IAEA surveillance data administration within Mat-DB

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Abstract. The Joint Research Centre - Institute for Energy (JRC-IE) has developed a web-enabled materials database (Mat-DB) for storing materials test data resulting from international research projects together with other documentation in a related document management database (DoMa) providing fast access to confidential and public data sets. The databases are implemented in the secure (On-line Data Information Network) ODIN portal. Mat-DB covers thermo-mechanical and thermo-physical properties data of engineering alloys at low, elevated and high temperatures for base materials and joints, including irradiated materials for nuclear fission and fusion applications, thermal barrier coated materials for gas turbines and properties of corroded materials. The corrosion part refers to weight gain/loss data of high temperature exposed engineering alloys and ceramic materials. For each test type the database structure reflects international test standards and recommendations. Mat-DB features an extensive library of evaluation programs for web-enabled assessment of uniaxial creep, fatigue, crack growth and high temperature corrosion properties. Evaluations can be performed after data retrieval or independently of Mat-DB by transferring other materials data in a given format to the programs. The fast evaluation processes help the user to get a detailed data analysis or data extrapolation for component design and life-time prediction. Within a bi-lateral agreement Mat-DB hosts also thousands IAEA surveillance data of the International Database of Reactor Pressure Vessel Materials (IDRPVM) of the International Atomic Energy Agency (IAEA). These data come from reactor pressure vessel materials of different nuclear power plants of IAEA member states. These tensile and impact materials data tested before and after irradiation are uploaded in a confidential area of Mat-DB only accessible for the entitled IAEA administrators.

1. INTRODUCTION

In order to reduce Greenhouse Gas and CO2 emissions on the one hand side and satisfy the electrical power demand on the other hand nuclear energy is an important energy source for the next decades. During the recent EURELECTRIC conference 2009[1] of electrical power suppliers such as ENEL, RWE, VATTENFALL and E.ON it was pointed out that nuclear power in Europe has to play even a larger role in 2030 than today to decarburize the emissions. Generation IV reactor systems[2] are probably not yet ready by then to replace existing nuclear pressurised water reactor technology.

For the extension of remaining operation time the knowledge of reliable rest life-time of existing reactor vessels is crucial. The understanding of the exact degradation process of Western and Russian type reactor pressure vessels and piping materials under irradiation is also fundamental as well as for the design, construction and licensing and for safe, reliable and cost-effective operation of the next generation nuclear reactor systems.

As more surveillance data available with detailed metadata information as better life-time analysis can be performed. Within a bilateral agreement the IAEA surveillance reactor vessel materials data have been transferred into the JRC-IE web-enabled Mat-DB. Since the data transfer has been finished Mat-DB hosts thousands of IAEA surveillance data from different nuclear power plants of their member states in secure and confidential data pools only accessible by IAEA or member state data administrators. The pools contain experimentally measured tensile, fracture toughness and impact data covering base and weld materials as well as the weldments with their heat affected zones tested before and after irradiation.

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[1] website: http://www.eurelectric.org/AfterBucharest2009/Welcome.htm
[2] website: http://www.world-nuclear.org/info/inf77.html

2. MAT-DB

The materials database Mat-DB of JRC-IE is deployed to the secure ODIN (On-line Data Information Network) portal: https://odin.jrc.ec.europa.eu. Registration for access control is mandatory. The ODIN portal provides access to various web-enabled database applications for engineering and nuclear safety. The databases share fast cabling, firewall, secure connection, redundancy to guarantee high availability, central data and user management, professional hard- and software infrastructure in order to facilitate maintenance and further development, e.g. ORACLE as a powerful RDBMS, and professional database servers with high capacity Raid Arrays for the storage of data and documents. The databases are continuously maintained and updated.

Final reports of R&D projects, drawings of any format and the whole project documentation including minutes of meetings can additionally be stored in a structured manner (e.g. public and confidential areas) in the documentation management database DoMa and linked to project specific data sets. As regards confidential data, access is restricted by the responsible project leader acting as an administrator who can grant access rights.

2.1. Data content

Mat-DB covers thermo-mechanical and thermo-physical properties data of engineering alloys at low, elevated and high temperatures for base materials and joints, including irradiated materials for nuclear fission and fusion applications, thermal barrier coated materials for gas turbines and properties of corroded materials. The corrosion part refers to weight gain/loss data of high temperature exposed engineering alloys and ceramic materials. For each test type (see table 1) the database structure reflects international test standards and recommendations and is described in a file accessible for any user. The database structure is extended and contains more than 130 tables and 1850 fields.

Table 1: Materials test types covered by Mat-DB

MECHANICAL PROPERTIES	IRRADIATION
CRACK GROWTH & FRACTURE	Irradiation creep
Creep crack growth	Swelling
Cyclic creep crack growth	In-pile relaxation
Fatigue crack growth	TENSILE
Fracture toughness	Compression
Impact	Multiaxial tensile
CREEP	Uniaxial tensile
Cyclic creep	Small punch tensile
Multiaxial creep	THERMO-PHYSICAL PROPERTIES
Torsional creep	Density
Uniaxial creep	Electrical resistivity
Small punch creep	Emissivity
RELAXATION	Linear thermal expansion
Multiaxial relaxation	Poisson’s ratio
Uniaxial relaxation	Specific heat
FATIGUE	Shear modulus
High cycle fatigue	Thermal conductivity
Low cycle fatigue (load control)	Thermal diffusivity
Low cycle fatigue (strain control)	Young's modulus
Thermal fatigue	CORROSION
Thermo-mechanical fatigue	High temperature corrosion

