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Building an integrated digital environment for nuclear science and engineering

Norman Swindells[1]

[1] Managing Director, Ferroday Ltd, UK

ABSTRACT

This paper proposes that an integrated digital environment for nuclear science and engineering should be built from the established technology specified in the International Standards for product data representation and exchange developed by ISO TC184/SC4. These standards provide comprehensive, scalable and extendable representations of engineering data by using computer-processable information models to support interoperability between different software systems and through-life data management. Examples of the application of one of these Standards, ISO 10303-235, to the representation of steel plate and to data from three types of ultrasonic NDT inspections illustrate some of the capabilities of this technology.

INTRODUCTION

Throughout the supply chain and the life cycle of an engineered product there is the need for the transfer of digital information about the product between different software systems, each with its own internal method of representing the data. Figure 1 is an attempt to illustrate this life cycle. Digital interoperability between different systems therefore requires a method to ensure that the data in the message from one system can be understood and used by the receiving system. For the long life times of products and plant, such as in the nuclear sector, the digital data also needs to be conserved and yet be still understandable and usable when the originating software is obsolete or no longer available.

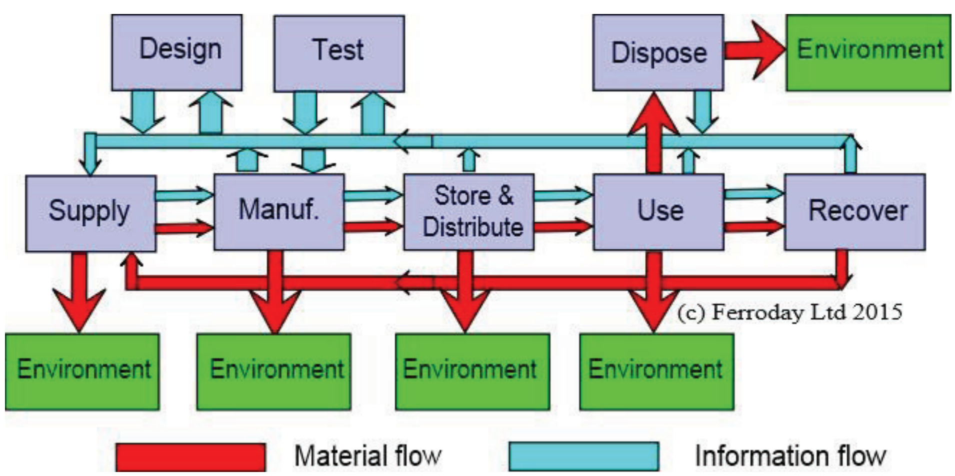

Figure 1. Illustration of the flow of digital information throughout the life of a product

The solution for interoperability and information conservation of product data adopted by the aerospace, automotive, defence, construction, machine tools, process plant, offshore oil & gas and other sectors is to represent the product data in non-proprietary, computer-understandable information models. The models are specified in a series of International Standards to provide a common language for the digital representation of engineering information. These Standards have been developed since 1984 within the ISO Technical Committee 184, Sub-committee 4 (ISO TC184/SC4) in a collaborative effort by hundreds of engineers from the main industrial nations and most of the global industrial sectors. An overview of some of technology based on these standards and of some of their applications has been published (Moreno, 2014).

The International Standards that are basis of this technology include:

- ISO 10303 Product data representation and exchange – a series of computer-processable specifications for the representation of technical information on individual products, processes and properties for all stages of the product life cycle;
- ISO 13584 Parts libraries – a classification model for collections of products or processes. This can act as a computer-processable data dictionary to define the terminology needed in an application of an ISO 10303 standard.
- ISO 15926 Integration of life cycle data – includes information models and reference data libraries as a standardised reference source for the technical terms used in major construction projects such as offshore oil and gas rigs and chemical process plant.

ISO 10303 also provides the technology for product data representation and exchange that is used for ISO 13584 and ISO 15926. The normative parts of all of these standards are written in the EXPRESS language (Schenk and Wilson, 1994, ISO, 2004). EXPRESS is a type of object-oriented language to specify the information objects (as entities), their properties (as attributes of an entity) and their relationships that form the models to represent a version of the real engineering world. A value of an attribute can be a reference to another entity and entities can be in a super type - subtype structure. Values of attributes and relationships can be constrained by rigorous rules. Data files of the instances of the model entities can be recorded in plain text (ISO, 2002), conforming to ISO 10303-21 (a Part 21 file), or as an XML conversion of a Part 21 file (ISO, 2007b). A standard data access interface (SDAI) is specified (ISO, 1998) and bindings to the SDAI are specified for C (ISO, 2001), C^{++} (ISO, 2000) and Java (ISO, 2007a). There are also specifications for the binding between EXPRESS and XML (ISO, 2005) and for the binary representation of EXPRESS data (ISO, 2011).

