NUCLEAR PROCESS THEORY: A SYMBOLIC MODEL FOR REPRESENTING NUCLEAR PHYSICS PROCESSES

Revision 1

by

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TR94-087 December 1994

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UNB Faculty of Computer Science Technical Report TR94-087
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Abstract

Nuclear Process Theory (NPT) models nuclear physics processes using a formal grammar. This, in turn, allows one to write computer programs which simulate nuclear process interactions. Knowledge of the nuclear physics process is expressed in terms of a basic nuclear physics model and an aggregate effects model. The basic nuclear physics model has the capability of expressing knowledge of nuclear physics process for different types of reactions. The products of reactions can be expressed in terms of either deterministic or probabilistic values. The aggregate effects model is used to simulate nuclear physics processes.

1 Background and Motivation

Several attempts and approaches have been made to enable symbolic computer representation of physical systems [1, 2, 3, 10, 11, 15, 16, 17]. Kleer and Brown [2] describe the behavior of a composite device from the generic behavior of its components. They provide a framework for modeling the generic behavior of individual components of a device based on the notions of qualitative differential equations and qualitative states. Kuipers[10, 11] derives qualitative behavior of a physical system directly from a set of constraints abstracted from differential equations. Bhaskar and Nigam [1] determine the behavior of physical systems using dimensional analysis, without explicit knowledge of physical laws that govern the operation of such a device. The three approaches mentioned above do not incorporate notions of physical processes and are purely qualitative approaches. Forbus and Woods [3, 15, 16, 17] incorporate the notions of physical processes for describing the behavior of a physical system. They provide a way of specifying processes and their effects that allows both

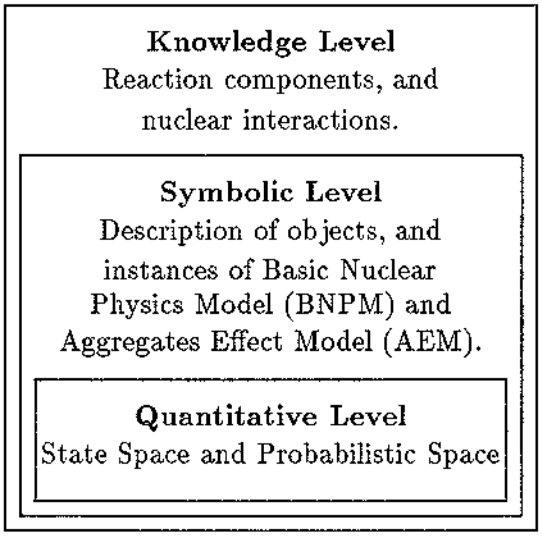

Figure 1: Model Hierarchy in NPT

deduction on what processes occur and how they might change. Forbus' approach is a purely qualitative approach.

By choosing a purely qualitative approach, many researchers have disqualified their methods from a vast number of application areas in engineering and science. Woods [17] introduced a combined qualitative and quantitative approach that can have a quantitative interpretation. His approach introduces parametric state space models which can represent parameters that physicists and engineers normally use. This enables a more direct use of the theory for scientific and engineering purposes. The common achievement of all of these different methods is the capability to explain how the physical systems work and follow the underlying physical laws that govern them. Physical system reasoners usually require a representational apparatus that deals with the vast amount of physical knowledge that is used in reasoning tasks. There are two kinds of knowledge required. First is knowledge about properties of different types of components of physical systems. Second is knowledge about physical interactions that follow the underlying physical laws. All of the methods have been developed to reason about different types of physical systems. None of these approaches has been developed to reason about nuclear physics processes [5].

This report introduces a method, called Nuclear Process Theory, for reasoning about nuclear physics processes. NPT formalizes how to structure parts of the available knowledge on nuclear physics processes to enable a computer program, taking a description of the topology of a nuclear physics process as its input, to derive conceivable dynamic interactions in the system. Both a quantitative state space model and a probabilistic space model of the system are incorporated. NPT integrates a symbolic, qualitative description of structural aspects of the process with a quantitative state space and probabilistic space model. Part of NPT's formal description is contained in a context free grammar. Knowledge on nuclear physics processes is expressed in descriptions of basic nuclear physics and aggregate effects models. NPT uses a novel approach to formalize the relationships between mathematical and probabilistic models of nuclear physics processes. NPT can be used to reason about nuclear physics processes such as fission reactions with different types of nuclides.

2 Modeling Assumptions

NPT extends the Hybrid Phenomena Theory (HPT), a framework for formalizing dynamic state space models for physical systems [17]. Besides allowing us to formalize the subset of the assumptions underlying a mathematical model, it also allows us to formalize non-deterministic actions which can possibly occur in a process being modeled, especially for nuclear physics reactions. NPT allows the explicit representation of knowledge of nuclear physics interactions, and formalize how these affect the structure and parameters of the model. The effects on the model are encoded in a symbolic structure. NPT has three different levels. These are shown in Fig. 1. Each of them is described separately.

2.1 Knowledge level

General descriptions of reaction components, materials and nuclear interactions are incorporated in the knowledge level. Knowledge describing the properties of various types of material substances is encoded in class descriptions. Knowledge on nuclear interactions is expressed by definitions in the basic nuclear physics model and the aggregate effect model.

2.1.1 Basic nuclear physics model

A basic nuclear physics model consists of descriptions of the underlying nuclear process being modelled. It contains conditions for when a process will occur, intermediate states in which a process will participate, and the products of a process. It is characterized by five fields: reactants, activity conditions, parametric_equation, intermediate_state, and products. Examples of such definitions are shown in Fig. 2.

Reactants describe what reagents are being used in the reaction being modelled, and relations between reagents which are necessary for the reaction to occur. In our example, obj1 and obj2 are the reagents, which their types are NUCLIDE and PARTICLE. These types are encoded in classes NUCLIDE and PARTICLE. The reaction occurs when obj1 and obj2 collide.

Activityconditions describe conditions which are necessary for processes to be active. Whenever the conditions are violated, the model is no longer an adequate description of the process. These conditions depend on the state on the system. This field limits the values of variables. It specifies either absolute limits on one variables, or limits relative to two variables.

Parametric_reactions field describes a set of parameters which are necessary for a system being modelled.

Intermediate_state field describes actions which occur before the reaction generates a set of products. The descriptions include a set of parameters which come into being as a consequence of the actions. For example, the intermediate_state of a fission reaction is a state where the projectile particle and the target nucleus form a compound nucleus. As a consequence, an atomic mass number of the compound nucleus, Ac and atomic number Zc exist.

Products describes a set of products generated as a consequence of an active reaction. The

```
basic_nuclear_physics_model bf is fission (obj1, obj2)
{
reactants {
    obj1 is NUCLIDE
    obj2 is PARTICLE
    COLLIDE(obj1, obj2)
}
activityconditions {  obj1.Tf > 0 }
intermediate_state {
    compound_nucleus (
        def_parameter Ac (value: obj1.A + obj2.A )
        def_parameter Zc (value: obj1.Z + obj2.Z )
parametric_reaction {  def_parameter nu(value: 2.43) }
products {
    Neutron.amount is PROBABILISTIC ( Poisson(2.43, 2.43, 0 to 7),
        def_vector pdf_neutron[7] (index: neutron_produced,
        value: decomposition(Poisson(2.43,2.43,0,7)) ))
    F1.A1 is PROBABILISTIC ( mass_yield1(obj1),
        def_vector pdf_A1 [44] (index: A1, value: look_up_table(mass_yield1(obj1))))
    F2.A2 is PROBABILISTIC ( mass_yield2(obj1),
        define-vector pdf_A2 [44] (index: A2, value: look_up_table(mass_yield2(obj1))))
    deltaZ is PROBABILISTIC (Gaussian(0, 7,-42 to 42),
        def_vector pdf_deltaZ [84] (index: deltaZ,value: decomposition(Gaussian(0,1,-42,42)) )))
    Energy_Neutron .amount is PROBABILISTIC (prompt_neutron_spectrum(obj1)),
        def_vector pdf_E_neutron[7] (index: E_neutron,
        value: look_up_table(prompt_neutron_spectrum(obj1) )
    Energy_Gamma.amount is PROBABILISTIC (prompt_gamma_spectrum(obj1)),
        def_vector pdf_E_gamma[7](index: E_gamma ,
        value: look_up_table(prompt_gamma_spectrum(obj1))
    Energy_F1 .amount is PROBABILISTIC (energy_distributions1(obj1),
        def_vector pdf_E_F1[44] (index: A1, value: look_up_table(energy_distributions1(obj1) ) ) )
    Energy_F2 .amount is PROBABILISTIC (energy_distributions2(obj1),
        def_vector pdf_E_F2[44] (index: A2, value: look_up_table(energy_distributions2(obj1) ) ) )
}
```

Figure 2: Basic nuclear physics model for fission.

descriptions of products are characterized by types of particles or nuclides being produced along with the descriptions of the quantities which characterize them. The values of the quantities may be probabilistic or deterministic; depends on the type of reaction itself. If the value of quantity is PROBABILISTIC, the distribution along with its parameters must be defined in the model. It is also required to define a vector whose indices represent range values of the distribution. The element of the vector represents either a probability of a parameter being in a certain interval or probability of a parameter having a certain value.

The probability of x being in interval (x_1, x_2) is defined by

$$P(x_1 < x < x_2) = \int_{x_1}^{x_2} f(x)\, dx \tag{1}$$

where f(x) represents the probability density functions (pdf) [8]. The probability of x having certain value is mapped by a probability measurement value (pmf) which is defined by [8]

$$P(X = x) = f(x) \tag{2}$$

In the case that the value of a quantity is PROBABILISTIC, its distribution is specified by a specific curve distribution and its range is known. The vector representing the curve must be defined and the vector values must represent the y axis values of the curve. In our example, when `obj1` represents U235, and `obj2` represents a neutron, the nuclear reaction for fission resulting from absorption in U235 splits into two fragments as follows

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{A_1}_{Z_1}F_1 + ^{A_2}_{Z_2}F_2 + \nu\, ^{1}_{0}n + Energy \tag{3}$$

where F_1 and F_2 indicate the products of fission fragments, A_1 and A_2 represent mass numbers of F_1 and F_2, respectively, and Z_1 and Z_2 represent atomic numbers of F_1 and F_2 respectively. The splitting of a fissioning nucleus does not always produce equal mass number. Mass numbers of fission fragments ranging from 72-163, with the most probable at range roughly 90-100 and 135-140 [9]. Symmetric fission, a fission producing equal mass numbers, is relatively uncommon occuring in only about 0.01 % of the fissions. This means that the symmetric fission occurs only once in 20,000 events [13].

Since NPT is used for reasoning about nuclear physics processes, the probabilities per unit mass of different fissionable nuclei must be provided either by the developer or by the system. In either case, a vector with indices representing the range of values of the mass distribution must be provided. The values of vector elements are the probability of a fragment having a certain mass number. For example, if the target of fission is U235, the probability of having a fission fragment with a mass 73,74,75 ... are 0.0001, 0.0003, 0.0010 and ... respectively. For each target, there will be a set pairs of mass number and the probability value of producing a fission fragment with that number. These pairs are provided as a look-up table (e.g. mass_yield).

2.1.2 Aggregate effects model

An aggregate effects model is used to simulate nuclear physics processes. It consists of conditions for when a simulation occurs, and the effects of this on both a state space and a probabilistic space model describing the process. In addition, the aggregate model can aggregate a set of products as

```
aggregate_effects_model fission (bf, RC,HWm, Hw) {
    material { obj1 }
    equipment { RC is REACTOR, HWm is MODERATOR, HWcl is CLADDING }
    preconditions { RC.power is ON }
    activityconditions  { RC.fuel_amount > 0 or Rs>0 }
    parametric_reaction  {
        def_constant NA (value: 6.02217 1e23, unit:" ") /* "Avogadro number */
        def_constant off_deltaZ (value: -20, unit:" ") /* an offset of deltaZ */
        def_constant off_A1 (value: 72, unit:" ") /* an offset of A2 */
        def_constant off_A2 (value: 117, unit:" ") /* an offset of A1 */
        def_constant ei (value: 1, unit:"MeV ") /* energy interval */
        def_parameter k (value: RC.eta * RC.epsilon * RC.p * f * * RC.PNLf * RC.PNLth )
        def_variable Rc ( value : k/nu * obj2.amount)
        unit: "fissions ") /* fissions per cycle */
        def_variable Rs ( unit: "fissions ") /* fissions per second */
        def_variable C (unit: "gr / sec") /* fuel consumed per second */
        def_parameter f (value: obj1.sigma_f *
        obj1.N /(obj1.sigma_f * obj1.N + HWm.sigma_a * HWcl.N + HWm.sigma_a * HWcl.N)
        def_parameter nc (value: tr/lp)
        def_variable pn (value: obj2.amount)
        def_vector distr_neutron[9] (index:neutrons_produced)
        def_vector distr_A1[44] (index: A1)
        def_array distr_F1[169,109](x_index: N, y_index: Z)
        def_vector distr_A2[45] (index: A2)
        def_array distr_F2[169,109](x_index:N , y_index: Z)
        def_vector distr_E_neutron[9] (index:energy_neutrons /* produced per fission */ )
        def_vector distr_E_gamma[9] (index:energy_gamma /* produced per fission */ )
        def_array distr_E_F1[89](index:energy_F1)
        def_vector distr_E_F2[89](index:energy_F2)
        def_vector nuclides_F1[169,109](x_index: neutrons per nuclide,y_index:Z)
        def_vector nuclides_F2[169,109](x_index: neutrons per nuclide,y_index:Z)
    }
    relations {
        cyc_infl { (Rc,Rs,pn,distr_neutron)(k, nu,pdf_neutron)
            ( (Rc = (k/nu) * pn;
            (distr_neutron[j] = Rc * pdf_neutron[j]) j = 0..8)
            (pn = (sum(j * distr_neutron[j])) j = 0..8)
            Rs = Rs + Rc;
            ) i = 1 .. nc }
        dyn_infl  { (B)(Rs,obj1.A)(B = Rs * obj1.A / NA) }
        dyn_infl  { (C)(obj1.sigma_f, obj1.sigma_g,B)
            ( C = ( ((obj1.sigma_f + obj1.sigma_g) /obj1.sigma_f) * B) }
        dyn_infl {(RC.fuel_amount)(C) ( RC.fuel.amount1 = RC.fuel.amount1 - C) }
        aggr_infl { (distr_neutron)(Rs) ( (distr_neutron[i] = Rs * pdf_neutron[i]) i = 0..8 ) }
        aggr_infl { (distr_A1)(Rs) ( ( distr_A1[i] = Rs * pdf_A1 [i]) i = 0..44 ) }
        aggr_infl { (distr_A2)(Rs) ( ( distr_A2[i] = Rs * pdf_A2[i]) i = 0..44 ) }
        cum_infl { (pn)(distr_neutron) ( (pn = sum(i * distr_neutron[i]) ) i = 0..8 ) }
        aggr_infl { (distr_E_neutron)(pn,pdf_E_netron)
        ( (distr_E_neutron[i] = pn * pdf_E_neutron [i]) i = 0..8 ) }
        aggr_infl { (distr_E_gamma) (Rs) ( (distr_E_gamma[i] = Rs * pdf_E_gamma [i]) i = 0..8 ) }
```

