BROOKHAVEN
NATIONAL LABORATORY

BNL-100634-2013-CP

Lessons Learned and Potential Paths Forward in Virtual Reality Developments for the International Atomic Energy (Member States Support Programs Supporting the International Atomic Energy Agency)

Josh K. Tackentien

Submitted to the Institute of Nuclear Materials Management (INMM) 54th Annual Meeting to be held in Palm Desert, California
July 14-18, 2013

July 2013

Department of Nonproliferation and National Security

Brookhaven National Laboratory

U.S. Department of State
National Nuclear Security Administration (NNSA)

Lessons Learned and Potential Paths Forward in Virtual Reality Developments for the International Atomic Energy Agency (Member States Support Programs Supporting the International Atomic Energy Agency)

Josh K. Tackentien[1], Chris Owens[2], Randy Brown[3]
[1]Brookhaven National Laboratory, Upton, NY, USA, [2]Applied Research Associates, Alexandria, VA, USA, [3]Applied Research Associates, Virtual Heroes Division, Raleigh, NC, USA.

Abstract:

The United States Support Program (USSP) to International Atomic Energy Agency (IAEA) Safeguards sponsored Applied Research Associates (ARA) to develop a virtual reality (VR) training tool for potential use by the IAEA. The IAEA selected a Pressurized Heavy Water Reactor (PHWR) as the basis for this VR development. The IAEA, USSP, and ARA also worked with the Canadian Safeguards Support Program (CSSP), which provided additional technical expertise and previously developed Canadian Deuterium Uranium (CANDU) reactor training materials. Throughout the planning, execution, and follow up to this development several obstacles were discovered, discussed, and many overcome. Several ideas were posited to increase the efficiency of future VR developments, minimizing the cost to Member States Support Programs while maximizing the benefit to the IAEA. These obstacles, solutions, and ideas to streamline future VR developments will be presented in this paper.

Background

Figure 1: External view of the PHWR and dry storage area

The International Atomic Energy Agency (IAEA) requested assistance from the United States Support Program (USSP) to IAEA Safeguards in 2008 for the development of a "virtual reality" training tool. Prior to accepting this request, the USSP discussed various aspects related to supporting this request, in particular the potential benefits to the IAEA, various possibilities of project scope, and the projected costs were discussed.

The USSP and the IAEA's Training Section discussed this request at length and eventually agreed to hold a "VR Workshop" in conjunction with the 51st Institute of Nuclear Materials

Management (INMM) Annual Meeting in Baltimore, Maryland. This workshop brought together personnel from the IAEA, the USSP, U.S. government agencies, national laboratories, and academia. The outcome of this workshop was provisional USSP support for a phased development of a pressurized heavy water reactor (PHWR) virtual reality (VR) training model. The scope of phase one of the task would include the modeling of the PHWR environment and safeguards related equipment.

Selection Process

After an extensive proposal evaluation process by the IAEA and the USSP, Applied Research Associates was selected to develop the PHWR VR environment. The SSTS approved the IAEA's task request with ARA as the contractor in late 2011.

Applied Research Associates, Inc. (ARA) is an international research and engineering company that was founded in Albuquerque, NM, in 1979. ARA has over 1200 employees with sixty-two offices throughout the United States and one in Canada. The company provides a broad range of technical expertise in defense and aerospace technologies, civil technologies, computer software and simulation, systems analysis, environmental technologies, and testing and measurement. ARA also provides sophisticated technical products for environmental site characterization, pavement analysis, and specialized robotic vehicles.[i]

As a complement to its existing computer software and simulation capabilities, ARA acquired Virtual Heroes Inc. in 2009. Virtual Heroes creates collaborative interactive learning solutions for the healthcare, federal systems and corporate training markets and specializes in creating immersive 3D serious games with realistic 3D simulations and models to accelerate learning, increase user proficiency and reduce training costs.[ii] Virtual Heroes has quickly become one of ARA's key divisions and has been an important element in establishing ARA as an industry-recognized leader in immersive, high-fidelity simulations for learning, serious games and virtual worlds training and education. ARA's Virtual Heroes Division has an outstanding record of success with previously released games, training, educational content, and virtual worlds including; Zero Hour-America's Medic, 3DiTeams, Pivotal Decision, Adaptive Thinking and Leadership, America's Army, Pamoja Mtaani, Virtual Peace, and Ultimate Team Play.

