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User Manual for the KfK Code PCROSS

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User Manual for the KfK Code PCROSS

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Benutzerhandbuch für das KfK-Programm PCROSS

Kurzfassung

Das Programm PCROSS berechnet sogenannte "Pseudo"- Wirkungsquerschnitte für sequentielle (x,n)-Reaktionen und vereinigt diese zusammen mit den effektiven Wirkungsquerschnitten von neutroneninduzierten Reaktionen zu einem Datensatz. Dieser evaluierte Datensatz dient als modifizierter Eingabedatensatz des Programms FISPACT. Das Programmpaket FISPACT berechnet die Aktivierung und abgeleitete radiologische Eigenschaften von Materialien, die in einem definierten Neutronenfluss bestrahlt werden. Der vorliegende Bericht beschreibt den Aufbau des Programms PCROSS. Ferner geht der Bericht auf die Aufgaben einzelner Unterprogramme ein und stellt dem Benutzer alle Informationen zur Verfügung, die eine Anwendung des Programms PCROSS erfordert. Für die Anwendung des Programms PCROSS wird ein Beispiel gegeben.

Abstract

The PCROSS code calculates the so-called "pseudo" cross sections for sequential (x,n) reactions and merges them together with "collapsed" cross sections for neutron induced reactions into one file of cross sections. The file is tailored to provide an input for the FISPACT inventory code that calculates the activation and related radiological quantities of material irradiated in a neutron flux. The present report describes the structure of the KfK code PCROSS, outlines the role of subroutines, and provides necessary information for a practical user of the code.

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1. INTRODUCTION

The PCROSS code calculates so-called "pseudo" cross sections for sequential (x,n) reactions and merges them together with "collapsed" cross sections for neutron-induced reactions into one file. The file is tailored to provide an input for the FISPACT inventory code that calculates activation of material irradiated in a given neutron flux [1, 2].

The inventory code FISPACT is well established, and designed to handle multi-step neutron-induced reactions rather than multi-step sequential (x,n) reactions, x being charged particle. Any change in this code should be avoided until strictly necessary. Due to that restriction we have developed an algorithm that allows to handle sequential (x,n) reactions without requiring whatever change in the inventory code FISPACT. This was possible by introducing the so called "pseudo" cross sections for (x,n) reactions [3]. Sequential (x,n) reactions were found to be of considerable importance in activation calculations for development of low activation materials (LAM) for fusion reactor applications [4, 5]. The nuclear data base needed for systematic inclusion of sequential (x,n) reactions into such calculations was recently developed [3]. Apart from the evaluated file REAC-ECN-5 for (n,x) cross sections, the base has three major libraries: KFKSPEC for normalized (n,x) spectra, KFKXN for (x,n) cross sections, and KFKSTOP for differential ranges of charged particles.

The present report describes the KfK code PCROSS, gives its structure, outlines the role of subroutines, and provides necessary information for a practical user of the code.

2. MAIN STRUCTURE OF THE PROGRAM

2.1. Structure

The calculational procedure is as follows. For a given initial composition of a fusion reactor material, which can be composed by using several Input Data Cards (see Chapter 3.1.), and for a given neutron flux one calculates a flux of charged particles of the type x, where $x = p, d, t, {}^3\text{He}$ and α . The charged particle flux from single isotopes/elements is added up to create a total charged particle flux for the initial elemental composition. This flux is then used to evaluate averaged cross sections for (x,n) reactions on all stable as well as radioactive isotopes included in any actual FISPACT input list. These cross sections known as "pseudo" cross sections are fully defined in [3]. They can be used in inventory

calculations exactly in the same manner as the usual "collapsed" cross sections for neutron induced reactions. "Collapsed" cross sections are usually calculated with the FISPACT program using the COLLAPSE option. We merge them together with "pseudo" cross sections to create a single input file of cross sections for the inventory code FISPACT.

For convenience we repeat here some basic definitions as introduced in [3]. The flux $\Phi_x(E_{x_k})$ ($cm^{-2}s^{-1}$) of charged particles x with the energy E_{x_k} created by neutrons incident on a material composed of various stable isotopes A is defined as

$$\Phi_x(E_{x_k}) = \sum_A \sum_{i=1}^{175} \Phi_n(E_{n_i}) \sigma_{n,x}(E_{n_i}) N_A \Delta E_{n_i} \sum_{j=k}^{24} f_{n,x}(E_{n_i}, E_{x_j}) \Delta E_{x_j} \Delta R_x(E_{x_k}). \quad (1)$$

