VIRTUAL REALITY FOR INSPECTION, MAINTENANCE, OPERATION AND REPAIR OF NUCLEAR POWER PLANT (VRIMOR)

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SUMMARY

VRIMOR is a shared cost project running for two years having commenced in February 2001. The consortium is led by NNC Ltd (UK) and includes Tecnatom (Spain), RTS Advanced Robotics (UK), CIEMAT (Spain), SCK-CEN (Belgium), and Universidad Politecnica de Madrid (Spain). The aim of the project is to combine environmental scanning technologies with human modelling and radiological dose estimating tools and to deliver an intuitive and cost-effective system for use by operators involved with human interventions in radiologically controlled areas.

Owing to the significant technological interfaces and the importance of the end user perspective, most effort to date has been placed on the development of a user and sub-systems requirements definition document. This has provided the framework from which to develop the individual technologies with some confidence that they will integrate smoothly and the resulting system will meet end-user aspirations and hence find practical application on project completion. Considerable debate has also been directed toward the selection of a test and evaluation area at Almaraz NPP. A candidate site has been selected which will test the functionality of the developed systems and will provide opportunity for end-user evaluation and feedback.

The objective of combining the technologies involved and making them simple to use is to help operators overcome the present situation where they are exposed to radiological doses in both assessing intervention requirements and executing them. If successful, the project will demonstrate the ability to capture detailed geometric and radiological data associated with a target area with minimal human exposure. Subsequently, operators will be able to quickly assess the optimum method of working to minimise exposure and risk using intuitive 3D modelling environments. The result will be improved ALARA assessments and greater operator confidence in executing human intervention tasks.

1. Introduction

The objective of VRIMOR is to develop a methodology and prove the viability of minimising occupational exposure, reducing safety risks, and minimising costs associated with manual maintenance and other activities on operational nuclear power plant (NPP). This will be achieved through the development of computer simulation tools and interfaces combined with the enhancement of laser and radiological scanning techniques to be applied cost effectively to the planning, training and assessment of maintenance tasks. The aims are to develop a suite of interchangeable technologies in response to nuclear plant operatives' needs, to evaluate its performance in a practical application, and to provide recommendations for the future development and adoption of the tools.

The individual technologies being utilised in the Project have been applied previously in isolation and in combination to go part way to achieving the Project objectives. Foe example, virtual reality has been used at several NPP around the world to provide training systems for plant operators. The PRVIR project, piloted at Vandellos II NPP, is an example of application to classified worker training, Ref 1. Equally, the combination of geometric, material and radiometric data has been addressed previously, Ref 2. However, the VRIMOR Project is novel in its combination of all the technologies involved as well as its strategy to achieve their ease of use as a combined system.

Sophisticated human computer simulation models are being used as the basis for developing intuitive user interfaces that will allow the plant operatives to use these complex tools. Two development streams are underway; a graphical interface complemented with voice control; and a hardware (multi degree of freedom control device) interface complemented with stereo vision. These are being developed on differing commercial software systems and will be used by operators to evaluate optimum methods of access and working.

The method of working can only be considered optimal if due consideration has been given to occupational exposure. It is therefore planned to develop automated methods for calculation of human dose uptake based on the human simulation. This is again following two parallel tracks; one where the dose calculation is integrated in the simulation tool and the dose to key body parts is computed as the simulation progresses, and the other where there are two separate tools. The latter comprise a simulation tool that computes and stores the trajectories followed by key body parts and a radiological tool that computes the dose uptake from the trajectories generated by the first tool.

The input requirements for the dose calculations will be in the form of a dose rate field that will be generated in one of two ways. Firstly, from the development of a radiological scanning system and secondly, from the development of a computational tool that uses conventional source and activity data derived for the plant.

The geometry of the plant area will be provided using laser-scanning technology that will be developed to provide a 3D model incorporating simplified radiological data that can be displayed by commercially available human simulation packages.

The developed technologies will be interface tested and station operators trained in their use in order to assess their performance and benefits. The applications will be reported, human factors assessed, technologies compared, and recommendations provided for future development and uptake.

It is anticipated that the developments planned for this project will provide a novel combination of technologies that is easy to use and has the potential to achieve significant benefits for NPP operational staff through improved efficiency, reduced costs, and reduced doses.

