Virtual Environments: The "Prompt Jump" for the Next Generation Energy Workforce

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THE WORKFORCE IS CHANGING, THE METHODS MUST FOLLOW SUIT

The "greying" and ultimate retirement of the current generation of energy (both exploration and power plant operators, but especially nuclear) operators present many challenges: a loss of experience, incomplete knowledge transfer, and the necessity to maintain demanding safety and operating standards. A study conducted by the International Atomic Energy Agency in 2004 (1) regarding the state of the worldwide nuclear industry workforce noted that the first generation of operators (those who commissioned most of the nuclear plants) had retired, but that the next group would be retiring in the next 10 years.

The ten year period has now transpired. In 2011, the Nuclear Energy Institute (2) forecast a need for up to 25,000 workers by 2015. This need was to meet the predicted loss of approximately 38% of the workforce within 5 years. Further, the article quoted Angel Garcia from Southern California Edison Co, who stated," finding applicants with the right skill sets can be even harder. With fewer potential new hires available from the nuclear Navy, there aren't a whole lot of people lined up for jobs that have the skills we need."" (3)

If the nuclear Navy cannot supply the numbers of operators required to staff the nuclear plants, then other accession sources are required. There is a significant difference in the education and training of operators from the alternative sources, since a great deal of the knowledge gained is theoretical in nature, or might be gained from operations in similar environments, such as conventional power plants. The issue then becomes how to transfer the required knowledge to this group of potential workers. According to research originally performed by Ed Dole and proven by the National Training Laboratory Institute, learners only retain 5% of information taught (and approximately 10 – 20% of that either read or obtained using audio visual or video methods) as opposed to nearly 75% using the practice by doing approach. (4)

The Next Generation of the Nuclear Workforce is comprised of "millennials" who are comfortable with technology and spend a large portion of their time with screen media. (5) The millennials who are the predominant part of the next generation of operators have had access to computers throughout their lives and are confident gamers. Virtual Environments (VE) now offer many advantages in presentation, realism, assessment, and robustness heretofore unattainable. Game Engines (GE) combine the fascination of gaming with the necessary theory and skills required for the Energy Industry workforce. Until very recently, the ability to perform significant tasks outside the actual power plant has been either extremely expensive (full scale mock ups) or technically unachievable using gaming technology. The visual capabilities lacked realism, and the other aspects of "operations" such as aural, haptic and olfactory were simply not possible.

GAMING IS NOT PLAYING ANY MORE

The Challenges to Overcome

During interactions with leadership and training personnel at several nuclear generating sites, the author has encountered resistance to the use of virtual environments for training. Some typical reactions are discussed below:

1) "We don't know how to use any of that gear." In visits to three different nuclear power plants, two energy consortiums, and two nuclear trade shows during 2014, the initial and visibly visceral reaction to a displayed Oculus Rift® and Xbox® was most often this one. It is also interesting to note that IF there was a mixed audience of attendees at these encounters, (i.e Millennials and Boomers) the Millennials reacted very positively and enthusiastically.

2) "The technology doesn't provide "real hands on" training." This was a pervasive sentiment, especially by emergency and firefighter supervisory personnel. The lack of accurate hose characteristics (notably the reaction force and visual pattern replication) was a major concern. These same personnel acknowledged that they did not have an adequate means of training personnel "on site" and that in two of three cases, were constrained by the locality's ability to support training as frequently as would be necessary for proficiency. The perceived lack of realism overrode the potential for using a VE that was representative of all aspects of their particular nuclear facility.

3) "It is too expensive." All the energy industry is facing the need to be cost competitive (6) and the high costs of maintaining nuclear facilities challenges plant owners to operate profitably due to overall lower market prices. There is a nearly immediate request to show Return-on-Investment (ROI) and a time table to achieve it. Even though the Nuclear Regulatory Commission (NRC) Regulatory Guide 1.149 (7) specifies the requirements for simulators and simulators were being utilized at all facilities visited, the potential cost savings for a VE didn't provide a case for even limited introduction. The NRC has not yet adopted VE as an acceptable training modality (B. Baker, personal communication, October 21, 2014) thus, adding this type of capability doesn't have any appeal.

