in this buffer layer may vary with fast neutron fluence.

4) The high density layers are composed of dense pyrocarbons and/or silicon carbide, and serve as the composite pressure vessel with mechanical strength. The elastic constants and coefficient of thermal expansion of individual layers may be assumed to be anisotropic with respect to the perpendicular and parallel directions to the deposition plane. For each layer, stresses and strains are calculated, taking into account the thermal expansion, irradiation-induced dimensional changes, irradiation-induced creep and pressures exerted on the inner and outer surfaces.
Debondings and fractures of these layers can be predicted with either a limiting hoop stress criterion or a limiting creep strain

criterion. After occurrence of the debonding or fracture of a layer, stresses will be calculated for the remaining intact layers.

2.2 A model coated fuel particle

The structure of a coated fuel particle is shown in Fig. 2.1. Let r_F be the fuel kernel radius, δ_B the thickness of the buffer layer, and δ_1, δ_2, ---, δ_J the thicknesses of the successive high density layers, from inside to outside.

In the stress analysis model each of these materials is characterized by the following properties.

Fuel kernel	
average density	ρ_K g/cm^3
effective porosity	P_K
heavy metal content in fuel of theoretical density	ρ_{HM} g/cm^3
average atomic weight of heavy metals	M g
fission induced swelling rate	β% $\Delta V/V$/% FIMA
coefficient of thermal expansion	α_F °C-1
Young's modulus	E_F kg/cm^2
Poisson's ratio	ν_F
Buffer layer	
average density	ρ_B g/cm^3
initial effective porosity	P_B
thermal conductivity	k_B w/cm°C
High density layer	
theoretical density	ρ_{TH} g/cm^3
average density	ρ_o g/cm^3
deposition temperature	T_C °C
Bacon Anisotropy Factor	X_B

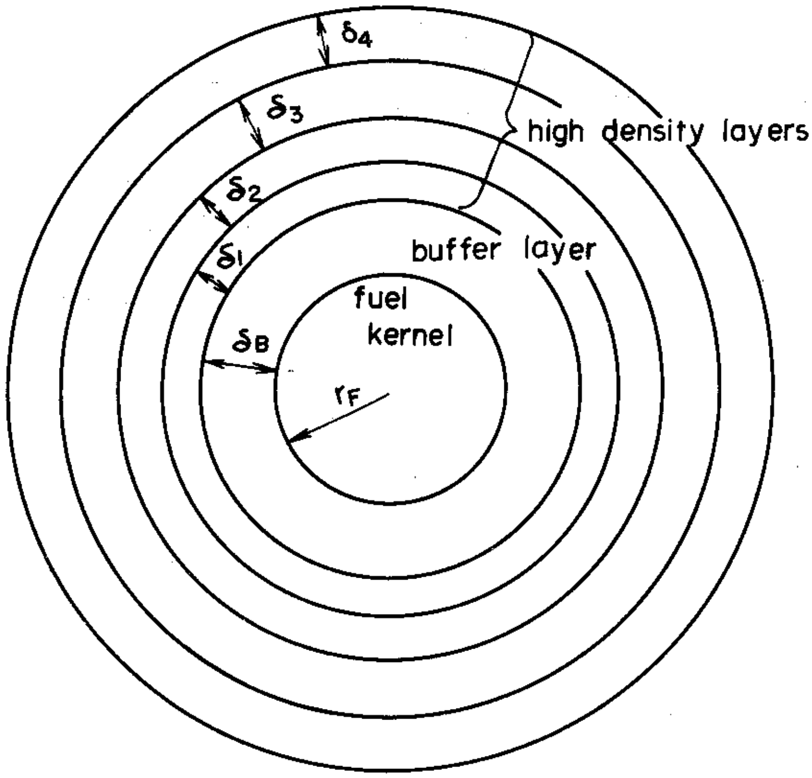

Fig.2.1 A model coated fuel particle

thermal conductivity	k w/cm°C
Young's modulus	E_1, E_2 kg/cm^2
Poisson's ratio	ν_1, ν_2
average coefficient of thermal expansion	α°C^{-1}
limiting hoop stress or limiting creep strain	S_F (kg/cm^2)
irradiation-induced dimensional changes	η_r, η_θ
irradiation-induced creep constants	K_C, K_T(kg/cm^2)$^{-1}$(n/cm^2)$^{-1}$
Poisson's ratio in creep	ν_C

In each high density layer the thickness is divided by K points distributed with equal distance. Thus, variables at the k-th point in the j-th layer are $X_{(k,j)}$ (k=1,2, ---, K; j=1,2, ---, J).

2.3 Changes with irradiation in fuel kernel and buffer layer

The irradiation temperature T_o is assumed constant through fuel lifetime, but the fuel burnup and fast neutron fluence change independently with irradiation time, i.e. at the irradiation time of τ_i days, the fuel burnup B_i and the fast neutron fluence γ_i.

The particle heat rating W is given by the following equation, for an increase of fuel burnup ΔB during an irradiation time interval of $\Delta\tau$ days:

$$W = \frac{2}{8.64\times 10^4}\cdot\frac{0.95}{6.24\times 10^{12}}\cdot N_{HM}\frac{\Delta B}{\Delta\tau} \quad \text{(watt)} \qquad (2.1)$$

where N_{HM} is the initial atom number of heavy metals in the whole fuel kernel, which is given by

$$N_{HM} = \frac{4}{3}\pi r_{FO}^3(1-P_K)\rho_{HM}\cdot 6.023\times 10^{23}/M \qquad (2.2)$$

With the particle rating W watts, the temperatures of coating layer and of fuel kernel are expressed as follows:

for the j-th coating layer

$$T_{(k,j)} = \frac{W}{4\pi kj}\left\{r^{-1}_{(k,j)} - r^{-1}_{(K,j)}\right\} \times 10^4 + T_{(K,j)} \quad (^\circ C) \qquad (2.3)$$

where $T_{(K,j)} = T_{(1,j+1)}$ and $T_{(K,J)} = T_o$,

on the fuel kernel surface

$$T_F = \frac{W}{4\pi R_B}\left(r_F^{-1} - r^{-1}_{(1,1)}\right) \times 10^4 + T_{(1,1)}. \qquad (2.4)$$

The fuel kernel radius under operating condition is determined, considering thermal expansion, elastic deformation and fission-induced swelling:

$$r_F = r_{FO}(1 + \alpha_F T_F - \frac{1-\nu_F}{E_F} P_{IN} + \frac{1}{3}\beta\frac{B}{100}). \quad (\mu m) \qquad (2.5)$$

The total internal pore volume consists of two parts. One is that in the kernel, remaining constant during irradiation. The other a gap between fuel kernal and high density layer, dependent on the fuel burn-up and fast neutron fluence. This consideration leads to the following expression for the total internal pore volume V_G,

$$V_G = V_{GF} + V_{G1} + V_{G2}, \quad (cm^3) \qquad (2.6)$$

where V_{GF} is the volume in the kernel at zero burnup, V_{G1} is the net increase or decrease of gap space between fuel kernel and high density layers, which results from the fuel kernel swelling and from the displacement of the inmost high density layer, and V_{G2} the effective or open pore volume in the buffer layer which is dependent only on the fast neutron fluence. Therefore,

$$V_{GF} = \frac{4}{3}\pi r^3_{FO} P_K \times 10^{-13} \quad (cm^3) \qquad (2\ 7)$$

$$V_{G1} = \frac{4}{3}\pi(r^3_{(1,1)} - r^3_F) \times 10^{-12} - V_{BO} \quad (cm^3) \qquad (2.8)$$

$$V_{G2} = V_{BO}\cdot f(\gamma). \quad (cm^3) \qquad (2.9)$$

The internal gases contributing to the pressure buildup results both from the release of gaseous fission products and the chemical reaction between pyrocarbon surrounding the kernel and oxygen liberated by fissions of the oxide fuels. The former gas accumulation N_{G1} is a function of the fuel burnup and the release fraction which also depends on the fuel burnup:

$$N_{G1} = \kappa_1 F_1(B) \frac{B}{100} \frac{N_{HM}}{N_A} \quad . \qquad \text{(mol)} \qquad (2.10)$$

The latter N_{G2} is expressed as

$$N_{G2} = \kappa_2 F_2(B) \frac{B}{100} \frac{N_{HM}}{N_A} \quad . \qquad \text{(mol)} \qquad (2.11)$$

The function $F_1(B)$ accounts for the dependence of the release fraction on the type of fuel material, irradiation temperature, fuel burnup rate, etc. On the other hand, the function $F_2(B)$ accounts for the dependence of the formation of carbon oxides on the chemical form of oxide fuels, irradiation temperature and production of Pu isotopes.

With the above, the total amount of gases is given by the following:

$$N_G = N_{G1} + N_{G2} \quad . \qquad \text{(mol)} \qquad (2.12)$$

With the internal pore volume V_G and the amount of gaseous molecules N_G, the internal pressure may be obtained assuming the ideal law of gas expansion:

$$P_{IN} = \frac{N_G R}{V_G} \{273. + 0.5(T_F + T_{(1,1)})\} \quad , \qquad (\text{kg/cm}^2) \qquad (2.13)$$

where R is a gas constant.

2.4 Stress-strain equations

In the multilayer coatings, stresses and strains may be caused by differential thermal expansion, irradiation-induced anisotropic dimensional changes, irradiation-induced creep and internal and external pressures.

Stress-strain equations suitable for this circumstances can be obtained by some modifications of those for a single high density layer, derived by Prados and Scott[1].

We will first consider a single layer subjected to an internal pressure P_a and an external pressure P_b, and then a mechanical interaction between two or more coating layers.

Assuming the anisotropy of elastic constants and coefficient of thermal expansion with regard to the parallel and perpendicular directions to deposition plane, the total strains are generally expressed as

$$\varepsilon_\theta = \frac{1-\nu_1}{E_1}\sigma_\theta - \frac{\nu_2}{E_2}\sigma_r + g_\theta \tag{2.14}$$

$$\varepsilon_r = -\frac{2\nu_2}{E_2}\sigma_\theta + \frac{1}{E_1}\sigma_r + g_r, \tag{2.15}$$

where g_θ and g_r are the non-elastic strains, including thermal strain dimensional changes and creep:

$$g_\theta = \sigma_\theta(T-T_C) + \eta_\theta + \int_0^\gamma \dot{\varepsilon}_\theta^c d\gamma \tag{2.16}$$

$$g_r = \alpha_r(T-T_C) + \eta_r + \int_0^\gamma \dot{\varepsilon}_r^c d\gamma \; . \tag{2.17}$$

Instantaneous creep strain rates $\dot{\varepsilon}_\theta^c$ and $\dot{\varepsilon}_r^c$ are assumed linear with the instantaneous stresses σ'_θ and σ'_r, as used in Stevens' analysis[5].

$$\dot{\varepsilon}_\theta^c = K\{(1-\nu_c)\sigma'_\theta - \nu_c\sigma'_r\} \tag{2.18}$$

$$\dot{\varepsilon}_r^c = K\{-2\nu_c\sigma'_\theta + \sigma'_r\} \; . \tag{2.19}$$

The compatibility equations and the equilibrium equation in a spherical system are expressed as

$$\varepsilon_\theta = \frac{u}{r} \tag{2.20}$$

$$\varepsilon_r = \frac{du}{dr} \tag{2.21}$$

and

$$\frac{d\sigma_r}{dr} + \frac{2}{r}(\sigma_r - \sigma_\theta) = 0. \tag{2.22}$$

The last equations are for the boundary conditions described earlier:

$$\sigma_r = -P_a \quad \text{at } r = a \quad \text{(inner surface)} \tag{2.23}$$

$$\sigma_r = -P_b \quad \text{at } r = b \quad \text{(outer surface)} \tag{2.24}$$

At this point, it should be noticed that because of the interdependence between stresses and creep strain rates and variation of the boundary or interfacial pressures, which are determined according to the layer interaction, a calculational technique called the incremental method is necessary to solve the above equations.

The calculational procedure using the incremental method is described in section 2.7. We still write, however, the equations in terms of the total stress and total strain and so forth for simplicity.