2.2. Data entry and retrieval

Project partners who are entitled to enter data into Mat-DB receive data entry rights for certain source identifiers under which they can upload their own materials data. For the sake of traceability, metadata for detailed batch, source, test condition and specimen details are mandatory. Predefined thesauri for alphanumeric fields and direct input of test results from customer formatted EXCEL files ease the data entry process. Assistance is also provided by the tool itself which gives user guidance and on-line help for data entry and retrieval. Once entered, data must be validated by the source partner before they can be retrieved by authorised project partners. Test type specific reports are automatically generated after selecting data subsets. These default reports can be changed into individual report structures. Predefined graphical views including numerical data presentation such as uniaxial creep curves or stress to rupture isothermals can be performed and exported as EXCEL objects by mouse click for further use. The same is valid for Mat-DB evaluation results.

2.3. Evaluation program library

Mat-DB features a library of evaluation programs for web-enabled assessment of uniaxial creep, fatigue, crack growth and high temperature corrosion properties (see table 2). Evaluations can be performed after data retrieval by pressing the evaluation button or independently of Mat-DB by transferring users' data in a given format to the programs. The evaluation routines are integrated under Flex, a new tool built by Adobe which combines the full range of user-interaction associated with client/server systems with the robust, low-maintenance environment of a web application and makes the evaluation process much faster and much more user-interactive. The results can be exported to MS EXCEL for further use on the local PCs of the users. The fast evaluation processes help the user to get a detailed data analysis or data extrapolation useful for component design and life-time prediction. Figure 1 and 2 show for example the extrapolation of materials data of a Ni-base alloy heat by using a 2^{nd} order polynomial of the Minimum Commitment Method [1]. The data pool which was used contained 227 test results in the temperature range between 800 and 1000°C. Figure 1 shows the parameter P_{MCM} figure 2 the corresponding isothermals.

Table 2: Mat-DB evaluation program library

Creep
Creep relations*:* Norton creep law, Prandtl creep law, Soderberg creep law, Monkman-Grant relation, Dobés-Milîcka relation
Extrapolation methods*:* Larson-Miller, Manson-Haferd, Manson-Brown, Orr-Sherby-Dorn, Spera, Minimum Commitment Method
Constitutive creep equations: Theta projection, Mc Vetty equation, Kachanov equation
Interpolation routines*:* Polynomial creep curve fit, Polynomial stress dependence, Isochronous & isostrain determination
Fatigue
Ludvik law, Manson-Coffin relation, Basquin analysis, Frequency modified Manson-Coffin relation
Crack growth
ASTM compliant creep crack growth analysis, Creep crack growth plot, Fatigue crack growth analysis
HT Corrosion
Weight gain/loss analysis: Power law, Power law-time, Parabolic m^2, Parabolic $t_{1/2}$, Kp(t), Breakaway

Evaluation results are immediately available for the user. Calculations are performed in a tenth of a second even for complex data sets. That enables the user for instance to compare in very short time different extrapolation methods and calculations performed with different polynomials. The user can find out very quickly which method fits the best to the material and related batch.