Using "the Gear"

The need to be completely facile with a controller such as an Xbox® is not the sole nor ultimate goal of the VE proposed solution. In the ultimate instantiation, a completely (or nearly so) "real" environment where the operator, and for the sake of a majority of the following discussion, we will use a firefighter, is dressed out in his/her actual equipment using either emulated or replicated firefighting equipment. An intermediate step would involve a game controller capability for either initial familiarization or very basic qualification. Even so, in two separate instances, one involving approximately 15 Virginia Beach Fire Department personnel (R. Vance Cooper, personal communication, September 4, 2014) and another involving the simulator superintendent at a nuclear power plant (J. Signorelli, personal communication, January 15, 2015 all but 2 of the VBFD personnel were over 50 years of age. Further, NONE over 50 had ever used a game controller. There was not one instance where ANYONE required more than 10 minutes to acclimate to the device, and most were comfortable enough to extinguish one of two types of fire capably. (In each instance, this meant without having the fire spread more than about 25%). The overriding remark was that, "It wasn't as hard as I thought, and we would get to use a real hose, right?"

In the instances from the above above and as observed at the two trade shows, one university visit, and at I/ITSEC 2014, all the Millennial participants (approximately 40 in number) in the firefighting "game" were able to extinguish the fire, using all the capabilities programmed into the game controller quite easily. Although the sample set of those who participated in the simulation can only be described as limited and empirical, the eagerness each of the participants displayed when asked to participate, and their immediate with the devices indicated the likely positive response to such a technology in the training programs.

The approach proposed in this paper would fit into the "blended" approach wherein a series of modalities from a tablet or screen based interactive training capability would be succeeded by ever more interactive experiences, culminating in a full motion experience in a multi-player, multi-role scenario. The advantage of this approach is that there is no specific training to "use the gear." Use is either intuitive (or easily adapted to depending upon the functionality programmed into the controller for the intermediate training scenarios) or already familiar as in the case of donning a Fire Fighting Ensemble (FFE), breathing device, or handling a thermal imager, gas monitor, or fire hose. The ability to discern the effects of the variety of physical effects integrated into the VE will be discussed later in this paper, but each of the series of training scenarios is envisioned to incorporate several of these effects.

Achieving "real" Hands-On Training

Once the discussion of the "use of the gear" in the previous section has been addressed, the real objections of the leadership (in all the venues discussed above) became clear. As a member of the generation (in this case those who were selected by Admiral Rickover and trained by veterans of the Korean and Vietnam conflicts) that is most representative of the leadership at most nuclear facilities, I am fully aware of the "hands on" mentality. Again using firefighting as the exemplar, those of us who were trained in the late 60's through the early 80's (specifically in the US Navy) were trained in shore based mock ups where replicas of shipboard engine rooms were set on fire. (Fuel was piped into a replica of a ship's bilge with some water already present and then set ablaze.) This was indeed a "hands on" experience. However, these sorts of trainers are no longer readily available, and indeed, all US Navy training facilities (N. Tyson, VADM, personal communication, July 11, 2014) are now either natural gas or propane sourced. Municipalities (R. Vance Cooper, personal communication, October 24, 2014) exclusively use an environmentally controlled "smoke house." In each case, the "fire" is strictly limited in its location and duration. Thus, "hands on" really only applies to being properly dressed out, using the detection equipment, and using the hose. These are not undesirable, but as noted by both the USN personnel (David Coles, personal communication, August 25, 2014) and VBFD (R. Vance Cooper, October 24, 2014) once a firefighter has encountered the trainer, other than the heat produced, very little additional learning is gained. So, other than using a fire hose in all its possible modes in a parking lot, what value is being gained?

