International Atomic Energy Agency INDC(NDS)-246/MO

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

"EVALUATION OF THERMO-MECHANICAL PROPERTIES DATA OF CARBON-BASED PLASMA FACING MATERIALS"

Report of a Consultants' Meeting
organized by the
International Atomic Energy Agency
and held in Vienna, 17-21 December 1990

Prepared by:

M. Ulrickson, V.R. Barabash, R. Matera, M. Rödig,
J.J. Smith and R.K. Janev

March 1991

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

INDC(NDS)-246/MO

"EVALUATION OF THERMO-MECHANICAL PROPERTIES DATA OF CARBON-BASED PLASMA FACING MATERIALS"

Report of a Consultants' Meeting
organized by the
International Atomic Energy Agency
and held in Vienna, 17-21 December 1990

Prepared by:

M. Ulrickson, V.R. Barabash, R. Matera, M. Rödig,
J.J. Smith and R.K. Janev

March 1991

Abstract

This Report contains the proceedings, results and conclusions of the work done and the analysis performed during the IAEA Consultants' Meeting on "Evaluation of thermo-mechanical properties data of carbon-based plasma facing materials", convened on December 17-21, 1990, at the IAEA Headquarters in Vienna. Although the prime objective of the meeting was to critically assess the available thermo-mechanical properties data for certain types of carbon-based fusion relevant materials, the work of the meeting went well beyond this task. The meeting participants discussed in depth the scope and structure of the IAEA material properties database, the format of data presentation, the most appropriate computerized system for data storage, retrieval, exchange and management. The existing IAEA ALADDIN system was adopted as a convenient tool for this purpose and specific ALADDIN labelling schemes and dictionaries were established for the material properties data. An ALADDIN formatted test-file for the thermo-physical and thermo-mechanical properties of pyrolytic graphite is appended to this Report for illustrative purposes.

Reproduced by the IAEA in Austria
May 1991

91-01583

Table of Contents

Appendices

1. INTRODUCTION

On recommendation of the IFRC Subcommittee on Atomic and Molecular (A+M) Data for Fusion (6th Subcommittee Meeting, September, 1990) and following the specific guidelines of the IAEA Consultants' Meeting on "Thermal response of plasma facing materials and components" (June 11-13, 1990; Report IAEA(NDS)-237/M6, 1990), the IAEA A+M Data Unit organized a small Consultants' Meeting on "Evaluation of thermo-mechanical properties data of carbon-based plasma facing materials" which was held during December 17-21, 1990 at the IAEA Headquarters in Vienna. The primary objectives of the meeting were to perform a critical analysis of the available thermo-physical and thermo-mechanical data for certain types of carbon-based materials of interest to fusion research and reactor design, and to establish a methodology for data evaluation in the area of material properties. The meeting, however, went well beyond these initial objectives and addressed questions related to the scope and structure of the IAEA material properties database, data presentation and formatting, choice of the most appropriate computerized system for data storage, retrieval and exchange, methods and procedures of a continuous development of the IAEA material properties database, etc.

Due to the very specific task of the meeting, only four experts were invited to take part in its work (see Appendix 1). They were joined by the IAEA A+M Data Unit staff when data formatting and data collection and evaluation procedures were discussed.

2. MEETING SUMMARY

After the opening remarks of the Head of IAEA A+M Data Unit, the meeting participants agreed to undertake the following tasks (see for details the Meeting Agenda, Appendix 2):

1) Definition of the scope and the structure of the IAEA material properties database, with prioritization of the materials,
2) Establishment of a detailed list of material properties for which data should be entered in the database (physical, mechanical and thermo-mechanical types of properties),
3) Selection of an appropriate format for data presentation,
4) To perform a critical assessments of the available data on carbon-based materials, Be and W,
5) To apply the selected format to a specific case and test the methodology of entry preparation, data storage and retrieval,
6) To prepare the draft report for the meeting.

All meeting participants have brought with themselves large collections of data for the properties of carbon-based materials, and some data for Be, W and stainless steels. The IAEA A+M Data Unit has also received a collection of data for graphites from the JAERI Materials Database. Dr. R. Matera has brought with himself samples of formatted material properties data from the CEC - High-Temperature Material (CEC-HTM) Database, while Dr. M. Ulrickson, before coming to the meeting, discussed at the Princeton Plasma Physics Laboratory with Dr. R. Hulse the appropriateness of ALADDIN database system for storage and exchange of material properties data. These elements constituted the basis for the work of the meeting. The extensive discussions on the issues 1)-3) above, and the data evaluation and formatting work under the items 4) and 5) can be summarized as follows:

ad 1): In accordance with the recommendations of the June 11-13, 1990, Consultants' Meeting on "Thermal response of plasma facing materials and components", the IAEA material properties database should initially consist of two categories of materials:

A) Plasma Facing Materials, and
B) Materials for the Structures of Plasma Facing Components.

Blanket and other structural materials should be left outside the database scope at this stage. A prioritization of candidate materials in the categories A) and B) above has been made taking into account the experiences on the operating large tokamaks, the ongoing laboratory experimental work, and the ITER reactor design criteria and long-term R+D programmes. The list of materials to be included in the IAEA database is given in Section 3.1 of this Report.

ad 2): The material properties for which data are to be collected, critically evaluated and included in the database in the initial stage fall in the following categories: (1) physical properties, (2) mechanical properties, and (3) thermo-mechanical properties and allowables. The types of data from these categories are specified in Section 3.2 and Section 4.2.

ad 3): After discussing various computerized database systems which could be used for data formatting, storage and exchange, priority was given to the Agency's ALADDIN system, which is already used by the IAEA A+M Data Unit and A+M/PMI Data Centre Network for management of atomic and plasma-surface interaction data. The flexibility of ALADDIN system allows easily to apply it to material properties data, after defining appropriate labelling schemes and dictionaries. The meeting participants discussed these matters in detail and established a consistent set of conventions and labelling rules for the material properties entries in ALADDIN system. The labelling conventions are given in Section 4.1, while material properties dictionary in Section 4.2. For convenience, a brief summary of the basic ALADDIN features is given in Appendix 3.

ad 4): Intercomparison and quality assessment was performed for the available data on graphites and other carbon-based materials. The analysis of these data is described in Section 5. It has been agreed that this set of data be introduced into the ALADDIN database by the IAEA A+M Data Unit staff. The collected data on Be and W were also analyzed.

ad 5): As test of the applicability of ALADDIN to the field of material properties data, as well as of the established labelling system, some data on pyrolytic graphite were introduced into ALADDIN. The result of this excersize, completed by the A+M Data Unit staff after the Meeting, is given in Appendix 4 of the present Report.