2. Work programme

Project VRIMOR comprises six partners whose aim is to develop and evaluate on real nuclear power plant a suite of systems for modelling radioactive plant both geometrically and radiologically, for simulating and planning manned inspections, maintenance, operation and repairs, and for estimating the dosage received by the simulated men (mannequins) during the operations. This is a two-year programme that commenced in February 2001.

There are a number of technological developments that must be performed in order to achieve this, and the aim of the consortium is to perform such developments. One of the key underpinning factors in the project is the establishment of close co-operation with the operators of a nuclear power plant. Tecnatom's main task is to facilitate this co-operation for the supply of data and support to the access of facilities and personnel at the Almaraz nuclear power plant where the practical evaluation is intended to take place.

The initial phase of the project was to perform a requirements analysis with the plant operators and produce a functional specification for the main technical developments and interfaces within the project. Tecnatom have played a key role in this initial phase. Based on the functional specifications the five technical contributors will develop the required hardware and software to perform the project. RTS Advanced Robotics brings skills in the area of 3-D environmental laser scanning. They will bring the geometry-scanning sensor and related expertise to the project and will integrate the radiological information with the 3-D geometrical information. CIEMAT are developing a gamma scanner that will provide the radiological dose information.

NNC is developing a tool with a custom hardware control interface that will import the integrated 3D geometrical and radiological information and allow plant operators to design and simulate maintenance and intervention tasks intuitively. This facility will allow them to compute absorbed dose estimates and will be based upon a commercially available human simulation package.

In a parallel development, UPM will establish a similar tool for the design and simulation of maintenance and intervention tasks using an integrated graphical and voice driven user interface based on a different commercial human simulation package. From the results of the simulation a set of trajectories will be computed for different body parts of the mannequins involved in the simulated operation. These data will be exported and together with the radiological data will be imported into an existing ALARA toll by SCK-CEN. This tool will be used to compute the absorbed dose during the simulated task. A comparison will be made between the results from the parallel developments.

The usefulness of these tools will be evaluated during the final stages of the project when the combined technologies will be evaluated at the Almaraz nuclear power plant. The intent is to scan geometric and radiological data during a convenient opportunity prior to its use during the evaluation. Appropriate training of station personnel (radiological protection, maintenance, and ALARA specialists) in the use of the various systems will be given, prior to their use of the systems. An evaluation of the project output from human factors, commercial, technical and safety perspectives will be completed as part of the evaluation process. In addition, the alternative tools and techniques will be compared and guidelines provided for the best options for different situational needs.

3. Achievements

From the inception of the project the importance of defining the project requirements and interfaces was identified and approximately one quarter of the project programme was allocated to the establishment of functional requirements documentation and the selection of a suitable test and demonstration environment. This involved an iterative process with considerable interaction with the candidate demonstration site at Almaraz NPP. The primary drivers in this process were; firstly, the aim to achieve improvements in the present ALARA process; secondly, the need to have a successful demonstration of the combined technologies that was not overburdened with task complexity; and finally, the ability to implement this at an operational power plant without prejudicing operations and power output.

Considering the potential improvements to the planning and assessment process, one of the first activities was to review present practices and to highlight where improvements were thought to be achievable. The prediction of expected doses, the evaluation of the physical viability of the task, the time to carry out the task, and the training programme are all carried out manually using separate methods (approximate calculations, visual inspections, operator experience, mock-ups etc). The integrated environment proposed for the VRIMOR Project has the potential to provide many operative and economic advantages over the present practices. In addition, it provides the opportunity to involve more stakeholders and to introduce greater added value to the process through increased generalisation, information and data exchange.

Based on an early assessment of the project, the following potential benefits have been identified:

- the accuracy of dose predictions can be improved
- dose mitigation strategies can be evaluated more readily (eg adding shielding, changing routes)
- greater confidence in maintenance strategies can be achieved through virtual exercises where operators can see the challenges and overcome them in a safe environment eg accessibility
- the virtual environment can be used for training saving both time and cost in building physical mock-ups
- if dose levels are relatively stable or predictable then the radiological exposure of health physicist technicians can be reduced as a result of fewer measurements
- greater confidence in the execution of the physical task can be achieved, equipment and tooling prepared, and optimal working strategies adopted which results in reduced exposure and reduced risk of unexpected events