Here, $\Phi_n(E_{n_i})$ ($cm^{-2}s^{-1}MeV^{-1}$) is the neutron flux in the i -th energy interval of the fusion spectrum, ΔE_{n_i} (u) refers to the neutron lethargy energy bin as also used in the REAC-ECN-5 library, $\sigma_{n,x}(E_{n_i})$ (cm^2) is the production cross section of charged particle x in the neutron energy group E_{n_i} , and N_A (cm^{-3}) is the number of atoms of the initial nuclide A . Next, $f_{n,x}(E_{n_i}, E_{x_j})$ (MeV^{-1}) represents the normalized charged particle spectrum from the reaction $A(n, x)$ given in uniform energy steps of $\Delta E_{x_j} = 1MeV$ and referring to the i -th incident neutron energy group, the charged particle energy being $E_{x_j} = 0.5, 1.5, \dots, 23.5$ MeV. Finally, $\Delta R_x(E_{x_k})$ (cm) is the differential thickness of the surrounding material corresponding to 1 MeV steps of energy losses of charged particles with the starting energy E_{x_k} . The "pseudo" cross section (cm^2) for the sequential reaction $\bar{A}(x, n)C$, where \bar{A} can be any isotope we are interested in, is then defined as

$$\sigma_{x,C}^{pseudo} = \frac{1}{\sum_{i=1}^{175} \Phi_n(E_{n_i}) \Delta E_{n_i}} \sum_{k=1}^{24} \Phi_x(E_{x_k}) \sigma_{x,C}(E_{x_k}). \quad (2)$$

Here, $\sigma_{x,C}(E_{x_k})$ (cm^2) stands for the production cross section of the nucleus C via the sequential reaction $\bar{A}(x, n)C$. The "pseudo" cross section is given per one initial neutron rather than per one charged particle, hence its name.

The calling sequence of the program is shown in Fig. 1. The main program PCROSS calls 6 subroutines: PCHEAD, PCINIT, PCREAD, PCRDU5, PCLOOP, and PCMERG. The charged particle flux is calculated in the subroutine PCCALS, this is followed by calculations of "pseudo" cross sections in the subroutine PCCALC, and merging is performed in the subroutine PCMERG. These subroutines together with adjacent ones are briefly described below. The corresponding flow chart is shown in Fig. 2.

2.2. Subroutines

2.2.1. Subroutine PCHEAD. This subroutine prints an output header on output unit number 6.

2.2.2. Subroutine PCINIT. It initializes the common blocks /PNames/, /CIAB/, /CIAW/, and /CIRO/, where basic elemental constants such as natural abundance, atomic weight and density of the condensed matter are given.

2.2.3. Subroutine PCREAD. It reads files from several input units and stores the data into the common blocks /SPECTA/, /STOPPS/ and /XNCROS/. The files have been allocated to the following input units.

- Input unit 21: 175 group neutron spectrum.
- Input unit 27: The FISPACT identifier file ACT10P.INDEX.
- Input unit 41: Energy range file for p of the KFKSTOP library.
- Input unit 42: Energy range file for d of the KFKSTOP library.
- Input unit 43: Energy range file for t of the KFKSTOP library.
- Input unit 44: Energy range file for ${}^3\text{He}$ of the KFKSTOP library.
- Input unit 45: Energy range file for α particles of the KFKSTOP library.
- Input unit 51: (p, n) cross section file of the KFKXN library.
- Input unit 52: (d, n) cross section file of the KFKXN library.
- Input unit 53: (t, n) cross section file of the KFKXN library.
- Input unit 54: (${}^3\text{He}, n$) cross section file of the KFKXN library.
- Input unit 55: (α, n) cross section file of the KFKXN library.
- Input unit 56: ($d, 2n$) cross section file of the KFKXN library.
- Input unit 57: ($t, 2n$) cross section file of the KFKXN library.

The contents of the above libraries are briefly described in the next chapter, for more details see [3].

2.2.4. Subroutine PCRDU5. It reads the Input Data Cards from the default input unit 5. The Input Data Cards which steer the program are listed in Chapter 3.1.

2.2.5. Subroutine PCLOOP. The subroutine PCLOOP is built in to call for major loops in order to calculate "pseudo" cross sections. The first major loop calls for the subroutines PCGCNX and PCGCPS which are tracing the files on the input units 22 and 25. Whenever the loop detects that an isotope belongs to the chosen initial composition, the subroutines PCPRES and PCCALS are called to compute the partial contribution to the charged particle flux of the initial material composition. In the second major loop the charged particle flux of the initial material composition is used to compute "pseudo" cross sections for individual isotopes. This part of the subroutine PCLOOP can also be steered by the Input Data Cards. The input/output units are allocated as follows:

-Input unit 22: REAC-ECN-5 file.