3. SCOPE AND STRUCTURE OF IAEA MATERIAL PROPERTIES DATABASE

3.1. Materials to be included in the database

A. Plasma Facing Materials

A.1 Low-Z Materials

A.1.1 Graphites

- A.1.1.1 Isotropic graphites
- A.1.1.2 Anisotropic graphites
- A.1.1.3 Doped graphites

A.1.2 Carbon Fiber Composites (CFC)

- A.1.2.1 Chopped Fiber Based
- A.1.2.2 Continuous Fiber Based
- A.1.2.3 Doped CFC

A.1.3 Beryllium

- A.1.3.1 Cast
- A.1.3.2 Plasma Sprayed

A.1.4 Carbides

- A.1.4.1 Silicon Containing
- A.1.4.2 Titanium Containing

A.2 Medium-Z Materials

A.2.1 Liquid Metals

- A.2.1.1 Gallium Based
- A.2.1.2 Lithium Based

A.2.2 Metals (See B)

A.3 High-Z Materials

A.3.1 Tungsten + Tungsten Alloys

- A.3.1.1 Cast
- A.3.1.2 Plasma Sprayed

A.3.2 Tantalum + alloys
A.3.3 Molybdenum + alloys

B. Plasma Facing Components Structures

B.1 Stainless Steel and Related Materials

B.1.1 Iron Based

B.1.1.1 Austenitic
B.1.1.2 Martensitic
B.1.1.3 Ferritic

B.1.2 Nickel Based

B.1.2.1 Age Hardenable
B.1.2.2 Non-age Hardenable

B.2 Copper and Copper Alloys

B.2.1 Pure Copper

B.2.1.1 OFHC
B.2.1.2 Electrolytic Copper

B.2.2 Copper Alloys

B.2.2.1 Solution Strengthend
B.2.2.2 Dispersion Hardened
B.2.2.3 Dispersion Strengthened (Precipitation Hardened)

B.3 Refractory Materials

B.3.1 Niobium
B.3.2 Molybdenum (See A.3.3)
B.3.3 Vanadium and Alloys

B.4 Aluminum and Alloys

B.5 Low Activation Alloys

B.5.1 Austenitic (low Ni)
B.5.2 Ferritic

3.2. Properties to be included in the data files

The meeting participants followed the general classification scheme of material properties data adopted at the last IAEA Consultants' Meeting on "Thermal Response of Plasma Facing Materials and Components" (June 11-13, 1990; Report IAEA(NDS)-237/M6, 1990) and work out a full list of material properties data required in fusion reactor design. For the initial stage of the database development, data for the following property categories have been specified for inclusion in the data files:

1. Physical properties (density, porosity, melting, evaporation and recrystalization temperetures, boiling point, thermal conductivity, specific electrical resistance, specific heat, heats of evaporation and fusion, coefficient of thermal expansion, emissivity).

2. Mechanical properties (elastic moduli, Poison's ratio, shear modulus, strengths, hardness, elongation, fatigue, creep fracture toughness).

3. Thermo-mechanical properties; allowables (creep crack growth, fatigue crack growth, high cycle fatigue, thermo-mechanical fatigue).

The material properties falling within these categories are further specified in Section 4.2.

4. FORMAT FOR DATA PRESENTATION

4.1. ALADDIN Labelling Schemes

A. Hierarchical labels

(These are searchable labels for which the order of appearance is fixed; see Appendix 3)

MAT-TYP: Type of Material, e.g. Pyrolytic Graphite, Tungsten, etc;
ORIENT: Material Orientation, e.g. Isotropic or Anisotropic;
NAME: Trade Name, e.g. ATJ, EK-98, 316L, UPV-1, etc.

B. Boolean labels

(These are searchable labels for which the order of appearance is not important; see Appendix 3).

PROPERTY: Type of data (one from the Property Dictionary)
QUALITY: Quality of data, e.g. tentative, recommended, etc.
SOURCE: Reference for data
MANUFACT: Material manufacturer
TEST-COND: Description of test conditions. This typically will contain pre-irradiation, post-irradiation, or in-pile identification, load control, strain control, or stress control, relaxation, test method (e.g. torsion), and environment of test for creep tests. It will typically contain waveform (including in/out of phase for thermo-mechanical fatigue), R factor, stress or strain ratio, amplitude, mode of failure, temperature cycle, test duration (creep tests) and environment of test. For in-pile or post-irradiation tests the flux, fluence, energy spectrum, type of particle (neutron, ion, etc.), and He content should be specified.
MEASURE-PLANE: Specification of the plane on which the measurement was performed. This may have values ab, ac, in-plane, etc.
MEASURE-PLANE-TO-LOAD: For specification of the measurement plane relative to the application of a mechanical or thermal load. This may have the values: PARALLEL, or PERP (for perpendicular).

SAMP-DESC:	Description of sample geometry, crack geometry, sample orientation and position in material, and load control.
MATERIAL:	Describe the material including microstructure, grain size, standard identification number (e.g. AISI 316), chemical composition, etc.
HISTORY:	Describe the treatment of material since purchase from the manufacturer including heat treatment, cold working, irradiation, etc.

4.2. <u>ALADDIN material property dictionary</u>:

Name	Description	Units
DEN	Apparent Density	kg/m**3
POR	Porosity	m**3/kg
HARD	Hardness (Identify method)	
T-MELT	Melting Temperature	K
T-BOIL	Boiling point (vapor pressure = 1 atm)	K
T-RECRZ	Recrystalization Temperature	K
TH-COND	Thermal Conductivity	W/m/K
SP-HEAT	Specific Heat (constant pressure)	J/kg/K
EVAP-HEAT	Heat of evaporation	J/kg
FUS-HEAT	Heat of fusion	J/kg
CTE	Coefficient of thermal expansion	10**-6/K
EMIS	Emissivity (blackbody)	---
ELEC-RES	Electrical Resistance	10**-6 Ohm m
EM-C	Compressive elastic modulus (Tangent method)	GPa
EM-T	Tensile elastic modulus (Tangent method)	GPa
EM-G	Shear modulus	GPa
EM-T-S	Tensile elastic modulus secant method	GPa
EM-C-S	Compressive modulus secant method	GPa
EM-BULK	Bulk modulus	GPa
NU	Poisson's ratio	---
STR-TEN-U	Ultimate tensile strength	MPa
STR-COM-U	Ultimate compressive strength	MPa
STR-SHR-U	Ultimate shear strength	MPa
STR-FLX3-U	Ultimate flexural strength (3 point bending)	MPa
STR-FLX4-U	Ultimate flexural strength (4 point bending)	MPa
STR-TEN-Y	Tensile yield strength	MPa
STR-COM-Y	Compressive yield strength	MPa
STR-SHR-Y	Yield strength in shear	MPa
STR-FLX3-Y	Yield strength in 3 point bending	MPa
STR-FLX4-Y	Yield strength in 4 point bending	MPa

ELNG-TOT	Total elongation at failure	---
ELNG-UNF	Uniform elongation	---
RA	Reduction in area	---
KIC	Fracture toughness	MPa/m**1/2
JIC	Critical J-integral	kJ/M^2
DBTT	Ductile Brittle Transition Temperature	K
CHRPY	Charpy Impact Energy	J
LOW-SHLF	Lower shelf for Charpy tests	J
UP-SHLF	Upper shelf for Charpy tests	J
CREP-G	Creep crack growth	m/s
CREP-ELNG	Elongation versus time (stress and temp)	---
CREP-TIME	Time to failure (versus stress and temp)	s
FRACT-CRYS	Fracture crystallinity	%
LAT-EXP	Lateral expansion	m
STRS-1%	Stress to reach 1% strain in given time (Must specify time, e.g. 10,000 hr)	MPa
STRS-FRACT	Stress to reach failure in a given time (Must specify time, e.g. 10,000 hr)	MPa
STRS-TER	Stress to reach tertiary creep in given time (Must specify time, e.g. 10,000 hr)	MPa
FTIG-G	Fatigue crack growth	m/cycle
FTIG-LC	Low cycle fatigue (strain versus cycles)	
FTIG-HC	High cycle fatigue (stress versus cycles)	
FTIG-THM	Thermo-mechanical fatigue (strain versus cycles)	
DIM-CHNG	Dimensional change under irradiation	---

5. DATA EVALUATION FOR CARBON-BASED AND OTHER PLASMA FACING MATERIALS

A large volume of data on carbon-based materials and some data on Be and W were analyzed in details at the meeting. The selected data on different types of materials and various properties are contained in the references given below. This list of references, however, is not exhaustive; it will serve to the IAEA A+M Data Unit only as an initial source for data to be included in the ALADDIN Material Properties Database. Refs. 1-4 provide extensive collections of already evaluated material data for fusion research. Refs. 5-19 contain high quality data for isotropic and anisotropic graphites and carbon-composites. Data on tungsten and beryllium are contained in Refs. 1(+2) and 20, respectively.