Figure 3: Aggregate effects model for fission.

```
    distr_infl { (nuclides_F1)(distr_A1, pdf_deltaZ) ( ( nuclides_F1
        [(Zc / (Ac - nu)) * (off_A1+ i) + off_deltaZ + j,
        off_A1 + i - [(Zc / (Ac - nu)) * (off_A2+ i) + off_deltaZ + j]
        distr_A1[i] ) i = 0..44, j = 0..13) }
    distr_infl { (nuclides_F2)(distr_A2, pdf_deltaZ) ( ( nuclides_F2
        [(Zc / (Ac - nu)) * (off_A2+ i) + off_deltaZ + j,
        off_A2 + i - [(Zc / (Ac - nu)) * (off_A2+ i) + off_deltaZ + j]
        distr_A2[i] ) i = 0..44, j = 0..13) }
    aggr_infl { (distr_E_F1)(Rs) ( (distr_E_F1 [i] = Rs * pdf_E_F1 [i]) i = 0..90 ) }
    aggr_infl { (distr_E_F2)(Rs) ( (distr_E_F2 [2] = Rs * pdf_E_F2 [i]) i = 0..90 ) }
}

products {

    def_object PARTICLE Neutron {
        cum_infl  { (Neutron.amount) (distr_neutron)
        ( (sum(i * distr_neutron[i])) i = 0..8 ) } }
    def_object ENERGY Energy_Neutron {
        cum_infl { (Energy_Neutron.amount)(distr_E_neutron)
        ( (sum( (i + ei/2) * distr_E_neutron[i])) i = 0..8 ) } }
    def_object ENERGY Energy_Gamma {
        cum_infl { (Energy_Gamma.amount)
        ( (sum( (i + ei/2 ) * distr_E_gamma[i])) i = 0..8 ) } }
    def_object PRODUCT_NUCLIDES F1 {
        par_infl { (F1.products)(nuclides_F1)
        ( (F1.products[i,j] = nuclides_F1[i,j]) i = 0..169, j = 0..108) } }
    def_object PRODUCT_NUCLIDES F2 {
        par_infl { (F2.products)(nuclides_F2)
        (( F2.products[i,j] = nuclides_F2[i,j]) i = 0..169, j = 0..108) } }
    def_object ENERGY Energy_F1 {
        cum_infl { (Energy_F1.amount) (distr_E_F1)
        ( (sum( (i + ei/2 ) * distr_E_F1[i]) ) i = 0..90 ) } }
    def_object ENERGY Energy_F2 {
        cum_infl { (Energy_F2.amount) (distr_E_F2)
        ( (sum( (i + ei/2 ) * distr_E_F2[i]) ) i = 0..90) } }
}
```

Figure 4: Continuation of aggregate effects model for fission.

a consequence of an active simulation of an active process. The aggregate effects model describes nuclear process interactions which incorporate dynamics, including any descriptions of influences which affect parameters of the system per over time (e.g once per second). It is characterized by fields material, equipments, preconditions, activityconditions, relations, and products such as shown in Fig.3.

Material field describes material being used in a reaction being modelled; it may be the same as one of the reactants in the basic model.

Equipments field specifies a place where a reaction is to be considered, along with its components.

Preconditions describes conditions which may depend on external actions. Turning a power switch on or off is an example. No reaction occurs unless the power is turned on, but, once on, the power is toggled depending on the state of the system.

Relations field specifies relationships to be associated with each instance of the definitions. The relationships are expressed as many influences, such as aggregate influences, cumulative influences, distribution influences, and parametric influences.

Products field specifies the creation of objects which come into being as a consequence of an active aggregate effects model. The aggregate effects model becomes active if the associated basic nuclear physics model is active. This causes a set of new objects to be created as a set of products. These created objects are products which are stated in the basic nuclear physics model.

The products field in the basic nuclear physics model gives any amount specifications of products being generated in a reaction. If the basic nuclear physics model of a specified reaction is active, the basic nuclear physics model generates a set of products symbolically, and their amounts are specified by either PROBABILISTIC or DETERMINISTIC values. The PROBABILISTIC values are represented in a vector, while the deterministic values are represented by either integer or real values.

A statement in the product field in the aggregate effects model does one of the following tasks:

1. Create an object which comes into being as a consequence of the instance becoming active. Each attribute of the object is obtained by any influence specified in the field.
2. Create a set of objects which come into being as a consequence of the instance becoming active. Each of the set of objects has attributes which are obtained by any influence specified in the field.

2.1.3 Neutron cycle in NPT

This section discusses a neutron cycle for thermal reactors. In a thermal reactor fast neutrons are born of fissions. The possibility of a chain reaction was recognized as soon as it was known that neutrons are released in a fission. Neutrons emitted by fissioning nuclei induce fissions on other fissile or fissionable nuclei. Neutrons generated by these induced fissions, cause fissions in other fissile or fissionable nuclei; and so on. Such a chain reaction can be described quantitatively in terms of multiplication factor, k [12]. The multiplication factor is defined as the ratio of the number of neutrons in the current generation, n_{i+1}, to the number of neutrons in the previous generation, n_i.

$$k = \frac{n_{i+1}}{n_i} \tag{4}$$

This factor can also be expressed in terms of four-factor formula [11] as follows

$$k = \eta \times \epsilon \times p \times f \times P_{NLf} \times P_{NLth} \tag{5}$$

where η is defined as the average neutrons emitted per neutron absorbed in fuel [11]. In the form of equation this is

$$\eta = \frac{\sigma_f}{\sigma_a} \times \nu \tag{6}$$

where ν the average number of neutrons released per fission.

The description of a neutron cycle for a thermal reactor in NPT model is expressed in terms of reactor parameters [4], see Fig.5.

The set of reactor parameters are [4] *fast fission factor*, ϵ, which is defined as the ratio of the total number of fast neutrons after fast fissions to the number of fast neutrons produced by thermal fissions; *fast nonleakage probability*, P_{NLf}, which is defined as the probability of neutorns remaining in the reactor core during slowing down; *resonance escape probability*, p, which is defined as the ratio of the number of neutrons thermalized to the total fast neutrons after allowing fast leakage; *thermal nonleakage probability*, P_{NLth}, which is defined as the probability of neutrons remaining in the reactor core during diffusion at thermal energy; and *thermal utilization factor*, f, which is defined as the ratio of the number of neutrons absorbed in the reactor fuel to the total number of absorptions in fuel, moderator, and cladding.

In NPT, a fission chain is initialized by a number of neutrons, $n_i = n_a$. The number of neutrons in the reactor core increases slightly after some of the neutrons involve in fast fissions resulting in a total number of fast neutrons of $n_i \times \epsilon$, see Fig. 5. Each fast neutron has a probability of remaining in the core reactor of P_{NLf} leaving $n_i \times \epsilon \times P_{NLf}$ neutrons remain in the core after allowing fast leakage. These fast neutrons scatter and slow down. A $(1-p)$ fraction of the remaining neutrons are captured in a resonance capture process. The remaining $n_i \times \epsilon \times P_{NLf} \times p$ escape from resonance capture during slowing down and thermalized. A fraction of the thermalized neutrons, $n_i \times \epsilon \times P_{NLth} \times p \times P_{NLf}$, remains in the core after diffusion at thermal energy. A fraction of these neutrons are absorbed in non fuel material leaving $n_i \times \epsilon \times P_{NLth} \times p \times P_{NLf} \times f$ neutrons absorbed in fuel. Only $\frac{\sigma_f}{\sigma_a}$ of the neutrons absorbed in fuel cause fissions and will produce a new number of neutrons.

These neutrons which cause fissions are denoted as the number fissions at the next cycle, $R_{c_{i+1}}$, computed as

$$R_{c_{i+1}} = n_i \times \epsilon \times P_{NLf} \times p \times P_{NLth} \times f \times \frac{\sigma_f}{\sigma_a}. \tag{7}$$

Subtituting equation (5) into the above equation will result in

$$R_{c_{i+1}} = \frac{k}{\nu} \times n_i \tag{8}$$

The factor n_i represents the number of fission neutrons in the previous generation.

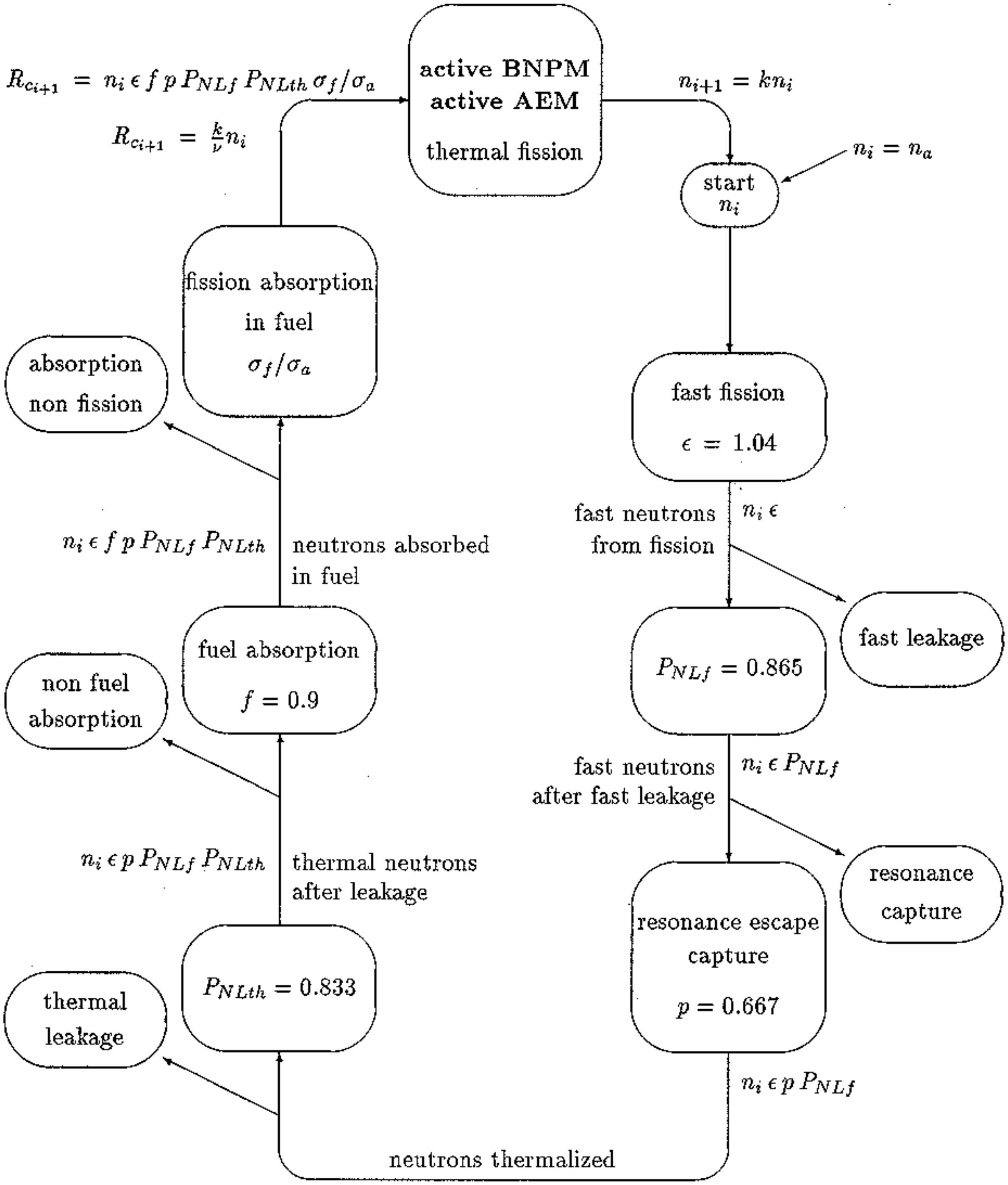

Figure 5: Neutron cycle in NPT.

Each cycle of Fig. 5 represents a generation of prompt neutrons, from their emmission until their absorption in fuel. The average time that the neutrons spend from their emmissiom until their absorption is called [11] the *prompt neutron lifetime* and is denoted as l_p.