-Input unit 25: Charged particle spectra file KFKSPEC.

-Output unit 6: Logfile of all calculations done.

The contents of the libraries REAC-ECN-5 and KFKSPEC is briefly described in the next chapter, for more details see [6] and [3].¹

2.2.6. Subroutine PCGCNX. It traces (n,x) cross section data from the file REAC-ECN-5 connected to the input unit 22. For one isotope at a time it reads all available (n,x) cross sections and stores them into the common block /NXCROS/.

2.2.7. Subroutine PCGCPS. It traces the charged particle spectrum from the file KFKSPEC connected to the input unit 25. It controls whether the data fetched by PCGCNX and PCGCPS correspond to the same isotope.

2.2.8. Subroutine PCGECO. It checks whether a certain isotope is in the FISPACT identifier list ACT10P.INDEX and whether elemental constants of the isotope are available. It determines the number of atoms of the isotope in the initial material composition and stores the results in the common block /CVALUE/.

¹As foreseen in the Report of [3], further developments in the KFKSPEC and KFKXN libraries have been done. The KFKSPEC, which contains (n,x) spectra, was extended to $Z \leq 84$ ($A \leq 210$), and it includes now also upper limit estimates of (n,t) and $(n,^3He)$ spectra. Similarly, the KFKXN, which contains (x,n) excitation functions, was extended to $Z \leq 84$ ($A \leq 210$), and it now includes $(d,2n)$ and $(t,2n)$ data. (KIK, Karlsruhe, July 1991).

2.2.9. Subroutine PCPRES. It sums up (n,x) cross sections from those reaction channels where an outgoing charged particle is identical. For example, total production cross sections for protons is obtained as $\sigma^{tot}(n,p) = \sigma(n,p) + \sigma(n,np) + 2\sigma(n,2p)$. The resulting charged particle production cross sections are stored in the common block /CVALUE/.

2.2.10. Subroutine PCCALS. It calculates the charged particle spectrum according to the data found by subroutines PCGCNX and PCGCPS. It adds this portion of the spectrum to the charged particle flux calculated previously, so that the charged-particle flux referring to the complete initial-material composition is created. This is done separately for each type of the charged particle so that altogether 5 different charged-particle fluxes are obtained. The final charged-particle fluxes are stored in the common block /CVALUE/.

2.2.11. Subroutine PCGCXN. It receives the (x,n) cross sections from the common block /XNCROS/ needed for the requested isotope.

2.2.12. Subroutine PCGSTP. It determines the differential ranges for the charged particle making use of the common block /STOPPS/. One considers that the charged particle moves in the surrounding defined by the initial material composition.

2.2.13. Subroutine PCCALC. It calculates the "pseudo" cross section for a certain reaction and a certain isotope. It is called in the case that the subroutine PCLOOP has successfully checked that all data needed for the calculation are available.

2.2.14. Subroutine PCRES/A/P/C. These are three different subroutines, PCRESA, PCRESP and PCRESC, that are cleaning up several common blocks after the subroutine PCCALC has been called.

2.2.15. Subroutine PCMERG. It merges all calculated "pseudo" cross sections together with the pre-calculated FISPACT "collapsed" cross sections into one file. The subroutine is sensitive to the order of initial isotopes which is required by the inventory code FISPACT. This process is steered by Input Data Cards. The input/output units are:

-Input unit 23: Pre-calculated "collapsed" cross sections from FISPACT.

-Output unit 31: "Pseudo" cross sections.

-Output unit 32: "Collapsed" cross sections merged with "pseudo" cross sections.

For more details concerning the file containing the pre-calculated "collapsed" cross sections see [2].

3. DESCRIPTION OF INPUT

Data needed to calculate "pseudo" cross sections are rather extensive. Apart from information concerning initial material composition, one needs to know the special neutron flux as a function of neutron energy and to have access to several nuclear data libraries that are described in detail in [3]. In addition, one needs usual pre-calculated "collapsed" neutron-induced cross sections from FISPACT.

3.1. Input Data Cards and Initial Material Composition

The Input Data Cards are steering the program PCROSS and allow the user to calculate "pseudo" cross sections either for a single element case or for a more complex case such as taking into account inter-elemental, charged-particle reactions. In addition, the user may compound an initial material composition such as an alloy. Note that the Input Data Cards SPECTRA, MERGE/NOMERGE have always to be set. However, at one time, the user can set only one out of the three Input Data Cards of the type ELEM, ELEP and ALLY. In this way, one steers what kind of "pseudo" cross sections one wants to calculate.