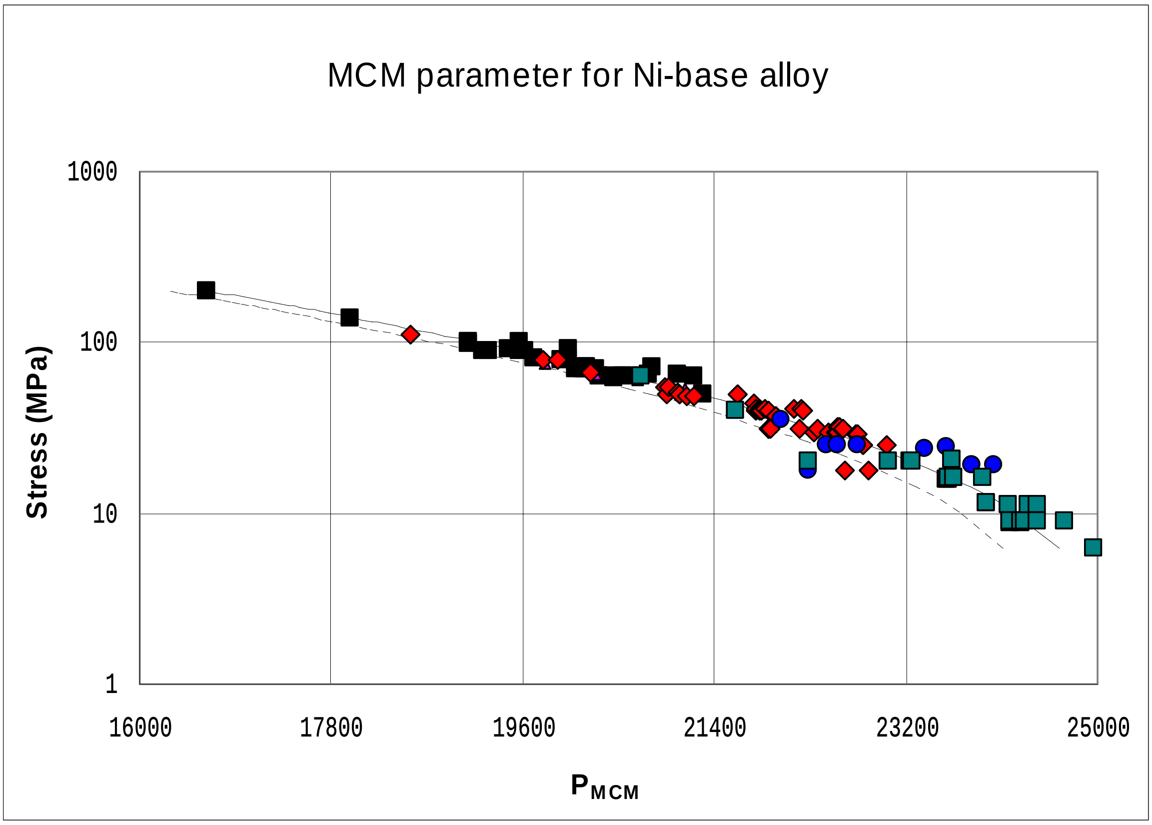

Fig. 1. Minimum Commitment Method P_{MCM} extrapolation of a Ni-base alloy

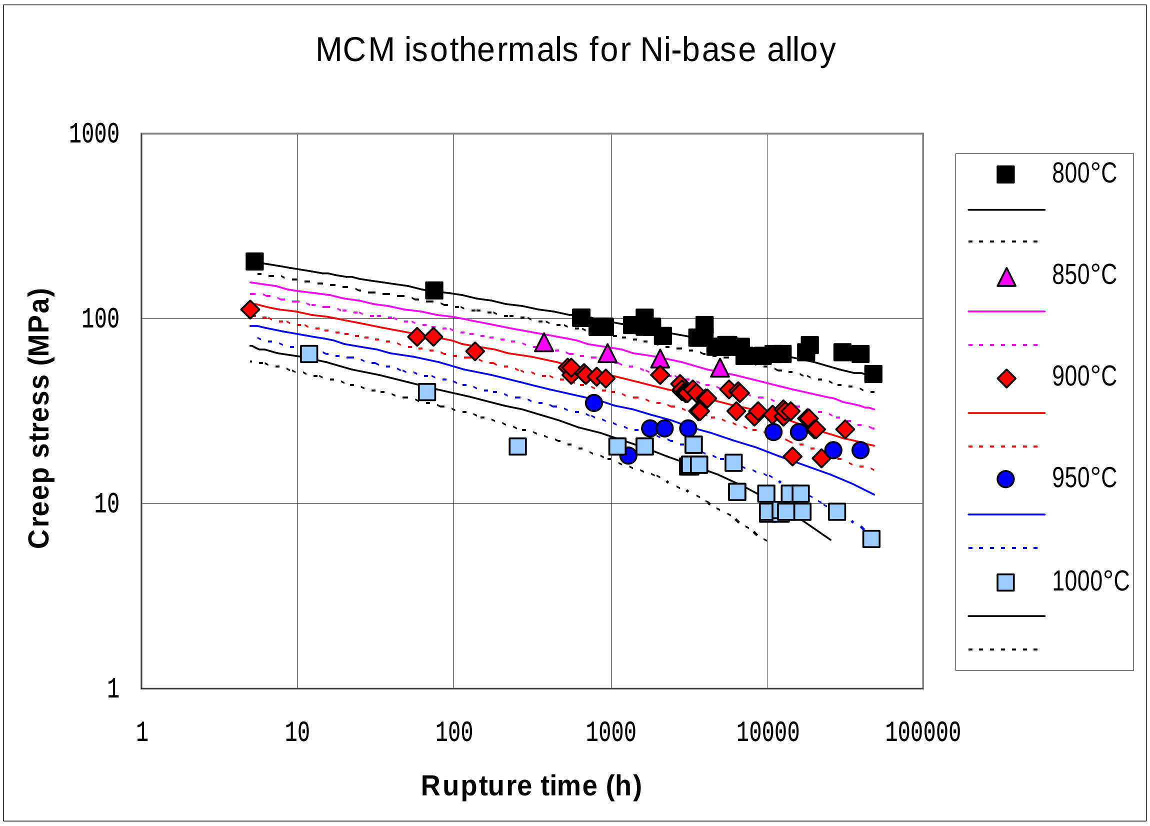

Fig. 2. Minimum Commitment Method isothermals of a Ni-base alloy

3. IAEA SURVEILLANCE DATA

The IAEA Reactor Pressure Vessel Material database was founded in 1986 to collect and evaluate the data of the large coordinated research program of the Agency (CRP-3) on the effect of chemistry on irradiation embrittlement. 21 laboratories worldwide irradiated and tested 14 different research heats and welds. The obtained large number of results required to elaborate a database. Later this database has been extended to collect data from other research programs and surveillance data. Since the surveillance data are sensitive information the data are open only for the database members and coded. Coding means that only the technical data can assessed by the members, the data source can only be named via the IAEA with the permission of the donor institutions [2, 3, 4].

The decision to transfer the IAEA surveillance data into Mat-DB was made because of the fact that the IAEA surveillance vessel database was locally installed on a PC and has had a very limited user-interface for data entry and retrieval. The database was built up on Microsoft Access and was only used to store and administrate the data. This application was hosted at the Hungarian Academy of Sciences KFKI Atomic Energy Research Institute in Budapest in cooperation with IAEA. The data were delivered by the member states in given EXCEL templates. From EXCEL they were uploaded in the surveillance vessel database by using simple SQL[3] commands. Retrieving the data was done in the same manner, with SQL. This kind of database interaction was little effective and work-intensive.