These benefits will only be achieved if certain criteria can be met and these have been established as follows:

- affordability – clear cost benefits must be demonstrable including through life maintenance and training cost implications
- versatility – ability to accommodate various physical and radiological scenarios and maintain the correct time frame reference
- speed – the time taken should be no greater than present practice
- realism – the level of detail should be adequate to be convincing and to reveal all essential aspects
- portability – the applications should run on standard PC's
- ergonomics – the use of the computer tools should be intuitive and not require extensive training
- validity – the integrated system of technologies should be validated against agreed acceptance criteria
- documentation – the facility will be supported with clear user documentation

In order to achieve a demonstration of the VRIMOR system that would address the above without being unduly complicated and introducing excessive project risk the following criteria for selection were established:

- interesting geometry – the geometry should be sufficiently challenging that it demonstrates the benefit of scanning over manual surveys
- adequate spatial freedom – this allows flexibility in choice of task and approach

- limited tool handling – maximum benefits will arise from evaluation of access not from modelling complex tool manipulations
- flexible task definition - this will allow for investigation of differing techniques and aspects of human maintenance interventions
- available site history – to enable extrapolation and comparison
- distributed sources – ideally more than one radiological source
- no pre-existing models – there are no established three-dimensional models of the candidate area
- constant geometry – enabling scan once, re-use many times philosophy
- negligible contamination – there should be no unacceptable risk of contamination of scanning equipment
- radiological data extrapolation – this aspect addresses the potential requirement to measure when doses are at one level and extrapolate to another
- acceptable dose levels – scanning dose levels should not be excessive

From consideration of the above selection criteria a candidate area was eventually selected and is referred to as corridor EA51, shown in Fig 1. The corridor is about 40 meters long and 5 meters high and is entered through a two meter high, one meter wide opening. There are many different pipe systems in the corridor ranging from 3/8 inch to 6 inches diameter and carrying different radioactive waste forms. EA51 is a classified area and is contained within an auxiliary building at the power plant.

The area was chosen from a range of candidates to meet the above selection criteria and demonstrates the following particular features:

- low risk of equipment contamination and tolerable dose levels
- no significant temperatures
- good access for scanning equipment
- interesting geometry and maintenance task

The strategy being adopted for data capture is that of scanning as much as possible within an acceptable time frame. In the case of the laser scanning device, large amounts of data can be captured very quickly. The manipulation and conversion of these data is carried out subsequently and can be time-consuming depending on the geometrical complexity of the scanned environment. It is planned therefore to capture large quantities of data but to post-process only the selected areas and features required for the task. This approach provides a data archive that can be processed for other features relevant to future interventions when required without the need to re-enter the area.

In contrast the radiometric scanner is much slower and the data to be scanned will be pre-planned to optimise the scanning time in line with the task requirements. It is reasonable to assume that this device may be re-deployed in intervention areas as radiological conditions may change.

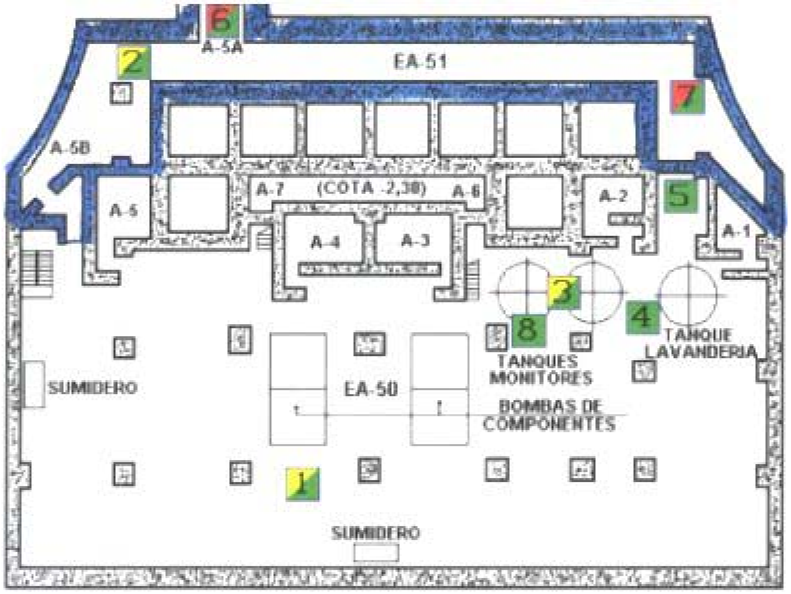

Fig 1 Candidate Trial Area – Corridor EA51

The maintenance task selected for the demonstration is that of the maintenance and repair of an isolation valve. The present process involves draining the line, installing access scaffolding, disassembling the valve, checking and cleaning outside the area, checking and cleaning in situ, lapping in situ and reassembling. The task may take from 3 to 6 hours with regular rest breaks. Fig 2 shows the area in which the candidate valve is located.