Assuming that the value of k is constant for every cycle, and average time consumed every cycle is l_p. Assuming that the reports of simulation will be taken every period of time t_r. The number of cycles in a report period is

$$n_c = \frac{t_r}{t_c} \tag{9}$$

Furthermore, the number of fissions per report period is accumulated such as

$$R_s = \sum_{i=0}^{n_c} R_{c_{i+1}} \tag{10}$$

To convert R_r into gram fissioned , it merely necessary to divide by Avogadro's number, $N_A = 6.02217e23$, and multiply by the mass number of target nucleus, A [11]. Since the fissile nucleus are consumed both in fission and in radiactive capture, and since the total absorption rate $=\frac{\sigma_a}{\sigma_f}$, where σ_a, σ_f are the cross section absorption and cross section fission respectively. Therefore the target is consumed in the next period is

$$C = \frac{R_r}{N_A} \times A \times \frac{\sigma_a}{\sigma_f} \tag{11}$$

The value of k indicates the criticality of a reactor. If $k > 1$ the number of fissions increases from generation to generation. The reactor is said to be *supercritical* and the power it generates rises exponentially. On the other hand, if $k < 1$ the reactor is said to be subcritical and the power it produces decreases from time to time. If $k = 1$ the reactor produces constant energy and the reactor is said to be in its critical stage.

2.2 The Symbolic level

The symbolic level consists of objects, relations and properties for these objects which are defined in the input description such as shown in Fig.6. The symbolic level also consists of objects representing instances of basic nuclear physics definitions and aggregate effects definitions.

The system identifies every set of objects which when assigned to reactants of the basic nuclear physics model, satisfy the reactant conditions. The system also identifies every basic nuclear physics model which when assigned to the aggregate effects model, satisfies the aggregate effects model conditions. For each set of objects which is bound to the reactants of the of basic nuclear physics models, instances of the basic nuclear physics model are created. Some of these instances are then bound to the aggregate effects models which in turn instantiates the aggregate effects models. For example, consider a set of objects defined in the input descriptions which are shown in Fig. 6. These objects are considered to be active. The subset of instantiations of these objects, *U235* and *Neutron* are bound to reactants of the basic nuclear physics model of *fission* and *radioactive capture.* The relation *COLLIDE (U235, Neutron)* matches the reactants condition specified at the reactant fields of the basic nuclear physics model *fission* and *radioactive capture.* This causes

```
U235 NUCLIDE
{
   Z          92
   A          235
   N          10e21 /* atoms per cm3 */
   sigma_f    585 /* barn */
   sigma_a    99 /* barn */
}

HWm Moderator
{
   sigma_a    0.883 /* barn */
   N          3.679e22 /* atoms per cm3 */
}

RC REACTOR {
   core         homogeneous
   eta          2.22 /* thermal fission factor */
   epsilon      1.03 /* fast fission factor */
   p            0.667 /* resonance escape probability */
   fuel         U235
   fuel_amount  100 /* gr */
   PNLth        0.833
   PNLf         0.865
}

COLLIDE (Uranium, Neutron)
```

```
Neutron PARTICLE
{
   Z          0
   A          1
   amount     3e20
}

HWcl Cladding
{
   sigma_a    0.66 /* barn */
   N          2.013e23 /* atoms per cm3 */
}
```

Figure 6: Input descriptions of NPT.

U235
Neutron
RC
HWm
HWcl
BNPM fission (U235, Neutron)
BNPM radioactive_capture (U235, Neutron)
AEM (BNPM fission (U235, Neutron),RC,HWm,HWcl)
AEM (BNPM radioactive_capture(U235, Neutron),RC,HWm,HWcl)

Figure 7: Symbolic instances of basic nuclear and aggregate effects models.

the instances of the basic nuclear physics models, *bnpm fission (U235, Neutron)* and *bnpm radioactive capture (U235, Neutron)*, to be created. These instantiations along with some instantiations of basic objects *RC,HWm,Hw* are bound to the aggregate effects models of *fission* and *radioactive capture*. This causes the instanstiation of the aggregate effects models,*AEM (BNPM fission (U235,Neutron),RC,HW,Hw)* and *EM (BNPM radioactive_capture(U235, Neutron),RC,HW,Hw)*.

Fig.7 shows a subset of objects which are bound to the reactants of a basic nuclear physics models which causes them to be bound to the aggregate effects models for a set of reactions. This figure also shows a subset of instances of the basic nuclear physics model and aggregates effects model.

2.3 Quantitative level

An instance of the basic nuclear physics model and aggregate effects model does not cause any analysis of the system. Only active instances can cause the analysis. The active instances are obtained when the objects are bound to the reactants and the basic nuclear model is bound to the aggregate effects model, and objects satisfy the preconditions and quantity conditions for both basic nuclear physics and aggregate effects models.After instantiation of basic nuclear and aggregate effects models, the next step of reasoning is to identify the active instances. The basic objects are always considered active, e.g. *U235, Neutron,RC, HWm,HWcl.* The set of active basic nuclear physics aggregate effect models are set to follow phenomena reaction in the current state. For example, we have specified the fuel amount ofreactor ($RC.fuel\_amount$) is greater than 0 and Uranium_U235 cross section fission ($obj1.Tf$) is greater than 0. This causes only *BNPM fission* and *AEM fission* to be active. Since the aggregate effects model describes nuclear interactions every second, then by combining all the influences defined by these instances, the system generates objects describing the system state model every second. Fig. 8 shows a state space model and probabilistic space model as consequence of the basic nuclear physics and aggregate effects models being actives.

The state space model consists of equations which are considered to consists of terms. Each instantiation of the basic nuclear physics model and the aggregate effects model comprises a set of equations which has a potential description of how a nuclear process understanding relates to the equations.

This state space model is used to answer questions, such as how will the state of the system

```
Neutron.amount is PROBABILISTIC          pdf_neutron
F1.A1 is PROBABILISTIC                   pdf_A1
delta.Z is PROBABILISTIC                 pdf_deltaZ
F2.A2 is PROBABILISTIC                   pdf_A2
Energy_Gamma.amount is PROBABILISTIC     pdf_E_gamma
Energy_Neutron.amount is PROBABILISTIC   pdf_E_neutron
Energy_F1 is PROBABILISTIC               pdf_F1
Energy_F2 is PROBABILISTIC               pdf_F2

k = RC.eta * RC.epsilon * RC.p * f * obj1.σ_f / (obj1.sigma_f + obj2.sigma_g
(Rc(i+1) = k / nu * Neutron.amount(i),
Rs = Rs + Rc(i+1)), i = 1..nc
B = (R /NA ) * Rs
C = ((obj1.Tf + obj1.Tg) / obj1.Tf) * B
RC.fuel_amount = RC.fuel_amount - C

distr_neutron                            distr_gamma
distr_A1                                 distr_F1
distr_A2                                 distr_F2
distr_E_neutron                          distr_E_gamma
distr_E_F1                               distr_E_F2
produce Neutron                          Neutron.amount = sum(i * distr_neutron[i])) i = 0..8
produce Energy_Neutron                   (sum( (i + ei/2) * distr_E_neutron[i])) i = 0..8 )
produce Energy_Gamma                     (sum( (i + ei/2 ) * distr_E_gamma[i])) i = 0..8 )
produce F1
F1.products[i,j] =
nuclides_F1[i,j])i = 0..169, j = 0..108
produce F2
F2.product[i,j] =
nuclides_F2[i,j]) i = 0..169, j = 0..108
produce Energy_F1
Energy_F1.amount =
(sum( (i + ei/2 ) * distr_E_F1[i]) ) i = 0..90
produce Energy_F2
Energy_F2.amount =
(sum( (i + ei/2 ) * distr_E_F2[i]) ) i = 0..90
```

Figure 8: State space and probabilistic space models of NPT.

elvolve over the next report period given the current initial state? For example, the number of reactions over period of time (R_r) is dependent upon the number of neutrons absorbed in fuel material which yields fissions. The fuel amount consumed is dependent upon the number of reactions R_r. Every report period the amount of reactor fuel decreases as much as fuel consumed.

The probabilistic space model consists of different types of distributions which govern the process. Each instantiation of the basic nuclear physics model and the aggregate effects model comprises a set of parameters which are considered to have non-deterministic values along with their distributions. These distributions constitute a sufficient conceptual basis for obtaining non-deterministic values from the process being modeled. The probabilistic space model is used to answer questions, such as what is the distribution of products (e.g. neutrons or fission fragments) in the current state? For example, the number of neutrons produced for each non-deterministic fission ranges from 0 to 8. The probability of producing 0 - 8 neutrons for each fission is controlled by Poisson distribution. This distribution is represented as *pdf_neutron* (see Fig. 8). The distribution of neutrons produced for a number of fissions is dependent on the number of reactions R_r and the *pdf_neutron*. The distribution of neutron products is represented by *distr_neutron*. If each state of the system changes R_r, it causes the distribution of neutrons produced, *distr_neutron*, to change.

Each distribution of products shown above changes every report period; this is dependent on the number of reactions. If the rate of reactions becomes less than or equal to zero, then the process is no longer active.

3 Influences in NPT

In general, influences express how one or a set of variables influence another variable or another set of variables. There are several types of influences in NPT. Two of them, dynamic and algebraic influences, are similar to HPT influences. Their syntax specifications are described in [14, 15, 16] and other influences, unique to NPT, are described in the following:

Cumulative influences specify how a set of elements of a vector variable cumulatively influences the influenced variable. The syntax for cumulative influence is as follows:

$$\begin{array}{ll} cum\_infl\ \{ & (< influenced\_variable >) \\ & (< influencing\_vector\_variable >) \\ & (< function\_spec >) \\ < function\_spec >: & < sum\ (vector\_expression) >\} \end{array}$$

As an example, consider neutron products generated by a fission reaction. The amount of neutrons is dependent on the neutron spectrum which is represented by a particular vector. The total number of neutrons is accumulated over the distribution values. These values are represented as values of the vector elements. Aggregate influences specify how a variable affects a set of vector values. The syntax of these influences are as follows:

$$\begin{array}{ll} aggr\_infl\ \{ & (< influenced\_vector\_variable >) \\ & (< influencing\_variable >) \\ & (< funct\_spec >) \\ < funct\_spec >: & < expression >\} \end{array}$$

A fission reaction with a rate of R fissions per second will generate fission fragments F_1 and F_2. Each fragment has a mass distribution which is represented by a vector. Element values represent the probability densities. The actual mass values of F_1 and F_2, for fission reactions with a rate R, are distributed with probability values as a function of R.

Distribution influences specify how two sets of distribution values affect another set of values for performing certain operation.

$$\begin{array}{ll} distr\_infl\ \{ & (< influenced\_set\_of\_values >) \\ & (< two\_sets\_of\_influencing\_values >) \\ & (< func\_spec >) \\ < funct\_spec >: & < expression >\} \end{array}$$

Parametric influences describe how a variable or parameter of element of a vector variable affects another variable directly without any functions describing their relationships. The syntax for these influences are as follows:

$$\begin{array}{ll} par\_infl\ \{ & (< influenced\_variable >) \\ & (< influencing\_variable >) \\ & (< influencing\_variable >)\} \end{array}$$

Cycle influences describe how parameters and results of a current cycle process affect a set of influenced variables in the next cycle repeatly. The syntax for these influences are as follows:

$$\begin{array}{ll} cyc\_infl\ \{ & (< influenced\_variable >) \\ & (< influencing\_variables >) \\ & (< func\_spec >) \\ < funct\_spec >: & < (set\_of\_expressions)\ i = range >\} \end{array}$$

4 Example

This section illustrates how NPT works. Nuclear reactions under consideration are fission reactions. The basic nuclear physics model and the aggregate effects model definitions are given in Fig. 2 and Fig. 3. The input descriptions to NPT program is shown in Fig.6. Part of the input values are taken from [8]. The define-object statement takes two required arguments; the name identifying object and the name of the class to be instantiated to describe the object. The rest of the arguments are optional and specify the initial values and parameters defined for the class being considered. The relationships between objects is shown as well.

Assuming that all relevant basic nuclear physics and aggregate effects models are included in the system, NPT will identify all possible instantiations of the basic nuclear physics and aggregate effects models. This task is accomplished when a set of existing objects match the requirements for the reactants and the material as stated in the basic nuclear physics and aggregate effects models.

The instantiation of a number of reaction definitions are considered as conceivable nuclear reactions. These may cause generating a set of products symbolically. The instances of objects, basic nuclear physics and aggregate effects models of a fission reaction are shown in Fig.9.

U235
Neutron
RC
HWm
HWcl
BNPM fission (U235, Neutron)
AEM (BNPM fission (U235, Neutron),RC,HWm,HWcl)

Figure 9: Instances of basic nuclear physics and aggregate effects models for fission.

When all possible nuclear reactions have been created, the program proceeds to test the validity of the activity conditions for each instance. This required that the initial values for at least a subset of parameters and variables have been specified. The result of this process is a set of active processes, which is a subset of conceivable nuclear reactions. The instantiations of active processes will generate a set of products which is expressed either in deterministic values or probabilistic values

The state space and probabilistic models always follow directly from the set of active processes. These are the consequences of a number of influences defined by these instances. The set of instantiations of active processes along with state space and probabilistic models is shown in Fig.8. If the complete initial state is known, then both state space and probabilistic models can be used to determine the behavior of the system.

An example is to use a set of objects and their relationships as shown in Fig. 6, and a reactor with parameters as given in the figure. The number of neutrons is initialized as 3e20. Only part of these neutrons are absorbed in fuel material which is dependent upon the parameters of the reactor. From a state space model, and the given parameters of a reactor such as shown in Fig. 6, R_r will have a value of 1.006132e+023 at the 10th cycle.

The number of neutrons produced for each fission has a non-deterministic value, ranging between 0 and 8. The probability of producing 0 to 8 neutrons per fission is controlled by Poisson distribution. For example, the probability values of producing a particular number of neutrons are tabularized as shown in Fig. 10. The *pdf_neutron* in the probability space model will consists of the probability values of the figure. Since R_r describes the number of fissions occuring per report period, then the number of neutrons produced for that particular R_r can be computed. In our example, R_r is 1.006132e+023, and the neutron products have a distribution as shown in Fig. 11. The *distr_neutron* in the probability space model consists of values of the distribution of neutron products, the second column of the Fig. 11. The total number of neutrons produced is accumulated as follows:

$$\sum_{i=0}^{8} i * distr\_neutron_i \tag{12}$$

where i is the number of neutron products produced by a particular number of fissions $distr\_neutron_i$. In our example, the neutron products produced by R_r = 1.006132e+023 fissions is 2.433833e+23.