D. Coppin, a senior training professional from AREVA, Inc. wrote an article entitled "Video game technology transforms operator training" (8) in which he states, "Virtual reality technology that was developed in the entertainment world can now be applied to the process plant industry. Thanks to advances in gaming technology, with detailed 3D modeling at the core, it has become practical, affordable and quick to create a fully navigable, hyper-real equivalent of a facility, whether already operational or yet to be constructed."

One other view on the potential for VE was explored by a team of several researchers investigating the applicability to disaster preparedness, "The immersive and participatory nature of VR training offers a unique realistic quality to training that is not generally present in classroom-based or web-based modalities, yet retains considerable cost advantages over large-scale real-life exercises."(9).

Each of the above reflects the findings of the author, in that, there are, as found by researchers from Deakin University representations for visual and notably haptic feedback that permit a one-for-one replacement of all the tools used in a "smoke house" scenario, and in fact, begin to permit use of an even wider set of tools in a VE. Thus, the ability to replicate and indeed surpass, the current "hands on" experience is achievable. (10) The real issue is, how can the current leadership be convinced it is sufficient? A greater explanation of the nature of the haptic feedback mechanisms that are now employable and achievable will follow in subsequent sections of this paper.

Combatting the Costs

Even once both of the above have been successfully confronted, or at least grudgingly accepted, the bottom line is finding the resources to implement a VE. The up-front costs are not the only concern, the ROI is also very important since a change in training methodologies is seen as both an investment and a cost saving strategy. If cost savings, personnel proficiency, or time savings (in the case of either outage planning or reducing the number of personnel required to complete an outage) cannot be forecast, then there is very little appetite for introducing any new technology. (Maria LaCal, personal communication, May 9, 2014 and B. Baker, personal communication, October 21, 2014) The costs associated with VE can be characterized in two familiar categories: Hardware and Software. The majority of the costs are associated with the Software in that a VE requires some sort of translation of an actual environment, whether this is from 3D Computer Aided Design (CAD), 2D drawings, photographs, or video files. The translation is dependent upon the format of the information and its compatibility with the chosen Game Engine (each has a series of formats that are easily used) or the requirement to gather information from some sort of metrology (e.g. LIDAR scans and photographs). The use of metrology, especially in the instance of a nuclear power plant may be quite expensive since some of the key information is in areas that are available only during a planned outage with the reactor in a shutdown condition. Even then, very careful consideration of the dose that might be received by the metrology team must be included in the estimate for time and cost. In early estimates for such work, the author has found that the costs associated with faithfully replicating the environment, significantly exceed the costs for the hardware. Estimates for the hardware vary with the number of potential users, but have typically been estimated between $5,000.00 and $7,500.00, so for a typical 10 person fire team, hardware costs should not exceed $75,000.00. Initial estimates for the software, which are dependent upon the availability of 3D data, can range from about $250,000.00 to $500,000.00, but these are very rough estimates for the conversion of data into an operational VE. Implementing the firefighting portion would increase the cost as well, and the exact nature of the increase is also inexact, but is not believed to exceed doubling the cost.

The issue becomes comparing the acquisition costs to current capabilities as well as a projected time to recover the resource allocation. As an example, the city of Virginia Beach (J. Spore, personal communication, September 4, 2014) expends approximately $15million over a three year period. If a VE could be utilized for even 50% of the training, then the resource allocation could be stretched to 6 years, a savings of nearly $7.5million. The ratio of the initial layout against this number starts to look attractive. It becomes more so when there is not an annual outlay, but merely changes to scenarios and the replacement of equipment through wear and tear. Finally, as the author discovered during his conversations with the VBFD leadership, the potential for other areas of training, using the same models was more extensive than had been first realized, therefore, additional training benefit could be gained thus eliminating other training costs without incurring any substantial cost. (V. Cooper, personal communication, February 5, 2014) An example of the usage of such a capability is shown in Figure 1, which depicts a multiple crane lift typical of an outage maintenance procedure.