To test the completeness and appropriateness of the ALADDIN labelling schemes and property dictionary, the data for anisotropic pyrolytic graphite from Refs. 5-7 were used to build a few initial files of the IAEA Material Properties Database. These files are given in Appendix 4.

Primary Material Properties Data Sources

1. International fusion materials handbook, J.W. Davis, Coordinator, Status Report, September 1990.

2. Materials Handbook for fusion energy systems, J.W. Davis, Coordinator, Materials Handbook Activities, Fusion Power Project, McDonnell Douglas Astronautics Company, USA, 1986.

3. ITER blanket and shield conceptual design and ITER material evaluation and database, Part B, D. Smith et al, ITER Report, 1990.

4. NET material data for predesign analysis of in-vessel components, E. Zolti, NET internal report N/I/3300 5/A, 1990.

5. Thermophysical properties of advanced carbon materials for tokamak limiters, E.P. Roth, W.D. Watson, M. Moss and W.D. Drotning, SANDIA report SAND88-2057, Sandia National Laboratories, 1989.

6. ITER material design databook, USSR contribution, 1990.

7. Final structural analysis report from the nozzle material properties mannual, R. Laramu, Thikol Corporation report SE025-A2D-C4-DEV-001.

8. Physical, mechanical and thermal properties of a PPPL-2D-carbon carbon at room and elevated temperatures, Princeton Plasma Physics Laboratory, 1988.

9. The dynamic fatigue behaviour of POCO and RC4 graphites and a general fatigue design criteria, B.J.S. Wilkins and A.R. Reich, Report AECL-4216, Whiteshell Nuclear Research Establishment, USA, 1972.

10. Experimental study of thermal shock resistance for Soviet carbon materials, I.V. Mazul, V.R. Komarov, S.I. Kurolenkiv, Submitted as ITER working group, USSR contribution, February 1990.

11. A review of irradiation induced creep in graphite under CAGR conditions, J.E. Brocklehurst and B.T. Kelly, Report ND-R-1406(S), Springfields Nuclear Power Development Laboratories, UK, 1989.

12. Evaluation of first wall and divertor materials for JT-60 upgrade, M. Yamamoto, T. Ando, H. Takatsu, M. Shimizu, T. Arai, K. Kodama, H. Horiike, K. Teruyama, A. Kiuchi and Y. Goto, JAERI report JAERI-M 90-119, Japan, 1990.

13. Comparison of high purity fine grain graphites from different suppliers with regard to physical, mechanical and thermal properties, W. Delle, J. Linke, H. Nickel, E. Wallura, Jülich Report 401, EURATOM 1987.

14. Development of carbon-carbon materials for fixed RF limiters, Materials Science Corporation Report to Princeton Plasma Physics Laboratory, May 1988.

15. Fatigue behaviour of fine-grained isotropic graphites for HTGR'S, S. Ishiyama, M. Eto, T. Oku, JAERI Report JAERI-M 86-192, Japan, 1986.

16. Fractures in polycrystalline graphite, J.E. Brocklehurst, in Chemistry and Physics of Carbon, Vol. 13, published by Marcel Dekker, 1977.

17. Fatigue behaviour of a high-density graphite and general design criteria correlation, H.L. Leichter and E. Robinson, Journal of the America Chemical Society, 53, 197, 1968.

18. Papers on effects of neutron irradiation on the thermal conductivity of pyrolitic graphite, compiled by R.D. Wakson, Sandia National Laboratories, USA.

19. Probability of failure of brittle materials subjected to dynamic or static fatigue, B.J.S. Wilkins, Journal of Materials, Vol. 7, no. 2, 251, 1972.

20. Thermal fatigue tests of a prototype beryllium limiter for JET, R.D. Watson, J.B. Whitley, Journal of Nuclear Engineering and design/Fusion 4, 49, 1986.

6. MEETING CONCLUSIONS AND RECOMMENDATIONS

This meeting was characterized by a free and open exchange of data information among the participants. A sufficient amount of data was collected to allow the starting of the establishment of IAEA material properties database, using data on pyrolytic graphite, some carbon fiber composites, beryllium, and some data on tungsten. More data will be gathered during the next few months and sent to the IAEA for entry into the database.

The participants at the meeting agreed to the following conclusions and recommendations:

1. A connection to other existing databases must be established. As a minimum, a link should be established to the IEA material data bank, the Japanese Fusion Materials Database, the CEC - High Temperature Material Database, and the IAEA Plasma-Surface Interaction Database. All programs will benefit from the exchange of data between the different databases. We recommend that the connections be established through the existing ITER agreements, as well as through the IAEA.

2. In order to shorten the time between data taking and data entry, and to avoid misinterpretation of the data, it is recommended that the data input be done as close to the data taking organization as possible. In order to facilitate the entry of data, we recommend a user friendly input program be created. Dr. Matera will check on the availability of the input program of the CEC-HTM-data bank, if an official request for access to this program is made by the IAEA. This is a IBM-PC program which can be easily adapted for our purposes.

3. Since the ALADDIN database system can be easily operated on a wide variety of computers (as is demonstrated by the success of the atomic and molecular database), we have set up the necessary definitions to allow the materials data to be put into ALADDIN format. This should make the data easily available to all fusion laboratories.

4. The IAEA should establish a mechanism for the protection of unpublished data and the owner's rights to publish the data.

5. The IAEA should invite all laboratories involved in fusion to participate in the plasma facing materials database activities.

6. We recommend that other nations not involved in fusion technology work be invited to participate in the effort through the use of IAEA Research Co-ordination Programmes, research contracts, fellowships, and other forms of effort integration.

7. The administrative procedures for distribution of the database should be established by the IAEA.

8. In the first phase, priority should be given to the data for materials which are the primary candidates for the plasma facing materials, and first wall materials in the ITER design.

9. The IAEA A+M Data Unit should be the data storage and distribution center for the material properties database and the ALADDIN system.

10. We recommend that a review board be established by the IAEA for the purpose of review and evaluation of the data submitted for inclusion in the database. This review board should consist of representatives from all the major data contributors and data users, and meet annually on a regular basis.

11. Revisions to the database should be announced by the IAEA through either a newsletter or through electronic mail, or both.

12. After entry of the initial set of data, we recommend that the review board meet to evaluate the database organization and data dictionary. This will allow changes to be made before extensive editing would be required to incorporate suggested improvements. We anticipate this meeting will take place during next year.

13. After the data on pyrolytic graphite, evaluated at the present meeting, is entered into the database, the database should be sent to the meeting participants for their review and comment.

14. We recommend a letter be sent to fusion materials research laboratories by the IAEA inviting them to participate in the establishment of the international material properties database for fusion.

