USE OF THE DEPARTMENT OF DEFENSE OPERATIONAL REQUIREMENTS-BASED CASUALTY ASSESSMENT (ORCA) SOFTWARE SYSTEM TO DETERMINE OCCUPANT RESPONSE TO FIRE AND THE EXTINGUISHMENT PROCESS

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ABSTRACT

The objective of this effort is to translate data on the toxicity and compatibility with humans of new extinguishants and their principal degradation products during the fire extinguishment process to their effects on personnel in performing their key functions or evacuating, and the platform effect on overall mission effectiveness. One product of this project is the determination of acceptable exposure levels of combustion extinguishant byproducts or different missions and operating conditions that can accommodate personnel evacuation or other required length of exposure. These byproduct particulates may irritate the lungs and eyes, cause visual obscuration, mental acuity degradation ("lightheadedness"), or cardiac sensitization (since some chemicals can excite the heart to dangerous levels), contaminate the bloodstream, and often have other toxic uptake effects. This determination can establish the upper permissible concentration thresholds in which the extinguishants must demonstrate successful fire extinguishing performance. The proposed method will utilize ORCA to determine the effects of the compatibility of new extinguishants on the mission performance of the individual. A methodology will be developed using compatibility data for existing fire suppression technologies (HFC-125, dry chemicals, aerosols, water-mist...) as a starting point until new fire extinguishing technologies and their corresponding compatibility data are identified. Probabilistic scenarios will be generated for the applicable weapon systems. Such systems include: armored vehicles, aircraft cargo bays, ship engine and machine rooms, mission critical facilities, helicopters, and for maintenance personnel exposed to the pure extinguishant during its installation, replacement, demilitarization, banking, recycling, and destruction) using the interaction of the extinguishant and its decomposition products with humans. As the compatibility data for the new extinguishants are made available during the Department of Defense Next Generation Fire Suppression Technology Program, they would be implemented into the ORCA model and similar analyses would be performed as with the existing extinguishants.

OBJECTIVE

The objective of this effort is to obtain data on the toxicity and compatibility of humans with new extinguishants and their principal degradation products during the fire extinguishing process. As new, effective extinguishants are identified, a need exists for methods to determine other key indicators of their acceptability (e.g., effects of human exposure). The products of this project are the determination of acceptable exposure levels for different missions and operating conditions that accommodate personnel evacuation or other required duration of exposure, given exposure to toxic extinguishants and combustion byproducts, particulates that irritate lungs and eyes, visual obscuration, mental acuity degradation ("lightheadedness") and often toxic uptake effects. This will establish the upper permissible concentration thresholds in which extinguishants must demonstrate successful fire extinguishing performance. The proposed method will be to utilize the Operational Requirements-based Casualty Assessment software system to determine the effects of the compatibility of new extinguishants on the mission performance of the individual.

BACKGROUND

Fires and explosions are among the greatest threats to the safety of personnel and the survivability of military aircraft, ships, land combat vehicles, and facilities in peacetime and combat operations. Halon 1301 is used for fire extinguishment and explosion suppression applications in most military weapon systems and mission critical facilities. Due to its high ozone-depleting potential (ODP), halon was banned from production in the US by the beginning of 1994. Alternatives developed by industry to date have sizable weight and volume penalties, and their application to fielded current weapon systems could require considerable expense and other compatibility issues. In particular, it is necessary to obtain data on the toxicity and operational compatibility of new extinguishants with humans and their principal degradation products during the fire extinguishant process.

The Operational Requirements-based Casualty Assessment (ORCA) software system allows users to assess the operational casualty of military personnel due to various insults. The casualty is assessed by modeling injuries to the personnel from various insults such as blast overpressure, penetration, blunt trauma, toxic substances, and thermal overload. Each occupation must be analyzed in terms of the required task elements and the associated elemental capabilities for each occupation (24 fundamental capabilities possessed by people to function). The capabilities possessed by an individual or required for a job must be quantitatively specified. These requirements are then compared against the degraded capabilities to determine whether an operational casualty occurs.[1]

The assessment is made up of three parts, the insult, the individual capability, and the required capability as shown in Figure 1. The user inputs parameters $\{P_i\}$ that quantify an insult from a damage mechanism. The damage mechanisms in ORCA include: blast overpressure, penetration, blunt trauma, acceleration, toxic substances, thermal overload, and directed energy. For each damage mechanism, there is a methodology (M), which relates the insult to a body injury.