Similar discussions can be made with nuclear facilities, whose possibilities are also quite extensive. The annual operating budgets are quite substantial, and though most budgets are based upon a 5 year projection, some costs are expected annually (typically there are two outages, one in the spring and one in the fall). The costs for major capital projects often include planning and design, where funds could be leveraged for use in constructing a 3D VE. (J. Signorelli, personal communication, January 15, 2015). Again, once the 3D VE is constructed, no further work other than updates would be required, so no additional costs would be incurred. The costs for features such as health physics modeling, outage animation and planning, procedural, or security training could be estimated and incurred in a phased in approach. Another method would be to construct the VE as a part of new construction so that the benefits of the VE could be used as part of the initial training and certification. This approach has been introduced to the NRC (B. Baker, personal communication, October 21, 2014) and been at least considered for the new construction plants. All costs in this approach could be incurred as part of new construction and thus, would be incorporated prior to plant operations and any additional costs could be scheduled with the routine maintenance outages.

Figure 1.Example of 3D CAD and Texture Information imported into a Game Environment

There is never a "free" resource, and the early costs would seem to be high, and in some cases, daunting. The most restrictive case is that of a municipality, and when investigated as done above, there seems to be an argument for resourcing.

SEEING IS NOT BELIEVING

Visual Fidelity is just the start

The proliferation of games available on the market and their popularity as a form of entertainment has forced the leading game companies to use game engines with increasing video and audio fidelity. The ability to interact with the game by use of game controllers either singly or with multiple players is also common. Games also provide the opportunity to have very large numbers of simultaneously engaged geographically disparate players, commonly referred to as Massive Multiplayer Online Games (MMOG). They can be accessed in several modes or on a variety of mobile devices. The interactivity and fidelity of these games has had the effect of raising the expectations of the millennials who are now entering the workforce in large numbers and who will eventually become the majority of the workforce. In a recent article in Forbes Magazine, John Zogby conducted a poll of over 1000 millennials in which he found that 57% indicated that they play video games AT LEAST 3 times a week. Just as importantly, nearly 70% felt that video games were important in the development of work and life skills. (11) So not only have the millennials (aka digital natives, and now their successors born after 2001) incorporated games into their lives, they believe that games are a key to learning. The Boomers (aka Digital Immigrants) who are now in leadership positions can delay acceptance of this learning methodology until their own retirements, but the failure to transfer the knowledge they have gained during their careers will be nearly irreversible.

Just because Boomers are not comfortable with game controllers, doesn't mean they cannot appreciate, or even marvel, at the tremendous video fidelity of currently available games. Further, the realism of the games in terms of physics effects, sound, and interactivity provide an insight into the potential for video games to become not only a "game," but a very effective and immersive training tool. An example of the video fidelity possible (which also incorporates aural and infrared effects) is shown in Figure 2.

Figure 2. Game Quality Virtual Scene for Fire Fighting Response

Suspension of Disbelief is the key

The key to any scenario being useful as an predictor of performance by operators during an actual operation, whether it is a normal procedure or a casualty, is the ability for the operators to believe that the is a realistic representation of an actual situation. The author spent 30 years in the Navy, including nearly 17 years aboard ship. He participated in training for nuclear power plant operations, combat systems operations, and damage control operations. The training for these became increasingly realistic over his career, culminating in the deployment of the Fleet Synthetic Training (FST) capability as the means to train shipboard Combat Systems teams in a distributed, real time war game. The FST incorporated actual communications, weapons system stimulation, electromagnetic spectrum information, digital information, and the ability to engage simulated targets. The displays in the individual ship's Combat Information Centers (CIC) mirrored those of the actual theater, and the scenarios ran continuously for as long as 72 hours. This was as immersive as could be constructed for the crews of warships. It was common for personnel to leave the CIC after their watch and realize that they were next to the pier in their homeport, and not underway.