Appendix 1

IAEA Consultants' Meeting on "Evaluation of Thermo-Mechanical Properties Data of Carbon-Based Plasma Facing Materials"

December 17-21, 1990, Vienna

List of Meeting Participants

M. Ulrickson	Plasma Physics Laboratory, Princeton University, P.O. Box 451, Princeton, NJ 08543, U.S.A.
V.R. Barabash	D.V. Efremov Scientific Research Institute of Electrophysics Apparatus, P.O. Box 42, Leningrad 189631, Metallostroi, U.S.S.R.
R. Matera	CEC - Commission of the European Communities, Joint Research Centre, Ispra Establishment, I-21020 Ispra, Italy
M. Rödig	Forschungszentrum Jülich GmbH, Postfach 1913, D-5170 Jülich 1, Germany
R.K. Janev	IAEA A+M Data Unit, Division of Physical and Chemical Sciences
J.J. Smith	IAEA A+M Data Unit, Division of Physical and Chemical Sciences

Appendix 2

IAEA Consultants' Meeting on "Evaluation of Thermo-Mechanical Properties Data of Carbon-Based Plasma Facing Materials"

December 17-21, 1990, Vienna

Meeting Agenda

Monday, December 17

09:30	Opening Remarks (R.K. Janev)
10:00	Definition of Scope of the Database
12:00	Lunch
13:30	Preliminary Selection of Keywords and Elements of ALADDIN Database Elements
15:45	Coffee Break
16:15	Prioritization of Materials List
17:30	Adjourn

Tuesday, December 18

09:00	Working Session to Gather and Compare Data on Carbon Based Material
12:00	Lunch
13:30	Working Session Continued
16:15	Selection of the Format for Data Presentation
17:30	Adjourn

Wednesday, December 19

09:00	Working Session to Define data Dictionary
12:00	Lunch
13:30	Working Session for Data on Be and W
17:30	Adjourn

Thursday, December 20

09:00	Working Session to Refine Data Dictionary and Entry of Sample Data
12:00	Lunch
13:30	Discussion of Meeting Conclusions and Recommendations
17:30	Adjourn

Friday, December 21

09:00	Write Draft Report
13:30	Adjourn

Appendix 3

Basic features of ALADDIN system*

ALADDIN is a database system adopted by the IAEA A+M Data Unit and by the international A+M Data Centre Network for storage, exchange and managment of atomic, particle-surface interaction and other types (e.g. material properties) of data related to fusion energy research.

1. ALADDIN Structure

The ALADDIN system comprises several related components, consisting of a data format, supporting software, specific data labelling schemes, and finally, the data itself. Users can select and adapt various elements of the system as best suits their own needs.

The most fundamental ALADDIN component is a defined but extremely flexible data format for entering and labelling atomic data as entries in ASCII (text) data files.

Next, the ALADDIN system includes specific supporting FORTRAN-77 software to facilitate user access to ALADDIN data. The ALADDIN code provides interactive data search and access from a user's terminal, while the ALPACK subroutine package provides a "black box" subroutine interface to ALADDIN data files from a user's FORTRAN codes.

Any given practical implementation of ALADDIN relies on specific choices of ALADDIN data labelling schemes appropriate for these applications. These labelling schemes can combine standardized systems established by the IAEA and other data centers along with a user's own schemes to describe their application-specific data.

Finally, the ALADDIN system includes specific data available either directly in ALADDIN-based datafile compilations or from other databases and codes which can read and write ALADDIN format files for data exchange. Associated ALADDIN dictionary files provide documentation and user information via keywork reference from the data files.

2. System's Design

The basic ALADDIN data storage format employs ASCII data files consisting of concatenated, independent entries. Such sequential "text" data files are by far the most readily transmitted and read across all computer systems, using media such as floppy disks, tape, computer networks and electronic mail. Also, the user's favorite text editor can serve as a basic and familiar way of searching, reading, and editing data entries. These data files can also be simply sorted by data type and printed out, allowing easy publication and use of the data even by those without convenient access to computers. Each ALADDIN data entry contains searchable attribute labels, together with the data itself.

* A full description of ALADDIN base features is given in the article by R. Hulse in "Atomic Processes in Plasmas", Amer. Inst. Phys. Conference Proceedings #206, MD USA 1989, p. 63; as well as in the "ALADDIN Manual, Version 1.0" (Report IAEA(NDS)-AM-17, Vienna, 1989). The text presented here is taken from these sources.

Following the same emphasis on portability, primary supporting ALADDIN software is written in strict FORTRAN 77. This is, in practice, still the principal programming language for scientific applications, and as such, it is widely available on a full range of systems from PC's to Crays. Conveniently, the FORTRAN 77 standard also offers some support for character string manipulation, which simplifies ALADDIN's label-based searching and data handling approach.

3. ALADDIN Labelling Schemes

ALADDIN represents the searchable attributes of each data entry by lists of arbitrary character string-based labels in the entry header. These "searchable labels" include the physics identifiers, data source and revision number, and other information, as well as identifying the procedure to call to read this entry's specific format and the procedure to call the data. An important additional application for these labels are as keywords referring to entries in the "dictionary files" associated with the ALADDIN data files. These dictionary files provide whatever documentation is necessary to fully support the data entries themselves.

The searchable labels serve to identify each ALADDIN entry. These labels are treated by ALADDIN as a list of arbitrary character strings, and can be placed in both hierarchical and boolean search structures to provide flexibility in designing specific labelling schemes.

Hierarchical labels are defined as a sequence of labels where the order of appearance is significant. Much information (especially physics or material labelling) naturally has this form.

Boolean labels are used to represent independent attributes whose entry order does not have a fixed sequence, and which are tested individually in a search using the Boolean logical operators .AND. and .NOT.. Typical boolean label information would be the data source, a dictionary file keywork reference to documentation, etc. ALADDIN uses two reserved boolean label types for special functions. An "access label" with a $ prefix flags special procedures to read the coefficient field data, while the "evaluation label" dnoted by a # prefix specifies the data fitting functiona and associated procedure call.

4. Supporting Software

ALADDIN supporting software is intended to provide the functionality essential to allow new users to rapidly incorporate ALADDIN into their work. At the present, this consists of a set of FORTRAN 77 routines, conceptually divided into two functional groups: the ALADDIN interactive code, and the ALPACK subroutine package.

The ALADDIN interactive code provides a basic interactive data searching, display, and manipulation capability from the user's terminal. It is a command-based program, which can be installed on a wide variety of hardware, requiring only a true FORTRAN-77 compatible compiler. The user specifies the hierarchical and boolean labels to be searched for in a given ALADDIN data file, and the ALADDIN interactive program will sequentially search through the data file until a matching data entry is found. The search strings include "wild cards" and other constructs to provide a flexible searching capability.

Once found, data entries can be displayed to the terminal, and the data function (fitting function) can be evaluated at specified points (energies, temperatures, etc.) with the resulting data values (cross sections, rate coefficients, etc.) displayed to the screen or written to a file. On-line access to documentation describing not only the ALADDIN data files but also other ALADDIN nomenclature, fitting forms, references to the literature, etc., can also be accessed on-line from the ALADDIN interactive program by asking for keyword searches in associated ALADDIN dictionary files.

The ALPACK subroutine package provides a simple interface to ALADDIN data files for user's applications codes. ALPACK reproduces the same basic search capability as the on-line ALADDIN interactive code, but now via subroutine calls from the user's code. Successive data entries are read in using ALREAD. The desired dierarchical and boolean search label sequences (again, with possible wild card constructs) are passed to the ALCOMP subroutine, which compares these with the entry header, flagging successful matches. The label and coefficient field information from the ALADDIN entry are then available in COMMON blocks for use by the calling code. The subroutine ALRECF provides conversion of standard (default) coefficient field data from character strings to real (floating point) values which are then passed to the appropriate evaluation subroutine.

The basic philosophy of ALADDIN design allows for its easy application to various types of data, provided a self-consistent labelling scheme is defined for each specific area of data.

Appendix 4

Initial ALADDIN Data Files for An-Isotropic Pyrolitic Graphite

1. Data files

   1.1. Material properties data for UPV-1 and UPV-1T.
   1.2. Material properties data for PKHPA, A1PK, A2PK, B1PK and B2PK
   1.3. Materials properties data for PFIZER-SORT.