Introducing the stress function X difined as $X = r\sigma_r$, and expressing the stresses and strains in stress function, the compatibility equations reduce to a differential equation of the form:

$$r^2\frac{d^2X}{dr^2} + 2r\frac{dX}{dr} - \frac{2(1-\nu_2)E_1}{(1-\nu_1)E_2}X = \frac{2E_1}{1-\nu_1}\left\{r(g_r - g_\theta) - r^2\frac{dg_\theta}{dr}\right\}. \tag{2.25}$$

This differential equation can easily be solved, coupled with the boundary conditions eq. (2.23) and (2.24). The final expressions for tangential and radial stresses are given as

$$\sigma_\theta(r) = \frac{(n_1+1)\left(\frac{r}{a}\right)^{n_1-1}\left(\frac{b}{a}\right)^{n_2-1} - (n_2+1)\left(\frac{b}{a}\right)^{n_1-1}\left(\frac{r}{a}\right)^{n_2-1}}{\left(\frac{b}{a}\right)^{n_1-1} - \left(\frac{b}{a}\right)^{n_2-1}} \frac{P_a}{2}$$

$$- \frac{(n_1+1)\left(\frac{r}{a}\right)^{n_1-1} - (n_2+1)\left(\frac{r}{a}\right)^{n_2-1}}{\left(\frac{b}{a}\right)^{n_1-1} - \left(\frac{b}{a}\right)^{n_2-1}} \frac{P_b}{2}$$

$$+ \frac{E_1}{(1-\nu_1)(n_1-n_2)} \left\{ [I_1(b)-I_2(b)] \left[\frac{(n_2+1)\left(\frac{r}{a}\right)^{n_2-1} - (n_1+1)\left(\frac{r}{a}\right)^{n_1-1}}{\left(\frac{b}{a}\right)^{n_1-1} - \left(\frac{b}{a}\right)^{n_2-1}} \right] \right.$$

$$\left. + (n_1+1) I_1(r) - (n_2+1) I_2(r) \right\} \qquad (2.26)$$

$$\sigma_r(r) = - \frac{\left(\frac{b}{a}\right)^{n_1-1}\left(\frac{r}{a}\right)^{n_2-1} - \left(\frac{b}{a}\right)^{n_2-1}\left(\frac{r}{a}\right)^{n_1-1}}{\left(\frac{b}{a}\right)^{n_1-1} - \left(\frac{b}{a}\right)^{n_2-1}} P_a - \frac{\left(\frac{r}{a}\right)^{n_1-1} - \left(\frac{r}{a}\right)^{n_2-1}}{\left(\frac{b}{a}\right)^{n_1-1} - \left(\frac{b}{a}\right)^{n_2-1}} P_b$$

$$+ \frac{2E_1}{(1-\nu_1)(n_1-n_2)} \left\{ [I_1(b)-I_2(b)] \left[\frac{\left(\frac{r}{a}\right)^{n_1-1} - \left(\frac{r}{a}\right)^{n_2-1}}{\left(\frac{b}{a}\right)^{n_1-1} - \left(\frac{b}{a}\right)^{n_2-1}} \right] + I_1(r) - I_2(r) \right\} .$$

$$(2.27)$$

Here,

$$I_1(r) = \left(\frac{r}{a}\right)^{n_1-1} g_\theta(a) - g_\theta(r) + r^{n_1-1} \int_a^r \frac{g_r(r) - n_1 g(r)}{r^{n_1}} dr \qquad (2.28)$$

$$I_2(r) = \left(\frac{r}{a}\right)^{n_2-1} g_\theta(a) - g_\theta(r) + r^{n_2-1} \int_a^r \frac{g_r(r) - n_2 g_\theta(r)}{r^{n_2}} dr \qquad (2.29)$$

and

$$n_1,\ n_2 = -\frac{1}{2} \pm \sqrt{1+8\frac{(1-\nu_2)E_1}{(1-\nu_1)E_2}} \quad . \tag{2.30}$$

We will then consider mechanical interaction between the adjacent layers to derive a complete set of the equations expressing interdependence of the interfacial pressures. Consider three successive layers as shown in Fig. 2.2. Referring to Fig. 2.2, and assuming tight bonding between the layers, one can obtain an equation of the small changes in the j-th interfacial pressure $\Delta P_{IN,j}$, of the form:

$$\Delta P_{IN,j} = (B_j - A_{j,j-1}\Delta P_{IN,j-1} - A_{j,j+1}\Delta P_{IN,j+1})/A_{j,j} \tag{2.31}$$

Let J be the number of high density layers, suffix 1 is an internal, and (J+1) an external.

$\Delta P_{IN,1} = \Delta P_{IN}$ (internal pressure change)

$\Delta P_{IN,J+1} = \Delta P_{EX}$ (external pressure change).

Then a total of (J-1) equations of the above form are constructed for the interfaces from the second to the j-th boundary. Therefore, the coefficients in the above equation may be written as

$$A_{j,j-1} = -\frac{1-\nu_{1,j-1}}{2E_{1,j-1}} \cdot \frac{(n_{1,j-1}-n_{2,j-1})\zeta(j-1,1)\zeta(j-1,2)}{\zeta(j-1,1)-\zeta(j-1,2)} \tag{2.32}$$

$$A_{j,j} = \frac{1-\nu_{1,j-1}}{2E_{1,j-1}} \cdot \frac{(n_{1,j-1}+1)\zeta(j-1,1)-(n_{2,j-1}+1)\zeta(j-1,2)}{\zeta(j-1,1)-\zeta(j-1,2)} - \frac{\nu_{2,j-1}}{E_{2,j-1}}$$

$$+ \frac{1-\nu_{1,j}}{2E_{1,j}} \cdot \frac{(n_{1,j}+1)\zeta(j,1)-(n_{2,j}+1)\zeta(j,2)}{\zeta(j,1)-\zeta(j,2)} + \frac{\nu_{2,j}}{E_{2,j}} \tag{2.33}$$

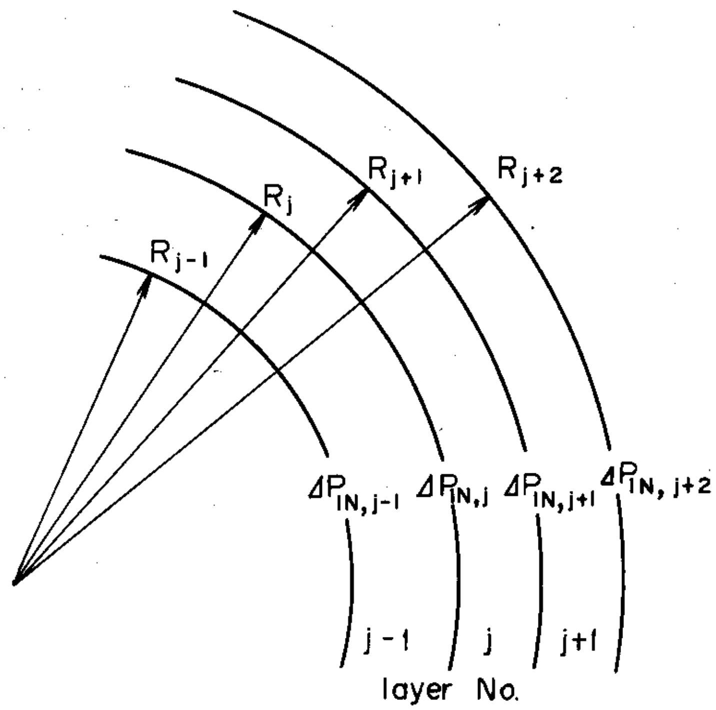

Fig. 2.2 A model for mechanical interaction

$$A_{j,j+1} = -\frac{1-\nu_{1,j}}{2E_{1,j}} \cdot \frac{n_{1,j}-n_{2,j}}{\zeta(j,1)-\zeta(j,2)} \tag{2.34}$$

$$B_j = \frac{1-\nu_{1,j-1}}{E_{1,j-1}} \sum_{S}^{T,D,C} \Delta\sigma^{s}_{\theta(K,j-1)} + \Delta g_{\theta(K,j-1)} - \frac{1-\nu_{1,j}}{E_{1,j}} \sum_{S}^{T,D,S} \Delta\sigma^{s}_{\theta(1,j)}$$

$$+\Delta g_{\theta(1,j)} + \frac{\delta'_j}{r_{(1,j)}} \quad , \tag{2.35}$$

where,

$$\zeta_{(j,1)} = \left(\frac{r_{(K,j)}}{r_{(1,j)}}\right)^{n_{1,j}-1}$$

$$\delta'_j = r_{(K,j-1)} - r_{(1,j)}$$

and Δg_θ is the tangential strain increments due to thermal strain, dimensional changes and creep, and $\Delta\sigma^s_\theta$ (S=T,D,C) the concomitantly induced tangential stress increments.

This set of equations will be solved either by a conventional matrix method or by a successive iteration method.

2.5 Occurrence of layer debonding

For a coated fuel particle with a TRISO-2 type coating (a stable SiC layer sandwitched by inner and outer isotropic PyC layers), theoretical calculation shows that the smaller the particle size or the lower the density of the inmost PyC layer, the higher the radial stress at the interface between the inner PyC and SiC layers, and that this stress may be as high as about 500 kg/cm^2 or more in the early stage of irradiation. This possiblly results in debonding between two layers.

This program takes into consideration this layer debonding and calculates stress-strain variations after debonding. The criterion of occurrence of the debonding is of the limiting radial stress type. That is, if the radial stress $\sigma_{r(1,j)}$ at the inner surface of the j-th layer exceeds the limiting stress or bonding strength $S_{B,j}$, the j-th layer will be separated from the (j-1)-th layer.

2.6 Occurrence of coating fracture

Another and the most important aspect of the stress analysis for coated fuel particles is the occurrence and the effect of fractures in one or more layers. This program considers also this problem of much interest. The problem demands, however, determination of an accurate and reliable failure criterion for a particular material. But in the present state of knowledge the failure criterion for dense isotropic PyC or SiC is not entirely clarified yet. Then, a typical failure criterion such as a limiting hoop stress criterion or a limiting creep strain criterion may be adopted in the present version of the program.

Let $\sigma^{M}_{\theta,j}$ and $\varepsilon^{CM}_{\theta,j}$ be the maximum tangential stress and the maximum creep strain in the j-th layer at a certain stage of irradiation. If $\sigma^{M}_{\theta,j}$ exceeds the limiting stress of the j-th layer or if $\varepsilon^{CM}_{\theta,j}$ exceeds the limiting creep strain, the j-th layer will fracture. Subsequently, stress-strain calculations will continue for the intact layer but not for the fractured.

2.7 Sequence of calculation

Main part and procedure of the stress calculations are shown in Fig. 2.3. Some attentions will be described, including iterations and their convergence criteria.

A complete set of the stress-strain distributions in all high density layers is obtained in such a way that the three convergence tests may be satisfied within certain allowances. The first convergence criterion is for the iteration of incremental creep strains, which will terminate if the incremental stress changes are all less than 1.0 kg/cm^2. The second is for the inner iteration for a set of interfacial pressures described in section 2.4, which will terminate if the maximum of incremental pressure changes is less than 0.5 kg/cm^2. And the third is for the outer iteration of interfacial pressures, including the internal pressure. This iteration will terminate if all incremental pressure changes are less than 0.5 kg/cm^2.