The injury is modeled as an A vector and B processes. The A vector contains 470 body elements which have been specifically defined and geometrically modeled. Each of the elements contains a scale, which quantifies the extent of the injury to that body element. In addition to causing local damage to body elements, the insults can initiate body processes that have wide-ranging or systemic effects. Some of the B processes that might be initiated include bleeding, respiratory failure, infection, and build-up of intra-cranial pressure.

Once the injury has been determined, the C operator, or mapping, relates the injury to the capability of the individual. The C mapping includes the effects of the physical damage (A vector) and the deleterious B processes. The taxonomy, which describes the methodology, as shown in Figure 1, is the basis for the ORCA software. The ability of a human to perform tasks depends upon a number of elemental human capabilities such as hearing, vision, mental processing, and physical responses. Each of these 24 capabilities is quantified by a set of parameters which form the Elemental Capability Vector ($\underline{X}$) as shown in Table 1. Because some injuries can cause certain capabilities to decrease or increase with time, the Elemental Capability Vector (ECV) is stored for several significant times after injury. These times are immediate, 30 seconds, 5 minutes, 1 hour, 24 hours, and 72 hours.

The requirements of military personnel to complete a military job can also be defined as 24 basic human capabilities. This vector (Z) uses essentially the same set of parameters as shown in Table 1. These requirements are then compared against the degraded capabilities to determine whether an operational casualty occurs. Operational casualty is defined as an individual who does not have the elemental capabilities to perform the job.

Since the determination of operational casualty involves both the degraded capabilities and the requirements, it is possible that the individual may be able to complete some sub-tasks of a job or perhaps meet a lesser requirement. It is also possible that the individual capabilities of the individual may fall short of the requirements without an injury. The sub-standard performance is called a partial casualty. ORCA considers partial casualties by allowing the user to specify a lower, or minimal requirements level for each job or task. The degraded capabilities can be measured against the minimal levels to determine partial casualties. The standard requirements level is called the full requirements.[1]

To operationalize personnel vulnerability assessments, it is necessary to understand exactly what the job requirements are for key combat occupations. Each job must be decomposed into tasks and task elements. Once these task elements have been determined, they must be evaluated in terms of the 24 elemental capability vectors (shown in Table 1). Each occupation must be researched in terms of the required task elements and the associated elemental capabilities for each occupation (24 fundamental capabilities possessed by people to function). The capabilities possessed by an individual or required for a job must be quantitatively specified.[2] Even though ORCA is at the present time primarily a military-oriented software system, its application could be broadened to address issues faced by other individuals (such as, firefighters, law enforcement officers, Federal agents, emergency personnel, etc.). With slight adaptations, the ORCA software could be modified to include the operational requirements of the aforementioned individuals, and would provide a means to assess possible losses or incapacitations these individuals might obtain during an incident. ORCA could be used in campaign analysis (Federal assault teams, firefighters, SWAT teams, etc.) regarding domestic terrorist-related events or other such similar events. It could provide casualty assessment and aid in tactics studies in deterministic or probabilistic scenarios.