Information models in the ISO 10303 family of standards are of two types:

- Integrated Generic Resources (IGR) – a description of the basic concepts of engineering and manufacturing in a single generic information model;
- Application Protocols (AP) – selections from and extensions of the generic model to represent specific industrial situations. It is an AP that is implemented in, or interfaced to, engineering application software for real-time processing, communication and archiving.

The information models are developed by very rigorous, formal methods to describe, in a computer processable form, aspects of the real world of manufactured products, manufacturing processes and their properties. They provide engineering specifications for this data with the important benefit that they are independent of proprietary software. These specifications can also be used as the basis for quality control and quality assurance of the engineering data, just as with any other engineered product. The additional value of these information models is that they conserve both the syntax and the semantics of the data, ensuring that the information that the data represents can still be understood and interpreted correctly in the future.

Ferroday Ltd is responsible for the development of two information models in the ISO 10303 series. ISO 10303-45: 'Material and other engineering properties' is a part of the IGR and is an information model for the representation for any property of any product and its value (ISO, 2014a). ISO 10303-235: 'Engineering properties for product design and verification' is an AP that extends the IGR to represent the collection of processes by which the value of the property of a product is obtained (ISO, 2009). The scope of ISO 10303-235 is summarised in Table 1.

A more extended description of the technology and some potential applications of ISO 10303-235 to some nuclear requirements have been described (Swindells, 2014). The Building Information Model – BIM (Simpson, 2013) uses information objects in an entity-relationship model to describe the physical and functional characteristics of constructed places but this is one model for one sector. The Standards from ISO TC18/SC4 provide many information models for many sectors and there are many fundamental engineering concepts in common between these models.

Table 1 Summary of the scope of ISO 10303-235

Technical	Administrative
Products, product history	Persons, organizations, addresses
Properties of products and resources	Approvals, qualifications, certifications
Processes and their properties	Dates, times
Numerical and descriptive values	Documents and files
Mathematical expression values	External references
Uncertainty and reliability of all values	Effectivity
Product substance composition and structure	Languages
Dimensional and positional tolerances	Locations
Resources	Requirements

APPLICATION OF ISO 10303-235 TO STEEL PLATE

The application of ISO 10303-235 to describe the characteristics of steel plate was stimulated by the requirements of the AFCEN Engineering Code for Generation IV nuclear reactors and ITER (AFCEN, 2011). The AFCEN RCC-MRx Code requires detailed information to be recorded for all of the stages of the history of a component and a record of the location of the samples removed from a component for the manufacture of any test pieces. Steels are becoming more complex to meet the requirements of modern energy plant and the presence of some elements in micro quantities has a major effect on the expected behaviour. The requirements for any representation of the characteristics of a component to conform to the Code must therefore be able to deal with the full complexity of all the information relating to a steel product in one file record. The complete information will also be compiled from several sources and so each must conform to the same specification of representation so that the different inputs can be combined.

ISO 10303-235 has been designed for just this collection of requirements. Relevant concepts defined in ISO 10303-235 were therefore selected to create an instance of the information model in the Standard to represent the properties of a steel plate, 20mm thick made from P265PH steel. This model identified three stages of manufacture: melt, ingot and hot-rolled plate in order to represent an example of the stages for an actual plate. The model also included the representation of a standard product of P265PH steel so that the properties of an actual product could be compared with the standard specification. Since the details of an actual plate were not available, the full chemical composition of 18 elements was referenced to the standard product in this example but the information structure could have been duplicated and populated with the values for the actual plate if these were known. The values for the chemical analysis of the standard product were the specification for P265PH steel in EN 10028-2:2003 (BSI, 2003). The model also provides representations for the samples taken from the heat and from the plate so that compositions and measured properties could be attached to the appropriate stage of manufacture and to the artefacts that were actually measured.