The data transfer into Mat-DB was a very time-consuming and complex procedure because both database structures were totally different. A program using the Visual Basic language was written to download the data via MS EXCEL from the IAEA database upload them into Mat-DB. Afterwards the data were checked and validated in Mat-DB. During a VAMAS[4] database meeting in Osaka, Japan in 2001 a Japanese scientist reported about a similar study work to transfer data between two different structured material databases and pointed out that the transfer of the test data including all metadata took him half a year to finish it [5]. Since then the Japanese were very active within the framework of CODATA[5] in the definition of material ontologies and semantics [6].

Mat-DB for instance is organized in different entities. Figure 3 shows the Mat-DB structure with entities containing information about source, specimen, material, test condition and test result and linked through a relation table. In case of material tests performed on dissimilar welds there is additional information on the second material and the joining technology necessary. The entities contain different tables such as in case of the material one: tables for material designation & production, chemical composition, heat treatment, grain size, hardness and microstructure. The input of important fields for better traceability is mandatory.

[3] SQL: Structured Query Language
[4] VAMAS: Versailles Project on Advanced Materials and Standards
[5] CODATA: Committee on Data for Science and Technology: http:[[www.codata.org[index.html

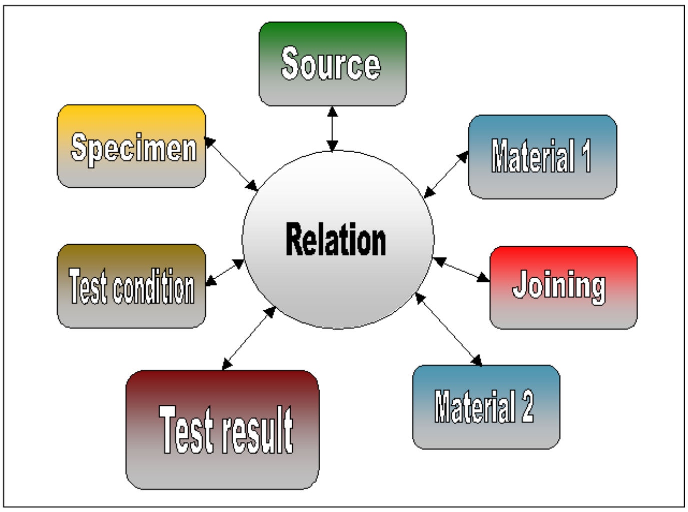

Fig. 3. Mat-DB entities linked through a relation table

Taking into consideration material ontologies and semantics an XML[6] schema has been implemented in Mat-DB [7] to ease complex materials data exchange for the future, e.g. for agreed data exchange with GIF[7] partners. An XML schema is an XML document that defines the valid contents of a particular class of XML documents. Some well-known examples of technical schemas are e.g. MathML schema, which is an XML application for describing mathematical notation and capturing both its structure and content, and femML, Finite Element Modeling Markup Language, which is an effort addressing the problems of data interpretation and application interoperability in the Finite Element Modeling domain of activities for model and/or product specification portability. The Mat-DB XML schema prototype refers to MATML. The Materials Markup Language (MatML) is a de facto standard which serves as a general purpose markup language for the exchange of material properties data but not yet considering experimentally measured materials data [8]. Because of the importance of interoperability a new European CEN activity on 'Economics and Logistics of Standards compliant Schemas and Ontologies' has been initiated [9].

4. IRRADIATION EMBRITTLEMENT ANALYSIS

The understanding of the exact degradation process of different reactor pressure vessels, in-core structures, fusion device materials under irradiation is fundamental as well as for the design, construction and licensing and for safe, reliable and cost-effective long-term operation of the recent and next generation nuclear reactor systems. The key embrittlement mechanisms taking place during irradiation of structural materials are described as follows [10]:

- Direct matrix damage due to neutron bombardment can be assumed to be root square dependent on fluence for a given material and a given irradiation temperature.
- During direct matrix damage formation, Cu together with other elements is known to lead precipitation mechanism of nano-precipitates also including matrix hardening and embrittlement. Such a mechanism is assumed to continue until saturation depending on the available amount of precipitants, Cu concentration in particular.
- Other elements such as phosphor can segregate in grains or at grain boundaries, also in combination with matrix damage or attracted into Cu-type precipitate. Since diffusion of segregants also plays a role, this mechanism becomes rather difficult to understand in detail.

Material embrittlement shifts the transition temperature from brittle to ductile fracture to higher temperatures and reduces the overall ductility of the materials. There are series of national codes

[6] XML: eXtended Markup Language
[7] GIF: International Forum for future GEN IV Reactor Systems

which gives guidelines to determine the embrittlement of RPV materials. The codes are requesting tensile, impact and fracture mechanics materials testing.

The Master Curve approach [11] for assessing the fracture toughness of a sampled irradiated material has been gaining acceptance throughout the world. This direct measurement approach is preferred to the indirect and correlative methods used in the past to assess irradiated RPV integrity. The other methods have used the Charpy V-notch transition temperature shift (usually defined at the 41J temperature, T41J) as the measure of radiation embrittlement. These methods, when combined with reference fracture toughness curves, such as the ASME code K_{IC} and K_{Ia} (or K_{IR}) curves, allow the determination of a lower bound linear elastic fracture toughness that has consistently been shown to be conservative relative to the measurement of actual fracture toughness. RPV material database is basic source for preparing these type material characteristics.