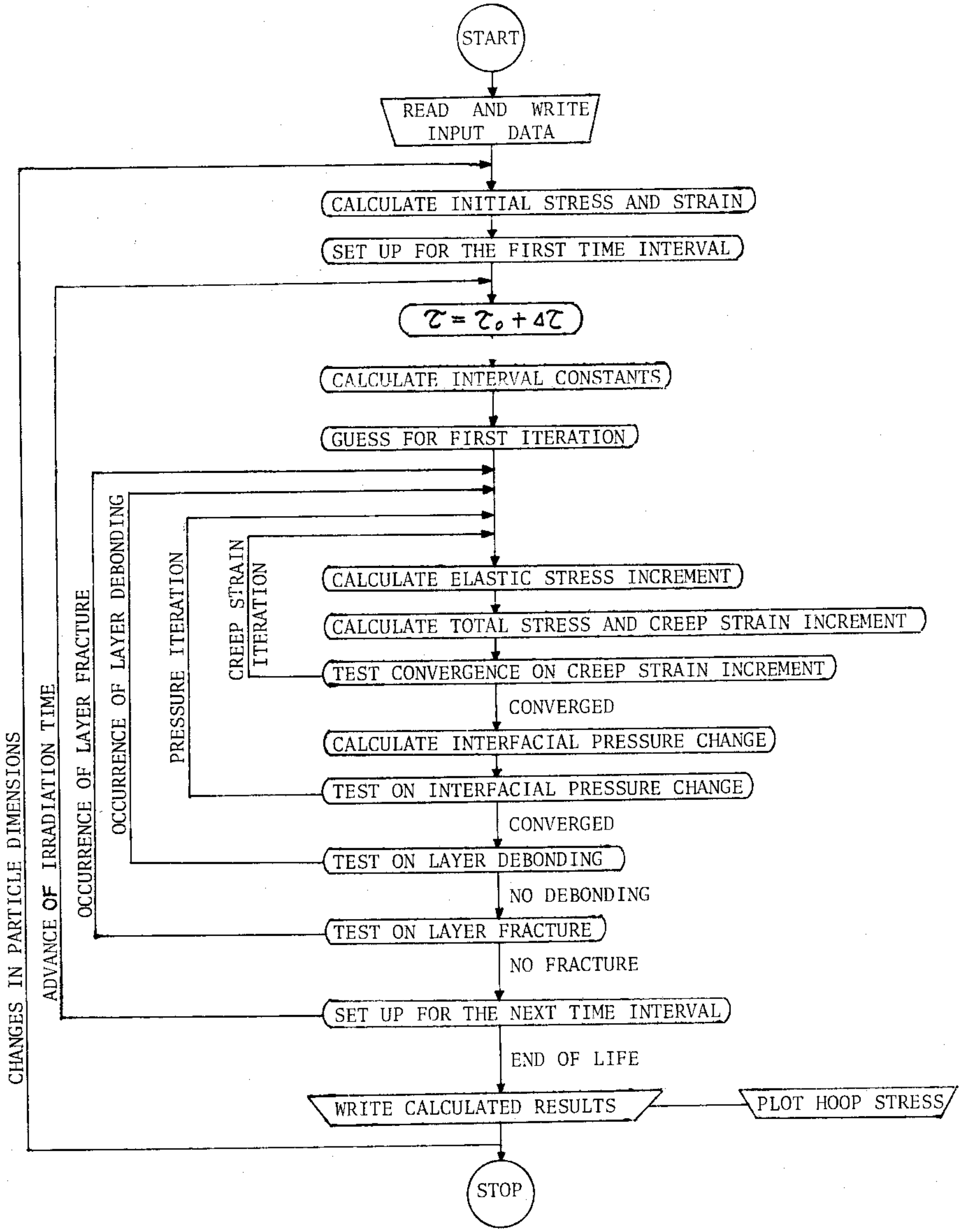

Fig.2.3 Main calculation sequence in the program

3. MICROS-2 program

3.1 Program structure and operation

The MICROS-2 program is a revised version of the original MICROS program. This program is constructed with a main program and a total of thirty-five subprograms, including those for the graphical representation of calculated tangential stress variations. The program is written in FORTRAN Ⅳ for computer FACOM 230/60, but there should be no difficulty in setting up and operating this program, except for the plotter subroutines, for other computers capable of compiling FORTRAN Ⅳ.

The input data will be described below. The input data list, output data list and graphical output for a sample problem are presented in the APPENDIX A, B and C, respectively.

3.2 Input instructions

Input instructions in detail for the MICROS-2 code are presented in Table 3.1. Some additional explanations will be given, with the aim of helping preparation of the input data.

Firstly, the whole fuel lifetime should be divided with an equal interval $\Delta\tau$ into a total of ITMAX intervals, which makes it possible to apply an incremental method.

Two of the fast neutron fluence dependent properties must then be noticed. One concerns the irradiation induced dimensional changes η_r and η_θ, appearing in eq. (2.16) and (2.17). Dimensional changes are given as a function of the fast neutron fluence:

$$\eta_r(\gamma) = C_{R1}+C_{R2}\gamma+C_{R3}\gamma^3+ \cdots\cdots$$

$$\eta_\theta(\gamma) = C_{T1}+C_{T2}\gamma+C_{T3}\gamma^3+ \cdots\cdots \quad .$$

The other concerns the creep constants. The creep constant in the early stage of irradiation (transient creep constant) will be higher than that in the later stage. Then it is assumed that at the beginning of irradiation the creep constant is K_T+K_C, then it decreases linearly with irradiation to a value of K_C till the fast neutron fluence reaches a certain value of γ_C, and it remaines a constant of K_C to the end of the fuel lifetime.

Still another in the program is that the calculations are performed for some varieties of particles of different dimensions with the other parameters unchanged. This may facilitate the prediction of satistical nature in particle performance due to manufacturing tolerances.

Whole data for a problem are classified into the ten card groups. This classification makes it easier to prepare input for the subsequent problems. These problems, except the first, will require input of only the card groups that will change input of the previous problem.

References

1) Prados, J.W., Scott, J.L.: Nucl. Appl., 3, 488 (1967)

2) Kaae, J.L.: J. Nuclear Materials, 29, 249 (1969)

3) Kaae, J.L.: ibid, 32, 322 (1969)

4) Walther, H.: Nucl. Eng. Design, 18, 11 (1972)

5) Stevens, D.W.: Nucl. Technology, 10, 301 (1971)

6) Arai, T.: JAERI-M-4718 (1972)

7) Martin, D.G.: J. Nuclear Materials, 48, 35 (1973)

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Still another in the program is that the calculations are performed for some varieties of particles of different dimensions with the other parameters unchanged. This may facilitate the prediction of satistical nature in particle performance due to manufacturing tolerances.

Whole data for a problem are classified into the ten card groups. This classification makes it easier to prepare input for the subsequent problems. These problems, except the first, will require input of only the card groups that will change input of the previous problem.

References

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4) Walther, H.: Nucl. Eng. Design, 18, 11 (1972)

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6) Arai, T.: JAERI-M-4718 (1972)

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Table 3.1 Input data for MICROS-2

CARD	FORTRAN DATA	FORMAT

CASE IDENTIFICATION DATA

1)	MTITLE	20A4
2)	IP(1)---IP(10)	10I1

MTITLE : Literal description of the problem

IP : Option parameters for reading or omittimg card groups. If IP(1)=1, the data cards of group #1 are read in this case,and otherwise should be deleted.

CARD GROUP #1 (FUEL KERNEL DATA)

1)	ROUK,PK,ROUHM,MW,BETA,ALPHAK,YOUNGK,POISK	8E10.3
2)	NBF,RARE,OTHER	I10,2E10.3
3)	BURN(1)---BURN(NBF)	8E10.3
4)	FI(1)---FI(NBF)	8E10.3
5)	FC(1)---FC(NBF)	8E10.3

ROUK : Average density, g/cm^3

PK : Effective porosity,

ROUHM : Heavy metal content in fuel material of theoretical density, g/cm^3

MW : Average atomic weight of heavy metals, g

BETA : Swelling rate of fuel kernel, % $\Delta v/v$ / %FIMA

ALPHAK : Coefficient of thermal expansion, $°C^{-1}$

YOUNGK : Young's modulus, kg/cm^2

POISK : Poisson's ratio,

NBF : Number of data points for release fraction table, ≤ 20

RARE : Reference release fraction of rare gases, mol/mol-fissions

OTHER : Reference formation rate of other gases, mol/mol-fissions

BURN : Variable of release fraction table, %FIMA

FI : Relative release fraction of rare gases

FC : Relative formation rate of other gases

CARD	FORTRAN DATA	FORMAT

CARD GROUP #2 (BUFFER LAYER DATA)

1)	ROUB,PB,KB,NGF	3E10.5,I5
2)	GAB(1)---GAB(NGF)	8E10.3
3)	FP(1)---FP(NGF)	8E10.3

ROUB : Average density, g/cm^3
PB : As-deposited effective porosity
KB : Thermal conductivity, W/cm°C
NGF : Number of data points for porosity table, ≤20
GAB : Variable of porosity table, 10^{20} n/cm^2
FP : Buffer porosity

CARD GROUP #3 (HIGH DENSITY LAYER DATA I)

1)	JSO	I10
2)	MNAME	20A4
3)	ROUTH(1)---ROUTH(JSO)	5E10.3
4)	ROU0(1)---ROU0(JSO)	5E10.3
5)	TC(1)---TC(JSO)	5E10.3
6)	XB(1)---XB(JSO)	5E10.3

JSO : Number of high density layers, ≤5
MNAME : Literal description of the material, one card per each material
ROUTH : Theoretical density, g/cm^3
ROU0 : Average density, g/cm^3
TC : Deposition temperature, °C
XB : Bacon anisotropy factor

CARD	FORTRAN DATA	FORMAT

CARD GROUP #4 (high density layer data II)

1) KMEC(1)---KMEC(JSO) 5I10

2) IM(1)---IM(JSO) 5I10

KMEC : Option parameters to specify material properties. If KMEC=1, material properties are dependent on fast neutron fluence, and otherwise not.

IM : Number of data points for property table, ≤ 20

For KMEC(J)=0

3) KZERI(J),EZERO1(J),EZERO2(J),PZERO1(J),PZERO2(J), ALPHA0(J),SFZERO(J) 7E10.3

KZERO : Thermal conductivity, w/cm°C

EZERO1 : Young's modulus(tangential), kg/cm^2

EZERO2 : Young's modulus(radial), kg/cm^2

PZERO1 : Poisson's ratio(tagential-tangential), kg/cm^2

PZERO2 : Poisson's ratio(radial-tangential), kg/cm^2

ALPHA0 : Average coefficient of thermal expansion, $°C^{-1}$

SFZERO : Failure criteria. If SFZERO > 1.0, it is a limiting hoop stress(kg/cm^2), and if SFZERO < 1.0, it is a limiting creep strain.

For KMEC(J)≠0

3) P1(J),P2(J),SF(J) 3E10.3

4) DOSE(1,J)---DOSE(IC,J) 8E10.3

5) K1(1,J)---K1(IC,J) 8E10.3

6) E1(1,J)---E1(IC,J) 8E10.3

7) E2(1,J)---E2(IC,J) 8E10.3

8) ALPHA(1,J)---ALPHA(IC,J) 8E10.3

CARD	FORTRAN DATA	FORMAT

P1,P2 : Poisson's ratio
SF : Failure criteria
IC : IC=IM(J), ≤20
DOSE : Fast neutron fluence, 10^{20} n/cm^2
K1 : Thermal conductivity, w/cm°C
E1,E2 : Young's modulus, kg/cm^2
ALPHA : Average coefficient of thermal expansion, °C^{-1}

CARD GROUP #5 (IRRADIATON -INDUCED DIMENSIONAL CHANGES)

1) KETA(1)---KETA(JSO) 5I10

Only for KETA=1, two cards per one layer
2) CR(1,J)---CR(8,J) 8E10.3
3) CT(1,J)---CT(8,J) 8E10.3

KETA : Option parameters for irradiation-induced dimensional changes. If KETA=1, dimensional changes occur ,and otherwise not.
CR : Coefficients of the polynomial function(radial)
CT : Coefficients of the polynomial function(tangential)

CARD GROUP #6 (CREEP CONSTANTS)

1) KCREEP(1)---KCREEP(JSO),CKT,GAMC 8E10.3
2) PC(1)---PC(JSO) 8E10.3

KCREEP : Steady-state creep constant, (kg/cm^2)$^{-1}$(10^{20}n/cm2)$^{-1}$
CKT : Additive creep constant, (kg/cm^2)$^{-1}$(10^{20}n/cm^2)$^{-1}$
GAMC : Fast neutron fluence at which transient creep vanishes, 10^{20}n/cm^2
PC : Poisson's ratio in creep

CARD	FORTRAN DATA	FORMAT

CARD GROUP #7 (BONDING STRENGTH)

1)	SB(1)---SB(JSO)	5E10.3

SB : Bonding strength, kg/cm^2

CARD GROUP #8 (IRRADIATION CONDITIONS)

1)	TO,PEX,ITB	2E10.3,I10
2)	TAU(1)---TAU(ITB)	8E10.3
3)	BUP(1)---BUP(ITB)	8E10.3
4)	GAM(1)---GAM(ITB)	8E10.3

TO : Irradiation temperature, °C
PEX : External pressure, kg/cm^2
ITB : Number of data points for irradiation conditions table, ≤ 20
TAU : Irradiation time, day
BUP : Fuel burnup, %FIMA
GAM : Fast neutron fluence, $10^{20} n/cm^2$

CARD GROUP #9 (CALCULATION PARAMETERS)

1)	DT,ITMAX,KSO	E10.3,2I10
2)	ICHECK,IOUTL,IOUTP	3I10

DT : Time increment, day
ITMAX : Number of calculation time steps, ≤ 200
KSO : Number of mesh points per a layer, ≤ 20
ICHECK : If ICHECK=1,check data are printed.
IOUTL : If IOUTL=1, the results of each time step are printed.
IOUTP : If IOUTP=1, graphic output are given.