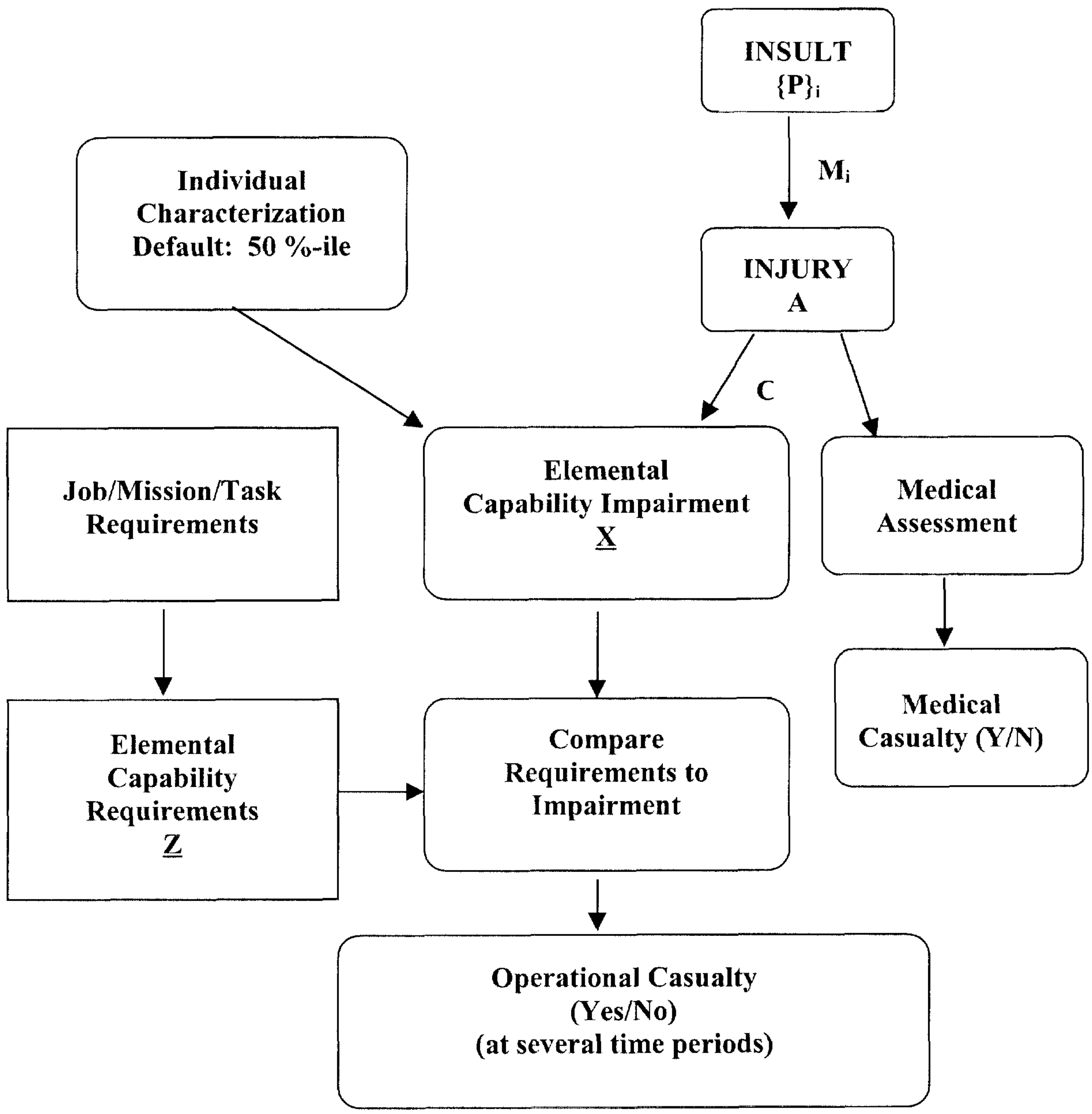

Figure 1. Crew Casualty Taxonomy

Table 1. Elemental Capability Vector

Element Number	Capability	Metric
1	Visual Acuity and Color Discrimination	Snellan (20/20, 20/40, etc.)
2	Night Vision	NV Scale
3	Visual Field of View	Degrees
4	Binocularism and Motility	Yes/No
5	Hearing-Threshold: Low Frequency	dB
6	Hearing-Threshold: High Frequency	dB
7	Binauralism	Yes/No
8	Somatic Senses	Yes/No
9	Balance	Standing Scale
10	Cognitive Mental Processing	Workload Scale
11	Visual Mental Processing	Workload Scale
12	Auditory Mental Processing	Workload Scale
13	Psychomotor Mental Processing	Workload Scale
14	Speech Articulation/Intelligibility	Articulation Level/Intelligibility Scale
15	Vocal Power/Background Noise	dB at 1m/dB
16	Left Leg Strength	Strength
17	Right Leg Strength	Strength
18	Left Arm/Hand Strength	Strength
19	Right Arm/Hand Strength	Strength
20	Left Hand/Arm Dexterity	Strength
21	Right Hand/Arm Dexterity	Strength
22	Torso Support	Strength
23	Head/Neck Movement	Strength
24	Endurance (Aerobic)	Activity vs. Time

The objective of ORCA (which began as the Crew Casualty Project) was to produce a methodology and computer model to evaluate personnel casualties for all (conventional) insults (blast overpressure, penetration, thermal injury, directed energy, toxic gases/agents, blunt trauma and abrupt acceleration), for any crew position (pilot, gunner, infantry, etc.), in a manner consistent with the needs of the medical community. This methodology assumes that no medical treatment is given, no motivational effects are incorporated, and the casualties are operational in nature only. The ORCA methodology has a strong reliance on adaptation of existing models. These include the following existing, accepted models (used and accepted by the U.S. military):

- Penetrating Injury: ComputerMan (U.S. Army)
- Blast Overpressure Injury: INJURY (U.S. Army), and Price Ear Model (U.S. Army)
- Thermal Injury: BURNSIM (U.S. Air Force)
- Directed Energy: ILPEM (U.S. Air Force)
- Chemical Injury: Chemical Man (U.S. Army)
- Acceleration Injury: Articulated Total Body (ATB) Model (U.S. Air Force)

APPROACH

Research is underway to screen new fire extinguishant products to replace ozone-depleting chemicals. Their effect on humans, which is multi-faceted, is one of the key issues in the screening process. The maximum allowable concentration to continue to perform a mission or to survive (evacuate, drive away, man the missile control panels, enter a smoldering ship machinery space, etc.) could be one of the factors in determining the allowable sizing of the fire extinguishing systems to prevent harmful exposure.