5. IAEA SURVEILLANCE REACTOR PRESSURE VESSEL DATA

The IAEA surveillance data pools contain in total 41523 experimentally measured impact, tensile and fracture toughness data sets from nuclear power plants in Brazil, France, Hungary, Korea, Spain, Russia and USA. The histogram in figure 4 shows the number of surveillance data sets coming from these countries and the histogram in figure 5 the number of reactors of different member states providing data.

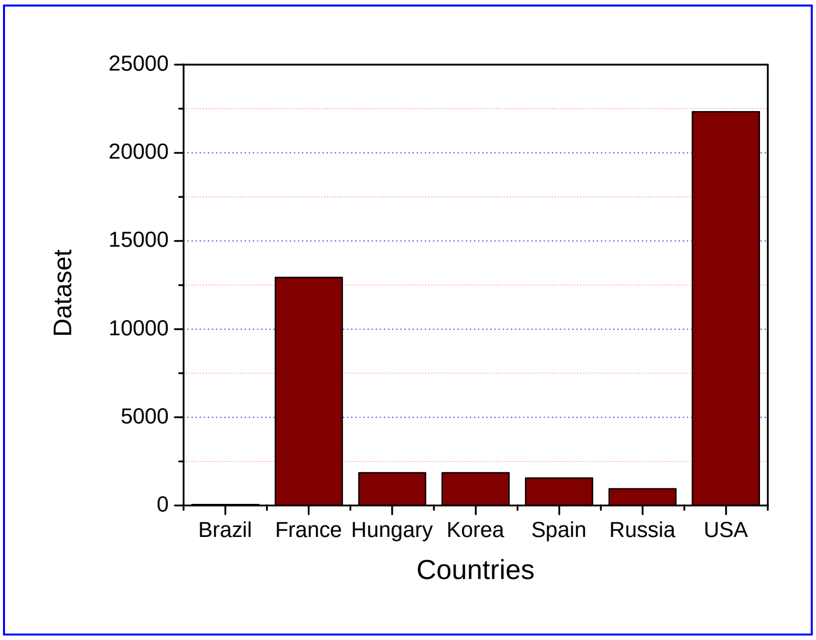

Fig. 4. Number of surveillance data coming from different member states

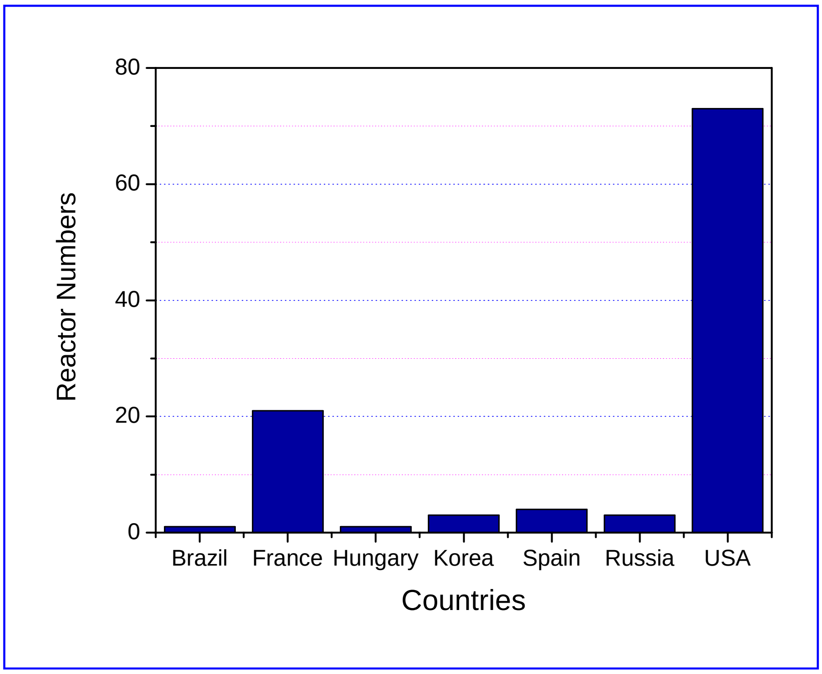

Fig. 5. Number of member state reactors providing surveillance data

The following figures 6 to 11 show results of Mat-DB surveillance data. Selected sets of 15H2MFA material and welds in received and aged conditions were filtered out. Such datasets are the base of the evaluation process for reliability, safety and lifetime of operating units. From them Charpy transition temperature, Master curve, flow curve and other aged material characteristic trend curves can be analyzed by using built-in database routines, or by data export to the favorite mathematical software package of the user.

Material testing is very expensive. Data on aged materials are even more valuable since the ageing process (e.g. thermal, fatigue, corrosion, irradiation etc.) are also very costly and time consuming. Using surveillance data obtained on trepans cut from shut-down units after long operation, surveillance data and laboratory data can be compared and flux as well as the synergetic effect of different ageing mechanisms can also be evaluated. Storing data in a materials database is a general task of Knowledge Management.

