# Chemical Agent Simulator for Emergency Preparedness Training

Paul N. Kizakevich, Steve Duncan, Jimmy Zimmer, Henry Schwetzke, Warren Jochem
*RTI International, 3040 Cornwallis Road, Research Triangle Park, NC 27709*

Michael L. McCartney
*MLM Technical Services, Durham, NC 27704*

Kenton Starko, N. Ty Smith
*Advanced Simulation Corporation, Point Roberts, WA 98281*

## 1. Background/Problem:

For several years, the medical and public health communities have expressed concern over preparedness for terrorism attacks. In 1999, the Institute of Medicine recommended that simulation software be developed to provide interactive training for personnel involved in management of chemical or biological terrorism incidents [1]. A recent survey of 30 hospitals found that 73% were inadequately prepared for a chemical or nuclear event [2]. In a different survey of over 180 emergency departments, fewer than 20% of hospitals had plans of biological or chemical weapons events [3]. Waeckerle et al, [4] reported that adequate training is lacking in our current educational process for the target groups faced with a WMD incident. Moreover, local and state agencies remain ill-prepared to deal with bioterrorism. In the GAO analysis of seven cities, all indicated that their hospitals had an insufficient response training [5].

We previously reported on research and development for trauma and bioterrorism simulation [6,7,8]. In the present paper, we describe enhancements to these works that support chemical casualty representation and preparedness training, with an initial focus on cyanide casualty simulation.

## 2. Virtual Patient Simulation

STATCare (Simulation Technologies for Advanced Trauma Care) provides interactive medical practice for multiple occupational domains and workplace environments. Medical providers can sharpen assessment and decision-making skills, as well as develop an appreciation for patient responses to appropriate or inappropriate treatment. STATCare guides the user through standardized protocols and then challenges the user with complex scenarios. The Learn mode provides step-by-step, interactive instruction on patient assessment and care. The Practice mode allows scenario-based practice at a self-set pace with free-play of any interaction. All user interactions are recorded for after-action reviews, as are the pertinent physiological data.

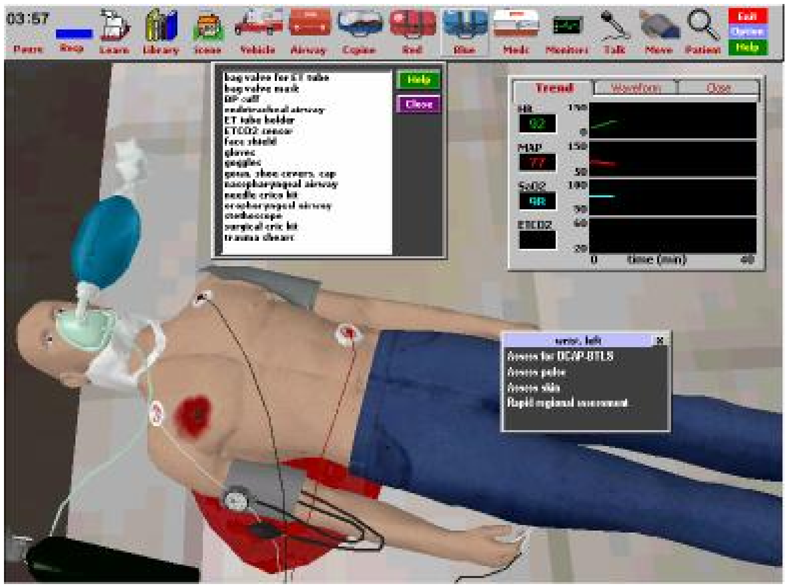


**Figure 1. Interactive 3D trauma patient in the STATCare simulator.**

The STATCare simulator presents a scenario comprising a setting (e.g., trauma scene, medical clinic, emergency room), conditions, and one or more patients. The caregiver can navigate and survey the scene, interact and converse with each virtual patient, use medical devices, monitor data, and perform interventions. To interact with the virtual patient (e.g., take a pulse), the user right-clicks on the body region of interest (i.e., the wrist). A menu appears near the selected region, and an interaction may be selected (i.e., Assess pulse). The results of any interaction is then reported.