3.1.1. Input Data Card SPECTRA. The Input Data Card SPECTRA controls the group structure of the neutron flux, the REAC-ECN-5 file as well as the KFKSPEC file. The maintenance of the SPECTRA Input Data Card is to allow further modifications of the group structure of the input libraries in future. The flux presently favoured has 175 groups (VITAMIN-J), so that one should use the SPECTRA card as follows:

SPECTRA

175

3.1.2. Input Data Card MERGE/NOMERGE. This card controls whether the calculated "pseudo" cross sections have to be merged into a file with already pre-calculated "collapsed" cross sections. If the Input Data Card MERGE is set, the input units 23 and 32 have to be allocated (see Chapter 2.2.13.) If the Input Data Card NOMERGE is set, the subroutine PCMERG will be skipped and no allocation is necessary.

3.1.3. Input Data Card ELEM n. With the Input Data Card ELEM the user is controlling the case that he wants to calculate "pseudo" cross sections for one, several or all single elements in one run. This means that the total charged particle flux referring to a given single element A is reacting only on isotopes of the same element A . If the user sets $n = 0$, then all single element cases will be calculated for those elements where input data are available. The use of the ELEM card for the case of two single elements (Cr and Fe) is as follows:

```
ELEM 2  
CR  
FE
```

3.1.4. Input Data Card ELEP n. With the Input Data Card ELEP the user controls the case that he wants to calculate a more complex case for one element A . This element represents the initial material composition and builds up the charged-particle flux. This flux is then used to calculate "pseudo" cross sections for those isotopes I which are close Z -neighbours of the original element, $|Z(A) - Z(I)| < n$, Z being the charge number. This means that one considers sequential (x, n) reactions on all isotopes of the initial element A as well as on all isotopes of those elements that are closest to the initial one. In the case that the user sets $n = 0$ the code will calculate the charged particle flux that corresponds to the initial element A and will give "pseudo" cross sections for the overall list of isotopes where input data are available.

An example of the use of the ELEP card for the case that Cr is the initial material and altogether 6 neighbouring elements are considered is as follows:

```
ELEP 3  
CR
```

3.1.5. Input Data Card ALLY n. With the Input Data Card ALLY the user controls the case that he wants to calculate "pseudo" cross sections for an alloy. This means that the charged particle flux comes from a mixture of elements A_i with relative atomic weights w_i . The sum over all weights needs not to be equal 1.0. An example of the ALLY card for an alloy of 3 elements, Fe (90 %), Cr (8 %) and V (2 %), is given below:

```
ALLY 3
FE 0.90
CR 0.08
V 0.02
```

The total charged particle flux from the alloy will react with all isotopes where input data are available. Note that the calculation of a single elemental case (say, for chromium) with the ELEM 0 Input Data Card leads to the same result as with the following input:

```
ALLY 1
CR 1.0
```

3.2. Neutron flux

The neutron flux should be given in its most detailed internationally accepted 175-group VITAMIN-J structure. However, one can optionally use also an older 100-group (GAM-II) structure.

3.3. Library REAC-ECN-5

The library contains neutron activation and transmutation cross sections and it is given in the format described in [6]. The library is essential for calculations of "collapsed" cross sections. In the present program, it is used in calculations of "pseudo" cross sections, where it serves as a source of charged particle production cross sections. These are obtained by summing, for a particular target isotope, all reaction channels containing a given charged particle so that full charged-particle production cross section is recovered.

3.4. Library KFKSPEC

The library contains normalized charged particle spectra from (n,x) reactions. It is given in the format described in [3]. The starter library [3] was limited to target isotopes with the mass number $10 \leq A \leq 100$ and to p, d, α as outgoing particles. In the meantime, the library was extended to cover all stable as well as radioactive nuclides with $T_{1/2} > 1$ day and masses $10 \leq A \leq 210$, and it includes also upper limit estimates for (n,t) and (n, 3He) spectra.

3.5. Library KFKXN

The library contains production cross sections for sequential (x,n) reactions as induced by p, d, t, 3He and α particles. It is given in the format described in [3]. The starter library [3] was limited to target isotopes with mass numbers $10 \leq A \leq 100$. The current version was extended to cover all stable as well as radioactive nuclides with $T_{1/2} > 1$ day and masses $10 \leq A \leq 210$, and it includes also (d,2n) and (t,2n) cross sections.