2. Dictionary files for the An-Isotropic Pyrolitic Graphites

   2.1. Material description file
   2.2. Test conditions file
   2.3. Sample description file

3. Common material properties files

   3.1. References file
   3.2. Evaluation functions file

MATERIALS PROPERTIES ALADDIN DATA FILE

Materials properties file for : PKHPA, A1PK, A2PK, B1PK, B2PK,

```
$ PYRGRAP ANISO A2PK
& CTE SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Pfizer
TEST-COND=CTE/SAND88-2057 SAMP-DESC=A1PK-SAMPLE1 MEASURE-PLANE=in-plane
23/01/91 #CTEFUN1
 -0.745  4.21E-3 -1.225E-6

$ PYRGRAP ANISO A1PK
& DEN SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Pfizer
23/01/91 #VALUE
2.185
$ PYRGRAP ANISO A2PK
& DEN SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Pfizer
23/01/91 #VALUE
2.235
$ PYRGRAP ANISO B1PK
& DEN SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Goodrich-B.F.
23/01/91 #VALUE
2.195
$ PYRGRAP ANISO B2PK
& DEN SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Goodrich-B.F.
23/01/91 #VALUE
2.232
$ PYRGRAP ANISO PKHPA
& DEN SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Goodrich-B.F.
23/01/91 #VALUE
2.240

$ PYRGRAP ANISO A1PK
& CTE SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Pfizer
TEST-COND=CTE/SAND88-2057 SAMP-DESC=A1PK-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
13.9   352.640   14.1 438.135   15.5  362.930   21.3  369.755
64.1   430.405   66.1 419.335  139.1  457.339  142.8  436.643
257.1  421.804  527.2 308.605  598.4  281.814  619.3  286.565
698.7  279.814  708.0 271.246  718.0  273.970  798.2  259.100
803.1  258.852  908.2 243.610  910.0  244.213  991.9  257.534
999.6  253.246 1107.0 230.953  1112.0 230.611  1327.0 210.354
1327.0 201.103 1502.0 206.408

$ PYRGRAP ANISO A1PK
& SP-HEAT SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Pfizer
TEST-COND=CTE/SAND88-2057 SAMP-DESC=A1PK-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
13.9   2.604E-01 14.1   1.605E-01 15.5   1.616E-01 21.3   1.659E-01
64.1   1.968E-01 66.1   1.982E-01 139.1  2.455E-01 142.8  2.477E-01
257.1  3.069E-01 229.9  3.369E-01
619.3  4.108E-01 698.7  4.240E-01 708.0  4.255E-01 718.0  4.269E-01
798.2  4.378E-01 803.1  4.384E-01 908.2  4.503E-01 910.0  4.505E-01
991.9  4.583E-01 999.6  4.590E-01 1107.0 4.679E-01 1112.0 4.682E-01
1327.0 4.828E-01 1327.0 4.828E-01 1502.0 4.921E-01

$ PYRGRAP ANISO B1PK
& CTE SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Goodrich-B.F.
TEST-COND=CTE/SAND88-2057 SAMP-DESC=B1PK-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
21.8    336.128 51.1    394.276 51.7    385.473 161.3    402.230
161.3   401.461 253.2   368.706 268.9   371.159 360.2    349.912
```

```
364.3  351.161  429.3   323.990 438.8   315.164 541.2   299.450
544.3  301.900  638.1   279.244 641.3   287.301 743.5   277.129
750.6  261.627  848.1   257.363 856.3   257.562 958.2   249.733
961.7  242.450  961.7   242.450

$ PYRGRAP ANISO B1PK
& SP-HEAT SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P
MANUFACT=Goodrich-B.F.  TEST-COND=CTE/SAND88-2057 SAMP-DESC=A1PK-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
!  Units in Cal/gm/deg.
21.8    1.663E-01 51.1    1.877E-01 51.7    1.881E-01 161.3 2.585E-01
161.3   2.585E-01 253.2   3.056E-01 268.9   3.126E-01 360.2 3.475E-01
364.3   3.489E-01 429.3   3.685E-01 438.8   3.711E-01 541.2 3.960E-01
544.3   3.961E-01 638.1   4.141E-01 641.3   4.147E-01 743.5 4.306E-01
750.6   4.316E-01 848.1   4.438E-01 856.3   4.447E-01 958.2 4.552E-01
961.7   4.555E-01 961.7   4.555E-01

$ PYRGRAP ANISO PKHPA
& CTE SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Goodrich-B.F.
TEST-COND=CTE/SAND88-2057 SAMP-DESC=PKHPA-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
152.3   1150.841 301.6    814.601 450.3    611.605 601.8    522.666
750.9   404.206  901.0    395.811 1052.8   339.491 1281.7   306.828
1348.3  283.957  1491.8   261.551 1737.0   270.108 1981.0   201.688

$ PYRGRAP ANISO PKHPA
& SP-HEAT SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P
MANUFACT=Goodrich-B.F. TEST-COND=CTE/SAND88-2057 SAMP-DESC=PKHPA-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
!  Units in Cal/gm/deg.
152.3   2.533E-01 301.6   3.262E-01 450.3   3.741E-01 601.8   4.076E-01
750.9   4.361E-01 901.0   4.495E-01 1052.8  4.635E-01 1281.7  4.748E-01
1348.3  4.841E-01 1491.8  4.916E-01 1737.0  5.032E-01 1981.0  5.117E-01

$ PYRGRAP ANISO B2PK
& CTE SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Goodrich-B.F.
TEST-COND=CTE/SAND88-2057 SAMP-DESC=B2PK-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
59.5    658.109 60.36   668.207 126.2    755.113 246.6    581.256
260.1   606.490 376.4   496.932 383.7    490.120 479.3    416.393
487.8   422.293 578.6   402.606 684.7    347.870 691.1    345.782
788.5   316.288 898.7   317.617 905.9    295.515 982.4    290.785
985.0   262.131 985.0   262.131

$ PYRGRAP ANISO B2PK
& SP-HEAT SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P
MANUFACT=Goodrich-B.F.  TEST-COND=CTE/SAND88-2057 SAMP-DESC=B2PK-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
!  Units in Cal/gm/deg.
59.5    1.936E-01 60.36   1.940E-01 126.2   2.376E-01
246.6   3.026E-01 260.1   3.087E-01 376.4   3.528E-01
383.7   3.551E-01 479.3   3.815E-01 487.8   3.836E-01
578.6   4.031E-01 684.7   4.219E-01 691.1   4.229E-01
788.5   4.366E-01 898.7   4.493E-01 905.9   4.501E-01
982.4   4.575E-01 985.0   4.577E-01 985.0   4.577E-01

$ PYRGRAP ANISO A2PK
& CTE SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Pfizer
TEST-COND=CTE/SAND88-2057 SAMP-DESC=A2PK-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
45.7   674.063 45.8   721.298 162.7   601.684 168.6   604.389
277.0  574.067 290.9  559.600 404.5   480.916 407.4   471.793
510.4  428.764 523.5  416.089 628.1   377.511 631.9   361.653
730.9  350.564 831.0  305.383 832.7   334.889 943.7   311.832
```

```
947.5  298.739 995.3  292.161 997.4  297.497 997.4  297.497

$ PYRGRAP ANISO A2PK
& SP-HEAT SANDIA SOURCE=SAND88-2057 AUTHOR=ROTH.E.P MANUFACT=Pfizer
TEST-COND=CTE/SAND88-2057 SAMP-DESC=A2PK-SAMPLE1
MEASURE-PLANE=in-plane 23/01/91 #TAB
!  Units in Cal/gm/deg.
45.7   1.838E-01 45.8   1.839E-01 162.7  2.593E-01 168.6 2.627E-01
277.0  3.161E-01 290.9  3.218E-01 404.5  3.614E-01 407.4 3.622E-01
510.4  3.890E-01 523.5  4.921E-01 628.1  4.124E-01 631.9 4.131E-01
730.9  4.288E-01 831.0  4.418E-01 832.7  4.420E-01 943.7 4.538E-01
947.5  4.542E-01 995.3  4.586E-01 997.4  4.588E-01 997.4 4.588E-01
```