The examples of properties that were selected for representation by the model were the yield strength and the maximum tensile strength and the values chosen to attach to the standard product for demonstration purposes were those specified for 200 degrees Celsius in the AFCEN RCC-MRx Code. The testing process to measure these property values was represented as conforming to the procedure specified in EN 10002-5 (CEN, 1991) and the rates of deformation during the test were chosen to be within the limits specified for the measurement of the yield stress and the tensile stress respectively. The model also included the dependence of the values of these properties on the temperature of the test and on the thickness of the plate from which the sample was taken. The specification for the steel plate includes the requirement that it shall be normalised. The normalisation can be either achieved in the rolling process or by separate heat treatment of the plate and how this was done should be recorded. An information structure that can record the conditions of the normalisation process has therefore been included in the model and the microstructure of the steel was also described.

APPLICATIONS OF ISO 10303-235 TO DATA FROM ULTRASONIC NDT INSPECTIONS

Representations of data for three examples of ultrasonic NDT inspections were developed as applications of ISO 10303-235: the detection of a defect in a welded structure by the phased array method, the detection of Hydrogen induced cracking (HIC) in the hemi-spherical end of a steel pressure vessel by the pulsed echo method and the detection of three defects in a welded structure by time-of-flight diffractrometry (ToFD). These examples were developed as a Feasibility Study, funded as part of the UK Government project: ‘Developing the civil nuclear supply chain’, intended to introduce innovation into the nuclear sector. Each example of the report of the data was in two sections: a printed copy of a screen image from the control and measurement instrument and a table for some of the values of the settings of the control instrument, the ultrasonic probe and the beam. The images for the phased array and the pulsed echo method showed in four quadrants: the top view(C-scan); the side view (D-scan); the end view (S-scan) and a portion of the line of the scan through the defect (A-scan). The image also contained some information about the item being inspected, the location and direction of the path of the scan and the dimensions and location of the defects that were detected. The ToFD report showed a cross section of a welded structure. The application models referenced the data files of the A-scans as an external source of data.

Phased Array Method

Figure 2 illustrates an example of an inspection of a welded pipe assembly by use of a phased array NDT method. All of the items visible in the image contribute information that is important in determining the validity of the inspection and the verification of the structural integrity of the component.

Figure 2. An illustration of an example of an NDT inspection by the phased array method

The challenge therefore was to represent in a digitally standardised form all of the information relating to all of the relevant items in the image.

The illustration is of the inspection of a weld between two steel pipes and for the purpose of the modelling it was assumed that the pair of pipes was a component of a piping system that was a part of a processing unit in a process plant. The selection of entities from ISO 10303-235 to create the model for this application was guided by the experience with steel plate example, described above, and by the requirements of the AFCEN Code for the representation of the details of the product, its composition and properties specified for the mechanical items in a nuclear installation. In the application model the compositions of the pipes on both sides of the weld were represented. The application model also took account of the recommendations from the UK Health and Safety Executive (HSE, 2015) for the operation of NDT inspection. The properties of the products that were represented were: the yield and tensile strengths, the percentage elongation, the Charpy impact value, the fracture toughness, the microstructure and the velocity of sound. The mechanical properties are needed for the engineering critical assessment (ECA) of the structural integrity as recommended by the HSE and specified in BS 7910 'Guide to the methods for assessing the acceptability of flaws in metallic structures' (BSI, 2013).

The application model derived from ISO 10303-235 for this example of ultrasonic NDT inspection enabled the representation in a single file of the syntax and the semantics of the data for:

- Product location, identification and assembly relationships
- Product composition, structure, dimensions and properties for engineering critical assessment
- NDT instrument identification and its settings
- NDT probe description and the beam characteristics
- NDT method: type of inspection, path of scan, start and finish of scan, direction, etc.
- References to standards and written procedures
- NDT results: location, shape, dimensions and type of defect
- Verification and approval of method and of product integrity
- Identification, qualifications, certification and approvals of organizations and personnel
- Customer and contract identifications

The Part 21 file for the collection of the instances of the model representation for all of the information in Figure 2 was 31kB.

Pulsed echo method

The example of data supplied for the pulsed echo method was the detection of a large number of individual defects in the hemi-spherical end of a steel pressure vessel due to Hydrogen induced cracking (HIC). In this case, the inspection report recorded the damage as a single volume of defective material in a component and so the model represented this as a single defect. The information structure for the product section of the application model was therefore simpler than the example for the phased array method. The report also included the thickness of the steel and its identification and so the composition and property values could be obtained from European Standards.