3.6. Library KFKSTOP

The library contains energy ranges of p, d, t, 3He and α particles in energy steps of 1 MeV for $E_x = 0.5, 1.5, \dots, 23.5 MeV$ on all elements from $Z = 1$ through 92. It is given in the format described in [3].

3.7. Collapsed Cross Sections

This file has to be created by the FISPACT code using the COLLAPSE option. The file contains usual averaged cross sections for neutron induced reactions on all isotopes that are included in the FISPACT list.

4. SAMPLE RUN

4.1. Input

Given in Appendix A is an example of data input. In this case, chromium was chosen as the initial material and 2 closest (that is 1 with higher Z and 1 with lower Z) neighbouring elements were considered for sequential (x,n) reactions. The initial neutron

flux is given in the 175-group structure, and "pseudo" cross sections should be merged with the usual "collapsed" cross sections. The input cards are:

SPECTRA

175

MERGE

ELEP 1

CR

The corresponding sample job is valid for the operational system MVS on the IBM 3090 mainframe. To avoid system dependent input/output, the input of the KFKXN and KFKSTOP libraries is achieved by allocating an extra input unit for each charged particle.

4.2. Output

An essential part of the output concerns calculated "pseudo" cross sections. In the present example these were calculated for all stable as well as long lived isotopes of vanadium ($Z = 23$, $A = 48, 49, 50$ and 51), chromium ($Z = 24$, $A = 50, 51, 52, 53$ and 54), and manganese ($Z = 25$, $A = 52, 53, 54$ and 55). The corresponding output can be found in the Appendix B. One can see that "pseudo" cross sections are, as expected, rather small and in the chosen example they are in the range of microbarns or fraction of microbarns.

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APPENDIX A: Sample Job

```
//UIDnnnX JOB (xxxx,xxx,xxxxx),Username
// EXEC FVCLG
//C.SYSIN DD DSN=UIDnnn.PCROSS.FORTRAN ,DISP=SHR
//G.FT06F001 DD DSN=UIDnnn.PCROSS.LOGFILE ,DISP=SHR
//G.FT21F001 DD DSN=UIDnnn.NFLUX.DATA ,DISP=SHR
//G.FT22F001 DD DSN=UIDnnn.REACECN.DATA ,DISP=SHR
//G.FT23F001 DD DSN=UIDnnn.COLLAPS.CROSS ,DISP=SHR
//G.FT25F001 DD DSN=UIDnnn.KFKSPEC.DATA ,DISP=SHR
//G.FT27F001 DD DSN=UIDnnn.ACT1OP.INDEX ,DISP=SHR
//G.FT31F001 DD DSN=UIDnnn.PCROSS.RESULT ,DISP=SHR
//G.FT32F001 DD DSN=UIDnnn.PCROSS.COLLAPS ,DISP=SHR
//G.FT41F001 DD DSN=UIDnnn.KFKSTOP.P ,DISP=SHR
//G.FT42F001 DD DSN=UIDnnn.KFKSTOP.D ,DISP=SHR
//G.FT43F001 DD DSN=UIDnnn.KFKSTOP.A ,DISP=SHR
//G.FT44F001 DD DSN=UIDnnn.KFKSTOP.T ,DISP=SHR
//G.FT45F001 DD DSN=UIDnnn.KFKSTOP.H ,DISP=SHR
//G.FT51F001 DD DSN=UIDnnn.KFKXN.PN ,DISP=SHR
//G.FT52F001 DD DSN=UIDnnn.KFKXN.DN ,DISP=SHR
//G.FT53F001 DD DSN=UIDnnn.KFKXN.AN ,DISP=SHR
//G.FT54F001 DD DSN=UIDnnn.KFKXN.TN ,DISP=SHR
//G.FT55F001 DD DSN=UIDnnn.KFKXN.HN ,DISP=SHR
//G.FT56F001 DD DSN=UIDnnn.KFKXN.D2N ,DISP=SHR
//G.FT57F001 DD DSN=UIDnnn.KFKXN.T2N ,DISP=SHR
//G.SYSIN DD *
SPECTRA
175
MERGE
ELEP 1
CR
/*
```