CARD	FORTRAN DATA	FORMAT

CARD GROUP #10 (PARTICLE DIMENSIONS)

1)	NSET	I10
2)	DK(J),DB(J),DL(1,J)---DL(JSO,J)	7E10.3

NSET : Number of sets of particle dimensions, ≤ 10

DK : Diameter of fuel kernel, μm

DB : Thickness of buffer layer, μm

DL : Thickness of high density layer, μm

The second card is required for each of particle dimensions.

APPENDIX A Sample input list

```
....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

 TRISO-2 SAMPLE PROBLEM  ((PYC(LTI)  1.80 G/CC  950 DEG.C))       JUNE 25
1111111111
  10,4      0.05      8.8       237.      1.5       1.05  -5 1.4   +6  0.3
         4  0.30       0.10
  0,0       1.5       7.5       50.0
  1,0       1.0       1.0       1.0
  1,0       1.0       1,0       1.0
  1,1       0.2      0.015         3
  0,0       10.0      100.0
     0.2       0.5       0.5
         3
 GGA-PYC(LTI) PROPANE  1.60 G/CC  TI=900-1000 C
SILICON CARBIDE ( FROM  J. NUCLE. MATER. .VOL.32 322-329 (1969) )
 GGA-PYC(LTI) PROPANE  1.60 G/CC  TI=900-1000 C
   2,22       3.20      2.22
  1,80      3.15      1.80
  1400.     1400.     1400.
   1,0       1.0       1.0
         0         0         0
         0         0         0
  0,04      5.6   +5  5.6   +5  0.22      0.22      6.0    -6  3000.
   0,08      4.2  +5   4.2  +5   0.2       0.2       5.5   -6  3000.0
  0,04      5.6   +5  5.6   +5  0.22      0.22      6.0    -6  3000.
         1         0         1
  0.0      -3,56104-3 1.49205-4-1.94414-6 1.55274-6-5.9312-11
  0,0      -4.05011-3 1.26766-4-2,35321-6 1.99342-6-6.3622-11
  0,0      -3,56104-3 1.49205-4-1.94414-6 1.55274-6-5.9312-11
  0,0      -4,05011-3 1.26766-4-2.35321-6 1.99342-6-6.3622-11
  2,0    -6 0.0       2.0   -6  4.0    -6 10.0
  0,4       0.0       0.4
  0,0       500.      500.
  950.      0.0                3
   0,0      2000.    4000.
   0,0      7.0       14.0
  0,0       50,0       100.
   16,          126           11
         0         C         1
         1
  500,0     40,0      30.0      25.0      45.0
```

APPENDIX B　Sample output list

```
           TRISO-2 SAMPLE PROBLEM  ((PYC(LTI)  1.80 G/CC  950 DEG.C))      JUNE 25
( I N P U T   D A T A )

 1. FUEL KERNEL

   * GENERAL ---------------------- EFFECTIVE DENSITY   (G/CM3) ------  0.104E 02
                                    EFFECTIVE POROSITY --------------  0.500E-01
                                    HEAVY METAL DENSITY (G/CM3) ------  0.880E 01
                                    MOLUCULAR WEIGHT    (G) ----------  0.237E 03
                                    SWELLING RATE       (PCT/FIMA) ---  0.150E 01

   * MECHANICAL PROPERTY ---------- THERMAL EXPANSION   (/C) ---------  0.105E-04
                                    YOUNGS MODULUS      (KG/CM2) -----  0.140E 07
                                    POISSONS RATIO -------------------  0.300E 00

   * GAS PRODUCTION --------------- NUMBER OF ARRAY ------------------          4
                                    RARE GAS PRODUCTION --------------  0.300E 00
                                    OTHERS GAS PRODUCTION ------------  0.100E 00
                                    RELEASE RATE -------------------------------------------.
                                    BURN-UP             (PCT) --------------.               .
                                                                        0.0        0.100E 01  0.100E 01
                                                                        0.150E 01  0.100E 01  0.100E 01
                                                                        0.750E 01  0.100E 01  0.100E 01
                                                                        0.500E 02  0.100E 01  0.100E 01

 2. BUFFER LAYER ------------------ EFFECTIVE DENSITY   (G/CM3) ------  0.110E 01
                                    EFFECTIVE POROSITY ---------------  0.200E 00
                                    THERMAL CONDUCTIVITY(W/CM.C) -----  0.150E-01
                                    POROSITY VARIATION ---------------------------------.
                                    FAST DOSE          (E20N/CM2) ----.
                                                                        0.0        0.200E 00
                                                                        0.100E 02  0.500E 00
                                                                        0.100E 03  0.500E 00

 3. HIGH DENSITY LAYER ------------ NUMBER OF LAYERS -----------------          3

   * MATERIAL NAME ---------------   1   GGA-PYC(LTI) PROPANE  1.80 G/CC  TI=900-1000 C

   * MATERIAL NAME ---------------   2  SILICON CARBIDE ( FROM  J. NUCLE. MATER. .VOL.32 322-329 (1969) )

   * MATERIAL NAME ---------------   3   GGA-PYC(LTI) PROPANE  1.80 G/CC  TI=900-1000 C

                                                                          (1)        (2)        (3)       (

   * STRUCTURAL PROPERTY ---------- THEORETICAL DENSITY (G/CM3) ------  0.222E 01  0.320E 01  0.222E 01
                                    EFFECTIVE DENSITY   (G/CM3) ------  0.180E 01  0.315E 01  0.180E 01
                                    DEPOSIT.TEMPERATURE (C) ----------  0.140E 04  0.140E 04  0.140E 04
                                    BACON ANISOTROPY FACTOR ----------  0.100E 01  0.100E 01  0.100E 01
                                    MECHANICAL PROPERTY INDEX (KMEC) -          0          0          0
                                    MECHANICAL PROPERTY INDEX --------          0          0          0

           TRISO-2 SAMPLE PROBLEM  ((PYC(LTI)  1.80 G/CC  950 DEG.C))      JUNE 25
( I N P U T   D A T A )
                                                                          (1)        (2)        (3)       (

   * MECHANICAL PROPERTY ---------- POISSONS RATIO (1) ---------------  0.220E 00  0.200E 00  0.220E 00
                                    POISSONS RATIO (2) ---------------  0.220E 00  0.200E 00  0.220E 00
                                    LIMITING STRESS OR CREEP STRAIN --  0.300E 04  0.300E 04  0.300E 04
                                    YOUNGS MODULUS (1)  (KG/CM2) -----  0.560E 06  0.420E 06  0.560E 06
                                    YOUNGS MODULUS (2)  (KG/CM2) -----  0.560E 06  0.420E 06  0.560E 06
                                    THERMAL CONDUCTIVITY(W/CM.C) -----  0.400E-01  0.800E-01  0.400E-01
                                    THERMAL EXPANSION   (/C) ---------  0.600E-05  0.550E-05  0.600E-05
                                    DIMENSIONAL CHANG PARAMETER ------          1          0          1
                                    COEFF.OF POLY.FUNCTION -- CR(I,J)
                                                                        0.0        0.0        0.0
                                                                       -0.356E-02  0.0       -0.356E-02
                                                                        0.149E-03  0.0        0.149E-03
                                                                       -0.194E-05  0.0       -0.194E-05
                                                                        0.155E-07  0.0        0.155E-07
                                                                       -0.593E-10  0.0       -0.593E-10
                                                                        0.0        0.0        0.0
                                                                        0.0        0.0        0.0
                                                        -- CT(I,J)
                                                                        0.0        0.0        0.0
                                                                       -0.405E-02  0.0       -0.405E-02
                                                                        0.127E-03  0.0        0.127E-03
                                                                       -0.235E-05  0.0       -0.235E-05
                                                                        0.199E-07  0.0        0.199E-07
                                                                       -0.636E-10  0.0       -0.636E-10
                                                                        0.0        0.0        0.0
                                                                        0.0        0.0        0.0

   * IRRADIATION CREEP ------------ CREEP CONSTANT      (CM4/KGE20N) -  0.200E-05  0.0        0.200E-05
                                    TRANSIENT CREEP                     0.400E-05  0.100E 02
                                    CREEP POISSONS RATIO -------------  0.400E 00  0.0        0.400E 00

 4. BONDING STRENGTH -------------- BONDING STRENGTH    (KG/CM2) -----  0.0        0.500E 03  0.500E 03

 5. IRRADIATION CONDITIONS -------- NUMBER OF TIME STEP --------------          3
                                    IRRADIATION TEMPERATURE (C) ------  0.950E 03
                                    EXTERNAL PRESSURE   (KG/CM2) -----  0.0

                                    FAST DOSE          (E20N/CM2) ----------------------------.
                                    BURN UP            (PCT) -----------------------.          .
                                    IRRADIATION DAY    (DAY) --------------.        .          .
                                                                           .        .          .
                                                                        0.0        0.0        0.0
                                                                        0.200E 04  0.700E 01  0.500E 02
                                                                        0.400E 04  0.140E 02  0.100E 03

 6. CALCULATION PARAMETER --------- TIME INCREMENT      (DAY) --------  0.160E 02
                                    NUMBER OF TIME STEP --------------        126
                                    LAYER MESH POINT -----------------         11
```

```
          TRISO-2 SAMPLE PROBLEM  ((PYC(LTI)  1.80 G/CC  950 DEG.C))        JUNE 25
        / KERNEL / BUFFER / LAYERS / = /  500.00 /   40.00 /   30.00 /   25.00 /   45.00 /

** PARTICLE OVERALL PARAMETER
   1. OUTER DIAMETER ------------  0.50000E 03 /  0.29000E 03 /  0.32000E 03 /  0.34500E 03 /  0.39000E 03 /

   2. VOLUME AND WEIGHT ---------- VOLUME(CM3) ------ WEIGHT(G)

     * KERNEL ------------------  0.65450E-04        0.68068E-03
     * BUFFER ------------------  0.36711E-04        0.40382E-04
     * COATING LAYER ----  1 ----  0.35098E-04        0.63176E-04
                           2 ----  0.34749E-04        0.10946E-03
                           3 ----  0.76468E-04        0.13764E-03
                                  ----------------------------
     * TOTAL -------------------  0.24847E-03        0.10313E-02

   3. SOLID AND PORE ------------ SOLID(CM3) ------- PORE(CM3)

     * KERNEL ------------------ 0.62177E-04        0.32725E-05
     * BUFFER ------------------ 0.29368E-04        0.73421E-05
                                 ----------------------------
     * TOTAL ------------------- 0.91546E-04        0.10615E-04

   4. EFFECTIVE PORE VOLUME FRACTION ---------------  0.10390E 00
   5. ATOMIC NUMBER OF HEAVY METAL (N) -------------  0.13905E 19
   6. PARTICLE RATING (W) --------------------------  0.17152E-01

          TRISO-2 SAMPLE PROBLEM  ((PYC(LTI)  1.80 G/CC  950 DEG.C))        JUNE 25
        / KERNEL / BUFFER / LAYERS / = /  500.00 /   40.00 /   30.00 /   25.00 /   45.00 /

STEP NO.  0   TIME       =    0.0DAYS           PARTICLE RATING =  0.0172   WATT       BONDING   -1  1  1
              BURNUP     =  0.0  PCT.FIMA       PORE VOLUME     = 0.1061E-04@B-CM      FRACTURE     1  1  1
              FAST DOSE  =   0.0 E20N/SQ-CM     INTERNAL GAS    = 0.0       MOLES
     INNER RADIUS   248.82  289.23  319.15  344.09           DIMENS.(R) 0.0       0.0      0.0
     OUTER RADIUS   289.23  319.15  344.09  388.96           CHENGE (T) 0.0       0.0      0.0
     TEMPERATURE    950.77  950.26  950.15  950.11           DELTA-P        0.0   -4.95    9.16    0.0
     STRESS (T) I     28.8   -99.9    35.2                 STRESS (R) I     0.0     5.0    -9.2
                O     26.5   -92.8    30.8                              O     5.0    -9.2     0.0

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

          TRISO-2 SAMPLE PROBLEM  ((PYC(LTI)  1.80 G/CC  950 DEG.C))        JUNE 25
        / KERNEL / BUFFER / LAYERS / = /  500.00 /   40.00 /   30.00 /   25.00 /   45.00 /
```