The important lesson from this example was that the data for the instrument and probe settings were also sufficiently different from the phased array method to need a slightly different application model for this section of the data. The sections of the model for the composition of the product, the product properties, the identification of the technician, the approvals and certification, etc. were the same as in the example of the phased array method. The size of the Part 21 file for this example was 32kB.

ToFD method

The report provided for the ToFD method did not provide any data for the product being inspected but indicated that it was a weld. Accordingly, it was assumed for the purpose of the exercise that the inspection scenario was similar to that in the first application described above and so the section describing the products could be copied from the application model for the phased array method. Several other sections of the models were similar and so were able to be reused but with different values for the relevant attributes. The ToFD method uses two probes and so this section of the model had to be different from the previous examples and the report identified three defects in the product in this example. The capability to be able to reuse several sections of the models from the phased array example enabled this application model to be completed in a shorter time than for the other two cases. The size of the Part 21 file for this example was 36 kB.

DISCUSSION

The mechanical engineering design and operation of a nuclear energy system is a complex system but no more complex than that of a large chemical plant, offshore oil platform or a modern passenger airliner. These major engineering constructions are subject to as rigorous a regulatory oversight as are nuclear systems and the design and operating lifetimes are just as long. Therefore there should be lessons for the nuclear sector to learn from the strategies used and the progress that has been achieved by these other major engineering sectors in moving towards entirely digital operations. A report from the Aerospace and Defence Industries Association of Europe (ASD-SSG, 2014) identifies the adoption of Application Protocols from ISO 10303 as the basis for their strategy for this change. The Building Information Model is being used in the construction phase for new build nuclear systems but this model does not have the means to cope with the mechanical and electrical engineering details for the components of the plant that can be represented by the standards from ISO TC18/SC4.

Patterson and Taylor (2014) have proposed an Integrated Nuclear Digital Environment based on the use of supercomputers which would need a large supply of data that would be generated from different sources by different software systems. Their remarks on the prospects of using the ISO Standards for data representation for this purpose suggest that are that they are probably not comprehensive enough to handle the diversity and quantities of data envisaged in their proposals. International experience of the use of these Standards and the applications of ISO 10303-235 that are described in this paper, together with many other examples, show that the technology is more adaptable than they suggest. There are several examples where ISO 10303 standards have been used for applications which were not envisaged for the original development and the titles of the standards are often not an appropriate guide to their internal capability. This adaptability is possible because of the level of abstraction of the information models in the IGR and the fundamental engineering concepts that they represent.

Evidence for the international support for this technology is demonstrated by the recent cooperation between the international aerospace and automobile companies for the update of the standards for 3-D CAD geometry, automobile assembly, composite product design, finite element analysis and CFD analysis. These two sectors have jointly supported the development of a new application of the technology to combine the updates of these applications into a single standard to achieve ISO 10303-242 Managed model-based 3D engineering (ISO, 2014b). Both sectors will adopt this standard so that vendors of engineering software will have to implement only one standard for aerospace and automobile applications. This new development uses the model for the representation of properties that is defined in ISO 10303-45.

As the result of the cooperation and efforts of hundreds of engineers over the last 30 years of continuous development the scope and application of the standards from ISO TC184/SC4 therefore now goes much further than the representation and exchange of 3-D CAD geometry, which was an original aim. This is due to the recognition that the representation of information for unambiguous communication always requires: the data items that represent the information, an information model to define the syntax and the semantics for the representation and a dictionary to define the meaning of the data items. A sentence in a natural language is an example of a standard information model that can be repeatedly used for the instances of the representation of information and its communication. For any unambiguous communication it is essential that all of those involved use the same information model and the same dictionary.

These are the fundamental concepts that are the basis of the standards for data representation developed within ISO TC184/SC4. They have provided a globally supported system that is: comprehensive, increasingly integrated, scalable for different amounts of data and extendable to new engineering concepts and new requirements as they will arise through the future progress of engineering development.

CONCLUSION

The applications of ISO 10303-235 to the representation of data for steel plate and the inspection of components by ultrasonic NDT inspection has shown that this example of the technology of data representation by an International Standard is extendable to situations of interest to the nuclear sector and demonstrates the flexibility and extensibility of the technology.

The fundamental features of this technology of data representation by standardised information models are being used as the basis for the strategies of integration, interoperability and conservation by most high value engineering sectors.