APPENDIX B: Sample output

PSEUDO CROSS SECTIONS EVALUATED BY PCROSS

V - 48	(D,N)	Cr- 49	4.8463E-08	(barn)
V - 48	(T,2N)	Cr- 49	1.6325E-11	(barn)
V - 48	(T,N)	Cr- 50	1.6318E-11	(barn)
V - 48	(A,N)	Mn- 51	8.5603E-08	(barn)
V - 49	(P,N)	Cr- 49	2.7605E-06	(barn)
V - 49	(D,2N)	Cr- 49	7.5890E-11	(barn)
V - 49	(D,N)	Cr- 50	5.9354E-08	(barn)
V - 49	(T,2N)	Cr- 50	4.7063E-11	(barn)
V - 49	(T,N)	Cr- 51	1.8313E-11	(barn)
V - 49	(H,N)	Mn- 51	6.2471E-15	(barn)
V - 49	(A,N)	Mn- 52	1.3680E-07	(barn)
V - 50	(P,N)	Cr- 50	3.9648E-06	(barn)
V - 50	(D,2N)	Cr- 50	3.2261E-08	(barn)
V - 50	(D,N)	Cr- 51	4.6300E-08	(barn)
V - 50	(T,2N)	Cr- 51	3.8963E-11	(barn)
V - 50	(T,N)	Cr- 52	3.5259E-11	(barn)
V - 50	(H,N)	Mn- 52	9.8843E-15	(barn)
V - 50	(A,N)	Mn- 53	1.6672E-07	(barn)
V - 51	(P,N)	Cr- 51	4.6974E-06	(barn)
V - 51	(D,2N)	Cr- 51	4.4793E-09	(barn)
V - 51	(D,N)	Cr- 52	8.9610E-08	(barn)
V - 51	(T,2N)	Cr- 52	6.3053E-11	(barn)
V - 51	(T,N)	Cr- 53	1.4065E-11	(barn)
V - 51	(H,N)	Mn- 53	7.9314E-15	(barn)
V - 51	(A,N)	Mn- 54	1.9573E-07	(barn)
Cr- 50	(D,N)	Mn- 51	4.0306E-08	(barn)
Cr- 50	(T,N)	Mn- 52	3.9563E-11	(barn)
Cr- 50	(H,N)	Fe- 52	2.9925E-15	(barn)
Cr- 50	(A,N)	Fe- 53	6.1426E-08	(barn)
Cr- 51	(P,N)	Mn- 51	1.7615E-06	(barn)
Cr- 51	(D,N)	Mn- 52	5.9899E-08	(barn)
Cr- 51	(T,N)	Mn- 53	2.3364E-11	(barn)
Cr- 51	(H,N)	Fe- 53	6.1936E-15	(barn)
Cr- 51	(A,N)	Fe- 54	1.1766E-07	(barn)
Cr- 52	(P,N)	Mn- 52	1.8638E-06	(barn)
Cr- 52	(D,N)	Mn- 53	7.4879E-08	(barn)
Cr- 52	(T,N)	Mn- 54	5.5344E-11	(barn)
Cr- 52	(H,N)	Fe- 54	1.0158E-14	(barn)
Cr- 52	(A,N)	Fe- 55	1.5894E-07	(barn)
Cr- 53	(P,N)	Mn- 53	4.5272E-06	(barn)
Cr- 53	(D,2N)	Mn- 53	1.7595E-08	(barn)
Cr- 53	(D,N)	Mn- 54	6.6377E-08	(barn)
Cr- 53	(T,2N)	Mn- 54	2.7445E-11	(barn)
Cr- 53	(T,N)	Mn- 55	2.7306E-11	(barn)
Cr- 53	(H,N)	Fe- 55	9.2204E-15	(barn)
Cr- 53	(A,N)	Fe- 56	1.6943E-07	(barn)
Cr- 54	(P,N)	Mn- 54	5.0205E-06	(barn)
Cr- 54	(D,2N)	Mn- 54	2.2413E-10	(barn)
Cr- 54	(D,N)	Mn- 55	8.4248E-08	(barn)
Cr- 54	(T,2N)	Mn- 55	3.0961E-11	(barn)
Cr- 54	(T,N)	Mn- 56	4.1705E-11	(barn)
Cr- 54	(H,N)	Fe- 56	9.9838E-15	(barn)
Cr- 54	(A,N)	Fe- 57	1.7479E-07	(barn)
Mn- 52	(P,N)	Fe- 52	1.0604E-06	(barn)
Mn- 52	(D,2N)	Fe- 52	2.4875E-11	(barn)
Mn- 52	(D,N)	Fe- 53	3.1230E-08	(barn)
Mn- 52	(T,2N)	Fe- 53	3.0745E-12	(barn)
Mn- 52	(T,N)	Fe- 54	9.9415E-12	(barn)
Mn- 52	(H,N)	Co- 54	2.4483E-15	(barn)
Mn- 52	(A,N)	Co- 55	6.4497E-08	(barn)
Mn- 53	(P,N)	Fe- 53	1.4191E-06	(barn)
Mn- 53	(D,N)	Fe- 54	5.0181E-08	(barn)
Mn- 53	(T,2N)	Fe- 54	2.8296E-11	(barn)
Mn- 53	(T,N)	Fe- 55	1.8516E-11	(barn)
Mn- 53	(H,N)	Co- 55	3.9674E-15	(barn)
Mn- 53	(A,N)	Co- 56	1.0800E-07	(barn)
Mn- 54	(P,N)	Fe- 54	3.6807E-06	(barn)
Mn- 54	(D,2N)	Fe- 54	1.4843E-08	(barn)
Mn- 54	(D,N)	Fe- 55	5.1572E-08	(barn)
Mn- 54	(T,2N)	Fe- 55	2.9475E-11	(barn)
Mn- 54	(T,N)	Fe- 56	2.1160E-11	(barn)
Mn- 54	(H,N)	Co- 56	5.9881E-15	(barn)
Mn- 54	(A,N)	Co- 57	1.2421E-07	(barn)
Mn- 55	(P,N)	Fe- 55	4.4331E-06	(barn)
Mn- 55	(D,2N)	Fe- 55	4.3428E-09	(barn)
Mn- 55	(D,N)	Fe- 56	6.8056E-08	(barn)
Mn- 55	(T,2N)	Fe- 56	4.8989E-11	(barn)
Mn- 55	(T,N)	Fe- 57	7.6672E-12	(barn)
Mn- 55	(H,N)	Co- 57	4.2617E-15	(barn)
Mn- 55	(A,N)	Co- 58	1.4328E-07	(barn)