This "suspension of disbelief" was the key to assessing the readiness of the individual ship's crews. Some of the exercises were so realistic (simulated missile launches) that if the ship's company did have to perform the same evolution while underway, the only difference noted was that there was the sound of the missile actually leaving the ship. The author was able to experience these phenomena not only as the Commanding Officer of a ship, but while riding several other ships as a Senior Observer subsequent to the FST completion.

The reasons that the simulations or scenarios (in the case of the nuclear power plants, some actual conditions were imposed, so actions by the operators were a necessary part of the training and assessment) were so effective was that the immersion was effective. The displays, sounds, actions on equipment or panels were actually carried out, so it was "real". The same sort of immersion has been employed in both Civil and Military aviation, and has become increasingly accepted as a vital part of training. The issue is that for many of the operators in power plant spaces, emergency responders, security force personnel, or supervisory personnel, similar capabilities were not available or possible, until very recently.

Achieving Immersion without a trainer

How does one achieve the immersion that is currently available in large scale trainers, or created by connecting actual operating spaces? Recent developments in Head Mounted Devices (HMDs) provide entrée to the desired immersion. Visual fidelity, especially without having to be in any specific location, creates the opportunity to expand the immersive environment meaningfully. The desire to expand the environment has been the focus of the work done by the author and his team of game developers.

The initial effort undertaken by the game development team was creating a fire that could be extinguished. This doesn't, in itself, seem like a daunting task. Yet, the team quickly found that fires are not really the focus of commercial "first person shooter" games. The fires are generally the result of explosions and then create a backdrop or obstacle to movement. Actually having the fire expand and then extinguishing it are NOT prime considerations. Confronted with the need to do something out of the ordinary spurred several other questions:

1) Is sound a major component in finding, combatting and extinguishing a fire?
2) How does smoke propagate, and how does a firefighter overcome the effects?
3) If the smoke is thick, or if a space is confined, how does the firefighter find the fire?
4) How does the firefighter confirm the fire is extinguished?
5) How can the fire hose or hand held extinguisher be realistically represented?
6) Does firefighting technique matter?
7) Can the equipment worn by the firefighter, especially the air tank and mask be simulated?

Each of these led the team to the conclusion that EVEN IF a visual representation of the fire could be created, the environment would only be truly representative if all the effects, but specifically sound (aural), touch (haptic), heat, smell (olfactory) and communications could be included. No matter how "good" the fire was, unless the firefighter had the chance to actually "fight the fire" or at least replicate the experience to the maximum extent possible with present technology, while it would be a "cool" game, it would be nothing more. There would be utility, but there are already firefighting trainers that permit fire teams to extinguish fires.

The development team proceeded to develop the scenario based upon the experience of the author who had fought several large shipboard fires and had trained on several firefighting trainers throughout his career. This approach permitted the author to explore solutions to the questions while not delaying the development of the scenario. The ultimate goal was to have active firefighters validate the initial effort and provide feedback regarding the additional realism necessary to implement the virtual environment as a training solution.

The initial implementation of aural effects included the addition of the sound of the fire. It became apparent that the sound would need to "follow" the propagation of the fire during prosecution. One complicating factor was that different materials combust in differing modalities. Further, the various modes of heat transfer play a role in fire propagation, and as the fire "grows" it does become nearly deafening. The development team was able to link all of the above to the aural component. In the first demonstration to a public audience at a nuclear power conference, one of the conference attendees, who was skeptical that the fire would have any realism, stated that because of his skepticism, he let the fire "get ahead of him." The result was a very determined effort to use proper firefighting technique, which did permit him to extinguish the fire. After removing the HMD, the perspiration was apparent on his face and head, and he stated that he really did begin to "feel" heat and sweat. (Event Attendee, personal communication, August 9, 2014) At least at first usage, the aural component of the VE seemed appropriate.