STEP NO.	TIME (DAY)	BURN-UP (PCT)	FAST DOSE	R A D I U S KERNEL	PARTICLE	PORE VOLUME	GAS MOLES	KERNEL TEMP.	P R E S S U R E INTERNAL	2	3	
1	16.0	0.06	0.40	250.16	388.50	0.9756E-05	0.5171E-09	950.77	5.50	-36.70	68.17	0.0
2	32.0	0.11	0.80	250.23	388.08	0.9851E-05	0.1034E-08	950.75	10.89	-67.98	113.99	0.0
3	48.0	0.17	1.20	250.30	387.72	0.1001E-04	0.1551E-08	950.75	16.08	-97.00	150.46	0.0
4	64.0	0.22	1.60	250.37	387.39	0.1021E-04	0.2069E-08	950.74	21.01	-122.61	180.60	0.0
5	80.0	0.28	2.00	250.44	387.09	0.1046E-04	0.2586E-08	950.74	25.64	-144.68	205.95	0.0
6	96.0	0.34	2.40	250.51	386.82	0.1074E-04	0.3103E-08	950.74	29.97	-163.35	227.60	0.0
7	112.0	0.39	2.80	250.58	386.58	0.1104E-04	0.3620E-08	950.74	34.00	-179.15	246.16	0.0
8	128.0	0.45	3.20	250.65	386.36	0.1137E-04	0.4137E-08	950.73	37.73	-192.49	262.16	0.0
9	144.0	0.50	3.60	250.72	386.15	0.1172E-04	0.4654E-08	950.73	41.18	-203.74	276.01	0.0
10	160.0	0.56	4.00	250.79	385.96	0.1208E-04	0.5171E-08	950.73	44.39	-213.27	288.05	0.0
11	176.0	0.62	4.40	250.86	385.79	0.1246E-04	0.5689E-08	950.73	47.35	-221.34	298.58	0.0
12	192.0	0.67	4.80	250.93	385.62	0.1284E-04	0.6206E-08	950.73	50.11	-228.18	307.86	0.0
13	208.0	0.73	5.20	251.00	385.47	0.1324E-04	0.6723E-08	950.73	52.67	-234.00	316.09	0.0
14	224.0	0.78	5.60	251.07	385.33	0.1364E-04	0.7240E-08	950.72	55.06	-239.94	323.46	0.0
15	240.0	0.84	6.00	251.14	385.19	0.1404E-04	0.7757E-08	950.72	57.30	-243.21	330.11	0.0
16	256.0	0.90	6.40	251.21	385.06	0.1445E-04	0.8274E-08	950.72	59.39	-246.90	336.17	0.0
17	272.0	0.95	6.80	251.28	384.94	0.1486E-04	0.8792E-08	950.72	61.37	-250.13	341.76	0.0
18	288.0	1.01	7.20	251.35	384.82	0.1527E-04	0.9309E-08	950.72	63.23	-252.95	346.99	0.0
19	304.0	1.06	7.60	251.42	384.71	0.1568E-04	0.9826E-08	950.72	64.99	-255.50	351.92	0.0
20	320.0	1.12	8.00	251.48	384.61	0.1609E-04	0.1034E-07	950.72	66.66	-257.83	356.64	0.0
21	336.0	1.18	8.40	251.55	384.50	0.1650E-04	0.1086E-07	950.72	68.24	-260.00	361.22	0.0
22	352.0	1.23	8.80	251.62	384.40	0.1691E-04	0.1138E-07	950.72	69.76	-262.05	365.71	0.0
23	368.0	1.29	9.20	251.69	384.30	0.1732E-04	0.1189E-07	950.71	71.21	-264.02	370.19	0.0
24	384.0	1.34	9.60	251.76	384.21	0.1773E-04	0.1241E-07	950.71	72.60	-265.96	374.70	0.0
25	400.0	1.40	10.00	251.83	384.12	0.1814E-04	0.1293E-07	950.71	73.94	-267.40	379.27	0.0
26	416.0	1.46	10.40	251.90	384.03	0.1811E-04	0.1345E-07	950.71	77.01	-268.23	383.28	0.0
27	432.0	1.51	10.80	251.97	383.96	0.1809E-04	0.1396E-07	950.71	80.06	-267.94	386.24	0.0
28	448.0	1.57	11.20	252.04	383.89	0.1807E-04	0.1448E-07	950.71	83.10	-266.97	388.34	0.0
29	464.0	1.62	11.60	252.11	383.83	0.1806E-04	0.1500E-07	950.71	86.11	-265.40	389.67	0.0
30	480.0	1.68	12.00	252.17	383.78	0.1806E-04	0.1551E-07	950.71	89.10	-263.25	390.33	0.0
31	496.0	1.74	12.40	252.24	383.73	0.1806E-04	0.1603E-07	950.71	92.08	-260.55	390.40	0.0
32	512.0	1.79	12.80	252.31	383.69	0.1806E-04	0.1655E-07	950.71	95.04	-257.37	389.95	0.0
33	528.0	1.85	13.20	252.38	383.66	0.1806E-04	0.1707E-07	950.71	97.98	-253.73	389.05	0.0
34	544.0	1.90	13.60	252.45	383.62	0.1807E-04	0.1758E-07	950.70	100.90	-249.65	387.76	0.0
35	560.0	1.96	14.00	252.52	383.60	0.1808E-04	0.1810E-07	950.70	103.82	-245.22	386.11	0.0
36	576.0	2.02	14.40	252.59	383.58	0.1809E-04	0.1862E-07	950.70	106.72	-240.46	384.15	0.0
37	592.0	2.07	14.80	252.66	383.56	0.1811E-04	0.1913E-07	950.70	109.60	-235.43	381.92	0.0
38	608.0	2.13	15.20	252.72	383.54	0.1812E-04	0.1965E-07	950.70	112.48	-230.13	379.45	0.0
39	624.0	2.18	15.60	252.79	383.53	0.1814E-04	0.2017E-07	950.70	115.34	-224.61	376.80	0.0
40	640.0	2.24	16.00	252.86	383.52	0.1815E-04	0.2069E-07	950.70	118.20	-218.90	373.98	0.0
41	656.0	2.30	16.40	252.93	383.51	0.1817E-04	0.2120E-07	950.70	121.05	-213.01	371.03	0.0
42	672.0	2.35	16.80	253.00	383.51	0.1818E-04	0.2172E-07	950.70	123.89	-206.97	367.96	0.0
43	688.0	2.41	17.20	253.07	383.51	0.1820E-04	0.2224E-07	950.70	126.74	-200.81	364.82	0.0
44	704.0	2.46	17.60	253.14	383.51	0.1821E-04	0.2275E-07	950.70	129.57	-194.55	361.60	0.0
45	720.0	2.52	18.00	253.20	383.51	0.1823E-04	0.2327E-07	950.70	132.41	-188.20	358.35	0.0
46	736.0	2.58	18.40	253.27	383.52	0.1824E-04	0.2379E-07	950.70	135.25	-181.79	355.06	0.0
47	752.0	2.63	18.80	253.34	383.52	0.1826E-04	0.2431E-07	950.70	138.08	-175.33	351.76	0.0
48	768.0	2.69	19.20	253.41	383.53	0.1827E-04	0.2482E-07	950.70	140.92	-168.84	348.46	0.0
49	784.0	2.74	19.60	253.48	383.54	0.1828E-04	0.2534E-07	950.70	143.77	-162.33	345.18	0.0
50	800.0	2.80	20.00	253.54	383.55	0.1829E-04	0.2586E-07	950.70	146.62	-155.82	341.92	0.0

TRISO-2 SAMPLE PROBLEM ((PYC(LTI) 1.80 G/CC 950 DEG.C)) JUNE 25
/ KERNEL / BUFFER / LAYERS / * / 500.00 / 40.00 / 30.00 / 25.00 / 45.00 /