The prompt neutrons per fissions are emitted with continuous distribution of energies which is called *prompt-neutron-spectrum* [12]. Equation (13) gives the distribution of this *prompt-neutron-spectrum* [11].

$$\chi(E) = 0.453e^{1.036E} sinh\sqrt{2.29E} \tag{13}$$

neutrons produced	*probability of producing neutrons*
index	*pdf_neutrons*
0	0.089
1	0.215
2	0.260
3	0.211
4	0.126
5	0.062
6	0.025
7	0.009
8	0.003

Figure 10: Probability per unit neutron products.

#neutrons produced	*#fissions producing neutrons*	*fraction*
0	8.954574e+021	0.089
1	2.163184e+022	0.215
2	2.615943e+022	0.260
3	2.122938e+022	0.211
4	1.267726e+022	0.126
5	6.238017e+021	0.062
6	2.515330e+021	0.025
7	9.055186e+020	0.009
8	3.018396e+020	0.003

Figure 11: Distribution of neutron products for a certain number of fissions.

neutron energy En (MeV)	*probability of producing En (MeV)*
(0-1)	0.3101635382
(1-2)	0.2965603757
(2-3)	0.1858727779
(3-4)	0.1033541111
(4-5)	0.0538716708
(5-6)	0.0269146713
(6-7)	0.0130406600
(7-8)	0.0061712412
(8-9)	0.0028658063

Figure 12: Probability per unit interval of energy of neutron products calculated from [12].

The probability of having an energy in a certain interval $(e_1 - e_2)$ is obtained by calculating part of an area under *prompt-neutron-spectrum* which bounded by $(e_1 - e_2)$. For example, the probabilities of a neutron having an energy in a certain interval are tabularized such as shown in Fig. 12. The *pdf_E_neutrons* in probabilistic space model consists of probability values of the figure.

The total energy of neutron products for a number of occurred fissions is accumulated such as follows

$$\sum_{i=0}^{8}(i + 0.5) * distr\_neutron_i \tag{14}$$

where $i + 0.5$ is the average energy of the ith energy interval of neutrons products by a particular number of fissions $distr\_neutrons[i]$. In our example, the energy of neutron products is 2.456551e+023 Mev. This energy is produced by 2.433833e+023 neutrons which comes from 1.006132e+023 fissions.

The fission gamma are emitted with continuous distribution of energies which is called *prompt-gamma-spectrum* [12]. Equation 15 gives the distribution of this *prompt-gamma-spectrum.*

$$N(E) = e^{1.10E} \tag{15}$$

The probability of having an energy in a certain interval $(e_1 - e_2)$ is obtained by calculating part of an area under *prompt-gamma-spectrum* which bounded by $(e_1 - e_2)$. For example, the probabilities of fission fragments gamma having an energy in a certain interval are tabularized such as shown in Fig. 13. The *pdf_E_gamma* in the probabilistic model consists of the probability values of the figure.

The total energy of gamma products for a number of occurred fissions is accumulated in the same manner of calculating the energy of neuron products.

In a fission, the two fragments $F1$ and $F2$ do not have unique values of mass A, and atomic number Z. Mass number ranging from 72 to 162 are observed [12]. The yields of fission products are observed as a function of mass number.

gamma energy Eg (MeV)	*probability of producing Eg (MeV)*
(0-1)	0.666481
(1-2)	0.221880
(2-3)	0.077200
(3-4)	0.022369
(4-5)	0.007446
(5-6)	0.002479
(6-7)	0.000825
(7-8)	0.000275
(8-9)	0.000091
(9-10)	0.000030

Figure 13: Probability per unit interval of energy of gamma products.

The probability of a fission fragment having a given mass number is controlled by *mass-yield* curve. The *mass-yield* is typical from fission to fission which depend upon target nucleus, and the type of reactor.

For example, the probabilities of fission fragments $F1$ (light nucleus) having a certain mass number, and $F2$ (heavy nucleus) having a certain mass number are tabularized such as shown in Fig. 14.

These values appears as in the *pdf_A*1 and *pdf_A*2 at the probabilistic space model. The distributions of fission fragments F1 and F2 for a particular number of fissions occurred (e.g. 1.006132e+023 fissions) are shown in the Appendix.

The major fraction of the energy released in fission appears as kinetic energy of the fission fragments. The distribution in kinetic energy of the fission fragments appears as energy-yield curve.

The probability of a fission fragment having a specific energy is controlled by *energy-yield* curve. For example, the probabilities of fission fragments having certain energy for fission of U235 are tabularized such as shown in Fig. 15.

The distribution of energy of fission fragments for a particular number of fissions occurred fissions occurred (e.g. 1.006132e+20 fissions) are shown in the Appendix.

The total energy of fission fragments are computed in a similar manner as for computing total energy of neutron products. This is accomplished by taking an energy average of each interval, then multiplying it by the number of fission fragments producing that energy in the interval.

Having done all computations explained above, the distribution of fission fragments, the number of both neutrons and gamma produced, the energy of neutron products, the energy of gamma products along with the energy of fission fragments are obtained (see the Appendix). Having known distribution of mass numbers of the fission fragments is not adequate to explain about the products of the process being modelled. It is required to know about what the real byproducts are, since only knowing mass number can represent different types of nuclides. Some of them may cause another process such as decay process.

A1	*% yield*	*A1*	*% yield*	*A2*	*% yield*	*A2*	*% yield*
	pdf_A1		*pdf_A1*		*pdf_A2*		*pdf_A2*
72	0.000026	95	6.50	118	0.013	142	6.21
73	0.0001	96	6.50	119	0.011	143	6.58
74	0.0003	97	6.3	120	0.013	144	6.584
75	0.001	98	5.98	121	0.013	145	6.595
76	0.003	99	5.78	123	0.013	146	5.50
77	0.008	100	6.1	124	0.016	147	3.93
78	0.021	101	6.28	125	0.0159	148	3.00
79	0.044	102	5.18	126	0.027	149	2.25
80	0.13	103	4.29	127	0.031	150	1.67
81	0.13	104	3.03	128	0.059	151	1.08
82	0.19	105	1.88	129	0.126	152	0.653
83	0.32	106	0.96	130	0.35	153	0.417
84	0.535	107	0.41	131	0.75	154	0.268
85	1.00	108	0.145	132	1.81	155	0.158
86	1.317	109	0.054	133	2.89	156	0.074
87	1.96	110	0.031	134	4.31	157	0.032
88	2.55	111	0.025	135	6.69	158	0.0149
89	3.57	112	0.019	136	7.87	159	0.0062
90	4.76	113	0.013	137	6.54	160	0.0033
91	5.8	114	0.015	138	6.32	161	0.0010
92	5.84	115	0.013	139	6.19	162	0.0003
93	6.03	119	0.0096	140	6.71	163	0.0085
94	6.37	117	0.016	141	6.4		

Figure 14: Probability of fission fragments having a certain mass number.

energy F1 (E_F1)	*probability of having E_F1*	*energy F2 (E_F2)*	*probability of having E_F2*
(51-52)	0.000021	(84-85)	0.000360
(52-53)	0.000007	(85-86)	0.000229
(53-54)	0.000000	(86-87)	0.000222
(54-55)	0.000025	(87-88)	0.000229
(55-56)	0.000156	(88-89)	0.000251
(56-57)	0.000634	(89-90)	0.000511
(57-58)	0.001763	(90-91)	0.001572
(58-59)	0.003152	(91-92)	0.005581
(59-60)	0.006337	(92-93)	0.013204
(60-61)	0.013358	(93-94)	0.032126
(61-62)	0.023160	(94-95)	0.056033
(62-63)	0.037102	(95-96)	0.076542
(63-64)	0.054187	(96-97)	0.086469
(64-65)	0.072399	(97-98)	0.081042
(65-66)	0.080046	(98-99)	0.082919
(66-67)	0.087555	(99-100)	0.089334
(67-68)	0.093530	(100-101)	0.093530
(68-69)	0.089333	(101-102)	0.087555
(69-70)	0.082740	(102-103)	0.080046
(70-71)	0.081222	(103-104)	0.070242
(71-72)	0.082787	(104-105)	0.053107
(72-73)	0.080224	(105-106)	0.040337
(73-74)	0.056033	(106-107)	0.023163
(74-75)	0.032126	(107-108)	0.013358
(75-76)	0.013204	(108-109)	0.006337
(76-77)	0.005581	(109-110)	0.003152
(77-78)	0.001571	(110-111)	0.001763
(78-79)	0.000512	(111-112)	0.000572
(79-80)	0.000231	(112-113)	0.000215
(80-81)	0.000249	(113-114)	0.000025
(81-82)	0.000222	(114-115)	0.000000
(82-83)	0.000229	(115-116)	0.000007
(83-84)	0.000248	(116-117)	0.000021

Figure 15: Probability per unit interval of energy of fission fragments.

deltaZ	*probability* of deltaZ
-11	0.00003
-10	0.00018
-9	0.00075
-8	0. 00270
-7	0.00761
-6	0.01843
-5	0.03754
-4	0.06495
-3	0.09798
-2	0.12774
-1	0.14594
0	0.14510
1	0.12707
2	0.09602
3	0.06330
4	0.03628
5	0.01777
6	0.00723
7	0.00254
8	0.00068
9	0.00013
10	0.00003
11	0.00000

Figure 16: Probability of deltaZ having certain values.

To know a particular nuclide, we must know its mass number A and Z. From the obtained distribution of mass number of fission fragments, we get a set of mass numbers $A_1, A_2.....A_n$. For each A, there is an associated Z. This value is approximated by *proton-neutron* ratio [11], which is defined as follows:

$$Z_i = (Zc/(Ac - nu)) * A_i + deltaZ \tag{16}$$

with uncertainty $deltaZ$ has non-deterministic value. It is controlled by Gaussian distribution. This $deltaZ$ represents deviation of the product nuclide (Z_i, A_i) from stable zone of nuclides, and nu is the average of product neutrons per fission. The probability of $deltaZ$ having a certain value is computed by decomposing the area under the Gaussian distribution curve. For example, the probability of $deltaZ$ having certain values is tabularized such as shown in Fig. 16. Once the number of fission fragments (product nuclei) having a particular mass number is known, then its isotopes along with its distributions are obtained easily. For example, the number of product nuclei having mass number $A = 72$ is 2.615943e+016. The distribution of isotopes is generated and shown in Fig. 17, where the associated Z for each isotope is computed using formula (16). The result of running a simulation after 10 seconds is shown in the Appendix. This result includes distribution of neutron products, distribution of gamma products, distribution of energy of neutron products, energy of gamma products, distribution of mass number of fission fragments for light nuclei (A1), and heavy nuclei (A2), the distribution of fission fragments for light nuclei (A1), and heavy nuclei (A2) along with the distribution of isotopes, the total energy of fission fragments, energy of neutron products, energy of gamma products, and total energy produced by fissions.

A1	Isotopes	# nuclides
72	17	7.847829e+011
72	18	4.708697e+012
72	19	1.961957e+013
72	20	7.063046e+013
72	21	1.990733e+014
72	22	4.821183e+014
72	23	9.820250e+014
72	24	1.699055e+015
72	25	2.563101e+015
72	26	3.341605e+015
72	27	3.817707e+015
72	28	3.795733e+015
72	29	3.324079e+015
72	30	2.511828e+015
72	31	1.655892e+015
72	32	9.490641e+014
72	33	4.648531e+014
72	34	1.891327e+014
72	35	6.644495e+013
72	36	1.778841e+013
72	37	3.400726e+012
72	38	7.847829e+011
72	39	0.000000e+000

Figure 17: Isotopes of a nuclide with A = 72.

5 Concluding remarks

This report describes a formal knowledge representation system for nuclear physics processes. The real challenges ahead lie in developing a set of basic nuclear physics and aggregate effects models which are as universal as possible. It remains to implement a complete set of computer-based tools which can perform a simulation based on NPT models. The current quantitative model assumes a one millisecond cycle, and reports overall products every two cycles.

Acknowledgements

The author would like to express her sincere gratitude to Dr. Brad Nickerson for his supervision, constructive criticism, his patient and for suggesting a number of improvements in my use of English grammar. The author also would like to thank Dr. George DeMille of the Department of Physics of UNB for the many useful discussions. This research is partly funded by the Higher Education Development Project of the Republic of Indonesia, and by the Faculty of Computer Science at UNB.

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Appendix

This section shows the results of running a simulation after 10 seconds (10 cycles of Fig. 5). The number of fissions, cycle are computed using equations (10) and (11).

The total number of prompt neutrons is obtained using equation (12), and the total prompt gamma is obtained in a similar manner.

The total energy of prompt neutrons is obtained using equation (14), and the same calculation is applied to obtain the total energy of prompt gamma.