The development team didn't feel that this was sufficient. After viewing several videos of firefighters, they also felt that introducing the sound of the water emitting from the hose would be effective. The ability to add aural components in this fashion was instructive in that, during later developments, sounds for industrial environments, including ventilation, background machinery noise, and crane movements were requested as proof of the capability to replicate a power plant evolution.

Although the ability to use a thermal imaging capability is another "visual" component, the inclusion of such a capability was viewed as the ability to add a flash application to the VE. There were several other flash applications that were envisioned including gas monitoring devices, radiation dosimeters, and radiation detection devices. (The last two were based upon the belief that at some point, these would be necessary for creating VEs for the nuclear industry.) The development of the flash application of the thermal imaging device was also necessary for the instantiation of the VE when a fire fighter would have an emulated device and use it as would be appropriate for detecting a fire and confirming that the fire was extinguished. The ability for modern game engines to accommodate additional applications provides remarkable expandability that appears critical to the suspension of disbelief.

The first real validation of the effectiveness of the VE in terms of aural reality and appropriate flash application was provided by the VBFD in September of 2014. In the presence of the City Manager, the Fire Department Chief, and the Senior Leadership of the department, several firefighters were placed in the VE and confirmed that the aural effects and the thermal imaging replicated their experience in combatting fires. They remarked that in one of the scenarios, it would NOT have been possible to locate the fire due to the density of the smoke without these two characteristics.

The ability to create a very complex VE seemed within the grasp of the team. Still, there were components missing; the communications and haptics. The inclusion of communications not only adds realism, but is a key component to assessment of team performance and progress, whether the evolution is real or a training scenario. There is a requirement for communication between members of the response team or operators while the leader of the team must also communicate separately with a controlling station. Again, the composability of modern game engines made implementing this sort of communications protocol possible. There was still one hurdle left, which would have to be solved to move the firefighting or any operational VE into a truly acceptable state, haptics.

Haptics are the "long pole"

The development team, concurrent with the submission of this paper, has completed the development of two different fire simulations, developed two additional environments (an air traffic control tower and a power generation turbine building), developed the ability to use various formats, notably .XML and HTML5 to drive animation within the environments, and begun development of multi-player, multi-role capability. Additionally, a motion capture studio has been constructed to permit more realistic gestures and to permit capture of the motions expected in several scenarios, to wit: hand wheel operations for valves, use of tools such as wrenches, use of firefighting equipment, specifically vari-nozzles, and the body (hand) actions required to combat a fire.

There have been advances in other “accessory” technologies such as 360° treadmills, which will permit operators, to move and experience the realistic movement in a building, power plant or ship, while also having the ability to monitor cardiac impact. HMDs continue to improve in form factor and capability, which will permit longer wear, the ability to use the devices in a wifi environment, and use them while wearing actual protective clothing. The advances in HMDs may also permit the VE to be used in both a completely virtual OR augmented reality application, allowing operators to train in their actual work spaces. Still, these are NOT the most significant factors in achieving a fully immersive experience.

The jet reaction force of a fire hose with 150 psig of firefighting water is something no firefighter ever forgets. One must brace to counteract this jet reaction force when operating a fire nozzle. The reaction force changes when the pattern of the nozzle changes. The hose is very hard to maneuver (since it is also rigid), and when additional 25 foot lengths of hose are added, becomes heavy while the pressure at the nozzle drops. All of these effects are necessary to effectively train a fire fighting team. The ability to pressurize the hose, thus providing the rigidity and weight are easily accomplished, and by using a cover plate, the emission of water onto operating equipment can be avoided. (12) So, some realistic training can be implemented anywhere, but it is not practical to spray water in an environment where other simulations which require electricity exist, and thus, there would seem to be a major obstacle to achieving suspended disbelief.