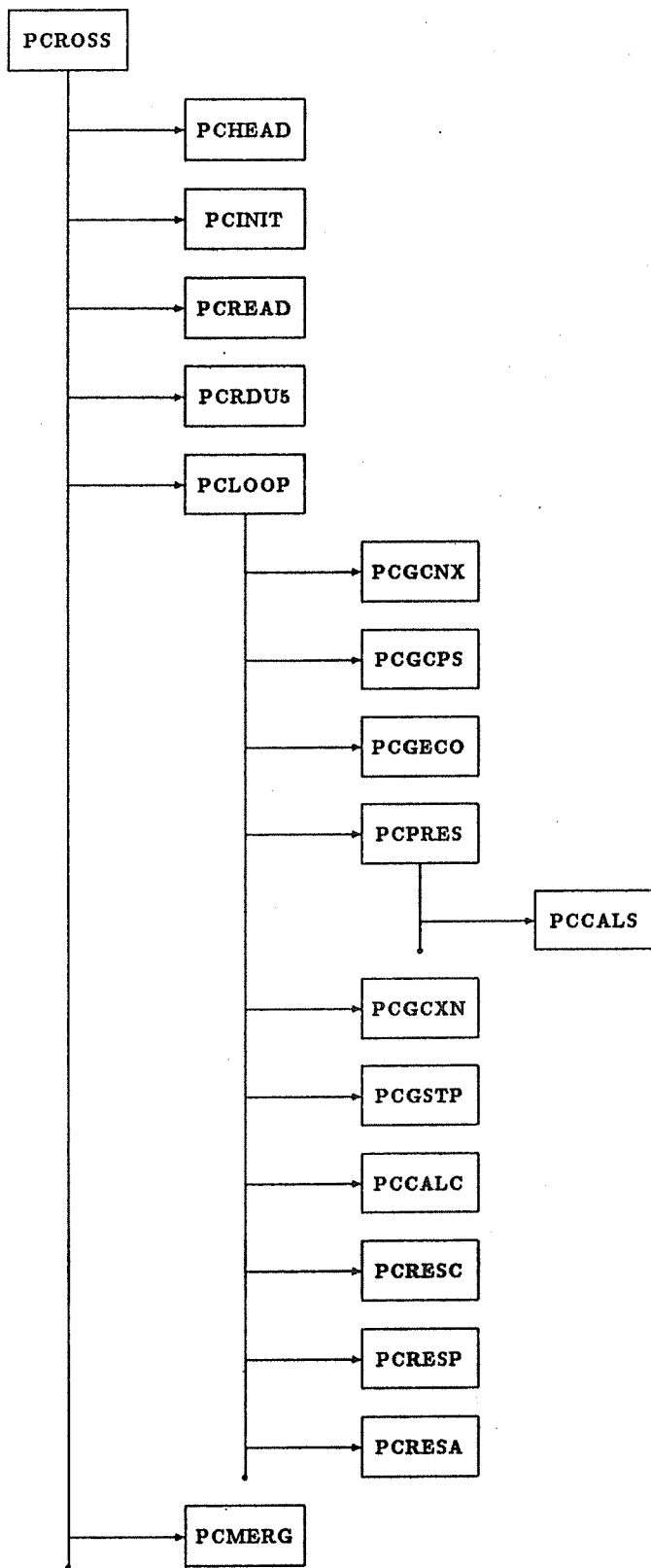


Figure 1: Sequence of calls for the PCROSS code.