STEP NO.	TIME (DAY)	BURN-UP (PCT)	FAST DOSE	RADIUS KERNEL	RADIUS PARTICLE	PORE VOLUME	GAS MOLES	KERNEL TEMP.	PRESSURE INTERNAL	2	3	
51	816.0	2.86	20.40	253.61	383.56	0.1830E-04	0.2637E-07	950.70	149.47	-149.31	338.70	0.0
52	832.0	2.91	20.80	253.68	383.57	0.1831E-04	0.2689E-07	950.70	152.33	-142.81	335.53	0.0
53	848.0	2.97	21.20	253.75	383.59	0.1832E-04	0.2741E-07	950.69	155.20	-136.33	332.41	0.0
54	864.0	3.02	21.60	253.82	383.60	0.1832E-04	0.2793E-07	950.69	158.08	-129.89	329.35	0.0
55	880.0	3.08	22.00	253.88	383.62	0.1833E-04	0.2844E-07	950.69	160.97	-123.49	326.36	0.0
56	896.0	3.14	22.40	253.95	383.63	0.1833E-04	0.2896E-07	950.69	163.88	-117.13	323.44	0.0
57	912.0	3.19	22.80	254.02	383.65	0.1833E-04	0.2948E-07	950.69	166.79	-110.83	320.60	0.0
58	928.0	3.25	23.20	254.09	383.67	0.1833E-04	0.2999E-07	950.69	169.72	-104.57	317.85	0.0
59	944.0	3.30	23.60	254.16	383.68	0.1833E-04	0.3051E-07	950.69	172.66	-98.38	315.19	0.0
60	960.0	3.36	24.00	254.22	383.70	0.1832E-04	0.3103E-07	950.69	175.61	-92.26	312.62	0.0
61	976.0	3.42	24.40	254.29	383.72	0.1832E-04	0.3155E-07	950.69	178.59	-86.21	310.14	0.0
62	992.0	3.47	24.80	254.36	383.74	0.1831E-04	0.3206E-07	950.69	181.57	-80.22	307.76	0.0
63	1008.0	3.53	25.20	254.43	383.76	0.1831E-04	0.3258E-07	950.69	184.58	-74.30	305.49	0.0
64	1024.0	3.58	25.60	254.49	383.78	0.1830E-04	0.3310E-07	950.69	187.60	-68.45	303.33	0.0
65	1040.0	3.64	26.00	254.56	383.80	0.1829E-04	0.3361E-07	950.69	190.65	-62.67	301.27	0.0
66	1056.0	3.70	26.40	254.63	383.82	0.1827E-04	0.3413E-07	950.69	193.71	-56.96	299.32	0.0
67	1072.0	3.75	26.80	254.70	383.84	0.1826E-04	0.3465E-07	950.69	196.79	-51.33	297.47	0.0
68	1088.0	3.81	27.20	254.77	383.86	0.1824E-04	0.3517E-07	950.69	199.90	-45.77	295.73	0.0
69	1104.0	3.86	27.60	254.83	383.88	0.1823E-04	0.3568E-07	950.69	203.02	-40.29	294.10	0.0
70	1120.0	3.92	28.00	254.90	383.90	0.1821E-04	0.3620E-07	950.68	206.17	-34.89	292.57	0.0
71	1136.0	3.98	28.40	254.97	383.92	0.1819E-04	0.3672E-07	950.68	209.34	-29.56	291.15	0.0
72	1152.0	4.03	28.80	255.03	383.94	0.1817E-04	0.3723E-07	950.68	212.54	-24.30	289.83	0.0
73	1168.0	4.09	29.20	255.10	383.97	0.1815E-04	0.3775E-07	950.68	215.76	-19.13	288.62	0.0
74	1184.0	4.14	29.60	255.17	383.99	0.1812E-04	0.3827E-07	950.68	219.00	-14.02	287.51	0.0
75	1200.0	4.20	30.00	255.24	384.01	0.1810E-04	0.3879E-07	950.68	222.27	-8.99	286.50	0.0
76	1216.0	4.26	30.40	255.30	384.03	0.1807E-04	0.3930E-07	950.68	225.57	-3.95	285.64	0.0
77	1232.0	4.31	30.80	255.37	384.05	0.1804E-04	0.3982E-07	950.68	228.90	0.88	284.78	0.0
78	1248.0	4.37	31.20	255.44	384.07	0.1801E-04	0.4034E-07	950.68	232.25	5.74	284.09	0.0
79	1264.0	4.42	31.60	255.51	384.09	0.1798E-04	0.4085E-07	950.68	235.64	10.49	283.45	0.0
80	1280.0	4.48	32.00	255.57	384.11	0.1795E-04	0.4137E-07	950.68	239.05	15.14	282.88	0.0
81	1296.0	4.54	32.40	255.64	384.14	0.1791E-04	0.4189E-07	950.68	242.50	19.70	282.39	0.0
82	1312.0	4.59	32.80	255.71	384.16	0.1788E-04	0.4241E-07	950.68	245.97	24.18	281.98	0.0
83	1328.0	4.65	33.20	255.77	384.18	0.1784E-04	0.4292E-07	950.68	249.47	28.59	281.65	0.0
84	1344.0	4.70	33.60	255.84	384.20	0.1781E-04	0.4344E-07	950.67	253.01	32.93	281.40	0.0
85	1360.0	4.76	34.00	255.91	384.22	0.1777E-04	0.4396E-07	950.67	256.57	37.20	281.24	0.0
86	1376.0	4.82	34.40	255.97	384.24	0.1773E-04	0.4447E-07	950.67	260.16	41.41	281.15	0.0
87	1392.0	4.87	34.80	256.04	384.26	0.1769E-04	0.4499E-07	950.67	263.79	45.56	281.15	0.0
88	1408.0	4.93	35.20	256.11	384.28	0.1765E-04	0.4551E-07	950.67	267.45	49.66	281.23	0.0
89	1424.0	4.98	35.60	256.17	384.30	0.1760E-04	0.4603E-07	950.67	271.14	53.70	281.38	0.0
90	1440.0	5.04	36.00	256.24	384.33	0.1756E-04	0.4654E-07	950.67	274.86	57.69	281.61	0.0
91	1456.0	5.10	36.40	256.31	384.35	0.1752E-04	0.4706E-07	950.67	278.62	61.64	281.91	0.0
92	1472.0	5.15	36.80	256.37	384.37	0.1747E-04	0.4759E-07	950.67	282.40	65.54	282.29	0.0
93	1488.0	5.21	37.20	256.44	384.39	0.1743E-04	0.4809E-07	950.67	286.23	69.39	282.73	0.0
94	1504.0	5.26	37.60	256.51	384.41	0.1738E-04	0.4861E-07	950.67	290.08	73.21	283.24	0.0
95	1520.0	5.32	38.00	256.57	384.43	0.1733E-04	0.4913E-07	950.67	293.97	76.98	283.82	0.0
96	1536.0	5.38	38.40	256.64	384.45	0.1728E-04	0.4965E-07	950.67	297.90	80.72	284.46	0.0
97	1552.0	5.43	38.80	256.71	384.47	0.1723E-04	0.5016E-07	950.66	301.85	84.42	285.16	0.0
98	1568.0	5.49	39.20	256.77	384.49	0.1719E-04	0.5068E-07	950.66	305.85	88.09	285.92	0.0
99	1584.0	5.54	39.60	256.84	384.51	0.1713E-04	0.5120E-07	950.66	309.88	91.73	286.74	0.0
100	1600.0	5.60	40.00	256.91	384.53	0.1708E-04	0.5171E-07	950.66	313.94	95.34	287.61	0.0

TRISO-2 SAMPLE PROBLEM ((PYC(LTI) 1.80 G/CC 950 DEG.C)) JUNE 25
/ KERNEL / BUFFER / LAYERS / * / 500.00 / 40.00 / 30.00 / 25.00 / 45.00 /

STEP NO.	TIME (DAY)	BURN-UP (PCT)	FAST DOSE	RADIUS KERNEL	RADIUS PARTICLE	PORE VOLUME	GAS MOLES	KERNEL TEMP.	PRESSURE INTERNAL	2	3	
101	1616.0	5.66	40.40	256.97	384.55	0.1703E-04	0.5223E-07	950.66	318.04	98.93	288.54	0.0
102	1632.0	5.71	40.80	257.04	384.57	0.1698E-04	0.5275E-07	950.66	322.17	102.49	289.51	0.0
103	1648.0	5.77	41.20	257.10	384.59	0.1693E-04	0.5327E-07	950.66	326.35	106.02	290.53	0.0
104	1664.0	5.82	41.60	257.17	384.61	0.1687E-04	0.5378E-07	950.66	330.55	109.54	291.60	0.0
105	1680.0	5.88	42.00	257.24	384.63	0.1682E-04	0.5430E-07	950.66	334.80	113.04	292.71	0.0
106	1696.0	5.94	42.40	257.30	384.65	0.1677E-04	0.5482E-07	950.66	339.08	116.52	293.86	0.0
107	1712.0	5.99	42.80	257.37	384.67	0.1671E-04	0.5533E-07	950.66	343.39	119.98	295.05	0.0
108	1728.0	6.05	43.20	257.44	384.69	0.1666E-04	0.5585E-07	950.66	347.75	123.44	296.28	0.0
109	1744.0	6.10	43.60	257.50	384.72	0.1660E-04	0.5637E-07	950.65	352.14	126.88	297.54	0.0
110	1760.0	6.16	44.00	257.57	384.74	0.1655E-04	0.5689E-07	950.65	356.57	130.31	298.83	0.0
111	1776.0	6.22	44.40	257.63	384.76	0.1649E-04	0.5740E-07	950.65	361.03	133.74	300.16	0.0
112	1792.0	6.27	44.80	257.70	384.78	0.1643E-04	0.5792E-07	950.65	365.54	137.15	301.51	0.0
113	1808.0	6.33	45.20	257.77	384.80	0.1638E-04	0.5844E-07	950.65	370.08	140.57	302.90	0.0
114	1824.0	6.38	45.60	257.83	384.82	0.1632E-04	0.5895E-07	950.65	374.65	143.98	304.30	0.0
115	1840.0	6.44	46.00	257.90	384.84	0.1626E-04	0.5947E-07	950.65	379.27	147.39	305.73	0.0
116	1856.0	6.50	46.40	257.96	384.86	0.1620E-04	0.5999E-07	950.65	383.92	150.80	307.18	0.0
117	1872.0	6.55	46.80	258.03	384.88	0.1615E-04	0.6051E-07	950.65	388.62	154.21	308.65	0.0
118	1888.0	6.61	47.20	258.09	384.90	0.1609E-04	0.6102E-07	950.65	393.34	157.63	310.14	0.0
119	1904.0	6.66	47.60	258.16	384.92	0.1603E-04	0.6154E-07	950.65	398.11	161.05	311.64	0.0
120	1920.0	6.72	48.00	258.23	384.94	0.1597E-04	0.6206E-07	950.64	402.92	164.48	313.15	0.0
121	1936.0	6.78	48.40	258.29	384.97	0.1592E-04	0.6257E-07	950.64	407.76	167.91	314.68	0.0
122	1952.0	6.83	48.80	258.36	384.99	0.1586E-04	0.6309E-07	950.64	412.64	171.36	316.21	0.0
123	1968.0	6.89	49.20	258.42	385.01	0.1580E-04	0.6361E-07	950.64	417.56	174.81	317.76	0.0
124	1984.0	6.94	49.60	258.49	385.03	0.1574E-04	0.6413E-07	950.64	422.52	178.28	319.31	0.0
125	2000.0	7.00	50.00	258.55	385.05	0.1568E-04	0.6464E-07	950.64	427.52	181.76	320.86	0.0
126	2016.0	7.06	50.40	258.62	385.08	0.1562E-04	0.6516E-07	950.64	432.56	185.25	322.42	0.0

TRISO-2 SAMPLE PROBLEM ((PYC(LTI) 1.80 G/CC 950 DEG.C)) JUNE 25
/ KERNEL / BUFFER / LAYERS / = / 500.00 / 40.00 / 30.00 / 25.00 / 45.00 /

STEP NO.	FRACTURED LAYERS	TANGENTIAL STRESS ((1))		((2))		((3))		((
1	0	235.21	219.60	-743.36	-690.78	256.30	229.22	
2	0	438.65	409.16	-1285.60	-1194.34	428.70	384.20	
3	0	629.97	587.09	-1743.42	-1619.27	565.39	507.38	
4	0	801.59	746.63	-2131.10	-1978.99	677.41	608.57	
5	0	952.30	886.77	-2460.20	-2284.30	770.98	693.34	
6	0	1081.58	1007.16	-2739.82	-2543.70	850.74	765.85	
7	0	1192.62	1110.78	-2978.05	-2764.70	918.86	828.06	
8	0	1287.88	1199.94	-3181.52	-2953.45	977.23	881.70	
9	0	1369.24	1276.38	-3355.61	-3114.95	1027.50	928.24	
10	0	1439.24	1342.46	-3505.29	-3253.81	1070.77	968.67	
11	0	1499.46	1399.65	-3634.51	-3373.70	1108.17	1004.02	
12	0	1551.35	1449.28	-3746.64	-3477.74	1140.64	1035.11	
13	0	1596.16	1492.51	-3844.51	-3568.56	1168.98	1062.66	
14	0	1634.56	1529.97	-3930.36	-3648.23	1193.98	1087.38	
15	0	1668.09	1563.05	-4006.50	-3718.90	1216.01	1109.59	
16	0	1697.47	1592.44	-4074.70	-3782.21	1235.61	1129.78	
17	0	1723.36	1618.72	-4136.48	-3839.56	1253.24	1148.36	
18	0	1745.81	1641.97	-4192.88	-3891.94	1269.44	1165.80	
19	0	1766.05	1663.30	-4245.35	-3940.67	1284.28	1182.18	
20	0	1784.49	1683.09	-4294.89	-3986.68	1298.09	1197.79	
21	0	1801.45	1701.65	-4342.37	-4030.77	1311.14	1212.87	
22	0	1817.24	1719.27	-4388.54	-4073.66	1323.67	1227.66	
23	0	1832.14	1736.21	-4434.09	-4115.98	1335.90	1242.35	
24	0	1846.40	1752.70	-4479.64	-4158.29	1349.01	1257.11	
25	0	1860.25	1768.96	-4525.74	-4201.11	1360.17	1272.09	
26	0	1873.07	1784.02	-4557.27	-4230.47	1370.32	1285.17	
27	0	1882.54	1795.91	-4577.39	-4249.24	1376.32	1294.50	
28	0	1887.61	1803.68	-4586.78	-4258.05	1379.12	1300.89	
29	0	1889.02	1808.01	-4586.65	-4258.03	1378.90	1304.56	
30	0	1886.95	1809.07	-4577.94	-4250.06	1376.06	1305.84	
31	0	1881.58	1807.06	-4561.51	-4234.93	1370.92	1305.02	
32	0	1873.17	1802.19	-4538.15	-4213.37	1363.75	1302.37	
33	0	1861.95	1794.70	-4508.59	-4186.07	1354.80	1298.09	
34	0	1847.60	1784.30	-4473.24	-4153.40	1344.48	1292.56	
35	0	1831.08	1771.86	-4433.00	-4116.20	1332.72	1285.71	
36	0	1812.62	1757.61	-4388.45	-4075.01	1319.69	1277.72	
37	0	1792.40	1741.71	-4340.13	-4030.32	1305.58	1268.73	
38	0	1770.60	1724.32	-4288.51	-3982.57	1290.54	1258.90	
39	0	1747.40	1705.63	-4234.04	-3932.16	1274.72	1248.35	
40	0	1722.98	1685.79	-4177.12	-3879.52	1258.24	1237.20	
41	0	1697.50	1664.95	-4118.14	-3824.95	1241.21	1225.54	
42	0	1671.11	1643.25	-4057.43	-3768.77	1223.74	1213.47	
43	0	1643.96	1620.84	-3995.31	-3711.29	1205.93	1201.07	
44	0	1616.20	1597.83	-3932.07	-3652.77	1187.84	1188.42	
45	0	1587.93	1574.35	-3867.97	-3593.45	1169.57	1175.58	
46	0	1559.29	1550.50	-3803.25	-3533.57	1151.19	1162.63	
47	0	1530.38	1526.39	-3738.13	-3473.31	1132.75	1149.61	
48	0	1501.30	1502.09	-3672.81	-3412.86	1114.32	1136.58	
49	0	1472.13	1477.71	-3607.48	-3352.40	1095.94	1123.59	
50	0	1442.97	1453.32	-3542.29	-3292.07	1077.67	1110.68	