In March 2014, the author re-established a business relationship with Deakin University (S. Nahavandi and J. Mullins, personal communication, March 21, 2014). The leading researchers Drs. Saeid Nahvandi and James Mullins conduct research in the area of haptic response, but this research had primarily addressed hand held weapons and small medical instruments. Dr. Mullins is a former fire fighter and believed that the firefighting challenge could enable some significant research as well as solving a problem he had encountered. Over the course of the next four months, Dr. Mullins’ research team developed solutions involving the inflation of a fire hose, the ability to control the nozzle pattern, the ability to impart jet reaction force, and the ability to simulate the drag force of the hose as additional lengths of hose were required. The additional lengths of hose necessitated the reduction in pressure and flow at the nozzle. All of these effects needed to match the aural and visual effects that would be appropriate.

The team also realized that the VE would need the sensation of the face mask alternately expanding and collapsing, in conjunction with the respiratory pattern of the firefighter. Inexperienced firefighters, when faced with a very large fire, tend to hyperventilate. Thus, they use the oxygen in the air system they are wearing at a much greater rate than would be expected from experienced firefighters. The ability to monitor the use of oxygen, regardless of the experience of the firefighter being monitored, is a key factor in the time that individual can combat the fire. If the firefighter is remote to the entry point, the need to evacuate the scene may be a very complicated and indeed dangerous situation.

In addition to motion (as provided by the treadmill), the aural effects of the fire, and the density of smoke, what other factors can lead to the firefighter becoming distressed to the point of hyper ventilating? The remaining factor the Deakin team believed most important was heat. The firefighting ensemble (FFE) is heavy, necessarily fire retardant, and very well insulated. During the combatting of a fire, the heat in the space and the firefighter’s proximity to the flames causes the firefighter to get hot. The Deakin University team implemented heating pads which could be controlled by a training director to impart heat to the operators.

The combination of all the above is the “element” that firefighters most request. The firefighters from VBFD, Great Lakes Naval Training Center, and Naval Education and Training Command all stated that if these haptic effects were included in the VE, then the utility of the VE would be at a level as to be both realistic and useful.

The haptic capabilities for tools such as crowbars, rakes, axes, and even chainsaws are being investigated by the research team at Deakin University. None of the research permitting implementation of the aforementioned tools is complete, and indeed, since these capabilities are very specialized, that development will very likely occur when a specific task is requested, so that the resourcing will not be borne by the university or author’s company.

NEXT STEPS

The development described herein has occurred at a very rapid pace. It has also occurred entirely on internally generated Research and Development funding, and only with periodic involvement of the four game developers who work with the author. All of the development described herein has been demonstrated either in a VE using a game controller device or in a "game slice" at the development sites. A full motion, multi-player, multi-role VE has not yet been constructed. The logical extension of the research is seen as coming from a couple of potential customers; the power generation industry or the military (and very likely the US Navy).

The development of the environment, to be cost effective, requires 3D CAD that requires minimal translation or manipulation. Texturing is generally not time consuming, so source files that are compatible with a given game engine reduce the time to "build" the environment, which reduces cost. Thus, the development that must take place to make the use of VE attractive is the ability to use the VE as an initial instruction tool, an initial qualification tool, and finally as a rehearsal tool. The construction of a new series of nuclear power plants provides an ideal opportunity to utilize 3D design data to train a "game ready" work force. The ability to drive animation with .XML or HTML5 outputs for procedures or schedules permits the ability to visualize a procedure, assess the performance of the procedure (and retain detailed records, including a video replay), visualize an entire outage plan, and introduce either casualties or train for casualties that involve effects (radioactivity) or damage that are currently ineffectively simulated. The evolution of the haptic feedback, increased "realism" using physics to impose restraints (no one wants to be able to move through walls or pipes), and addition of olfactory effects while introducing all of the aforementioned effects into a full motion capture will permit demonstration and fielding of the VE.

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