The distribution of neutron products, distribution of gamma products, distributions of $A1$, $A2$, and the distribution of fission fragments $F1$ and $F2$ are the results of NPT influences (see Fig. 3). These distributions are shown in the next p ages.

```
Fuel consumptions (gr) :   8.248373e-001
Fuel left         (gr) :   9.842642e+001

Products:
Particle/Nuclide:
   Fragments           :    not listed
   Prompt neutrons     :  4.373096e+021
Energy:
   Fragments           :  3.037293e+023 Mev
   Prompt neutrons     :  8.624642e+021 Mev
   Prompt gamma ray    :  1.794597e+021 Mev
   Total               :  3.141486e+023 Mev


Report# :        5
Time    :       0.010 seconds

Number of fissions     :   3.532402e+021
Fuel consumptions (gr) :   1.611704e+000
Fuel left         (gr) :   9.681472e+001

Products:
Particle/Nuclide:
   Fragments           :    not listed
   Prompt neutrons     :  8.544881e+021
Energy:
   Fragments           :  5.934767e+023 Mev
   Prompt neutrons     :  1.685226e+022 Mev
   Prompt gamma ray    :  3.506580e+021 Mev
   Total               :  6.138356e+023 Mev


Report# :        6
Time    :       0.012 seconds

Number of fissions     :   6.902193e+021
Fuel consumptions (gr) :   3.149214e+000
Fuel left         (gr) :   9.366550e+001

Products:
Particle/Nuclide:
   Fragments           :    not listed
   Prompt neutrons     :  1.669640e+022
Energy:
   Fragments           :  1.159633e+024 Mev
   Prompt neutrons     :  3.292873e+022 Mev
   Prompt gamma ray    :  6.851738e+021 Mev
   Total               :  1.199414e+024 Mev


Report# :        7
Time    :       0.014 seconds

Number of fissions     :   1.348665e+022
Fuel consumptions (gr) :   6.153457e+000
Fuel left         (gr) :   8.751205e+001

Products:
Particle/Nuclide:
   Fragments           :    not listed
   Prompt neutrons     :  3.262420e+022
Energy:
   Fragments           :  2.265884e+024 Mev
   Prompt neutrons     :  6.434161e+022 Mev
   Prompt gamma ray    :  1.338806e+022 Mev
   Total               :  2.343613e+024 Mev
```

```
Report# :       8
Time    :       0.016 seconds

Number of fissions        :   2.635245e+022
Burn-up             (gr)  :   1.028338e+001
Fuel consumptions   (gr)  :   1.202364e+001
Fuel left           (gr)  :   7.548840e+001

Products:
Particle/Nuclide:
   Fragments             :    not listed
   Prompt neutrons       :   6.374658e+022
Energy:
   Fragments             :   4.427459e+024 Mev
   Prompt neutrons       :   1.257213e+023 Mev
   Prompt gamma ray      :   2.615981e+022 Mev
   Total                 :   4.579340e+024 Mev


Report# :       9
Time    :       0.018 seconds

Number of fissions        :   5.149179e+022

Fuel consumptions   (gr)  :   2.349379e+001
Fuel left           (gr)  :   5.199461e+001

Products:
Particle/Nuclide:
   Fragments             :    not listed
   Prompt neutrons       :   1.245586e+023
Energy:
   Fragments             :   8.651104e+024 Mev
   Prompt neutrons       :   2.456551e+023 Mev
   Prompt gamma ray      :   5.111538e+022 Mev
   Total                 :   8.947874e+024 Mev


Report# :      10
Time    :       0.020 seconds

Number of fissions        :   1.006132e+023
Fuel consumptions   (gr)  :   4.590606e+001
Fuel left           (gr)  :   6.088556e+000

Products:
Particle/Nuclide:
   Fragments             :    listed
   Prompt neutrons       :   2.433833e+023
Energy:
   Fragments             :   1.690396e+025 Mev
   Prompt neutrons       :   4.800017e+023 Mev
   Prompt gamma ray      :   9.987770e+022 Mev
   Total                 :   1.748384e+025 Mev

#neutron produced       #fissions         fraction
         0           8.954574e+021        0.089000
         1           2.163184e+022        0.215000
         2           2.615943e+022        0.260000
         3           2.122938e+022        0.211000
         4           1.267726e+022        0.126000
         5           6.238017e+021        0.062000
         6           2.515330e+021        0.025000
         7           9.055186e+020        0.009000
         8           3.018396e+020        0.003000
```

A1	#fragments	fraction
72	2.615943e+016	0.000000
73	1.006132e+017	0.000001
74	3.018396e+017	0.000003
75	1.006132e+018	0.000010
76	3.018396e+018	0.000030
77	8.049055e+018	0.000080
78	2.112877e+019	0.000210
79	4.426980e+019	0.000440
80	1.307971e+020	0.001300
81	1.911651e+020	0.001900
82	3.219622e+020	0.003200
83	5.382806e+020	0.005350
84	1.006132e+021	0.010000
85	1.325076e+021	0.013170
86	1.972018e+021	0.019600
87	2.565636e+021	0.025500
88	3.591891e+021	0.035700
89	4.789188e+021	0.047600
90	5.835565e+021	0.058000
91	5.875810e+021	0.058400
92	6.066975e+021	0.060300
93	6.409060e+021	0.063700
94	6.539857e+021	0.065000
95	6.539857e+021	0.065000
96	6.338631e+021	0.063000
97	6.016668e+021	0.059800
98	5.815442e+021	0.057800
99	6.137404e+021	0.061000
100	6.318508e+021	0.062800
101	5.211763e+021	0.051800
102	4.316306e+021	0.042900
103	3.048580e+021	0.030300
104	1.891528e+021	0.018800
105	9.658866e+020	0.009600
106	4.125141e+020	0.004100
107	1.458891e+020	0.001450
108	5.433112e+019	0.000540
109	3.119009e+019	0.000310
110	2.515330e+019	0.000250
111	1.911651e+019	0.000190
112	1.307971e+019	0.000130
113	1.509198e+019	0.000150
114	1.307971e+019	0.000130
115	9.658866e+018	0.000096
116	1.609811e+019	0.000160

A2	#fragments	fraction
117	1.307971e+019	0.000130
118	1.106745e+019	0.000110
119	1.307971e+019	0.000130
120	1.307971e+019	0.000130
121	1.307971e+019	0.000130
122	1.609811e+019	0.000160
123	1.599750e+019	0.000159
124	2.716556e+019	0.000270
125	3.119009e+019	0.000310
126	5.936178e+019	0.000590
127	1.267726e+020	0.001260
128	3.521462e+020	0.003500
129	7.545989e+020	0.007500
130	1.821099e+021	0.018100
131	2.907721e+021	0.028900
132	4.336428e+021	0.043100
133	6.731022e+021	0.066900

```
     134          7.918258e+021          0.078700
     135          6.580102e+021          0.065400
     136          6.358753e+021          0.063200
     137          6.227956e+021          0.061900
     138          6.751145e+021          0.067100
     139          6.439244e+021          0.064000
     140          6.248079e+021          0.062100
     141          6.620348e+021          0.065800
     142          6.624372e+021          0.065840
     143          6.635440e+021          0.065950
     144          5.533725e+021          0.055000
     145          3.954098e+021          0.039300
     146          3.018396e+021          0.030000
     147          2.263797e+021          0.022500
     148          1.680240e+021          0.016700
     149          1.086622e+021          0.010800
     150          6.570041e+020          0.006530
     151          4.195570e+020          0.004170
     152          2.696433e+020          0.002680
     153          1.589688e+020          0.001580
     154          7.445376e+019          0.000740
     155          3.219622e+019          0.000320
     156          1.499136e+019          0.000149
     157          6.238018e+018          0.000062
     158          3.320235e+018          0.000033
     159          1.006132e+018          0.000010
     160          3.018396e+017          0.000003
     161          8.552121e+016          0.000001


 **** F1    fission fragments ****
   A1    Isotopes       # nuclides
   72          17    7.847829e+011
   72          18    4.708697e+012
   72          19    1.961957e+013
   72          20    7.063046e+013
   72          21    1.990733e+014
   72          22    4.821183e+014
   72          23    9.820250e+014
   72          24    1.699055e+015
   72          25    2.563101e+015
   72          26    3.341605e+015
   72          27    3.817707e+015
   72          28    3.795733e+015
   72          29    3.324079e+015
   72          30    2.511828e+015
   72          31    1.655892e+015
   72          32    9.490641e+014
   72          33    4.648531e+014
   72          34    1.891327e+014
   72          35    6.644495e+013
   72          36    1.778841e+013
   72          37    3.400726e+012
   72          38    7.847829e+011
   72          39    0.000000e+000
   73          17    3.018396e+012
   73          18    1.811037e+013
   73          19    7.545989e+013
   73          20    2.716556e+014
   73          21    7.656664e+014
   73          22    1.854301e+015
   73          23    3.777019e+015
   73          24    6.534826e+015
   73          25    9.858080e+015
   73          26    1.285233e+016
   73          27    1.468349e+016
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```
73            28   1.459897e+016
73            29   1.278492e+016
73            30   9.660878e+015
73            31   6.368815e+015
73            32   3.650246e+015
73            33   1.787896e+015
73            34   7.274334e+014
73            35   2.555575e+014
73            36   6.841697e+013
73            37   1.307971e+013
73            38   3.018396e+012
73            39   0.000000e+000
74            18   9.055187e+012
74            19   5.433112e+013
74            20   2.263797e+014
74            21   8.149669e+014
74            22   2.296999e+015
74            23   5.562903e+015
74            24   1.133106e+016
74            25   1.960448e+016
74            26   2.957424e+016
74            27   3.855699e+016
74            28   4.405047e+016
74            29   4.379692e+016
74            30   3.835475e+016
74            31   2.898264e+016
74            32   1.910644e+016
74            33   1.095074e+016
74            34   5.363689e+015
74            35   2.182300e+015
74            36   7.666725e+014
74            37   2.052509e+014
74            38   3.923914e+013
74            39   9.055187e+012
74            40   0.000000e+000
75            18   3.018395e+013
75            19   1.811037e+014
75            20   7.545989e+014
75            21   2.716556e+015
75            22   7.656664e+015
75            23   1.854301e+016
75            24   3.777019e+016
75            25   6.534826e+016
75            26   9.858080e+016
75            27   1.285233e+017
75            28   1.468349e+017
75            29   1.459897e+017
75            30   1.278492e+017
75            31   9.660878e+016
75            32   6.368814e+016
75            33   3.650246e+016
75            34   1.787896e+016
75            35   7.274333e+015
75            36   2.555575e+015
75            37   6.841697e+014
75            38   1.307971e+014
75            39   3.018395e+013
75            40   0.000000e+000
76            18   9.055186e+013
76            19   5.433112e+014
76            20   2.263797e+015
76            21   8.149668e+015
76            22   2.296999e+016
76            23   5.562903e+016
76            24   1.133106e+017
76            25   1.960448e+017
```

```
76          26   2.957424e+017
76          27   3.855698e+017
76          28   4.405047e+017
76          29   4.379692e+017
76          30   3.835475e+017
76          31   2.898263e+017
76          32   1.910644e+017
76          33   1.095074e+017
76          34   5.363689e+016
76          35   2.182300e+016
76          36   7.666725e+015
76          37   2.052509e+015
76          38   3.923914e+014
76          39   9.055186e+013
76          40   0.000000e+000
77          19   2.414716e+014
77          20   1.448830e+015
77          21   6.036791e+015
77          22   2.173245e+016
77          23   6.125331e+016
77          24   1.483441e+017
77          25   3.021615e+017
77          26   5.227861e+017
77          27   7.886464e+017
77          28   1.028186e+018
77          29   1.174679e+018
77          30   1.167918e+018
77          31   1.022793e+018
77          32   7.728702e+017
77          33   5.095052e+017
77          34   2.920197e+017
77          35   1.430317e+017
77          36   5.819467e+016
77          37   2.044460e+016
77          38   5.473357e+015
77          39   1.046377e+015
77          40   2.414716e+014
77          41   0.000000e+000
78          19   6.338631e+014
78          20   3.803178e+015
78          21   1.584658e+016
78          22   5.704768e+016
78          23   1.607899e+017
78          24   3.894032e+017
78          25   7.931740e+017
78          26   1.372313e+018
78          27   2.070197e+018
78          28   2.698989e+018
78          29   3.083533e+018
78          30   3.065784e+018
78          31   2.684833e+018
78          32   2.028784e+018
78          33   1.337451e+018
78          34   7.665517e+017
78          35   3.754582e+017
78          36   1.527610e+017
78          37   5.366707e+016
78          38   1.436756e+016
78          39   2.746740e+015
78          40   6.338631e+014
78          41   0.000000e+000
79          20   1.328094e+015
79          21   7.968565e+015
79          22   3.320235e+016
79          23   1.195285e+017
79          24   3.368932e+017
```