The physiological simulation integrates real-time cardiovascular, respiratory, and pharmacokinetic models based on the Advanced Simulation Corporation BODY™ model [9]. A supervisory layer provides overall control of the simulation, controls the physiology model, and stores data for subsequent review. The multiple-compartment BODY transport architecture represents physiological functions and pharmacological actions and interactions. Just like the human body, the physiology model centers around a cardiovascular model that consists of a beating heart; blood with which to transport gases, ions, chemicals, drugs, etc.; and compartments such as the brain, heart, and liver. The pulsatile cardiac function provides blood pressures and flows that resemble the real cardiovascular system and adds to the realism of the simulation.

## 3. Chemical Casualty Simulation

### *Physiological Modeling*

Cyanide affects virtually all body tissues. Its principal toxicity results from inactivation of cytochrome oxidase (cytochrome *aa3*) thereby affecting cellular respiration, even in the presence of adequate oxygen stores. Cyanide binds to cytochrome oxidase, blocking cellular oxygen utilization and forcing an eventual shift to anaerobic metabolism. Consequently, the tissues with the highest oxygen requirements (e.g., brain, heart, liver) are the most profoundly affected by acute cyanide poisoning.

Initial simulations of cyanide exposure focused on achieving both the physiological and temporal behavior of the agent and its antidotes [10]. Since the primary mechanism of cyanide toxicity is prevention of oxygen utilization, we modified the model to mimic cellular hypoxia rather than merely reducing oxygen consumption. Figure 2 shows key physiological variables and their reactions to a lethal (35 mg) dose of cyanide. The rapid increase of heart rate and perturbation of mean arterial pressure are responses to catecholamine release. Anaerobic metabolism increases pCO2, followed by respiratory arrest, decreasing SaO2 and eventual death. If 300 mg of sodium nitrite are infused over 5 min, beginning a minute after cyanide exposure, recovery can be achieved (Figure 3).

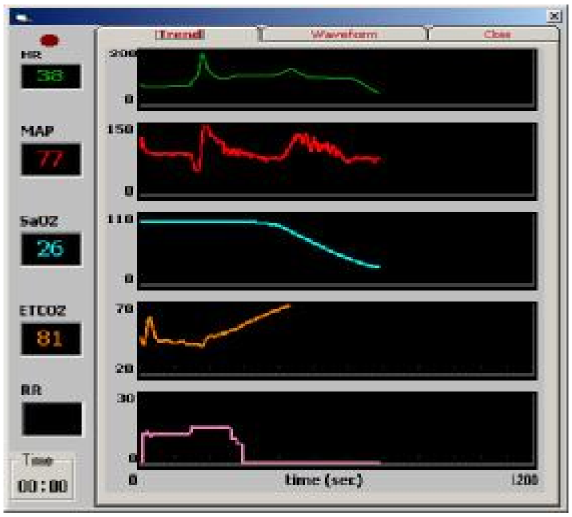


Figure 2. 35 mg cyanide dose resulting in apnea and cardiac arrest.

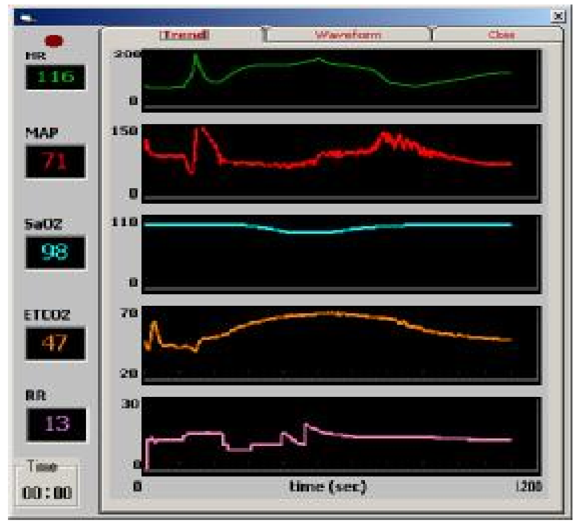


Figure 3. Recovery with treatment beginning 1 minute after cyanide exposure.