MATERIALS PROPERTIES ALADDIN DATA FILE

Materials properties file for : UPV-1, UPV-1T

```
$ PYRGRAP ANISO UPV-1T
& DEN SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
23/10/91 #VALUE2
  2.1E+03 2.2E+03
$ PYRGRAP ANISO UPV-1T
& POR SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
23/10/91 #VALUE
! The value is an upper limit to the porosity
  1.0E-05
$ PYRGRAP ANISO UPV-1T
& SP-HEAT SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
23/10/91 #VALUE
! The specific heat is defined in units of Joules per gram per deg k
  1.6
$ PYRGRAP ANISO UPV-1T
& EMIS SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
23/10/91 #VALUE
  0.5
$ PYRGRAP ANISO UPV-1T
& EM-? SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ab 23/10/91 #VALUE
! The application of the force and the technique used for measurement
! are not defined.
 -0.05
$ PYRGRAP ANISO UPV-1T
& EM-? SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ac 23/10/91 #VALUE
! The application of the force and the technique used for measurement
! are not defined.
 -0.16
$ PYRGRAP ANISO UPV-1T
& NU SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ab 23/10/91 #VALUE
0.27
$ PYRGRAP ANISO UPV-1T
& NU SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ac 23/10/91 #VALUE
0.7

$ PYRGRAP ANISO UPV-1T
& CTE SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB2X2Y
! The coefficient of thermal expansion is measured in the direction
! parallel to the applied thermal load.
  77  300 -1.2 -1.5     300  400 -0.9 -1.3     300  800  -0.1 -0.3
 300 1300  0.4  0.7     300 1800  0.85 1.2     300 2300   1.2  1.35
 300 2800  1.35 1.5     300 3300  1.5  1.65

$ PYRGRAP ANISO UPV-1T
& CTE SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PERP 23/10/91 #TAB2X2Y
  77  300  22  22        300  400 25   25       300  800  26 26.5
 300 1300  27 27        300 1800  27.5 27.5   300 2300   28  28

$ PYRGRAP ANISO UPV-1
& EM-T SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ab TEST-COND=UPV-1/EM-T-NOTE 23/10/91 #TABX2Y
! The method of measuring the elastic modulus is not defined.
```

```
! The data represent the range or scatter of the elastic modulus as a
! function of temperature.
   20 2.75E+04 3.02E+04   500 2.81E+04 2.93E+04   800 2.78E+04 2.88E+04
 1000 2.74E+04 2.86E+04  1200 2.68E+04 2.83E+04  1400 2.61E+04 2.80E+04
 1600 2.50E+04 2.76E+04  1800 2.40E+04 2.73E+04  2000 2.34E+04 2.63E+04
 2200 2.30E+04 2.62E+04  2400 2.25E+04 2.50E+04  2600 2.15E+04 2.33E+04

$ PYRGRAP ANISO UPV-1
& EM-T SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ab TEST-COND=UPV-1/EM-T-NOTE 23/10/91 #TAB
! The method of measuring the elastic modulus is not known.
! The data represent the mean value from a range of measurements of the
! elastic modulus.
   20 2.87E+04   500 2.86E+04   800 2.86E+04  1000 2.76E+04
 1200 2.75E+04  1400 2.71E+04  1600 2.65E+04  1800 2.60E+04
 2000 2.55E+04  2200 2.43E+04  2400 2.40E+04  2600 2.24E+04

$ PYRGRAP ANISO UPV-1
& EM-G SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ac TEST-COND=UPV-1/EM-T-NOTE 23/10/91 #TABX2Y
! The method of measuring the elastic modulus is not known.
! The data represent the range or scatter of the elastic modulus as a
! function of temperature.
   20 1.45E+04 1.55E+04   500 1.38E+04 1.47E+04 1000 1.29E+04 1.38E+04
 1500 1.16E+04 1.24E+04  2000 1.06E+04 1.13E+04 2200 0.94E+04 1.01E+04
 2500 0.67E+04 0.71E+04
$ PYRGRAP ANISO UPV-1
& EM-G SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ac TEST-COND=UPV-1/EM-T-NOTE 23/10/91 #TAB
! The method of measuring the elastic modulus is not known.
! The data represent the mean value from a range of measurements of the
! shear modulus.
 20 1.50E+04   500 1.43E+04   1000 1.34E+04 1500 1.20E+04  2000 1.10E+04
2200 0.98E+04 2500 0.69E+04
$ PYRGRAP ANISO UPV-1
& STR-TEN-U SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB2X2Y
! The data represent the range or scatter of the elastic modulus as a
! function of temperature.
   20 20.8 42.7  1000 58.5 87.5   1500 73.5 76.5   2000 21.6 62.7
  2500 71.2 85.4  2800 30.0 464.0  3200 31.8 77.0
$ PYRGRAP ANISO UPV-1
& STR-TEN-U SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB
! The data represent the mean value from a range of measurements of the
! ultimate tensile strength.
  20 32.0  1000 74.8 1500 74.2  2000 36.5 2500 75.9  2800 364.0
 3200 54.4
$ PYRGRAP ANISO UPV-1
& STR-COM-U SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TABX2Y
! The data represent the range or scatter of the compressive strength as
! a function of temperature.
   20 56.0 75.5  1000 54.3 132.2  2000 52.0 142.0
  2500 45.4 98.7  3000 34.1 40.9
$ PYRGRAP ANISO UPV-1
& STR-COM-U SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB
! The data represent the mean value from a range of measurements of the
! ultimate compressive strength.
   20 62.2 1000 100.7  2000 94.8 2500 74.6 3000 36.3
$ PYRGRAP ANISO UPV-1
& STR-COM-U SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PERP 23/10/91 #TABX2Y
```

```
! The data represent the range or scatter of the compressive strength as
! a function of temperature.
   20 282 345    1000 253  325    2000 139 255  2500 112 184
$ PYRGRAP ANISO UPV-1
& STR-COM-U SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PERP 23/10/91 #TAB
! The data represent the mean value from a range of measurements of the
! ultimate compressive strength.
   20 317.5 1000 281.3  2000 197.7 2500 153.0

$ PYRGRAP ANISO UPV-1
& CTE SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TABX2Y
 300  400 -0.6 -0.2    300  800  -0.4 -0.1
 300 1300  0.7  1.1     300 1800  1.2 1.6    300 2300   1.45 1.9
$ PYRGRAP ANISO UPV-1
& CTE SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PERP 23/10/91 #TABX2Y
 300  400  19 22    300  800  21 24
 300 1300  22 25.5  300 1800  23.5 26.5  300 2300  24 26.5
$ PYRGRAP ANISO UPV-1
& CTE SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=VARIABLE 23/10/91 #TABX2Y
 300  400  18.6 20.8   300  800  21.2 23.2
 300 1300  24.2 26.9  300 1800  26.7 28.9  300 2300  27.8 29.4

$ PYRGRAP ANISO UPV-1
& ELEC-RES SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB
 300  4.3   400 3.8  500 3.3 600 2.9  700 2.6  800 2.6
 900  2.6  1000 2.7  1500 3.0  2000 3.5  2500 4.0
$ PYRGRAP ANISO UPV-1
& ELEC-RES SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PERP 23/10/91 #TAB
 300  6000  400 5250 500 4650 600 4150 700 3740  800 3400
 900  3100 1000 2800 1500 1950 2000 1250 2500 700

$ PYRGRAP ANISO UPV-1T
& ELEC-RES SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB
 100  0.4   150 0.45  200 0.5 250 0.55 300 0.6  400 0.7
 500  0.8  600 0.9 700 1.0 800 1.1 900 1.2 1000 1.3 1500 1.8
 2000 2.3  2500 2.8
$ PYRGRAP ANISO UPV-1T
& ELEC-RES SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PERP 23/10/91 #TAB
300 2100 400 1650 500 1300  600 1050 700 850  800 700 900 570 1000 470
1500 180 2000 120  2500 80

$ PYRGRAP ANISO UPV-1
& TH-COND SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB
 100 150  150 200  200 280  250 340  300 330  400 310  500 290
 600 260  700 240  800 220  900 210 1000 200 1500 150 2000 125
2500 100
$ PYRGRAP ANISO UPV-1
& TH-COND SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PERP 23/10/91 #TAB
 100 0.8  150 2.0  200 2.4  250 2.2  300 2.2  400 2.05  500 1.95
 600 1.85  700 1.8  800 1.7  900 1.65 1000 1.6 1500 1.4 2000 1.45
2500 2.0

$ PYRGRAP ANISO UPV-1
& STR-? SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
```

```
  MEASURE-PLANE=ab TEST-COND=UPV-1/ELONG-NOTE 23/10/91 #TABX2Y
! The data represent the range or scatter of the ultimate  strength as
! a function of temperature.
 20  88 151  1000  118 170 2000 70.5 137
$ PYRGRAP ANISO UPV-1
& STR-? SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ab TEST-COND=UPV-1/ELONG-NOTE 23/10/91 #TAB
! The data represent the mean value from a range of measurements of the
! ultimate compressive strength.
 20  117 1000 140 2000 97

$ PYRGRAP ANISO UPV-1
& ELNG-TOT SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ab TEST-COND=UPV-1/ELONG-NOTE 23/10/91 #TABX2Y
! The Load is a temperature load
! The data represent the range or scatter of the elongation length at
! failure as a function of temperature.
! (The units are in meters)
 20  0.355E-03 0.87E-03 1000  0.75E-03 0.94E-03 2000 1.0E-03 1.27E-03
$ PYRGRAP ANISO UPV-1
& ELNG-TOT SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE=ab TEST-COND=UPV-1/ELONG-NOTE 23/10/91 #TABX2Y
! The Load is a temperature load
! The data represent the mean value from a range of measurements  of the
! elongation length at failure as a function of temperature.
! (The units are in meters)
 20  0.55E-03  1000  0.87E-03  2000 1.13E-03

$ PYRGRAP ANISO UPV-1T
& TH-COND SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB
! The Load is a temperature load
 100 1800  130 2350 150 2400 200 1950 250 1450 300 1110 400 700 500 500
 600 400  700 350  800 310  900 280 1000 270 1500 210 2000 170
2500 140
$ PYRGRAP ANISO UPV-1T
& TH-COND SOURCE=SOV-HANDBOOK-1 MANUFACT=USSR-SRIG
  MEASURE-PLANE-TO-LOAD=PARALLEL 23/10/91 #TAB
 100 2.8   130 3.4  150 4.4  200 6.5  250 6.6  300 6.5  400 5.9 500 5.4
 600 5.0  700 4.8  800 4.6  900 4.5 1000 4.4 1500 3.9 2000 3.8
```