79	25	8.158925e+017
79	26	1.661888e+018
79	27	2.875324e+018
79	28	4.337555e+018
79	29	5.655024e+018
79	30	6.460735e+018
79	31	6.423548e+018
79	32	5.625364e+018
79	33	4.250786e+018
79	34	2.802278e+018
79	35	1.606108e+018
79	36	7.866744e+017
79	37	3.200707e+017
79	38	1.124453e+017
79	39	3.010347e+016
79	40	5.755074e+015
79	41	1.328094e+015
79	42	0.000000e+000
80	20	3.923914e+015
80	21	2.354349e+016
80	22	9.809786e+016
80	23	3.531523e+017
80	24	9.953663e+017
80	25	2.410591e+018
80	26	4.910125e+018
80	27	8.495274e+018
80	28	1.281550e+019
80	29	1.670803e+019
80	30	1.908854e+019
80	31	1.897867e+019
80	32	1.662039e+019
80	33	1.255914e+019
80	34	8.279459e+018
80	35	4.745320e+018
80	36	2.324265e+018
80	37	9.456634e+017
80	38	3.322247e+017
80	39	8.894206e+016
80	40	1.700363e+016
80	41	3.923914e+015
80	42	0.000000e+000
81	20	5.734952e+015
81	21	3.440971e+016
81	22	1.433738e+017
81	23	5.161457e+017
81	24	1.454766e+018
81	25	3.523172e+018
81	26	7.176336e+018
81	27	1.241617e+019
81	28	1.873035e+019
81	29	2.441942e+019
81	30	2.789863e+019
81	31	2.773805e+019
81	32	2.429134e+019
81	33	1.835567e+019
81	34	1.210075e+019
81	35	6.935468e+018
81	36	3.397003e+018
81	37	1.382123e+018
81	38	4.855593e+017
81	39	1.299922e+017
81	40	2.485146e+016
81	41	5.734952e+015
81	42	0.000000e+000
82	21	9.658865e+015
82	22	5.795320e+016

```
82              23   2.414716e+017
82              24   8.692979e+017
82              25   2.450132e+018
82              26   5.933763e+018
82              27   1.208646e+019
82              28   2.091144e+019
82              29   3.154586e+019
82              30   4.112745e+019
82              31   4.698716e+019
82              32   4.671671e+019
82              33   4.091173e+019
82              34   3.091481e+019
82              35   2.038021e+019
82              36   1.168079e+019
82              37   5.721268e+018
82              38   2.327787e+018
82              39   8.177840e+017
82              40   2.189343e+017
82              41   4.185508e+016
82              42   9.658865e+015
82              43   0.000000e+000
83              21   1.614842e+016
83              22   9.689050e+016
83              23   4.037104e+017
83              24   1.453358e+018
83              25   4.096315e+018
83              26   9.920511e+018
83              27   2.020705e+019
83              28   3.496132e+019
83              29   5.274073e+019
83              30   6.875996e+019
83              31   7.855667e+019
83              32   7.810451e+019
83              33   6.839931e+019
83              34   5.168570e+019
83              35   3.407316e+019
83              36   1.952882e+019
83              37   9.565246e+018
83              38   3.891769e+018
83              39   1.367233e+018
83              40   3.660308e+017
83              41   6.997647e+016
83              42   1.614842e+016
83              43   0.000000e+000
84              22   3.018395e+016
84              23   1.811037e+017
84              24   7.545989e+017
84              25   2.716556e+018
84              26   7.656664e+018
84              27   1.854301e+019
84              28   3.777019e+019
84              29   6.534826e+019
84              30   9.858080e+019
84              31   1.285233e+020
84              32   1.468349e+020
84              33   1.459897e+020
84              34   1.278492e+020
84              35   9.660878e+019
84              36   6.368814e+019
84              37   3.650246e+019
84              38   1.787896e+019
84              39   7.274333e+018
84              40   2.555575e+018
84              41   6.841697e+017
84              42   1.307971e+017
84              43   3.018395e+016
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```
84          44   0.000000e+000
85          22   3.975227e+016
85          23   2.385136e+017
85          24   9.938068e+017
85          25   3.577704e+018
85          26   1.008383e+019
85          27   2.442115e+019
85          28   4.974334e+019
85          29   8.606366e+019
85          30   1.298309e+020
85          31   1.692652e+020
85          32   1.933816e+020
85          33   1.922685e+020
85          34   1.683774e+020
85          35   1.272338e+020
85          36   8.387729e+019
85          37   4.807374e+019
85          38   2.354659e+019
85          39   9.580297e+018
85          40   3.365692e+018
85          41   9.010515e+017
85          42   1.722598e+017
85          43   3.975227e+016
85          44   0.000000e+000
86          22   5.916055e+016
86          23   3.549633e+017
86          24   1.479014e+018
86          25   5.324450e+018
86          26   1.500706e+019
86          27   3.634430e+019
86          28   7.402957e+019
86          29   1.280826e+020
86          30   1.932184e+020
86          31   2.519056e+020
86          32   2.877964e+020
86          33   2.861399e+020
86          34   2.505844e+020
86          35   1.893532e+020
86          36   1.248288e+020
86          37   7.154483e+019
86          38   3.504277e+019
86          39   1.425769e+019
86          40   5.008927e+018
86          41   1.340973e+018
86          42   2.563624e+017
86          43   5.916055e+016
86          44   0.000000e+000
87          23   7.696908e+016
87          24   4.618145e+017
87          25   1.924227e+018
87          26   6.927218e+018
87          27   1.952449e+019
87          28   4.728468e+019
87          29   9.631398e+019
87          30   1.666381e+020
87          31   2.513810e+020
87          32   3.277344e+020
87          33   3.744290e+020
87          34   3.722738e+020
87          35   3.260154e+020
87          36   2.463524e+020
87          37   1.624048e+020
87          38   9.308128e+019
87          39   4.559136e+019
87          40   1.854955e+019
87          41   6.516716e+018
```

```
87        42   1.744633e+018
87        43   3.335327e+017
87        44   7.696908e+016
87        45   0.000000e+000
88        23   1.077567e+017
88        24   6.465404e+017
88        25   2.693918e+018
88        26   9.698106e+018
88        27   2.733429e+019
88        28   6.619855e+019
88        29   1.348396e+020
88        30   2.332933e+020
88        31   3.519335e+020
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88        34   5.211834e+020
88        35   4.564216e+020
88        36   3.448934e+020
88        37   2.273667e+020
88        38   1.303138e+020
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88        40   2.596937e+019
88        41   9.123403e+018
88        42   2.442486e+018
88        43   4.669458e+017
88        44   1.077567e+017
88        45   0.000000e+000
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89        25   8.620538e+017
89        26   3.591891e+018
89        27   1.293081e+019
89        28   3.644572e+019
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89        32   4.692446e+020
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89        35   6.949111e+020
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89        37   4.598578e+020
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89        39   1.737517e+020
89        40   8.510387e+019
89        41   3.462583e+019
89        42   1.216454e+019
89        43   3.256648e+018
89        44   6.225944e+017
89        45   1.436756e+017
89        46   0.000000e+000
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90        25   1.050402e+018
90        26   4.376674e+018
90        27   1.575603e+019
90        28   4.440865e+019
90        29   1.075495e+020
90        30   2.190671e+020
90        31   3.790199e+020
90        32   5.717686e+020
90        33   7.454350e+020
90        34   8.516423e+020
90        35   8.467404e+020
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90        37   5.603309e+020
90        38   3.693912e+020
90        39   2.117143e+020
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90          45   1.750669e+017
90          46   0.000000e+000
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91          25   1.057646e+018
91          26   4.406858e+018
91          27   1.586469e+019
91          28   4.471492e+019
91          29   1.082912e+020
91          30   2.205779e+020
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91          32   5.757119e+020
91          33   7.505760e+020
91          34   8.575158e+020
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91          36   7.466392e+020
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91          38   3.719388e+020
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91          42   1.492456e+019
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93          36   9.299546e+020
93          37   8.143992e+020
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94          27   1.177174e+018
94          28   4.904893e+018
94          29   1.765761e+019
94          30   4.976831e+019
94          31   1.205296e+020
94          32   2.455062e+020
94          33   4.247637e+020
94          34   6.407752e+020
94          35   8.354013e+020
94          36   9.544268e+020
94          37   9.489332e+020
94          38   8.310196e+020
94          39   6.279570e+020
94          40   4.139729e+020
94          41   2.372660e+020
94          42   1.162133e+020
94          43   4.728317e+019
94          44   1.661124e+019
94          45   4.447103e+018
94          46   8.501814e+017
94          47   1.961957e+017
94          48   0.000000e+000
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114	41	1.281550e+018
114	42	1.670803e+018
114	43	1.908854e+018
114	44	1.897867e+018
114	45	1.662039e+018
114	46	1.255914e+018
114	47	8.279459e+017
114	48	4.745320e+017
114	49	2.324265e+017
114	50	9.456634e+016
114	51	3.322247e+016
114	52	8.894206e+015
114	53	1.700363e+015
114	54	3.923914e+014
114	55	0.000000e+000
115	34	2.897660e+014
115	35	1.738596e+015
115	36	7.244150e+015
115	37	2.607894e+016
115	38	7.350397e+016
115	39	1.780129e+017
115	40	3.625938e+017
115	41	6.273433e+017
115	42	9.463757e+017
115	43	1.233824e+018
115	44	1.409615e+018
115	45	1.401501e+018
115	46	1.227352e+018
115	47	9.274443e+017
115	48	6.114062e+017
115	49	3.504237e+017
115	50	1.716381e+017
115	51	6.983360e+016
115	52	2.453352e+016
115	53	6.568029e+015
115	54	1.255653e+015
115	55	2.897660e+014
115	56	0.000000e+000
116	34	4.829433e+014
116	35	2.897660e+015
116	36	1.207358e+016
116	37	4.346490e+016
116	38	1.225066e+017
116	39	2.966882e+017
116	40	6.043230e+017
116	41	1.045572e+018
116	42	1.577293e+018
116	43	2.056372e+018
116	44	2.349358e+018
116	45	2.335836e+018

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  116          46   2.045587e+018
  116          47   1.545740e+018
  116          48   1.019010e+018
  116          49   5.840394e+017
  116          50   2.860634e+017
  116          51   1.163893e+017
  116          52   4.088920e+016
  116          53   1.094671e+016
  116          54   2.092754e+015
  116          55   4.829433e+014
  116          56   0.000000e+000


**** F2   fission fragments ****
  A2    Isotopes       # nuclides
  117          35   3.923914e+014
  117          36   2.354349e+015
  117          37   9.809786e+015
  117          38   3.531523e+016
  117          39   9.953663e+016
  117          40   2.410591e+017
  117          41   4.910125e+017
  117          42   8.495274e+017
  117          43   1.281550e+018
  117          44   1.670803e+018
  117          45   1.908854e+018
  117          46   1.897867e+018
  117          47   1.662039e+018
  117          48   1.255914e+018
  117          49   8.279459e+017
  117          50   4.745320e+017
  117          51   2.324265e+017
  117          52   9.455634e+016
  117          53   3.322247e+016
  117          54   8.894206e+015
  117          55   1.700363e+015
  117          56   3.923914e+014
  117          57   0.000000e+000
  118          35   3.320235e+014
  118          36   1.992141e+015
  118          37   8.300588e+015
  118          38   2.988212e+016
  118          39   8.422330e+016
  118          40   2.039731e+017
  118          41   4.154721e+017
  118          42   7.188309e+017
  118          43   1.084389e+018
  118          44   1.413756e+018
  118          45   1.615184e+018
  118          46   1.605887e+018
  118          47   1.406341e+018
  118          48   1.062697e+018
  118          49   7.005696e+017
  118          50   4.015271e+017
  118          51   1.966686e+017
  118          52   8.001767e+016
  118          53   2.811132e+016
  118          54   7.525866e+015
  118          55   1.438769e+015
  118          56   3.320235e+014
  118          57   0.000000e+000
  119          35   3.923914e+014
  119          36   2.354349e+015
  119          37   9.809786e+015
  119          38   3.531523e+016
  119          39   9.953663e+016
```