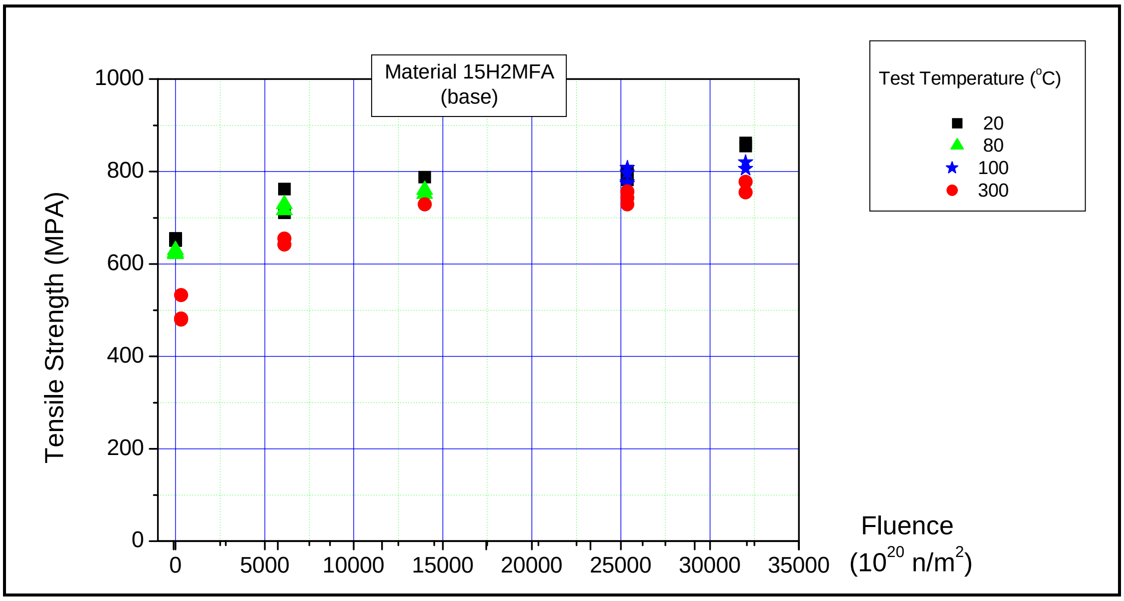

Fig. 6. Tensile strength versus fluence for 15H2MFA base material

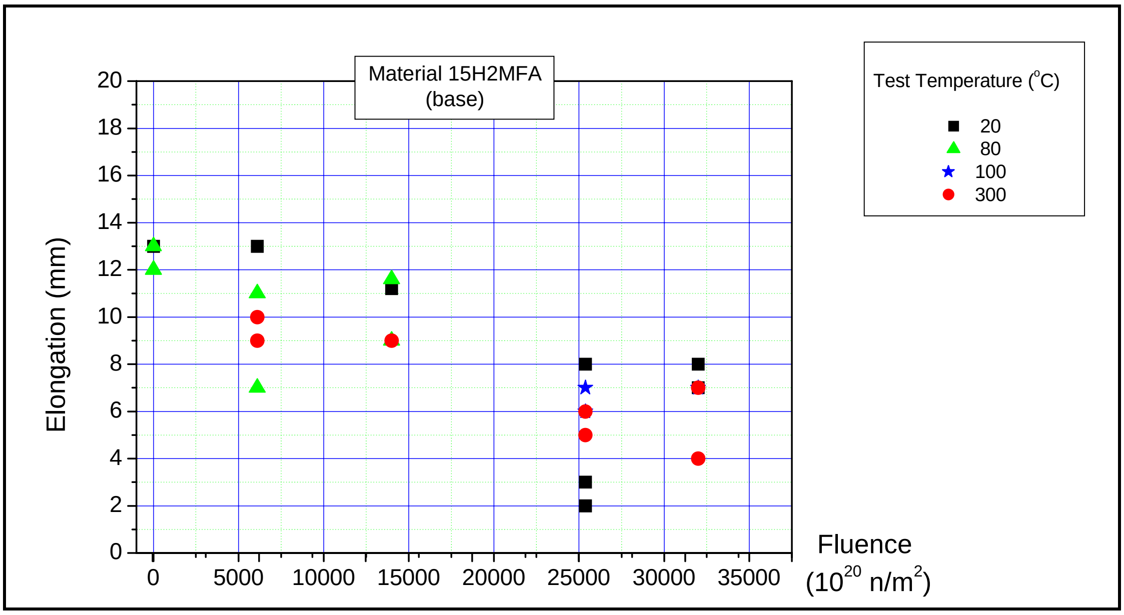

Fig. 7. Tensile elongation at rupture versus fluence for 15H2MFA base material