*Cyanide Treatment Modeling*

The chemical processes involved in cyanide treatment are illustrated in Figure 4. The first step in treatment is administration of a nitrite. Amyl nitrite or sodium nitrite converts hemoglobin (Hb) to methemoglobin (MetHb). Methemoglobin competes with cytochrome oxidase for cyanide to form cyanmethemoglobin (CNMetHb), and serves as a scavenging agent to pull cyanide from tissue. The CN - MetHb reaction is reversible, so free CN remains in the blood. Since MetHb also reduces the oxygen carrying capacity of the blood, we revised the O2 transport component of the model to decrease Hb (and O2Hb) based on the amount taken up as CNMetHb. To rid the body of the cyanide, sodium thiosulfate (Na2S2O3) is administered. Thiosulfate converts free cyanide (CN-) to thiocyanate (SCN-), which is excreted by the kidneys. All of these reactions occur simultaneously, and are influenced by enzyme activity, process saturation, circulation, and reaction kinetics.

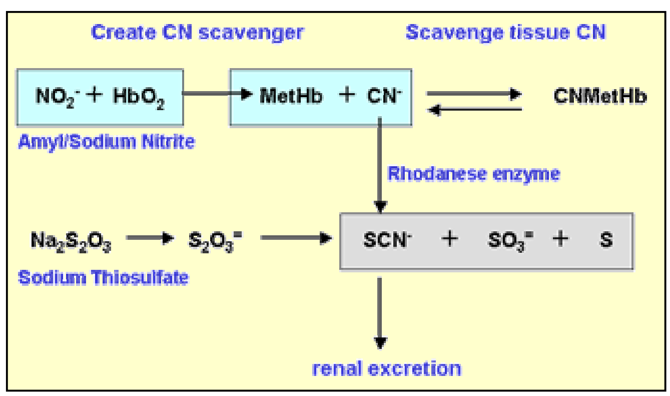


Figure 4. Reactions involved in cyanide treatment.

The resultant models are quite complex. Each of the treatment agents and internal chemical substances were modeled as a “drug” within the existing model framework. This allowed simulation of the uptake or formation of each substance, pharmacokinetics (i.e., circulation and distribution), concomitant physiological effects, interactions with other chemical constituents, and elimination by metabolism or excretion. To ease calculation of mass balance, all chemical processes were computed on a molar basis and assumed to take place in mixed blood at the vena cava. Nominal values for model properties, such as diffusion coefficients, were set for model development and left for revision later as the simulator becomes more refined.

The time course of the integrated cyanide treatment models is shown in Figure 5. Each plot is the blood concentration of a given chemical at the vena cava as a function of time. The scales were adjusted to highlight the dynamic nature and interplay of the various chemical reactions and processes.

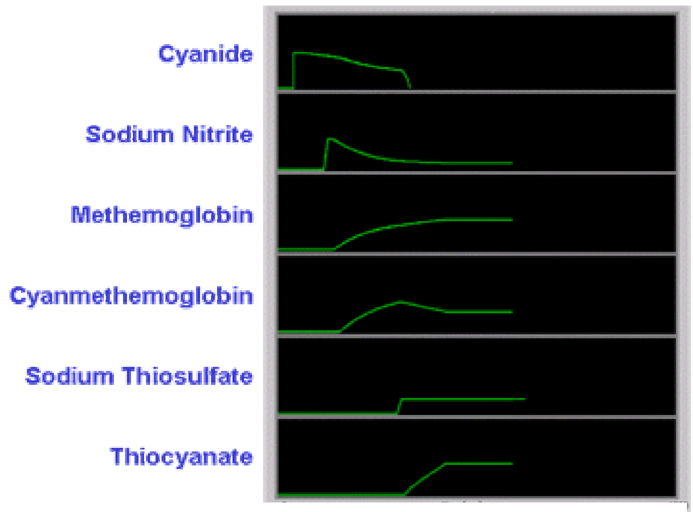


**Figure 5. Time course of cyanide treatment.**

*Virtual Character Modeling*

Virtual characters had previously been developed for trauma, bioterrorism and other diseases, and mentally-disturbed individuals [11]. Two additional 3D characters were created for chemical casualty simulation. A 12 year-old boy and a 30 year-old female were created using 3D character modeling tools and configured with a skeletal system for animation. Chemical exposure simulations required the following visualization enhancements:

- Dynamic skin texturing of clinical signs & injuries
- Full-body medically-relevant animations
- Multi-layered, deformable & removable clothing
- Breathing integrated with real-time physiology
- Set pupil size and animate pupil response
- Attachable medical devices
- Dynamic speech production (text-based and prerecorded speech with lip shaping)

Casualties will exhibit certain behaviors consistent with a given chemical and level of exposure. For example, profuse salivation, vomiting, or tearing would induce body movements like coughing and wiping the eyes. Other medically-relevant animations include convulsions, seizure, muscle twitching, and respiratory arrest. These are all visual signs that needed to be represented by an animated virtual patient. Such signs and behaviors are of diagnostic value and must be as accurate as possible for training or competency testing. Animations were initially developed using manual, interactive artistic methods using 3D character development software. Once the software framework was verified, motion capture data was acquired using instrumented actors playing out the various movements. The motions were captured at a studio called Modern Uprising (Long Island, NY). The animations were then redeveloped using RTI's motion capture data.

Facial expressions are displayed through the use of 3D morph technology. Like general body motions, facial expressions can depict level of consciousness, reaction to agents, pain, and blink rates. To visualize injured regions, rashes, bleeding and other variations in appearance, a regional "texture swapping" technology was implemented for both skin and clothing. Graphic images depicting chemical burns, irritation, and cyanosis in extremities can cover the skin like a decal, thereby altering its appearance to the trainee. The virtual patient also shows chest motion in concert with breathing. The virtual breathing can show normal breathing rates, slow breathing, and labored breathing.

*Chemical Casualty Scenarios*

Scenes were created for staging chemical scenarios, including a subway station and an emergency room allowing for pre-hospital and in-hospital simulations. The emergency room scene (Figure 6) is used to train healthcare personnel receiving casualties at a hospital. With this scene, the simulator may be used to train at a higher level of medical care and provide therapies not available to pre-hospital caregiver. The subway station scene (Figure 7) is used to portray a terrorism event either in a subway car or at the station. Casualties are presented near the entrance to the station, on a sidewalk in the open environment. In this way, a safe non-exposure environment is available to the caregiver to diagnose and treat the casualty.

**Figure 6. Emergency room setting.**


**Figure 7. Subway entrance setting.**

Multiple-casualty scenarios were developed with injury models, physiology, and medical signs and symptoms relevant to a mixed trauma and chemical exposure scenario (Figure 8). A "Triage Card" facilitates assignment of priority and triage category (immediate, delayed, minimal, expectant, and deceased). Triage interactions are consistent with the paradigm of Move, Assess, Sort, and Send as taught in the Basic Disaster Life Support (BDLS) curriculum [12].


**Figure 8. Multiple-casually cyanide and trauma triage simulation.**

## 4. Discussion

The chemical-agent patient simulator incorporates patient assessment, chemical exposure modeling, physiological modeling, antidote modeling, 3D patient visualization, medically-relevant animation, and interactive medical care on a desktop computer platform. Using this architecture, simulated casualties were implemented for one hazardous material, cyanide, as a demonstration the prototype system capabilities.

The simulator, with interactive 3D virtual patients, offers considerable advantages over current training technologies. Virtual patients can:

- be readily constructed to represent the range of human diversity, including ethnic, age, race, body habitus, and cultural variations.
- be animated, thereby enabling visualization of signs and behaviors like convulsions, vomiting, coughing, tearing, and cramping.
- dynamically change their appearance to visualize cyanosis, rashes, lesions, and skin reddening (associated with carbon monoxide and cyanide poisoning).
- be interactive, with lifelike conversation and behavior, for reporting of symptoms and events leading to the casualty situation.
- be mobile, moving about the scene in a purposeful or other manner, as with a dazed casualty of a terrorism event.
- be multiple, allowing practice of triage in a dynamic mass casualty simulation

- be very affordable, especially compared to mannequin patient simulators.