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119          40     2.410591e+017
119          41     4.910125e+017
119          42     8.495274e+017
119          43     1.281550e+018
119          44     1.670803e+018
119          45     1.908854e+018
119          46     1.897867e+018
119          47     1.662039e+018
119          48     1.255914e+018
119          49     8.279459e+017
119          50     4.745320e+017
119          51     2.324265e+017
119          52     9.456634e+016
119          53     3.322247e+016
119          54     8.894206e+015
119          55     1.700363e+015
119          56     3.923914e+014
119          57     0.000000e+000
120          36     3.923914e+014
120          37     2.354349e+015
120          38     9.809786e+015
120          39     3.531523e+016
120          40     9.953663e+016
120          41     2.410591e+017
120          42     4.910125e+017
120          43     8.495274e+017
120          44     1.281550e+018
120          45     1.670803e+018
120          46     1.908854e+018
120          47     1.897867e+018
120          48     1.662039e+018
120          49     1.255914e+018
120          50     8.279459e+017
120          51     4.745320e+017
120          52     2.324265e+017
120          53     9.456634e+016
120          54     3.322247e+016
120          55     8.894206e+015
120          56     1.700363e+015
120          57     3.923914e+014
120          58     0.000000e+000
121          36     3.923914e+014
121          37     2.354349e+015
121          38     9.809786e+015
121          39     3.531523e+016
121          40     9.953663e+016
121          41     2.410591e+017
121          42     4.910125e+017
121          43     8.495274e+017
121          44     1.281550e+018
121          45     1.670803e+018
121          46     1.908854e+018
121          47     1.897867e+018
121          48     1.662039e+018
121          49     1.255914e+018
121          50     8.279459e+017
121          51     4.745320e+017
121          52     2.324265e+017
121          53     9.456634e+016
121          54     3.322247e+016
121          55     8.894206e+015
121          56     1.700363e+015
121          57     3.923914e+014
121          58     0.000000e+000
122          37     4.829433e+014
122          38     2.897660e+015
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122            39   1.207358e+016
122            40   4.346490e+016
122            41   1.225066e+017
122            42   2.966882e+017
122            43   6.043230e+017
122            44   1.045572e+018
122            45   1.577293e+018
122            46   2.056372e+018
122            47   2.349358e+018
122            48   2.335836e+018
122            49   2.045587e+018
122            50   1.545740e+018
122            51   1.019010e+018
122            52   5.840394e+017
122            53   2.860634e+017
122            54   1.163893e+017
122            55   4.088920e+016
122            56   1.094671e+016
122            57   2.092754e+015
122            58   4.829433e+014
122            59   0.000000e+000
123            37   4.799249e+014
123            38   2.879550e+015
123            39   1.199812e+016
123            40   4.319324e+016
123            41   1.217410e+017
123            42   2.948339e+017
123            43   6.005460e+017
123            44   1.039037e+018
123            45   1.567435e+018
123            46   2.043520e+018
123            47   2.334675e+018
123            48   2.321237e+018
123            49   2.032802e+018
123            50   1.536080e+018
123            51   1.012642e+018
123            52   5.803892e+017
123            53   2.842755e+017
123            54   1.156619e+017
123            55   4.063364e+016
123            56   1.087830e+016
123            57   2.079675e+015
123            58   4.799249e+014
123            59   0.000000e+000
124            37   8.149668e+014
124            38   4.889801e+015
124            39   2.037417e+016
124            40   7.334701e+016
124            41   2.067299e+017
124            42   5.006613e+017
124            43   1.019795e+018
124            44   1.764403e+018
124            45   2.661682e+018
124            46   3.470128e+018
124            47   3.964542e+018
124            48   3.941723e+018
124            49   3.451927e+018
124            50   2.608437e+018
124            51   1.719580e+018
124            52   9.855665e+017
124            53   4.827320e+017
124            54   1.964070e+017
124            55   6.900052e+016
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124            57   3.531523e+015
124            58   8.149668e+014
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124          59   0.000000e+000
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125          39   5.614216e+015
125          40   2.339257e+016
125          41   8.421324e+016
125          42   2.373566e+017
125          43   5.748333e+017
125          44   1.170876e+018
125          45   2.025796e+018
125          46   3.056005e+018
125          47   3.984222e+018
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125          50   3.963324e+018
125          51   2.994872e+018
125          52   1.974333e+018
125          53   1.131576e+018
125          54   5.542479e+017
125          55   2.255043e+017
125          56   7.922282e+016
125          57   2.120926e+016
125          58   4.054711e+015
125          59   9.357026e+014
125          60   0.000000e+000
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126          39   1.068512e+016
126          40   4.452134e+016
126          41   1.602768e+017
126          42   4.517432e+017
126          43   1.094038e+018
126          44   2.228441e+018
126          45   3.855548e+018
126          46   5.816267e+018
126          47   7.582874e+018
126          48   8.663259e+018
126          49   8.613394e+018
126          50   7.543101e+018
126          51   5.699918e+018
126          52   3.757601e+018
126          53   2.153645e+018
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126          56   1.507789e+017
126          57   4.036601e+016
126          58   7.717032e+015
126          59   1.780853e+015
126          60   0.000000e+000
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127          40   2.281907e+016
127          41   9.507947e+016
127          42   3.422861e+017
127          43   9.647397e+017
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127          48   1.619393e+019
127          49   1.850120e+019
127          50   1.839471e+019
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127          52   1.217271e+019
127          53   8.024707e+018
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       128                 42    9.507947e+017
       128                 43    2.679832e+018
       128                 44    6.490054e+018
       128                 45    1.321957e+019
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       128                 47    3.450328e+019
       128                 48    4.498315e+019
       128                 49    5.139221e+019
       128                 50    5.109641e+019
       128                 51    4.474721e+019
       128                 52    3.381307e+019
       128                 53    2.229085e+019
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       128                 57    8.944513e+017
       128                 58    2.394594e+017
       128                 59    4.577900e+016
       128                 60    1.056438e+016
       128                 61    0.000000e+000
       129                 39    2.263797e+016
       129                 40    1.358278e+017
       129                 41    5.659492e+017
       129                 42    2.037417e+018
       129                 43    5.742498e+018
       129                 44    1.390726e+019
       129                 45    2.832764e+019
       129                 46    4.901120e+019
       129                 47    7.393560e+019
       129                 48    9.639246e+019
       129                 49    1.101262e+020
       129                 50    1.094923e+020
       129                 51    9.588688e+019
       129                 52    7.245658e+019
       129                 53    4.776611e+019
       129                 54    2.737685e+019
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       129                 56    5.455750e+018
       129                 57    1.916681e+018
       129                 58    5.131272e+017
       129                 59    9.809786e+016
       129                 60    2.263797e+016
       129                 61    0.000000e+000
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       130                 41    3.277978e+017
       130                 42    1.365824e+018
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       130                 44    1.385856e+019
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       130                 46    6.836405e+019
       130                 47    1.182804e+020
       130                 48    1.784313e+020
       130                 49    2.326272e+020
       130                 50    2.657712e+020
       130                 51    2.642414e+020
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130          60   2.367428e+017
130          61   5.463296e+016
130          62   0.000000e+000
131          40   8.723163e+016
131          41   5.233898e+017
131          42   2.180791e+018
131          43   7.850847e+018
131          44   2.212776e+019
131          45   5.358930e+019
131          46   1.091558e+020
131          47   1.888565e+020
131          48   2.848985e+020
131          49   3.714323e+020
131          50   4.243528e+020
131          51   4.219103e+020
131          52   3.694841e+020
131          53   2.791994e+020
131          54   1.840587e+020
131          55   1.054921e+020
131          56   5.167020e+019
131          57   2.102282e+019
131          58   7.385611e+018
131          59   1.977250e+018
131          60   3.780037e+017
131          61   8.723163e+016
131          62   0.000000e+000
132          40   1.300928e+017
132          41   7.805571e+017
132          42   3.252321e+018
132          43   1.170836e+019
132          44   3.300022e+019
132          45   7.992037e+019
132          46   1.627895e+020
132          47   2.816510e+020
132          48   4.248832e+020
132          49   5.539353e+020
132          50   6.328584e+020
132          51   6.292157e+020
132          52   5.510299e+020
132          53   4.163838e+020
132          54   2.744959e+020
132          55   1.573256e+020
132          56   7.705833e+019
132          57   3.135238e+019
132          58   1.101453e+019
132          59   2.948771e+018
132          60   5.637357e+017
132          61   1.300928e+017
132          62   0.000000e+000
133          41   2.019307e+017
133          42   1.211584e+018
133          43   5.048267e+018
133          44   1.817376e+019
133          45   5.122308e+019
133          46   1.240527e+020
133          47   2.526826e+020
133          48   4.371799e+020
133          49   6.595056e+020
133          50   8.598207e+020
133          51   9.823254e+020
133          52   9.766713e+020
133          53   8.553110e+020
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133	55	4.260737e+020
133	56	2.442015e+020
133	57	1.196103e+020
133	58	4.866529e+019
133	59	1.709680e+019
133	60	4.577095e+018
133	61	8.750329e+017
133	62	2.019307e+017
133	63	0.000000e+000
134	41	2.375477e+017
134	42	1.425286e+018
134	43	5.938693e+018
134	44	2.137930e+019
134	45	6.025794e+019
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134	47	2.972514e+020
134	48	5.142908e+020
134	49	7.758309e+020
134	50	1.011478e+021
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134	59	2.011237e+019
134	60	5.384415e+018
134	61	1.029374e+018
134	62	2.375477e+017
134	63	0.000000e+000
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135	43	1.184418e+018
135	44	4.935077e+018
135	45	1.776628e+019
135	46	5.007458e+019
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135	48	2.470170e+020
135	49	4.273776e+020
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135	60	1.671346e+019
135	61	4.474469e+018
135	62	8.554133e+017
135	63	1.974031e+017
135	64	0.000000e+000
136	42	1.907626e+017
136	43	1.144576e+018
136	44	4.769065e+018
136	45	1.716863e+019
136	46	4.839011e+019
136	47	1.171918e+020
136	48	2.387076e+020
136	49	4.130010e+020
136	50	6.230306e+020
136	51	8.122671e+020

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      136                 53    9.225551e+020
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      137                 44    4.670967e+018
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      137                 48    2.337975e+020
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      138                 44    1.215206e+018
      138                 45    5.063359e+018
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      138                 47    5.137622e+019
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      138                 61    1.714791e+019
      138                 62    4.590779e+018
      138                 63    8.776489e+017
      138                 64    2.025344e+017
      138                 65    0.000000e+000
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      139                 44    1.159064e+018
      139                 45    4.829433e+018
      139                 46    1.738596e+019
      139                 47    4.900265e+019
      139                 48    1.186753e+020
      139                 49    2.417292e+020
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139          52   8.225490e+020
139          53   9.397433e+020
139          54   9.343343e+020
139          55   8.182347e+020
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139          57   4.076042e+020
139          58   2.336158e+020
139          59   1.144254e+020
139          60   4.655574e+019
139          61   1.635568e+019
139          62   4.378686e+018
139          63   8.371018e+017
139          64   1.931773e+017
139          65   0.000000e+000
140          44   1.874424e+017
140          45   1.124654e+018
140          46   4.686059e+018
140          47   1.686981e+019
140          48   4.754788e+019
140          49   1.151521e+020
140          50   2.345529e+020
140          51   4.058127e+020
140          52   6.121868e+020
140          53   7.981296e+020
140          54   9.118447e+020
140          55   9.065962e+020
140          56   7.939434e+020
140          57   5.999405e+020
140          58   3.955034e+020
140          59   2.266803e+020
140          60   1.110284e+020
140          61   4.517361e+019
140          62   1.587012e+019
140          63   4.248694e+018
140          64   8.122503e+017
140          65   1.874424e+017
140          66   0.000000e+000
141          44   1.986104e+017
141          45   1.191663e+018
141          46   4.965261e+018
141          47   1.787494e+019
141          48   5.038085e+019
141          49   1.220130e+020
141          50   2.485279e+020
141          51   4.299916e+020
141          52   6.486617e+020
141          53   8.456832e+020
141          54   9.661736e+020
141          55   9.606125e+020
141          56   8.412476e+020
141          57   6.356858e+020
141          58   4.190680e+020
141          59   2.401862e+020
141          60   1.176436e+020
141          61   4.786512e+019
141          62   1.681568e+019
141          63   4.501837e+018
141          64   8.606453e+017
141          65   1.986104e+017
141          66   0.000000e+000
142          44   1.987312e+017
142          45   1.192387e+018
142          46   4.968279e+018
142          47   1.788581e+019
```

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142         48   5.041147e+019
142         49   1.220872e+020
142         50   2.486789e+020
142         51   4.302529e+020
142         52   6.490560e+020
142         53   8.461973e+020
142         54   9.667609e+020
142         55   9.611964e+020
142         56   8.417589e+020
142         57   6.360722e+020
142         58   4.193227e+020
142         59   2.403322e+020
142         60   1.177151e+020
142         61   4.789421e+019
142         62   1.682591e+019
142         63   4.504573e+018
142         64   8.611684e+017
142         65   1.987312e+017
142         66   0.000000e+000
143         45   1.990632e+017
143         46   1.194379e+018
143         47   4.976580e+018
143         48   1.791569e+019
143         49   5.049570e+019
143         50   1.222912e+020
143         51   2.490944e+020
143         52   4.309718e+020
143         53   6.501404e+020
143         54   8.476110e+020
143         55   9.683761e+020
143         56   9.628023e+020
143         57   8.431653e+020
143         58   6.371349e+020
143         59   4.200233e+020
143         60   2.407337e+020
143         61   1.179118e+020
143         62   4.797423e+019
143         63   1.685402e+019
143         64   4.512099e+018
143         65   8.626071e+017
143         66   1.990632e+017
143         67   0.000000e+000
144         45   1.660118e+017
144         46   9.960706e+017
144         47   4.150294e+018
144         48   1.494106e+019
144         49   4.211165e+019
144         50   1.019866e+020
144         51   2.077360e+020
144         52   3.594154e+020
144         53   5.421944e+020
144         54   7.068780e+020
144         55   8.075919e+020
144         56   8.029435e+020
144         57   7.031704e+020
144         58   5.313483e+020
144         59   3.502848e+020
144         60   2.007635e+020
144         61   9.833430e+019
144         62   4.000883e+019
144         63   1.405566e+019
144         64   3.762933e+018
144         65   7.193843e+017
144         66   1.660118e+017
144         67   0.000000e+000
145         46   1.186229e+017
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145            47   7.117377e+017
145            48   2.965574e+018
145            49   1.067607e+019
145            50   3.009069e+019
145            51   7.287403e+019
145            52   1.484368e+020
145            53   2.568187e+020
145            54   3.874225e+020
145            55   5.050965e+020
145            56   5.770611e+020
145            57   5.737396e+020
145            58   5.024472e+020
145            59   3.795725e+020
145            60   2.502944e+020
145            61   1.434547e+020
145            62   7.026432e+019
145            63   2.858813e+019
145            64   1.004341e+019
145            65   2.688787e+018
145            66   5.140328e+017
145            67   1.186229e+017
145            68   0.000000e+000
146            46   9.055186e+016
146            47   5.433112e+017
146            48   2.263797e+018
146            49   8.149668e+018
146            50   2.296999e+019
146            51   5.562903e+019
146            52   1.133106e+020
146            53   1.960448e+020
146            54   2.957424e+020
146            55   3.855698e+020
146            56   4.405047e+020
146            57   4.379692e+020
146            58   3.835475e+020
146            59   2.898263e+020
146            60   1.910644e+020
146            61   1.095074e+020
146            62   5.363689e+019
146            63   2.182300e+019
146            64   7.666725e+018
146            65   2.052509e+018
146            66   3.923914e+017
146            67   9.055186e+016
146            68   0.000000e+000
147            46   6.791390e+016
147            47   4.074834e+017
147            48   1.697848e+018
147            49   6.112252e+018
147            50   1.722749e+019
147            51   4.172178e+019
147            52   8.498293e+019
147            53   1.470336e+020
147            54   2.218068e+020
147            55   2.891774e+020
147            56   3.303785e+020
147            57   3.284769e+020
147            58   2.876606e+020
147            59   2.173698e+020
147            60   1.432983e+020
147            61   8.213054e+019
147            62   4.022767e+019
147            63   1.636725e+019
147            64   5.750044e+018
147            65   1.539382e+018
147            66   2.942936e+017
```