Project development

The development team (IAEA, ARA, and USSP) arranged for a kickoff meeting at IAEA Headquarters January 16th – 20th, 2012. The kickoff meeting documented several areas critical to a successful development project including overall scope, objectives detailed and broken down into phases, graphics fidelity parameters, as well as reviews of IAEA computer capabilities, available training materials, available 3D graphics assets, and input from IAEA inspectors with PHWR experience.

The kickoff meeting began with a detailed presentation on ARA capabilities that were not fully described in the proposal for the VR tools for training request. Many of these capabilities did not apply to the initial phase of this project, but all parties agreed it was beneficial to have a full understanding of simulation capabilities that could eventually be included in the software. With the basic parameters determined the development team then worked to outline a thorough project scope which included potential phase two development though the USSP had funded only the first phase. Phase one specified the modeling of a PWHR reactor with flythrough and walkthrough capabilities. Specifically, the IAEA requested a generic PHWR facility, a single unit reactor not based on an actual facility. This model would also include IAEA safeguards equipment and general information "pop ups" for key areas and equipment.

During the kickoff meeting ARA tested desktop computers in the IAEA Training Section training room, as well as a small sampling of IAEA issued laptops, for 3D graphics capabilities. The test was run with 3dmark06 software. After the initial test the graphics drivers for the IAEA computers were then updated and the computers retested. The training room desktop computers averaged 3545 and 3664 at 1280 x 1024 resolution; this score is sufficient to provide good quality 3D graphics without inhibiting computer performance. The graphics capabilities of Agency-issued laptops tested significantly lower, around 1,000. This lower level of 3D capability meant the PHWR VR environment would need to be designed to a lower level of graphic fidelity. After discussions it was decided that ARA would target a 3D mark sufficient to provide good graphics and compatibility with standard IAEA desktops and laptops.

One long term issue discussed during the kickoff meeting was software sustainability. The IAEA and USSP wanted the IAEA to be able to perform some updates to the PHWR model "in house." Discussions determined that updates to some file types which would be displayed in the model's information pop ups would be possible. When the IAEA needed to update specific items within the model, for example a video file, the IAEA could convert the file to the appropriate format, name it within the designated convention, and place it in the appropriate folder. The PHWR VR software would then reference and display the updated information. Another requirement for the VR project was the delivery of a product that consisted of non-proprietary software that would allow easier access to future developments or modifications. The PHWR virtual environment was developed using the Unreal Engine, which is a game engine developed by Epic Games. The Unreal Engine is a popular game engine used to develop 3D environments, and it allows for content to be modified by any company with an Unreal Engine license agreement.[iii]

With some basic parameters laid out, the IAEA, ARA, and the USSP began fleshing out details for phase one; how much of the facility should be modeled, what amount of detail should be modeled, what are the most safeguards relevant areas of the facility, what areas require more detail than others, what facility areas and safeguards equipment should be modeled, etc. The IAEA arranged for substantive experts to provide insight into PHWR inspections and their opinions regarding the areas of the facility that are the most important to model. Both inspectors conveyed their experiences in PHWRs, facility areas they felt were the most important, and the types and locations of safeguards equipment used in PHWRs. One key element discussed was the high volume of fuel movement that occurs in a PHWR. It was reinforced that detailing where fuel movement occurred was most important; therefore, fresh fuel storage, the fresh fuel loading room, the reactor containment area with the charging / receiving machine, the spent fuel discharge and handling areas, the spent fuel pond, and spent fuel dry storage would be emphasized.

The development team created a list of materials and information needed to construct and populate the PHWR model. ARA spent much of one day learning about and photographing various IAEA safeguards equipment relevant to PHWRs including Core Discharge Monitors (CDM), the Mobile Unit for Neutron Detection (MUND), the All in One Surveillance system (ALIS), the All in One Surveillance system Portable (ALIP), the VXI Integrated Fuel Monitor

(VIFM), the Digital Multi-camera Optical Surveillance system (DMOS), the HM-5, Type E metal seal, the paper temporary seal, the Cobra seal, the Electronic Optical Sealing System (EOSS), and the Variable Coding Sealing System (VACOSS). CTR also provided copies of training materials from its "CANDU / PHWR Comprehensive Training Course" to ARA for review and incorporation into the VR model.