MATERIALS PROPERTIES ALADDIN DATA FILE

Materials properties file for : PFIZER-SORI

```
$ PYRGRAP ANISO PFIZER-SORI
& STR-TEN-U THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MANUFACT=Pfizer MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Stength in PSI * 1.0E+03
 80.33 12.473 978.438 13.950 1988.102 12.729 3016.410 14.255 4014.983
14.434 4994.926 20.002

$ PYRGRAP ANISO PFIZER-SORI
& STR-TEN-U THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=c 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Stength in PSI * 1.0E+03
 78.822 334.197 947.099 138.033 2959.898 113.695 4955.851 168.883

$ PYRGRAP ANISO PFIZER-SORI
& EM-T THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
75.057 4.695 1017.417 4.673 1981.055 3.874 2995.292 4.261
4002.846 1.609 4996.998 1.272

$ PYRGRAP ANISO PFIZER-SORI
& ELNG-TOT THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Tensile Strain = Total elongation at failure in units of in./in
 32.235  7.025e-3 970.662   0.155 1944.942  0.312 2959.754 0.476
 3972.365  0.648 4987.917  0.847

$ PYRGRAP ANISO PFIZER-SORI
& NU THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! NU = Tensile Poisson's Ratio
! NU = Strain in direction 3 / strain in direction 1
! ( see Figure 2.6 and page 1-7)
84.337 0.661 87.591  0.801 1018.679  0.892 1019.871 0.862 994.168 1.160
2002.369 0.821 1998.564 0.667 2980.231 0.663 3999.374 0.818 3987.921
0.648 4017.537 0.514 5003.030 0.669 4990.862 1.150 3011.464 1.215
3017.034 1.294

$ PYRGRAP ANISO PFIZER-SORI
& STR-COM-U THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Stength in PSI * 1.0E+03
 75.574  14.905 985.249  14.645 1953.102 14.050 2966.235  13.651
3955.157  14.238 4956.750   13.936

$ PYRGRAP ANISO PFIZER-SORI
& STR-COM-U THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=c 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Stength in PSI * 1.0E+03
  91.166 35.319 1008.182 38.232 2983.668 35.506 4988.552  33.140
```

```
$ PYRGRAP ANISO PFIZER-SORI
& EM-C THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
 58.591 4.132 924.614  4.275 1954.154  3.726 2961.790 3.892 3930.480
3.029 4960.899 1.622
$ PYRGRAP ANISO PFIZER-SORI
& EM-C THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=c 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
 36.808 1.608 910.529 1.463 2920.637 1.630 4945.632  1.142

$ PYRGRAP ANISO PFIZER-SORI
& EM-C-S THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
 35.105 3.851 970.304 4.152 1966.491 3.759 2975.753 3.313 3999.66 2.540
4949.023 0.877
$ PYRGRAP ANISO PFIZER-SORI
& EM-C-S THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=c 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
 57.689 1.704 988.931 0.512 2948.320 0.251 4957.064 0.218

$ PYRGRAP ANISO PFIZER-SORI
& NU THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! NU = Compressive Poisson's Ratio
! NU = Strain in direction 3 / strain in direction 1
! ( see Figure 2.11 and page 1-7)
96.538 1.102 974.456 0.980 1949.663 0.932 2892.581 0.993 3831.797
1.135 4796.459 1.116
$ PYRGRAP ANISO PFIZER-SORI
& NU THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! NU = Compressive Poisson's Ratio
! NU = Strain in direction 1 / strain in direction 3
! ( see Figure 2.11 and page 1-7)
 99.624  0.295

$ PYRGRAP ANISO PFIZER-SORI
& STR-SHR-U THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
! PIN Data ?
102.781 1.358 964.757 1.077 3012.124 0.769
$ PYRGRAP ANISO PFIZER-SORI
& STR-SHR-U THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
! Double Notch Data ?
  97.570 0.667 4176.454 1.620 4509.699 0.725 4979.295 0.812
$ PYRGRAP ANISO PFIZER-SORI
& STR-SHR-U THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=c 23/01/91 #TAB
! Temperature in deg. Fahrenheit
```

```
! Modulus in PSI * 1.0E+06
  67.791 4.403 2998.788 4.982

$ PYRGRAP ANISO PFIZER-SORI
& EM-G THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=A 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
 85.644 0.360 992.475 0.334 2921.528 0.287 4973.868 0.128
$ PYRGRAP ANISO PFIZER-SORI
& EM-G THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
  73.614  3.048 1008.116  2.870 2956.101  2.332 4983.399  1.178
$ PYRGRAP ANISO PFIZER-SORI
& EM-G THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ac 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! Modulus in PSI * 1.0E+06
 40.202 0.194 996.344 0.188 2934.070 0.155 4971.264 6.668e-2

$ PYRGRAP ANISO PFIZER-SORI
& CTE THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! CTE units of in./(in.-Deg F) * 1.0E-06
209.458 -0.40500 405.085 -0.16120 501.458 -3.088e-2 1025.041  0.22830
1971.444  0.67340 3027.806  1.00656 4002.105  1.18786 4512.210  1.32641
4999.145  2.08277 5051.898  3.79617

$ PYRGRAP ANISO PFIZER-SORI
& CTE THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=normal-ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! CTE units of in./(in.-Deg F) * 1.0E-06
! the measurement is performed in Direction 3 - Normal to plane a
164.835 12.751 451.923 12.708 971.072 13.479 2017.048 14.147 3032.025
14.547 4045.977 14.742 4561.019 14.692 5103.888 13.906

$ PYRGRAP ANISO PFIZER-SORI
& SP-HEAT THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
23/01/91 #TAB
! Temperature in deg. Fahrenheit
! SP-HEAT  units of BTU/(LB -Deg F)
223.343 0.251 488.609 0.320 990.345 0.394 1997.544 0.446 2993.858 0.502
4017.384 0.527 4762.660 0.544

$ PYRGRAP ANISO PFIZER-SORI
& TH-COND THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=ab 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! TH-COND units of BTU/(Sec. - FT - Deg F)
324.954 58.474 465.506 51.532 980.488 42.096 1990.051 29.739 2473.935
24.438 2962.539 19.878 3985.429 15.749 4786.168 16.233
$ PYRGRAP ANISO PFIZER-SORI
& TH-COND THIKOL SOURCE=SE025-A2D-C4-DEV-001 AUTHOR=LARAMU.R
MEASURE-PLANE=c 23/01/91 #TAB
! Temperature in deg. Fahrenheit
! TH-COND units of BTU/(Sec. - FT - Deg F)
 90.205 0.350 407.887 0.311 889.502 0.252 1432.539 0.211 1907.795
0.191 2396.450 0.191 2910.184 0.212 3451.557 0.252 3973.959 0.310
4352.260 0.391
```