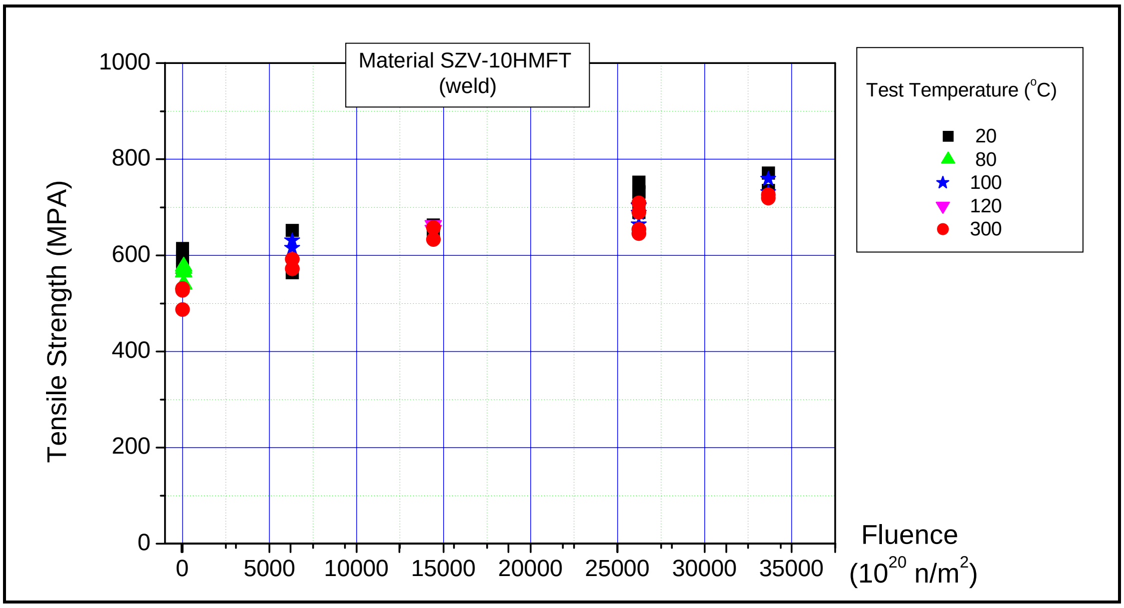

Fig. 8. Tensile strength versus fluence for SVZ-10HMFT weld material

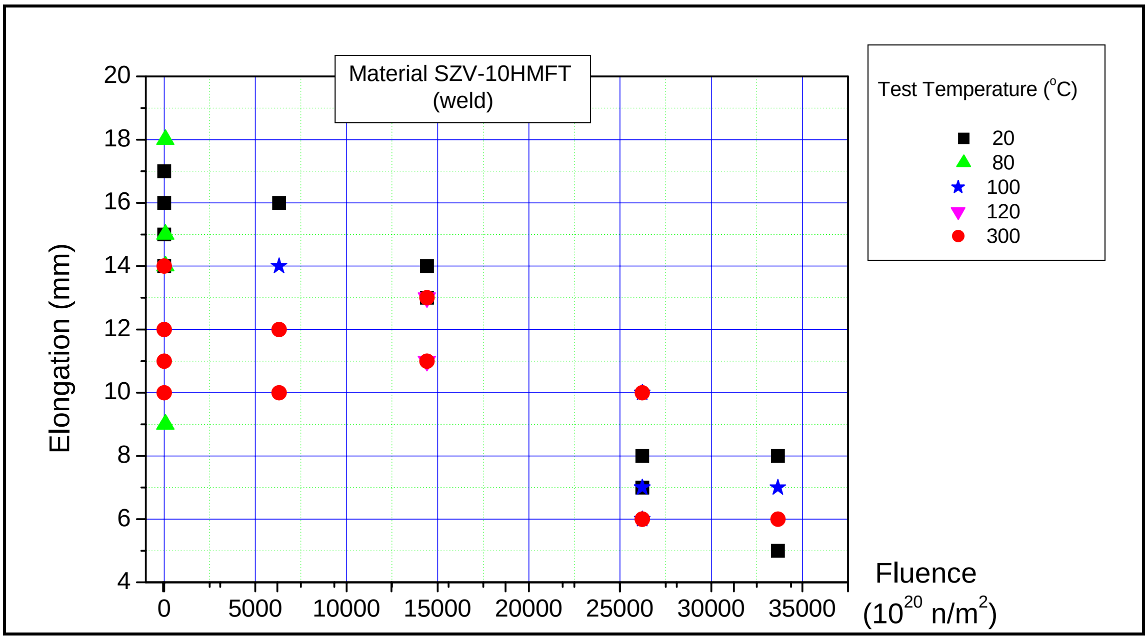

Fig. 9. Tensile elongation at rupture versus fluence for SVZ-10HMFT weld material