The development team had all researched available open source assets i.e. – 3D animations, 3D models, CAD files, technical drawings, images, etc. that could have been useful for this project. These open source reference materials were of varying degrees of quality and many of the better assets had been created by Canadian companies. The Canadian Nuclear Safety Commission (CNSC) and Canadian Safeguards Support Program (CSSP) have extensive expertise related to PHWRs, also known as CANadian Deuterium Uranium (CANDU) type reactors. All parties agreed it would be beneficial to include the CSSP in the VR development project.

Figure 2: Calandria face with fuel loading machine and information pop ups for general area (gold) and specific equipment (blue)

Initially it was hoped that acquiring some of these assets found in open sources would save effort and cost related to modeling certain aspects of a PHWR facility. Any savings in cost could then have been rolled into other aspects of the VR environment. The USSP contacted the CSSP in February 2012 to discuss collaboration on the VR project. The USSP, CSSP, and ARA arranged a meeting held May 10th, 2012, at CNSC headquarters in Ottawa, Ontario, Canada.

Pre-meeting discussions focused on creating a 'wish list' of assets the CSSP may have been able to supply such as 3D assets from various open source animations, access to original CANDU videos, an introduction to Canadian companies that owned 3D assets, and perhaps even access to a shutdown CANDU facility in Canada. While some of these requests would be more difficult to facilitate than others all would have been helpful. Acquisition of 3D assets, even dated assets considered crude by today's 3D modeling standards, would provide a useful starting point. CANDU videos originally produced on VHS and digitized in the 1990s could be redigitized using today's hardware and software to produce better overall quality digital video. An introduction by the CSSP to Canadian companies might have encouraged sharing of 3D assets. Access to a shutdown facility would have provided an excellent opportunity to model the PHWR environment. Any CAD files related to a decommissioned facility could have been simplified and rearranged to provide a basis for a generic PHWR facility.

The initial meeting between the USSP and CSSP covered the IAEA's request and project background, ARA capabilities, project scope, review of assets readily available from the CSSP, and a list of desired assets to support the development project. Numerous the CANDU-related materials the CSSP had collected were reviewed. The CSSP provided or arranged for provision of several of these assets, and all parties developed a list of follow up actions for the CSSP, USSP, and ARA.

ARA began modeling safeguards equipment and the fuel loading machine while the CSSP investigated the possibility of providing electronic media to ARA. The CSSP and DJ Films, a contracting firm to the CSSP, also scoured their archives looking for further useful assets to provide. The CSSP and DJ Films were able to provide some additional assets but, unfortunately, time was not an ally to the project. ARA was looking for raw materials that had been used to create training and public relations materials ten to twenty years prior, and the PHWR project also aligned with Atomic Energy of Canada Limited's (AECL's) licensing its CANDU technologies to newly formed CANDU Energy Limited. This hampered the possible acquisition of any commercial assets.

Once it was determined that all readily available assets were received ARA began modeling a generic PHWR facility. ARA's design team started with very limited knowledge of PHWRs but proved to be very quick learners and brought a facility to life based on available cutaway drawings of a few PHWR facilities, photos, and videos collected from the CSSP, IAEA, and open sources. The CSSP and IAEA provided expertise on the occasions when the design team lacked sufficient references for modeling. In addition to the facility itself, additional content was built into the model through the incorporation of "points of interest." This content is intended to provide additional information for training purposes. The "points of interest" provide additional information through video, pictures, drawings, and text and can be accessed by clicking on the floating information signs that have been inserted throughout the virtual environment.

Despite experiencing some planned delays in development while attempting to acquire the aforementioned 3D assets ARA had an "alpha build" ready for review and testing by mid-November 2012. The alpha build of the PHWR environment, as indicated by the name, was the first version of the model and was primarily focused on accurately capturing the facility features - various buildings, rooms, equipment, and interior features. This included video clips, active links to URLs, generic information about each room, various points of interest, ambient sound, and final lighting. ARA was also still refining the user interface. The intent of the alpha build was initial testing and feedback from the IAEA, the USSP, and the CSSP. The development team was looking for specific feedback.