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147             67   6.791390e+016
147             68   0.000000e+000
148             47   5.040720e+016
148             48   3.024432e+017
148             49   1.260180e+018
148             50   4.536649e+018
148             51   1.278663e+019
148             52   3.096683e+019
148             53   6.307622e+019
148             54   1.091316e+020
148             55   1.646299e+020
148             56   2.146339e+020
148             57   2.452143e+020
148             58   2.438028e+020
148             59   2.135081e+020
148             60   1.613367e+020
148             61   1.063592e+020
148             62   6.095911e+019
148             63   2.985787e+019
148             64   1.214814e+019
148             65   4.267810e+018
148             66   1.142563e+018
148             67   2.184312e+017
148             68   5.040720e+016
148             69   0.000000e+000
149             47   3.259867e+016
149             48   1.955920e+017
149             49   8.149668e+017
149             50   2.933881e+018
149             51   8.269197e+018
149             52   2.002645e+019
149             53   4.079181e+019
149             54   7.057612e+019
149             55   1.064673e+020
149             56   1.388051e+020
149             57   1.585817e+020
149             58   1.576689e+020
149             59   1.380771e+020
149             60   1.043375e+020
149             61   6.878320e+019
149             62   3.942266e+019
149             63   1.930928e+019
149             64   7.856280e+018
149             65   2.760021e+018
149             66   7.389033e+017
149             67   1.412609e+017
149             68   3.259867e+016
149             69   0.000000e+000
150             48   1.971012e+016
150             49   1.182607e+017
150             50   4.927531e+017
150             51   1.773911e+018
150             52   4.999801e+018
150             53   1.210859e+019
150             54   2.466393e+019
150             55   4.267241e+019
150             56   6.437326e+019
150             57   8.392570e+019
150             58   9.588318e+019
150             59   9.533129e+019
150             60   8.348551e+019
150             61   6.308553e+019
150             62   4.158836e+019
150             63   2.383611e+019
150             64   1.167496e+019
150             65   4.750140e+018
```

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150            66   1.668790e+018
150            67   4.467628e+017
150            68   8.541053e+016
150            69   1.971012e+016
150            70   0.000000e+000
151            48   1.258671e+016
151            49   7.552026e+016
151            50   3.146678e+017
151            51   1.132804e+018
151            52   3.192829e+018
151            53   7.732436e+018
151            54   1.575017e+019
151            55   2.725023e+019
151            56   4.110819e+019
151            57   5.359421e+019
151            58   6.123015e+019
151            59   6.087772e+019
151            60   5.331311e+019
151            61   4.028586e+019
151            62   2.655796e+019
151            63   1.522153e+019
151            64   7.455528e+018
151            65   3.033397e+018
151            66   1.065675e+018
151            67   2.852988e+017
151            68   5.454241e+016
151            69   1.258671e+016
151            70   0.000000e+000
152            48   8.089300e+015
152            49   4.853580e+016
152            50   2.022325e+017
152            51   7.280370e+017
152            52   2.051986e+018
152            53   4.969527e+018
152            54   1.012241e+019
152            55   1.751333e+019
152            56   2.641965e+019
152            57   3.444424e+019
152            58   3.935175e+019
152            59   3.912525e+019
152            60   3.426358e+019
152            61   2.589115e+019
152            62   1.706842e+019
152            63   9.782660e+018
152            64   4.791562e+018
152            65   1.949521e+018
152            66   6.848941e+017
152            67   1.833575e+017
152            68   3.505363e+016
152            69   8.089300e+015
152            70   0.000000e+000
153            49   4.769065e+015
153            50   2.861439e+016
153            51   1.192266e+017
153            52   4.292159e+017
153            53   1.209753e+018
153            54   2.929796e+018
153            55   5.967690e+018
153            56   1.032503e+019
153            57   1.557577e+019
153            58   2.030668e+019
153            59   2.319991e+019
153            60   2.306638e+019
153            61   2.020017e+019
153            62   1.526419e+019
153            63   1.006273e+019
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153          64   5.767389e+018
153          65   2.824876e+018
153          66   1.149345e+018
153          67   4.037809e+017
153          68   1.080988e+017
153          69   2.066595e+016
153          70   4.769065e+015
153          71   0.000000e+000
154          49   2.233613e+015
154          50   1.340168e+016
154          51   5.584032e+016
154          52   2.010251e+017
154          53   5.665931e+017
154          54   1.372183e+018
154          55   2.794994e+018
154          56   4.835771e+018
154          57   7.294979e+018
154          58   9.510723e+018
154          59   1.086578e+019
154          60   1.080324e+019
154          61   9.460839e+018
154          62   7.149050e+018
154          63   4.712923e+018
154          64   2.701182e+018
154          65   1.323043e+018
154          66   5.383007e+017
154          67   1.891125e+017
154          68   5.062855e+016
154          69   9.678988e+015
154          70   2.233613e+015
154          71   0.000000e+000
155          50   9.658865e+014
155          51   5.795320e+015
155          52   2.414716e+016
155          53   8.692979e+016
155          54   2.450132e+017
155          55   5.933763e+017
155          56   1.208646e+018
155          57   2.091144e+018
155          58   3.154586e+018
155          59   4.112745e+018
155          60   4.698716e+018
155          61   4.671671e+018
155          62   4.091173e+018
155          63   3.091481e+018
155          64   2.038021e+018
155          65   1.168079e+018
155          66   5.721268e+017
155          67   2.327787e+017
155          68   8.177840e+016
155          69   2.189343e+016
155          70   4.185508e+015
155          71   9.658865e+014
155          72   0.000000e+000
156          50   4.497409e+014
156          51   2.698446e+015
156          52   1.124352e+016
156          53   4.047669e+016
156          54   1.140843e+017
156          55   2.762909e+017
156          56   5.627758e+017
156          57   9.736891e+017
156          58   1.468854e+018
156          59   1.914997e+018
156          60   2.187840e+018
156          61   2.175247e+018
```

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156              62    1.904953e+018
156              63    1.439471e+018
156              64    9.489534e+017
156              65    5.438867e+017
156              66    2.663966e+017
156              67    1.083876e+017
156              68    3.807807e+016
156              69    1.019413e+016
156              70    1.948877e+015
156              71    4.497409e+014
156              72    0.000000e+000
157              50    1.871405e+014
157              51    1.122843e+015
157              52    4.678513e+015
157              53    1.684265e+016
157              54    4.747131e+016
157              55    1.149667e+017
157              56    2.341752e+017
157              57    4.051592e+017
157              58    6.112010e+017
157              59    7.968443e+017
157              60    9.103763e+017
157              61    9.051363e+017
157              62    7.926649e+017
157              63    5.989744e+017
157              64    3.948665e+017
157              65    2.263153e+017
157              66    1.108496e+017
157              67    4.510087e+016
157              68    1.584456e+016
157              69    4.241852e+015
157              70    8.109423e+014
157              71    1.871405e+014
157              72    0.000000e+000
158              51    9.960705e+013
158              52    5.976423e+014
158              53    2.490176e+015
158              54    8.964635e+015
158              55    2.526699e+016
158              56    6.119194e+016
158              57    1.246416e+017
158              58    2.156493e+017
158              59    3.253166e+017
158              60    4.241268e+017
158              61    4.845551e+017
158              62    4.817661e+017
158              63    4.219023e+017
158              64    3.188090e+017
158              65    2.101709e+017
158              66    1.204581e+017
158              67    5.900058e+016
158              68    2.400530e+016
158              69    8.433397e+015
158              70    2.257760e+015
158              71    4.316306e+014
158              72    9.960705e+013
158              73    0.000000e+000
159              51    3.018395e+013
159              52    1.811037e+014
159              53    7.545989e+014
159              54    2.716556e+015
159              55    7.656664e+015
159              56    1.854301e+016
159              57    3.777019e+016
159              58    6.534826e+016
159              59    9.858080e+016
```

```
    [3-4]            2.515466e+022   1.033541e-001
    [4-5]            1.311147e+022   5.387167e-002
    [5-6]            6.550581e+021   2.691467e-002
    [6-7]            3.173879e+021   1.304066e-002
    [7-8]            1.501977e+021   6.171241e-003
    [8-9]            6.974894e+020   2.865806e-003


Energy gamma           # gammas           fraction
    [0-1]            6.705676e+022        0.666481
    [1-2]            2.232405e+022        0.221880
    [2-3]            7.767338e+021        0.077200
    [3-4]            2.250610e+021        0.022369
    [4-5]            7.491629e+020        0.007446
    [5-6]            2.493747e+020        0.002479
    [6-7]            8.300962e+019        0.000825
    [7-8]            2.763150e+019        0.000275
    [8-9]            9.197727e+018        0.000091


Energy F1              # nuclides         fraction
[ 40- 41]            0.000000e+000        0.000000
[ 41- 42]            0.000000e+000        0.000000
[ 42- 43]            0.000000e+000        0.000000
[ 43- 44]            0.000000e+000        0.000000
[ 44- 45]            0.000000e+000        0.000000
[ 45- 46]            0.000000e+000        0.000000
[ 46- 47]            0.000000e+000        0.000000
[ 47- 48]            0.000000e+000        0.000000
[ 48- 49]            0.000000e+000        0.000000
[ 49- 50]            0.000000e+000        0.000000
[ 50- 51]            0.000000e+000        0.000000
[ 51- 52]            2.112877e+018        0.000021
[ 52- 53]            7.042923e+017        0.000007
[ 53- 54]            0.000000e+000        0.000000
[ 54- 55]            2.515330e+018        0.000025
[ 55- 56]            1.569566e+019        0.000156
[ 56- 57]            6.378876e+019        0.000634
[ 57- 58]            1.773811e+020        0.001763
[ 58- 59]            3.171328e+020        0.003152
[ 59- 60]            6.375858e+020        0.006337
[ 60- 61]            1.343991e+021        0.013358
[ 61- 62]            2.330201e+021        0.023160
[ 62- 63]            3.732950e+021        0.037102
[ 63- 64]            5.451927e+021        0.054187
[ 64- 65]            7.284294e+021        0.072399
[ 65- 66]            8.053683e+021        0.080046
[ 66- 67]            8.809187e+021        0.087555
[ 67- 68]            9.410351e+021        0.093530
[ 68- 69]            8.988078e+021        0.089333
[ 69- 70]            8.324735e+021        0.082740
[ 70- 71]            8.172004e+021        0.081222
[ 71- 72]            8.329464e+021        0.082787
[ 72- 73]            8.071592e+021        0.080224
[ 73- 74]            5.637659e+021        0.056033
[ 74- 75]            3.232299e+021        0.032126
[ 75- 76]            1.328497e+021        0.013204
[ 76- 77]            5.615222e+020        0.005581
[ 77- 78]            1.580633e+020        0.001571
[ 78- 79]            5.151395e+019        0.000512
[ 79- 80]            2.324165e+019        0.000231
[ 80- 81]            2.505268e+019        0.000249
[ 81- 82]            2.233613e+019        0.000222
[ 82- 83]            2.304042e+019        0.000229
[ 83- 84]            2.495207e+019        0.000248
[ 84- 85]            3.622075e+019        0.000360
```

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159          60   1.285233e+017
159          61   1.468349e+017
159          62   1.459897e+017
159          63   1.278492e+017
159          64   9.660878e+016
159          65   6.368814e+016
159          66   3.650246e+016
159          67   1.787896e+016
159          68   7.274333e+015
159          69   2.555575e+015
159          70   6.841697e+014
159          71   1.307971e+014
159          72   3.018395e+013
159          73   0.000000e+000
160          52   9.055187e+012
160          53   5.433112e+013
160          54   2.263797e+014
160          55   8.149669e+014
160          56   2.296999e+015
160          57   5.562903e+015
160          58   1.133106e+016
160          59   1.960448e+016
160          60   2.957424e+016
160          61   3.855699e+016
160          62   4.405047e+016
160          63   4.379692e+016
160          64   3.835475e+016
160          65   2.898264e+016
160          66   1.910644e+016
160          67   1.095074e+016
160          68   5.363689e+015
160          69   2.182300e+015
160          70   7.666725e+014
160          71   2.052509e+014
160          72   3.923914e+013
160          73   9.055187e+012
160          74   0.000000e+000
161          52   2.565636e+012
161          53   1.539382e+013
161          54   6.414091e+013
161          55   2.309073e+014
161          56   6.508164e+014
161          57   1.576156e+015
161          58   3.210466e+015
161          59   5.554602e+015
161          60   8.379368e+015
161          61   1.092448e+016
161          62   1.248097e+016
161          63   1.240913e+016
161          64   1.086718e+016
161          65   8.211746e+015
161          66   5.413492e+015
161          67   3.102709e+015
161          68   1.519712e+015
161          69   6.183183e+014
161          70   2.172239e+014
161          71   5.815442e+013
161          72   1.111776e+013
161          73   2.565636e+012
161          74   0.000000e+000

Energy neutrons       # neutrons         fraction
    [0-1]          7.548862e+022   3.101635e-001
    [1-2]          7.217784e+022   2.965604e-001
    [2-3]          4.523833e+022   1.858728e-001
```

```
Energy F2               # nuclides            fraction
[ 85- 86]             2.304042e+019          0.000229
[ 86- 87]             2.233613e+019          0.000222
[ 87- 88]             2.304042e+019          0.000229
[ 88- 89]             2.525391e+019          0.000251
[ 89- 90]             5.141334e+019          0.000511
[ 90- 91]             1.581639e+020          0.001572
[ 91- 92]             5.615222e+020          0.005581
[ 92- 93]             1.328497e+021          0.013204
[ 93- 94]             3.232299e+021          0.032126
[ 94- 95]             5.637659e+021          0.056033
[ 95- 96]             7.701134e+021          0.076542
[ 96- 97]             8.699922e+021          0.086469
[ 97- 98]             8.153894e+021          0.081042
[ 98- 99]             8.342745e+021          0.082919
[ 99-100]             8.988179e+021          0.089334
[100-101]             9.410351e+021          0.093530
[101-102]             8.809187e+021          0.087555
[102-103]             8.053683e+021          0.080046
[103-104]             7.067272e+021          0.070242
[104-105]             5.343466e+021          0.053109
[105-106]             4.058434e+021          0.040337
[106-107]             2.330201e+021          0.023160
[107-108]             1.343991e+021          0.013358
[108-109]             6.375858e+020          0.006337
[109-110]             3.171328e+020          0.003152
[110-111]             1.773811e+020          0.001763
[111-112]             5.785258e+019          0.000575
[112-113]             2.163183e+019          0.000215
[113-114]             2.515330e+018          0.000025
[114-115]             0.000000e+000          0.000000
[115-116]             7.042923e+017          0.000007
[116-117]             2.112877e+018          0.000021
[117-118]             0.000000e+000          0.000000
[118-119]             0.000000e+000          0.000000
[119-120]             0.000000e+000          0.000000
[120-121]             0.000000e+000          0.000000
[121-122]             0.000000e+000          0.000000
[122-123]             0.000000e+000          0.000000
[123-124]             0.000000e+000          0.000000
[124-125]             0.000000e+000          0.000000
[125-126]             0.000000e+000          0.000000
[126-127]             0.000000e+000          0.000000
[127-128]             0.000000e+000          0.000000
[128-129]             0.000000e+000          0.000000
[129-130]             0.000000e+000          0.000000

Report# :        11
Time    :         0.022 seconds

Number of fissions        :    1.965947e+023
Fuel consumptions (gr)    :    8.969886e+001
Fuel left         (gr)    :   -8.361031e+001

AEM : Activity condition violated.
```