TRISO-2 SAMPLE PROBLEM ((PYC(LTI) 1.80 G/CC 950 DEG.C)) JUNE 25
/ KERNEL / BUFFER / LAYERS / = / 500.00 / 40.00 / 30.00 / 25.00 / 45.00 /

STEP NO.	FRACTURED LAYERS	TANGENTIAL STRESS ((1))		((2))		((3))		((
51	0	1413.89	1428.97	-3477.39	-3232.02	1059.55	1097.89	
52	0	1384.95	1404.75	-3412.92	-3172.36	1041.63	1085.25	
53	0	1356.21	1380.70	-3348.99	-3113.21	1023.92	1072.81	
54	0	1327.75	1356.88	-3285.72	-3054.66	1006.48	1060.57	
55	0	1299.59	1333.34	-3223.20	-2996.81	989.32	1048.58	
56	0	1271.80	1310.11	-3161.51	-2939.74	972.48	1036.86	
57	0	1244.41	1287.24	-3100.74	-2883.50	955.97	1025.42	
58	0	1217.46	1264.76	-3040.94	-2828.18	939.81	1014.28	
59	0	1190.98	1242.70	-2982.17	-2773.81	924.03	1003.46	
60	0	1164.99	1221.08	-2924.50	-2720.45	908.64	992.98	
61	0	1139.77	1200.16	-2868.06	-2668.24	893.56	982.76	
62	0	1115.03	1179.67	-2812.78	-2617.11	878.93	972.93	
63	0	1090.82	1159.65	-2758.69	-2567.08	864.73	963.48	
64	0	1067.16	1140.12	-2705.82	-2518.18	850.99	954.41	
65	0	1044.07	1121.10	-2654.19	-2470.42	837.69	945.73	
66	0	1021.56	1102.62	-2603.80	-2423.83	824.83	937.43	
67	0	999.65	1084.68	-2554.67	-2378.40	812.43	929.52	
68	0	978.35	1067.28	-2506.81	-2334.15	800.47	922.00	
69	0	957.67	1050.44	-2460.22	-2291.07	788.97	914.87	
70	0	937.60	1034.16	-2414.90	-2249.18	777.91	908.13	
71	0	918.16	1018.44	-2370.85	-2208.46	767.31	901.77	
72	0	899.33	1003.29	-2328.05	-2168.90	757.15	895.80	
73	0	881.13	988.70	-2286.51	-2130.51	747.43	890.22	
74	0	863.55	974.66	-2246.21	-2093.27	738.15	885.01	
75	0	846.59	961.19	-2207.13	-2057.17	729.31	880.19	
76	0	828.84	946.98	-2168.82	-2021.79	721.45	876.21	
77	0	813.44	934.93	-2132.16	-1987.92	713.28	871.96	
78	0	797.11	922.01	-2096.23	-1954.75	706.15	868.61	
79	0	781.65	909.88	-2061.46	-1922.65	699.29	865.50	
80	0	766.97	898.46	-2027.83	-1891.62	692.73	862.64	
81	0	753.01	887.69	-1995.34	-1861.63	686.51	860.07	
82	0	739.72	877.52	-1963.94	-1832.66	680.63	857.80	
83	0	727.06	867.94	-1933.63	-1804.69	675.12	855.83	
84	0	715.01	858.89	-1904.37	-1777.70	669.96	854.18	
85	0	703.54	850.37	-1876.13	-1751.66	665.17	852.83	
86	0	692.62	842.35	-1849.90	-1726.55	660.73	851.78	
87	0	682.25	834.83	-1822.63	-1702.34	656.65	851.04	
88	0	672.40	827.77	-1797.31	-1679.00	652.92	850.60	
89	0	663.07	821.17	-1772.90	-1656.51	649.53	850.45	
90	0	654.22	815.01	-1749.38	-1634.85	646.48	850.58	
91	0	645.86	809.29	-1726.71	-1613.98	643.75	850.99	
92	0	637.97	803.99	-1704.87	-1593.87	641.35	851.67	
93	0	630.53	799.09	-1683.82	-1574.50	639.25	852.61	
94	0	623.53	794.58	-1663.54	-1555.85	637.46	853.80	
95	0	616.96	790.46	-1643.99	-1537.87	635.97	855.24	
96	0	610.81	786.71	-1625.15	-1520.56	634.76	856.92	
97	0	605.06	783.31	-1606.99	-1503.87	633.82	858.83	
98	0	599.71	780.26	-1589.47	-1487.78	633.16	860.96	
99	0	594.73	777.54	-1572.57	-1472.26	632.76	863.30	
100	0	590.11	775.15	-1556.25	-1457.29	632.60	865.85	

TRISO-2 SAMPLE PROBLEM ((PYC(LTI) 1.80 G/CC 950 DEG.C)) JUNE 25
/ KERNEL / BUFFER / LAYERS / = / 500.00 / 40.00 / 30.00 / 25.00 / 45.00 /

STEP NO.	FRACTURED LAYERS	TANGENTIAL STRESS ((1))		((2))		((3))	
101	0	585.85	773.06	-1540.49	-1442.83	632.69	863.60
102	0	581.94	771.28	-1525.26	-1428.87	633.01	871.54
103	0	578.35	769.78	-1510.53	-1415.37	633.56	874.65
104	0	575.08	768.56	-1496.27	-1402.31	634.32	877.94
105	0	572.11	767.60	-1482.45	-1389.66	635.30	881.40
106	0	569.44	766.90	-1469.05	-1377.39	636.47	885.01
107	0	567.04	766.43	-1456.03	-1365.49	637.83	888.78
108	0	564.92	766.20	-1443.37	-1353.92	639.38	892.68
109	0	563.06	766.19	-1431.05	-1342.66	641.11	896.72
110	0	561.45	766.38	-1419.03	-1331.68	643.00	900.89
111	0	560.07	766.78	-1407.29	-1320.96	645.05	905.17
112	0	558.91	767.36	-1395.80	-1310.47	647.25	909.57
113	0	557.97	768.12	-1384.54	-1300.20	649.60	914.07
114	0	557.24	769.04	-1373.48	-1290.11	652.08	918.66
115	0	556.69	770.12	-1362.59	-1280.19	654.69	923.35
116	0	556.33	771.35	-1351.86	-1270.41	657.42	928.12
117	0	556.14	772.71	-1341.26	-1260.75	660.27	932.97
118	0	556.11	774.20	-1330.76	-1251.19	663.22	937.88
119	0	556.23	775.80	-1320.34	-1241.70	666.27	942.86
120	0	556.49	777.51	-1309.98	-1232.27	669.41	947.89
121	0	556.88	779.32	-1299.66	-1222.88	672.65	952.97
122	0	557.40	781.22	-1289.34	-1213.49	675.96	958.10
123	0	558.03	783.19	-1279.03	-1204.10	679.34	963.25
124	0	558.76	785.24	-1268.68	-1194.68	682.79	968.44
125	0	559.59	787.35	-1258.28	-1185.22	686.29	973.66
126	0	560.50	789.51	-1247.82	-1175.70	689.86	978.88

TRISO-2 SAMPLE PROBLEM ((PYC(LTI) 1.80 G/CC 950 DEG.C)) JUNE 25
/ KERNEL / BUFFER / LAYERS / = / 500.00 / 40.00 / 30.00 / 25.00 / 45.00 /

STEP NO.	LAYER DENSITY (G/CC) 1	2	3	4	5	CREEP STRAIN (INNER AND OUTER SURFACE) 1		2		3	
1	1.108	1.822	3.180	1.822		0.0004	0.0004	-0.0012	-0.0011	0.0005	0.0004
2	1.150	1.829	3.185	1.830		0.0010	0.0009	-0.0023	-0.0020	0.0011	0.0009
3	1.159	1.836	3.189	1.837		0.0018	0.0015	-0.0032	-0.0028	0.0019	0.0015
4	1.167	1.843	3.192	1.844		0.0027	0.0022	-0.0039	-0.0035	0.0027	0.0021
5	1.174	1.849	3.195	1.851		0.0036	0.0031	-0.0046	-0.0041	0.0036	0.0028
6	1.179	1.855	3.198	1.857		0.0047	0.0039	-0.0051	-0.0046	0.0045	0.0035
7	1.184	1.861	3.200	1.863		0.0058	0.0049	-0.0056	-0.0050	0.0054	0.0043
8	1.188	1.866	3.202	1.869		0.0070	0.0058	-0.0059	-0.0053	0.0064	0.0050
9	1.191	1.872	3.203	1.875		0.0082	0.0068	-0.0063	-0.0056	0.0074	0.0058
10	1.194	1.877	3.204	1.881		0.0094	0.0078	-0.0066	-0.0059	0.0085	0.0066
11	1.196	1.882	3.206	1.887		0.0106	0.0088	-0.0068	-0.0061	0.0095	0.0074
12	1.198	1.887	3.207	1.892		0.0118	0.0098	-0.0070	-0.0063	0.0105	0.0082
13	1.200	1.891	3.207	1.897		0.0130	0.0108	-0.0072	-0.0065	0.0115	0.0090
14	1.201	1.896	3.208	1.902		0.0142	0.0117	-0.0074	-0.0066	0.0125	0.0097
15	1.202	1.900	3.209	1.907		0.0154	0.0127	-0.0075	-0.0067	0.0135	0.0105
16	1.204	1.904	3.210	1.912		0.0165	0.0137	-0.0077	-0.0069	0.0145	0.0113
17	1.205	1.908	3.210	1.917		0.0177	0.0146	-0.0078	-0.0070	0.0154	0.0120
18	1.206	1.912	3.211	1.921		0.0188	0.0156	-0.0079	-0.0071	0.0164	0.0128
19	1.207	1.916	3.211	1.926		0.0199	0.0165	-0.0080	-0.0071	0.0173	0.0135
20	1.208	1.920	3.212	1.930		0.0210	0.0174	-0.0081	-0.0072	0.0182	0.0142
21	1.209	1.924	3.212	1.934		0.0220	0.0182	-0.0082	-0.0073	0.0191	0.0149
22	1.210	1.927	3.212	1.938		0.0230	0.0191	-0.0083	-0.0074	0.0199	0.0156
23	1.211	1.931	3.213	1.942		0.0240	0.0199	-0.0083	-0.0075	0.0208	0.0162
24	1.212	1.934	3.213	1.946		0.0250	0.0207	-0.0084	-0.0075	0.0216	0.0169
25	1.214	1.937	3.214	1.949		0.0259	0.0215	-0.0085	-0.0076	0.0224	0.0175
26	1.215	1.940	3.214	1.953		0.0269	0.0223	-0.0086	-0.0077	0.0232	0.0182
27	1.215	1.943	3.214	1.956		0.0278	0.0231	-0.0086	-0.0077	0.0240	0.0188
28	1.216	1.946	3.214	1.959		0.0287	0.0239	-0.0086	-0.0077	0.0248	0.0194
29	1.216	1.949	3.214	1.962		0.0297	0.0247	-0.0086	-0.0077	0.0255	0.0201
30	1.216	1.951	3.214	1.965		0.0306	0.0254	-0.0086	-0.0077	0.0263	0.0207
31	1.217	1.954	3.214	1.968		0.0315	0.0262	-0.0086	-0.0077	0.0271	0.0213
32	1.216	1.956	3.214	1.971		0.0324	0.0270	-0.0085	-0.0076	0.0279	0.0219
33	1.216	1.958	3.213	1.973		0.0334	0.0278	-0.0085	-0.0076	0.0286	0.0226
34	1.216	1.960	3.213	1.976		0.0343	0.0285	-0.0084	-0.0075	0.0294	0.0232
35	1.216	1.962	3.213	1.978		0.0352	0.0293	-0.0083	-0.0075	0.0301	0.0238
36	1.215	1.964	3.212	1.981		0.0360	0.0300	-0.0083	-0.0074	0.0309	0.0244
37	1.215	1.966	3.212	1.983		0.0369	0.0308	-0.0082	-0.0073	0.0316	0.0250
38	1.214	1.968	3.212	1.985		0.0378	0.0315	-0.0081	-0.0072	0.0323	0.0256
39	1.214	1.970	3.211	1.987		0.0386	0.0322	-0.0080	-0.0071	0.0331	0.0262
40	1.213	1.971	3.211	1.989		0.0395	0.0330	-0.0078	-0.0070	0.0338	0.0268
41	1.213	1.973	3.210	1.991		0.0403	0.0337	-0.0077	-0.0069	0.0344	0.0273
42	1.212	1.974	3.210	1.992		0.0411	0.0344	-0.0076	-0.0068	0.0351	0.0279
43	1.211	1.975	3.209	1.994		0.0419	0.0350	-0.0075	-0.0067	0.0358	0.0285
44	1.211	1.977	3.208	1.996		0.0427	0.0357	-0.0074	-0.0066	0.0365	0.0290
45	1.210	1.978	3.208	1.997		0.0435	0.0364	-0.0072	-0.0065	0.0371	0.0296
46	1.210	1.979	3.207	1.999		0.0442	0.0371	-0.0071	-0.0064	0.0378	0.0301
47	1.209	1.980	3.207	2.000		0.0450	0.0377	-0.0070	-0.0063	0.0384	0.0306
48	1.209	1.981	3.206	2.001		0.0457	0.0383	-0.0069	-0.0061	0.0390	0.0312
49	1.208	1.982	3.206	2.002		0.0464	0.0390	-0.0067	-0.0060	0.0396	0.0317
50	1.208	1.983	3.205	2.003		0.0471	0.0396	-0.0066	-0.0059	0.0402	0.0322