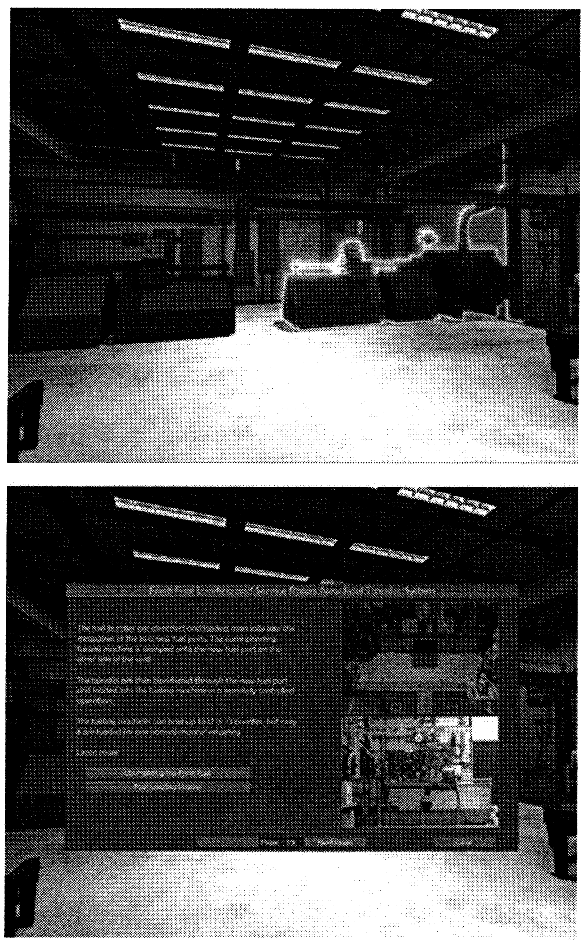

Figure 3: Fuel loading room with equipment highlighted via pointer roll over (top) and information pop-up (bottom)

Did the rooms feel "real?" Were all important elements placed in the correct locations? Were the points of interest placed correctly? The expertise provided by an IAEA experts group and CSSP personnel was very valuable during review of the alpha build. This release was also intended to check installation and operation on user hardware. ARA had completed initial testing of the model, but full quality assurance had not been completed at this phase of the development. During the alpha build, and throughout the model development, ARA maintained a "wish list" of additional features proposed during testing. This list included items beyond the minimum requirements outlined in the original statement of work. Features from this "wish list" would be added to the model as time and resources allowed.

ARA released the 'beta build' in mid-January 2013. The beta build integrated the training and instructional materials, refined visual aspects of the PHWR environment, and incorporated other feedback collected during the alpha build testing. This version was intended to be as close to a final product as possible. Many of the review requirements for the beta build were the same as they had been for the alpha build review. The beta testing also included a review of those items that were not included during the alpha review but had since been built into the model. These items included the additional points of interest video clips, active links to URLs, generic information about each room, various points of interest, ambient sound, and the final lighting. The user interface had been completed and was ready for review as well.

The IAEA, USSP, and ARA planned to introduce the PHWR environment to Agency personnel during delivery of the two day CANDU / PHWR Comprehensive Training Course which was scheduled to be held at IAEA headquarters on February 5th and 6th, 2013. ISPO and ARA wanted to demonstrate the VR environment to the SSTS prior to delivery to the IAEA. ARA, ISPO, and the SSTS held online and live demonstrations during the week of January 28th, 2013. These demonstrations were well received and included positive feedback from SSTS members. With the internal USSP demonstration complete the beta build was ready for introduction to IAEA personnel.

The development team held a rollout meeting at IAEA headquarters the week of February 4th, 2013. The PHWR software was installed, tested, and reviewed on Monday of that week. Tuesday and Wednesday consisted of the CANDU / PHWR Comprehensive Training Course during which the PHWR environment was used for the first time by course participants. In addition to the standard course materials provided to the participants, additional time was provided to allow participants to explore the PHWR environment and its built in training materials. On Thursday the IAEA, ARA and ISPO reviewed feedback from course participants, which provided some additional ideas for the environment and also arranged demonstrations for personnel from various Department of Safeguards divisions including Operations, Concepts and Planning, Information Management, Technical Support, and Analytical Support. After the demonstrations these personnel were then given the opportunity to use the PHWR environment and provide their feedback. On the final day of the rollout meeting CTR, ARA, and ISPO reviewed the feedback collected during the week and categorized it as phase one improvements to be considered for incorporation into the "charlie build" – i.e. final build" or items to be considered for incorporation into a potential phase two of the project.