Therefore the nuclear sector should not develop its own digital environment but can adopt the established technology, benefit from the experience of the pioneers and avoid the problems of digital interoperability and communication that were identified by the aerospace and auto industries 30 years ago.

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REFERENCES

AFCEN (2013). *RCC-MRx Code*, Association Française pour les règles de conception de construction et de surveillance en exploitation des matériels des Chaudièrs Électro-Nucléaires, Paris, France.

ASG-SSG (2014). *Through Life-cycle Interoperability*, Report of Aerospace and Defence Industries Association of Europe, http://www.asd-ssg.org/through-life-cycle-interoperability (accessed 2015-02-23).

BSI (2003). *BS EN 10028-2:2003: Flat products made of steel for pressure purposes – Part 2: Non alloy and alloy steels with specified elevated temperature properties*, British Standards Institute, London, UK.

BSI (2013). *BS 7010:2013: Guide to methods for assessing the acceptability of flaws in metallic structures*, British Standards Institute, London, UK.

CEN (1991). *EN 1002-5 Metallic materials –Tensile testing – Part 5: Method of testing at elevated temperatures*, European Committee for Standardization, Brussels, Belgium.

HSE (2015). Guidance – Inspection/Non Destructive Testing, http://www.hse.gov.uk/comah/sragtech/techmeasndt.htm (accessed 2015-02-23).

ISO (1998). *ISO 10303-28 Product data representation and exchange – Part 28: Implementation methods: Standard data access interface.* International Organization for Standardization, Geneva, Switzerland.

ISO (2000). *ISO 10303-23 Product data representation and exchange – Part 23: Implementation methods: C++ language binding of standard data access interface.* International Organization for Standardization, Geneva, Switzerland.

ISO (2001). *ISO 10303-24 Product data representation and exchange – Part 24: Implementation methods: C language binding of standard data access interface.* International Organization for Standardization, Geneva, Switzerland.

ISO (2002). *ISO 10303-21 Product data representation and exchange – Part 21: Implementation methods: Clear text encoding of the exchange structure*, International Organization for Standardization, Geneva, Switzerland.

ISO (2004). *ISO 10303-11 Product data representation and exchange – Part 11: Description methods: The EXPRESS language reference manual,* International Organization for Standardization, Geneva, Switzerland.

ISO (2005). *ISO 10303-25 product data representation and exchange – Part 25: Implementation methods – EXPRESS to XML binding*, International Organization for Standardization, Geneva, Switzerland.

ISO (2007a). *ISO 10303-27 Product data representation and exchange – Part 27: Implementation methods: Java TM language binding to the standard data access interface with Internet/Intranet extensions.* International Organization for Standardization, Geneva, Switzerland.

ISO (2007b). *ISO 10303-28 Product data representation and exchange – Part 28: Implementation methods: XML representations of EXPRESS schemas and data, using XML schemas,* International Organization for Standardization, Geneva, Switzerland.

ISO (2009). *ISO 10303-235 Product data representation and exchange – Part 235: Application protocol: Engineering properties for product design and verification.* International Organization for Standardization, Geneva, Switzerland.

ISO (2011). *ISO 10303-26 Product data representation and exchange – Part 26: Implementation methods: Binary representation of EXPRESS-driven data.* International Organization for Standardization, Geneva, Switzerland.

ISO (2014a). *ISO 10303-45 Product data representation and exchange – Part 45: Integrated generic resource: Material and other engineering properties*. International Organization for Standardization, Geneva, Switzerland.

ISO (2014b). *ISO 10303-242 Product data representation and exchange – Part 242:Application protocol: Managed model-based 3D engineering.* International Organization for Standardization, Geneva, Switzerland.

Moreno, A.,ed., (2014). *Interoperability for digital engineering systems*, FrancoAngeli, Milano, Italy.

Patterson, E.A. and Taylor, R. "An Integrated Nuclear Digital Environment", *Modelling & Simulation for the Nuclear Industry*, www.nafems/org/nuclear (accessed 2015-02-15).

Shenck, D. and Wilson, P. (1994). *Information Modelling: The EXPRESS Way*, Oxford, New York, USA.

Simpson, M (2013). "A definition of BIM", *The Structural Engineer, UK*, 91, 6-9.

Swindells, N. (2014). "Communicating and conserving digital data from nuclear science and engineering", *Journal of Nuclear Materials*, Elsevier B.V, 450, 3-7.