TRISO-2 SAMPLE PROBLEM ((PYC(LTI) 1.80 G/CC 950 DEG.C)) JUNE 25
/ KERNEL / BUFFER / LAYERS / = / 500.00 / 40.00 / 30.00 / 25.00 / 45.00 /

STEP NO.	LAYER DENSITY (G/CC) 1	2	3	4	5	CREEP STRAIN (INNER AND OUTER SURFACE) 1		2		3	
51	1.208	1.984	3.205	2.004		0.0478	0.0402	-0.0065	-0.0058	0.0408	0.0327
52	1.207	1.984	3.204	2.005		0.0485	0.0408	-0.0064	-0.0057	0.0414	0.0332
53	1.207	1.985	3.203	2.006		0.0492	0.0414	-0.0062	-0.0056	0.0420	0.0337
54	1.207	1.986	3.203	2.007		0.0498	0.0420	-0.0061	-0.0055	0.0426	0.0342
55	1.207	1.986	3.202	2.008		0.0505	0.0425	-0.0060	-0.0054	0.0431	0.0347
56	1.207	1.987	3.202	2.009		0.0511	0.0431	-0.0059	-0.0053	0.0437	0.0352
57	1.207	1.987	3.201	2.009		0.0517	0.0437	-0.0058	-0.0052	0.0442	0.0357
58	1.207	1.988	3.201	2.010		0.0523	0.0442	-0.0056	-0.0051	0.0447	0.0362
59	1.207	1.988	3.200	2.010		0.0529	0.0447	-0.0055	-0.0050	0.0453	0.0366
60	1.207	1.989	3.200	2.011		0.0535	0.0453	-0.0054	-0.0049	0.0458	0.0371
61	1.207	1.989	3.199	2.011		0.0541	0.0458	-0.0053	-0.0048	0.0463	0.0375
62	1.207	1.989	3.199	2.012		0.0546	0.0463	-0.0052	-0.0047	0.0468	0.0380
63	1.207	1.989	3.198	2.012		0.0552	0.0466	-0.0051	-0.0046	0.0473	0.0384
64	1.208	1.990	3.198	2.012		0.0557	0.0473	-0.0050	-0.0045	0.0478	0.0389
65	1.208	1.990	3.197	2.013		0.0563	0.0478	-0.0049	-0.0044	0.0483	0.0393
66	1.209	1.990	3.197	2.013		0.0568	0.0483	-0.0048	-0.0043	0.0487	0.0398
67	1.209	1.990	3.197	2.013		0.0573	0.0488	-0.0047	-0.0042	0.0492	0.0402
68	1.210	1.990	3.196	2.013		0.0578	0.0493	-0.0046	-0.0041	0.0497	0.0406
69	1.210	1.990	3.196	2.013		0.0583	0.0497	-0.0045	-0.0040	0.0501	0.0411
70	1.211	1.990	3.195	2.013		0.0588	0.0502	-0.0044	-0.0040	0.0506	0.0415
71	1.212	1.990	3.195	2.013		0.0593	0.0507	-0.0043	-0.0039	0.0510	0.0419
72	1.212	1.990	3.195	2.013		0.0598	0.0511	-0.0043	-0.0038	0.0515	0.0424
73	1.213	1.990	3.194	2.013		0.0603	0.0516	-0.0042	-0.0037	0.0519	0.0428
74	1.214	1.990	3.194	2.013		0.0607	0.0520	-0.0041	-0.0037	0.0523	0.0432
75	1.215	1.990	3.194	2.013		0.0612	0.0525	-0.0040	-0.0036	0.0528	0.0436
76	1.216	1.989	3.193	2.013		0.0617	0.0529	-0.0039	-0.0035	0.0532	0.0440
77	1.217	1.989	3.193	2.013		0.0621	0.0533	-0.0039	-0.0035	0.0536	0.0444
78	1.218	1.989	3.193	2.012		0.0625	0.0538	-0.0038	-0.0034	0.0540	0.0448
79	1.219	1.989	3.192	2.012		0.0630	0.0542	-0.0037	-0.0034	0.0545	0.0453
80	1.220	1.988	3.192	2.012		0.0634	0.0546	-0.0037	-0.0033	0.0549	0.0457
81	1.222	1.988	3.192	2.012		0.0638	0.0550	-0.0036	-0.0032	0.0553	0.0461
82	1.223	1.988	3.191	2.011		0.0642	0.0554	-0.0035	-0.0032	0.0557	0.0465
83	1.224	1.987	3.191	2.011		0.0647	0.0559	-0.0035	-0.0031	0.0561	0.0469
84	1.226	1.987	3.191	2.011		0.0651	0.0563	-0.0034	-0.0031	0.0565	0.0473
85	1.227	1.987	3.191	2.010		0.0655	0.0567	-0.0034	-0.0030	0.0569	0.0477
86	1.229	1.986	3.190	2.010		0.0659	0.0571	-0.0033	-0.0030	0.0573	0.0481
87	1.230	1.986	3.190	2.009		0.0663	0.0575	-0.0033	-0.0029	0.0577	0.0485
88	1.232	1.986	3.190	2.009		0.0667	0.0579	-0.0032	-0.0029	0.0581	0.0489
89	1.233	1.985	3.190	2.008		0.0671	0.0583	-0.0032	-0.0028	0.0585	0.0493
90	1.235	1.985	3.190	2.008		0.0675	0.0587	-0.0031	-0.0028	0.0589	0.0497
91	1.237	1.984	3.189	2.007		0.0679	0.0591	-0.0031	-0.0028	0.0593	0.0502
92	1.238	1.984	3.189	2.007		0.0682	0.0595	-0.0030	-0.0027	0.0597	0.0506
93	1.240	1.983	3.189	2.006		0.0686	0.0599	-0.0030	-0.0027	0.0601	0.0510
94	1.242	1.983	3.189	2.006		0.0690	0.0603	-0.0029	-0.0027	0.0605	0.0514
95	1.244	1.982	3.189	2.005		0.0694	0.0607	-0.0029	-0.0026	0.0609	0.0518
96	1.246	1.982	3.189	2.004		0.0698	0.0611	-0.0029	-0.0026	0.0613	0.0522
97	1.247	1.981	3.188	2.004		0.0702	0.0615	-0.0028	-0.0026	0.0617	0.0526
98	1.249	1.981	3.188	2.003		0.0705	0.0619	-0.0028	-0.0025	0.0621	0.0530
99	1.251	1.980	3.188	2.002		0.0709	0.0623	-0.0028	-0.0025	0.0625	0.0535
100	1.253	1.979	3.188	2.002		0.0713	0.0627	-0.0027	-0.0025	0.0628	0.0539

TRISO-2 SAMPLE PROBLEM ((PYC(LTI) 1.80 G/CC 950 DEG.C)) JUNE 25
/ KERNEL / BUFFER / LAYERS / = / 500.00 / 40.00 / 30.00 / 25.00 / 45.00 /

STEP NO.	LAYER DENSITY (G/CC) 1	2	3	4	5	CREEP STRAIN (INNER AND OUTER SURFACE) 1		2		3	
101	1.255	1.979	3.188	2.001		0.0717	0.0631	-0.0027	-0.0024	0.0632	0.0543
102	1.257	1.978	3.188	2.000		0.0721	0.0635	-0.0027	-0.0024	0.0636	0.0547
103	1.259	1.978	3.188	2.000		0.0724	0.0639	-0.0026	-0.0024	0.0640	0.0551
104	1.261	1.977	3.188	1.999		0.0728	0.0643	-0.0026	-0.0024	0.0644	0.0556
105	1.264	1.976	3.187	1.998		0.0732	0.0647	-0.0026	-0.0023	0.0648	0.0560
106	1.266	1.976	3.187	1.998		0.0736	0.0651	-0.0026	-0.0023	0.0652	0.0564
107	1.268	1.975	3.187	1.997		0.0739	0.0655	-0.0025	-0.0023	0.0656	0.0568
108	1.270	1.975	3.187	1.996		0.0743	0.0659	-0.0025	-0.0023	0.0660	0.0573
109	1.272	1.974	3.187	1.995		0.0747	0.0663	-0.0025	-0.0022	0.0664	0.0577
110	1.275	1.973	3.187	1.994		0.0751	0.0667	-0.0025	-0.0022	0.0668	0.0581
111	1.277	1.973	3.187	1.994		0.0755	0.0671	-0.0024	-0.0022	0.0673	0.0586
112	1.279	1.972	3.187	1.993		0.0759	0.0675	-0.0024	-0.0022	0.0677	0.0590
113	1.281	1.971	3.187	1.992		0.0762	0.0679	-0.0024	-0.0022	0.0681	0.0595
114	1.284	1.971	3.187	1.991		0.0766	0.0684	-0.0024	-0.0021	0.0685	0.0599
115	1.286	1.970	3.187	1.990		0.0770	0.0688	-0.0023	-0.0021	0.0689	0.0604
116	1.288	1.969	3.186	1.990		0.0774	0.0692	-0.0023	-0.0021	0.0693	0.0608
117	1.291	1.969	3.186	1.989		0.0778	0.0696	-0.0023	-0.0021	0.0697	0.0613
118	1.293	1.968	3.186	1.988		0.0782	0.0700	-0.0023	-0.0021	0.0702	0.0617
119	1.296	1.967	3.186	1.987		0.0786	0.0705	-0.0023	-0.0020	0.0706	0.0622
120	1.298	1.966	3.186	1.986		0.0790	0.0709	-0.0022	-0.0020	0.0710	0.0626
121	1.300	1.966	3.186	1.985		0.0794	0.0713	-0.0022	-0.0020	0.0714	0.0631
122	1.303	1.965	3.186	1.985		0.0798	0.0717	-0.0022	-0.0020	0.0719	0.0636
123	1.305	1.964	3.186	1.984		0.0802	0.0722	-0.0022	-0.0020	0.0723	0.0640
124	1.308	1.964	3.186	1.983		0.0806	0.0726	-0.0021	-0.0020	0.0727	0.0645
125	1.310	1.963	3.186	1.982		0.0810	0.0730	-0.0021	-0.0019	0.0732	0.0650
126	1.313	1.962	3.186	1.981		0.0814	0.0735	-0.0021	-0.0019	0.0736	0.0655

* END OF FORTRAN *

APPENDIX C Sample graphical output