The feedback provided by IAEA personnel was decidedly positive and several items they suggested were incorporated into some minor changes between the beta and charlie builds. These changes included adding the IAEA logo to the introduction sequence, adding highlighting and labeling on curser rollover of the bundle counters in the spent fuel discharge bay, adding use of the space bar to launch the help screen, lightening of images and videos, building in IAEA logo as a desktop icon to launch the program, changing the "landing" location in the dry storage area so the user can see all five points of interest, and updating the fly-through with fade to and from black when changing rooms. The charlie build is scheduled for delivery to the IAEA by July 1st, 2013 and will be the final version of the PHWR environment under the current contract with ARA.

Lessons Learned

The VR Tools for Training project has offered several valuable lessons regarding project planning and management to all stakeholders involved. While many of these lessons are not new concepts they do positively reinforce the benefits of clearly defining user requirements in the request for proposal, thorough review of proposals, review of demonstration software prior to contractor selection, clearly defining and agreeing upon a scope of work, acquisition of available assets, use of an iterative development approach, and the continual communication, feedback, and flexibility of stakeholders. While none of these practices are revolutionary the success of this project is based upon the stakeholders' strict adherence to them.

As detailed earlier in this paper, the IAEA and ISPO worked very closely to clearly define the user requirements and development plan for this project. This allowed potential contractors to clearly scope their proposals and provide more reliable cost estimates. The willingness of potential contractors to provide previously developed software to demonstrate their capabilities was also very useful.

The benefits of the well defined request for proposal carried over into the kickoff meeting. The overall benefit of a well planned and thorough kickoff meeting cannot be overstated. The detailed scope of work generated by the stakeholders after this meeting provided clear guidance moving forward.

The continual communication between stakeholders was also very important and helped maintain project focus and momentum. This communication also contributed to the iterative development process. When an issue arose or a clarification or revision of a particular item was needed a quick conversation between stakeholders provided rapid resolution. Rarely did a week pass when there were not communications between the IAEA, ARA, and ISPO. Teleconferences and web meetings were also scheduled as needed and generated insight and feedback from all stakeholders.

While the vast majority of this project progressed as planned and succeeded in delivering the overwhelming majority of items stakeholders had agreed upon there were some unforeseen circumstances and difficulties encountered. As mentioned previously, the aggressive timeline for this project, a twelve month period of performance, combined with other factors outside of the stakeholders' control limited access to many of the open source materials that had been considered for use. Following the kickoff meeting several aspects of the project were intentionally delayed as the IAEA, ARA, the USSP, and the CSSP all worked to gain access to various resources which would reduce development costs. After the collection, and attempted collection, of various assets, it was decided to move forward with the materials at hand and any new assets that might have been acquired would be worked into the project "on the fly'." While this situation was not ideal the close communications of all parties would minimize any negative impacts to the project.

Software development projects often encounter unforeseen issues; many are easily addressed while some are difficult to overcome. The most prominent outstanding issue relates to the ability of the IAEA to easily update certain basic items within the PWHR environment. As discussed earlier, the RFP noted that long term IAEA sustainability was critical – i.e. that the ability to conduct basic updates of certain audio, video, and other files would be built into the phase one deliverable. ARA had estimated this would be an item that could be addressed by their development team, but it has proven to be a more challenging issue than was originally envisioned. At the time of this writing possible solutions were still being explored.

Considerations for future VR developments

The development of the PHWR environment brought many related topics to the attention of the IAEA, ARA, and the USSP. Some of these items may directly affect future VR developments while others offer opportunities to increase the effectiveness of future developments. These items should not be interpreted as directives but merely as opportunities to ensure useful dialogue regarding future VR developments.

How could MSSPs and IAEA collaborate with industry to develop the standards to best facilitate implementation and an MSSP streamlined approach? Based on IAEA feedback from both PHWR development and other VE projects, uniformity for user interfaces, controls, and "look and feel" would increase the familiarity between the different virtual environments under development at the IAEA and would help minimize the learning curve for users new to a particular environment. A well planned and well documented set of guidelines would be beneficial.