Fig 2 Valve Maintenance Access Area – Corridor EA51

Although a candidate area and maintenance task have been established, entry into this area to scan the geometry and radiological conditions will not be undertaken until much later in the project.

In the meantime a controlled environment will be established at CIEMAT where several discrete sources will be used to create suitable radiological conditions for the validation of the dose estimation tools that are being developed. This will also give further information about the practicalities of using the equipment prior to its application to a NPP.

In order to integrate the project technologies considerable effort has been placed in establishing common formats for data exchange. A diagrammatic representation of this is shown in Fig 3.

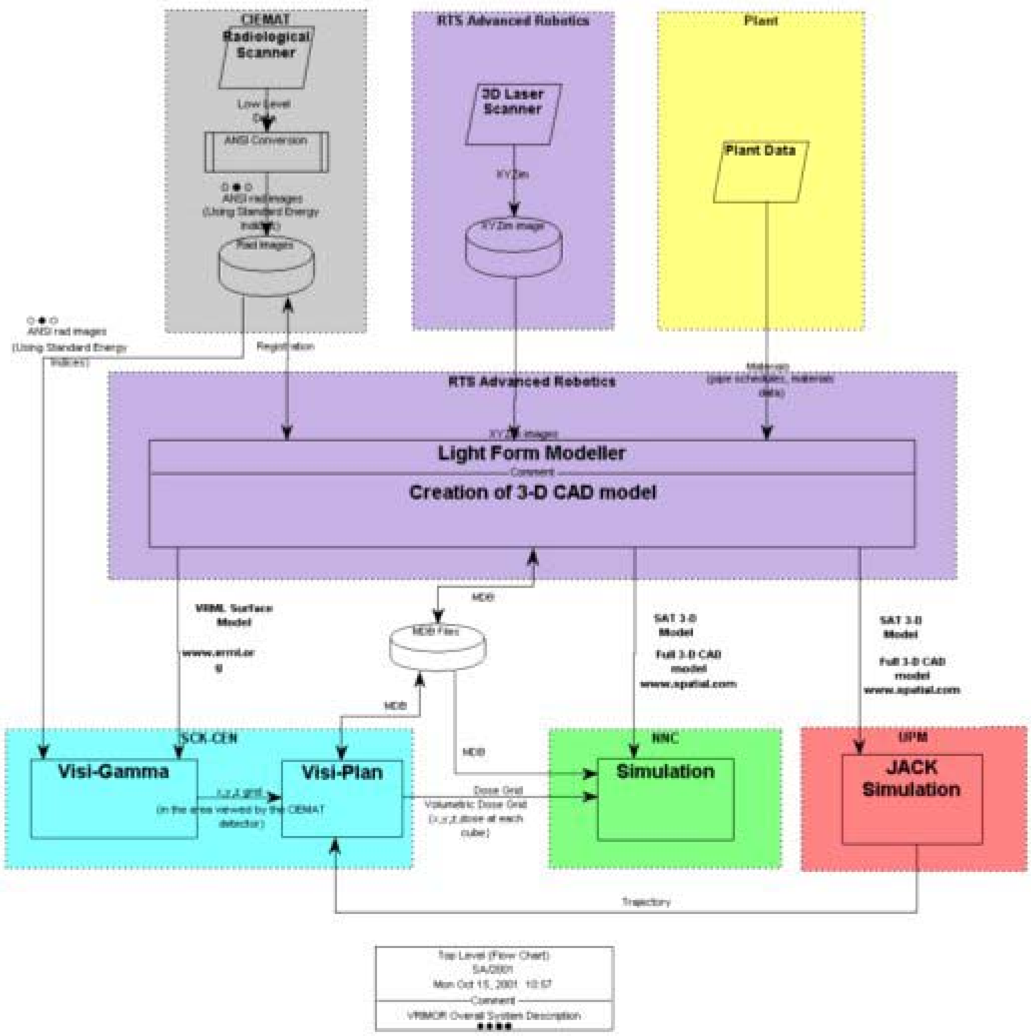

Fig 3 Data Exchange Diagram

One aim has been to achieve re-usable elements of the system with open standards wherever possible in order not to constrain the project or to hamper subsequent exploitation. As many elements of the system have legacy elements or are based on Commercial Off The Shelf (COTS) software, this has provided some constraint on achieving this objective. Nevertheless, formats have been agreed and the project is proceeding with its developments.

As part of this development, the radiological model being used with the gamma scanner has been modified and tested to incorporate the use of DXF model files including those generated from SAT files, the agreed standard geometry data exchange format. Accompanying this, the design of the gamma scanner, which is to be based on an existing development model shown in Fig 4, has been developed further and its construction is in progress. Some angular response tests have been carried out and it has been concluded that further improvements are necessary. Design changes are being developed now to improve the alignment of visual, radiometric and telemetric systems within the equipment.

Fig 4 Prototype Gamma Scanner

A six degree-of-freedom interface device has been successfully interfaced with the human modelling software ERGO from Delmia Inc. A library of postures and motions is now being determined and the ultimate interface requirements are being defined. These functional requirements have been reflected in the project sub-system requirements documentation. The user-system interfaces for the two simulation tools are being developed independently although both have the aim to establish ease of definition and control of potentially complex human manipulations.

The best strategy to combine voice and graphical user interfaces is presently being explored and the voice recognition software being selected based on a set of compatibility and functionality requirements. Several candidate systems are being analysed. Challenges such as timing, task duration, action sequences and the interdependence and synchronisation of several actors in the intervention are common to both tool development programmes.