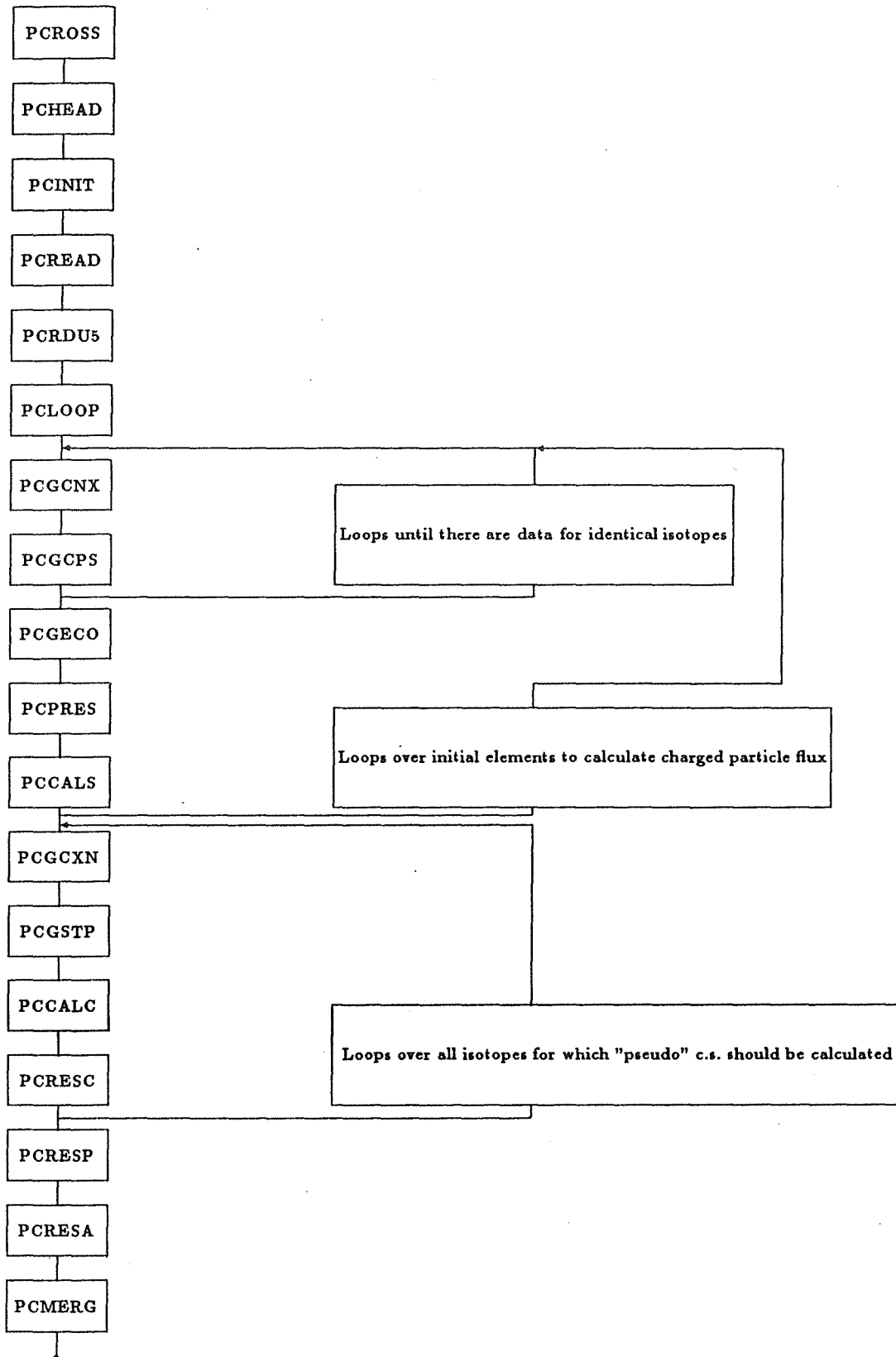


Figure 2: Flow chart of the PCROSS code.