ALADDIN Material Description File
for Anisotropic Pyrolitic graphites

```
MATERIAL=UPV-1T/1 ?
1. Basic Description
   Compression amnnealed pyrolitic graphite
   1.1 Chemical Composition
       Ballance - C
       Impurities : Fe, Al, Mg, B, Cu, Ti, Ni  < 10}-}5 %
   1.2 Structure
       Hexagonal Lattice  a - 3.36 - 3.40 An
                          c - 1.42 An
1.3 Technology
    Deposition

MATERIAL=UPV-1/1 ?
1. Basic Description
   1.1 Chemical Composition
       Ballance - C
       Impurities : Fe, Al, Mg, B, Cu, Ti, Ni  < 10}-}5 %
   1.2 Structure
       Hexagonal Lattice  a - 3.36 - 3.40 An
                          c - 1.42 An
   1.3 Technology
       Deposition

MATERIAL=B1PK ?
!  As deposited

MATERIAL=B2PK ?
! Annealed (3000 deg. C, 1 hr)

MATERIAL=PKHPA ?
! Compression Annealed (3000 deg. C, 1 hr)

MATERIAL=A1PK ?
!  As deposited

MATERIAL=A2PK ?
! Annealed (3000 deg. C, 1 hr)
```

IAEA A+M Data Unit ALADDIN Material Dictionary File

Dictionary of References

SOV-HANDBOOK-1 ?
"Handbook on Carbon Based Materials Properties", Sosedov V. P., in Metallurgica, 1975

SAND88-2057 ?
"Thermophysical Properties of Advanced Carbon Materials for Tokamak Limiters", E. P. Roth, R. D. Watson, M. Moss, W. D. Drotning, SANDIA Report, SAND88-2057, April, 1989.

USSR-SIG ?
Scientific Research Institute, USSR

SANDIA ?
Sandia National Laboratories,
Albuquerque,
New Mexico 87185,
USA

SE025-A2D-C4-DEV001 ?
"Nozzle Material Properties Mannual, Final Structural Analysis Report'' Larmur R., Thikol Report SE025-A2D-C4-DEV-001, Volume VIII A, November 1979

THIKOL ?
Thikol Corporation
Hercules-Thikol
USA

Pfizer ?
name and address of company

Goodrich-B.F. ?
name and address of company

ALADDIN Material Test Conditions File
for Anisotropic Pyrolitic graphites

TEST-COND=CTE/SAND88-2057
Thermal expansion measurements were performed using a Theta dual-pushrod a lumina dilatometer operated in the absolute (single pushrod) mode. The device was calibrated with an NBS-referenced platinum standard to correct for thermal expansion of the device. Data were obtained during heating at a raye of 3 deg. C/min over the range 20 to 1420 deg. C. The specimens were nominally 0.25 in. square x 1.00 in long. Expansion measurements were obtained along the long specimen axis with the samples held horizontally in the dilatometer by an alumina support block. Prior to heating, the device was flushed with argon at 15 cfh for about 10 minutes; during heating and data acquisition, a constant argon flow of 3 cfh was maintained through the sample region. Following thermal cycling in the dilatometer, the samples were checked for any irreversible changes in the length or weight. Typically, the carbon materials experienced no measureable length change and 0.1% weight loss after the exposure to 1420 deg. C.

TEST-COND=UPV-1/EM-T-NOTE ?
In the temperature interval +20 to -180 deg. centigrade the elastic modulus of the pyrolytic graphite which does not contain water is not changed.

TEST-COND=UPV-1/ELONG-NOTE ?
1. In the temperature interval 2500 to 2800 deg. centigrade the samples had a bending of 2-3 mm without destruction during linearly load. The samples had a cross section of 2.8 x 7 mm, and were cut from the base material. The distance between the supports is 36 mm and that between the knives is 12mm. 2. The mechanical properties of pyrolitic graphite containing no humidity in the temperature interval +20 to -50 deg. centigrade do not change.

ALADDIN Material Sample Descriptions File
for Anisotropic Pyrolitic graphites

SAMP-DESC=A1PK-SAMPLE1 ?
The thickness of the test samples used was 0.303 cm

SAMP-DESC=A2PK-SAMPLE1 ?
The thickness of the test samples used was 0.504 cm

SAMP-DESC=B1PK-SAMPLE1 ?
The thickness of the test samples used was 0.303 cm

SAMP-DESC=B2PK-SAMPLE1 ?
The thickness of the test samples used was 0.502 cm

SAMP-DESC=PKHPA-SAMPLE1 ?
The thickness of the test samples used was 0.966 cm

IAEA A+M Data Unit ALADDIN Material Dictionary File

Dictionary of Evaluation Functions

#VALUE ?
The coefficient record is a single value for a quantity (property).

#VALUE2?
The coefficient record is two values providing the range for a quantity (property).

#TAB ?
The coefficient records contain a series of data where for each measurement/calculation, a value for the independent variable, i.e. temperature, pressure etc is followed by a value of the dependent variable (the property) i.e. coefficient of thermal expansion, fatigue crack growth etc.

#TABX2Y ?
The coefficient records contain sets of data where for each measurement/calculation a values for the independent variable, i.e. temperature, pressure etc is followed by two values covering the range of the dependent variable (the property) i.e. coefficient of thermal expansion, fatigue crack growth etc.

#TAB2X2Y ?
The coefficient records contain sets of data where for each measurement/calculation two values for the range of the independent variable, i.e. temperature, pressure etc are followed by two values covering the range of the dependent variable (the property) i.e. coefficient of thermal expansion, fatigue crack growth etc.

#CTEFUN1 ?
The coefficient records contains the three coefficients of the third-order polynomial fit for the coefficient of thermal expansion.

```
   Fit = cf(1) + cf(2) * T + cf(3) * (T * T)
```