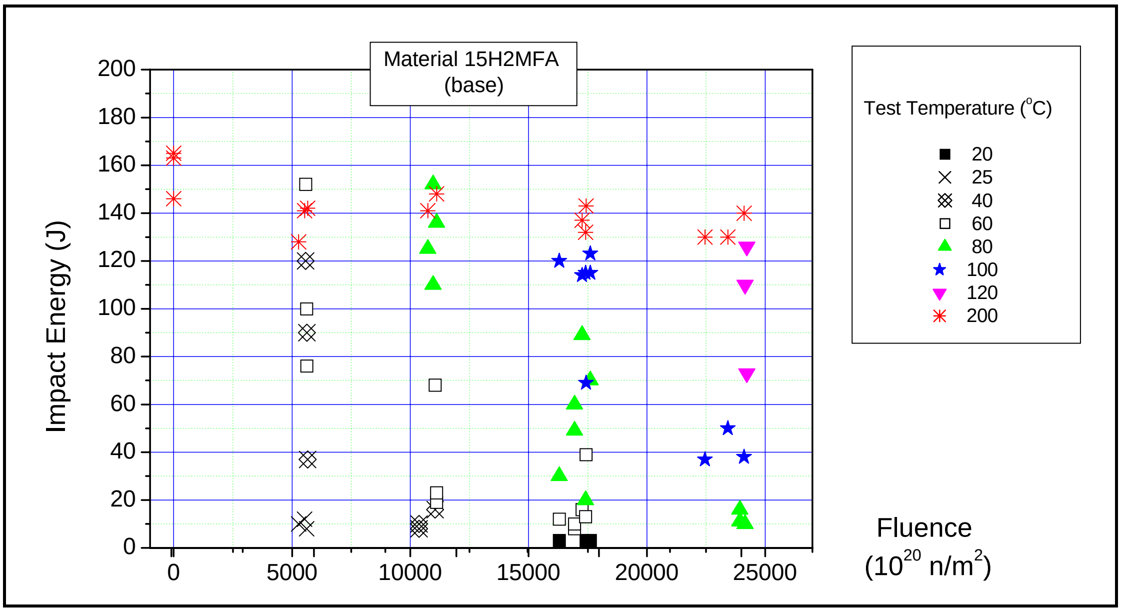

Fig. 10. Charpy-V impact energy versus fluence for 15H2MFA base material

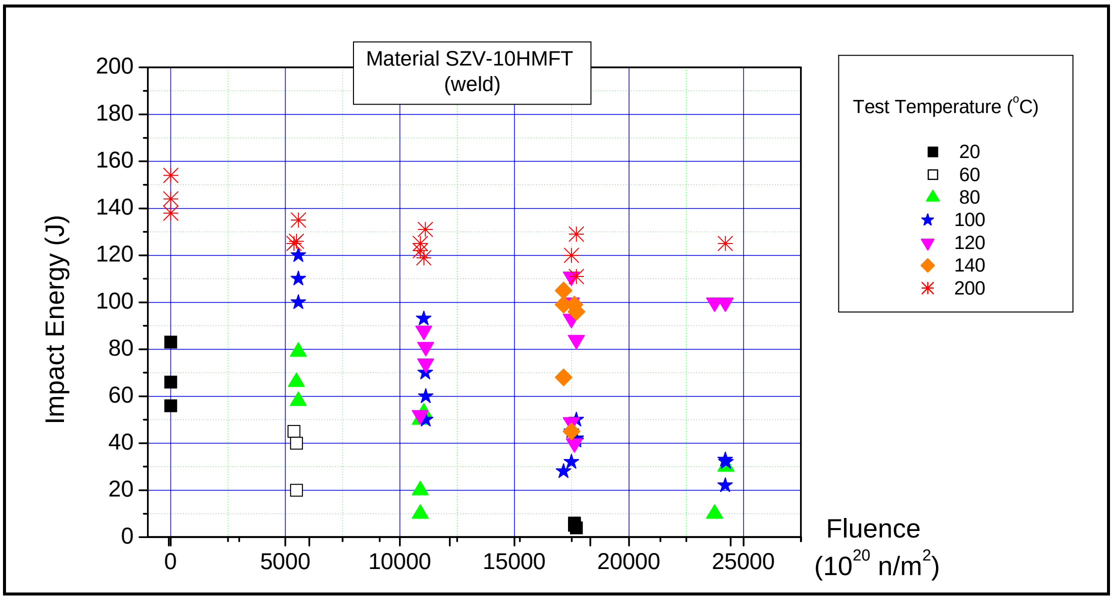

Fig. 11. Charpy-V impact energy versus fluence for SVZ-10HMFT weld material

6. ADVANTAGES IN USING MAT-DB

The IAEA surveillance data are stored on the secure Mat-DB server in confidential pools. Data access rights can be granted by the data owners of the IAEA member states. They can be shared with each other and retrieved on-line together with public R&D data in fast manner world-wide wherever Internet access is available. The data can be analysed graphically and numerically and processed for further use on the local PCs of the users. The data are important for design, construction and licensing. They can also be used to re-calculate the actual life-time after incidents which can cause increases of primary or secondary stresses in the reactor vessel wall. Surveillance data in combination with recent R&D data would also provide better information about embrittlement healing after annealing procedures for existing reactors.

Data entry of new surveillance data can remotely be done by the members themselves. The data entry process is easy and straight forward; test results together with curve information can be uploaded directly from the local PCs. Mat-DB data entry interface request mandatory information which is important for the evaluation process. The database also owns thesauri for many alphanumeric fields and specimen types. They can be selected from boxes and help to standardize the data content. Fracture mechanics data, if available, can be added to the existing data pools. The maintenance of Mat-DB is guaranteed by the JRC-IE. Upgrades, e.g. new test types or evaluation routines, and updates are permanently executed. The Master Curve Approach is for instance under implementation in the Mat-DB evaluation program library. Data entry and administration assistance are provided by JRC-IE.

7. CONCLUSION

To store the IAEA surveillance reactor vessel materials data in Mat-DB is not only an issue of knowledge preservation, it is also very useful for design, construction and licensing process of new reactors and for fast embrittlement analysis to actualise the life-time prediction. To build up own database tools with extended user-guidance demands very cost-intensive investments. JRC-IE as neutral European institution offers the use of the database free-of-charge to IAEA members and guarantees security, data confidentiality and maintenance of the database application. Necessary updates and upgrades, e.g. database extension to new test types or implementation of new evaluation routines, can be arranged on request. Other big projects such as the former German High Temperature

Reactor project [12] and European R&D projects for Generation IV rector systems such as the HTR[8] related ones HTR-M[9] and RAPHAEL[10] and the cross-cutting project GETMAT[11] have been using Mat-DB for central data storage and administration [13].

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[8] HTR: High Temperature Reactor
[9] HTR-M: High Temperature Reactor - Materials
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