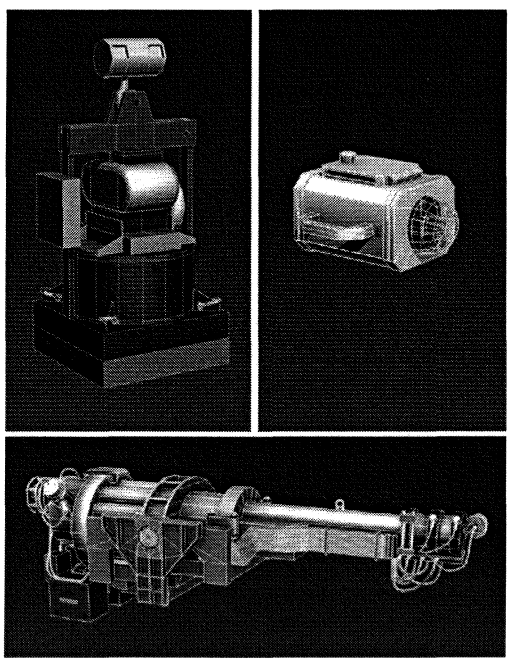

Figure 2: 3D asset examples; MUND, NGSS camera, and PHWR fuel loading machine

The availability of existing assets was an area the IAEA, ARA, the USSP, and the CSSP all pursued to support this development. All parties had seen assets that could have been useful if their raw assets had been available. But pursuing these existing assets often proved more time consuming than modeling them. The knowledge of existing nuclear related 3D models, regardless of their intended purpose, led to a discussion regarding the sharing of modeled assets.

One proposed solution is the creation of a repository of 3D assets that would be made available to MSSPs, NGOs, government agencies, companies, etc. to reduce modeling costs and facilitate the development of new 3D materials. The expectation would be for developers that made use of 3D assets provided by the repository to in turn provide any newly developed 3D assets from their project. The goal would not be to share a fully developed 3D environment but to share the building blocks of that environment. Once a fuel charging machine for a PHWR has been modeled why not make that asset available? The same holds true to various types of equipment pertaining to the fuel cycle, safeguards equipment, types of fuel, storage casks, etc. The assets would be useful not only for the creation of safeguards related materials but also for nuclear safety, security, transportation, energy, education, etc. As the library of 3D models grew, even if only the wireframes were made available, it would dramatically cut modeling time and expense. This reduction in cost would in turn make the development of new 3D virtual environments, training materials, animations, promotional materials more affordable to MSSPs, NGOs, government agencies, and companies. Many questions will need to be answered; who would develop it, how would it be populated, what file types of 3D assets should be provided, would it be available merely to parties supporting the IAEA or to others as well, who would determine access? While this goal of sharing 3D assets may face many hurdles it is very much worth discussing.

Software issues are also worth discussing. Which game engine or engines should be used? Disparate developers use disparate engines to power their 3D environments. Is this an issue even worth discussing provided that the engine is not proprietary? Assuming the 3D assets are provided in a standard file format i.e. 3dsMax, Maya, Collada, AutoCAD, etc. then their import to various 3D engines should be straight forward.

Lastly, the feedback provided by individuals who had been provided a demonstration or an opportunity to use the PHWR environment raised many interesting points some of which are within the scope of the USSP funded task but also many well beyond its scope. Perhaps the most important and most useful ideas posed were those pertaining to knowledge management. These ranged from the simple, the inclusion of a list of equipment inspectors should take with them when inspecting a PHWR, to the more complex, the inclusion of a library of videos which feature experienced inspectors providing details related to specific inspection scenarios, experiences, etc., as related to PHWR inspections. This video library would not only increase the value of the PHWR environment for training but it would also create sort of database for PHWR knowledge management.

The development of the PHWR Virtual Environment has been successful to date by clearly defining and agreeing upon a scope of work, acquisition of available assets, use of an iterative development approach, and the continual communication, feedback, and flexibility of stakeholders. The author would like to acknowledge all of the efforts of the various personnel from the IAEA, ARA, CSSP, and USSP who made phase one of this project a success.

---

[i] www.ara.com for additional information.
[ii] http://virtualheroes.com/about.
[iii] http://www.unrealengine.com/ for more information on the Unreal Engine