The partners in the VRIMOR Project have different levels of experience in the field of nuclear energy. For some it is their every-day business and they provide strong engineering and technical support to NPP operations. For others, their strengths are, for example, in software development and they have little nuclear domain experience. The functional requirements document produced through the first quarter of the Project programme served to synthesise both viewpoints. The experience that this has given to the partners is that “soft” and “hard” sciences can co-operate effectively but good communication and work planning is essential to avoid misunderstanding and abortive work.

4. Conclusion and Benefits

The project aim has been to develop existing scanning, modelling and computational tools in order to make their combined use readily available to nuclear plant operators. This in turn has the objective of reducing potential radiological dose by improving ALARA assessments while providing greater confidence to operators in executing non-routine tasks. The project is in its early stages and has spent considerable efforts in identifying end-user requirements and technological interface constraints. Throughout this stage there has been considerable enthusiasm from the operational staff at the proposed test site, Almaraz NPP. This demonstrates that there is a user requirement for improvements in this area and that successful implementation should result in the subsequent uptake and exploitation of the technologies.

The magnitude of dose reduction achieved from the use of this suite of technologies will vary from task to task. However, there are two distinct areas where savings will be demonstrable: pre-inspection exposure will be reduced through the use of remotely controlled scanning equipment with fewer re-entry requirements, and operational exposure will be reduced through task optimisation and operator training. The benefits being delivered will also include improved accuracy in dose estimation. Present techniques can have sizeable error in dose estimation albeit always conservative. The greater accuracy potential from the proposed system will provide greater confidence in dose predictions and the opportunity to minimise dose uptake through a more informed planning process.

Minimisation of the overhead to the plant in implementing this technology is also one of the main success criteria for the Project. In particular, the human computer interfaces are being developed to be intuitive with a target user training time of less than one day. A high degree of computer literacy is not being assumed in the design of the user interfaces and training programmes. The project success in this area will be measured during the plant trial and the findings published in the final Project deliverable.

The area selected for the trial was established based on criteria that would ensure that the Project evaluation requirements could be demonstrated. The process is however intended to be generically applicable to NPP and other radiologically controlled areas where human intervention is required. There are some potential physical limitations associated with scanning equipment access and target occlusions in confined and cluttered spaces. However, future equipment development will lead to more compact design such that for the majority of cases where man access is possible then these techniques may be employed. An assessment of the applicability of these technologies will be included in the evaluation report.

References

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