## 5. Conclusions

The terrorism events of 2001 re-emphasized a need to provide better educational materials for bioterrorism and chemical agent diagnosis and response. We have attempted to meet this need through the research and development of virtual standardized patient for chemical casualty simulation. Our next steps are to validate the quality of the cyanide simulator, add nerve agent and other chemical simulations, and evaluate the training effectiveness of such simulation in a regional medical training testbed.

## 6. Acknowledgements

The authors wish to thank the National Medical Technology Testbed (NMTB) at Loma Linda University and the Telemedicine and Advanced Technology Research Center (TATRC) of the U.S. Army Medical Research and Materiel Command for their cooperation and support. This work was supported, in part, by funding from the Department of the Army under Cooperative Agreement Number DAMD17-97-2-7016 and by RTI International. The content of the information does not necessarily reflect the position or the policy of the government or NMTB, and no official endorsement should be inferred.

## 7. References

[1] Institute of Medicine/National Research Council. *Chemical and Biological Terrorism.* Washington, DC: National Academy Press; 1999.

[2] Treat K.N. Hospital preparedness for weapons of mass destruction incidents: An initial assessment. Annals of Emergency Medicine Nov. 2001

[3] Wetter DC, Daniell WE, Treser CD. Hospital preparedness for victims of chemical or biological terrorism. Am J Public Health. 2001; 91: 710-716.

[4] Waeckerle, et al., Executive summary: Developing objectives, content, and competencies of training of Emergency Medical Technicians, Emergency Physicians, and Emergency Nurses to care for casualties resulting from Nuclear, Biological, or Chemical (NBC) incidents. Ann Emerg Med. 2001; 37(6):

[5] GAO. Bioterrorism: Preparedness Varied across State and Local Jurisdictions. GAO-03-373, Washington, D.C., April 7, 2003.

[6] Kizakevich, PN, ML McCartney, DB Nissman, K Starko, and N. Ty Smith. "Virtual Medical Trainer: Patient Assessment and Trauma Care Simulator." Medicine Meets Virtual Reality - Art, Science, Technology: Healthcare (R)evolution, J. D. Westwood, H.M. Hoffman, D. Stredney, and S.J. Weghorst, eds., pp. 309-315, IOS Press and Ohmsha, Amsterdam, 1998.

[7] Weaver, A.L., P.N. Kizakevich, W. Stoy, J.H. Magee, W. Ott, and K. Wilson. Usability Analysis of VR Simulation Software. Medicine Meets Virtual Reality 2002, J.D. Westwood, H.M. Hoffman, R. A. Robb, and D. Stredney eds., pp. 567-569, IOS Press and Ohmsha, Amsterdam, 2002.

[8] Kizakevich PN, L. Lux, S. Duncan, C. Guinn and M. L. McCartney. Virtual Simulated Patients for Bioterrorism Preparedness Training. Medicine Meets Virtual Reality 2003, J.D. Westwood, H.M. Hoffman, R. A. Robb, and D. Stredney eds., pp. 165-167, IOS Press and Ohmsha, Amsterdam, 2003. Stud Health Technol Inform. 2003;94:165-167

[9] N. Ty Smith, K. Starko, M. L. McCartney, and P. N. Kizakevich "Windows Dynamic Link Libraries Create a New Interface Tool for BODY™ Simulation. Its Use in Trauma Simulation. Abstracts from Simulation in Anesthesia, 1998 Joint Meeting of Society of Technology in Anesthesia & Rochester Simulator Meeting, Tucson, January 14-17, 1998.

[10] Sidell, FR, Patrick, WC, and Dashiell. TR. Jane's Chem-Bio Handbook, Jane's Information Group, Alexandria, VA. 1999.

[11] Frank, G., Guinn, C., Hubal, R., Pope, P., Stanford, M., & Lamm-Weisel, D. (2002). JUST-TALK: An Application of Responsive Virtual Human Technology. Proceedings of the Interservice/Industry Training, Simulation and Education Conference, December 2-5, 2002, Orlando, FL.

[12] Basic Disaster Life Support Provider Manual, Pepe, PE, Schwartz, RB eds., 2003.