It has been proposed for a methodology to be developed using compatibility data for the existing fire suppression technologies (HFC-125, dry chemicals, water-mist, etc.) as a starting point until the new fire extinguishing technologies and their corresponding compatibility data are identified. This methodology would involve determining the effects of these extinguishants on military personnel using the ORCA model. Probabilistic scenarios would be generated for the applicable weapon systems (those with fire extinguishing systems) using the interaction of the extinguishant with humans. As the compatibility data for the new extinguishants are made available during additional research, they would be implemented into the ORCA model and similar analyses would be performed as with the existing agents.

ORCA could be useful to this effort in several facets. It could use the generated toxicity data (as it becomes available) to evaluate how these new fire extinguishing agents affect military personnel and their missions. ORCA could be used to assess how these agents affect visibility (obscuration of eyesight), breathing (such as, particulates into the lungs), mental state (disorientation, decision making ability), bloodstream, and cardiac sensitization (since some chemicals excite the heart to dangerous levels), along with the remainder of the 24 identified human capabilities required by ORCA. Not only would assessment of the new agent in its "clean" agent status be necessary, but also its decomposition as it reacts with the fire environment.

The following are several possible Department of Defense applications:

a. Armored vehicles have total flood fire extinguishing systems in them. If a fire occurs and the extinguishing system is activated, crewmembers are exposed to the clean agent, the byproducts of combustion, the clean agent plus the byproducts of combustion, and the decomposition of the new agent in the fire environment. These crewman need to be able to either continue performing their mission, or discontinue the mission entirely and drive the vehicle away or at least be able to evacuate. These individuals could be exposed to fire (resulting in burns), obscuration of the eyes due to the nature of the extinguishant (dry powder, particulate (mist, fog)), toxic gases, particulates which could get into the lungs and effect breathing, cardiac sensitizers, disorientation, impeded decision making ability, degraded visibility, just to mention a few examples. ORCA could be used to evaluate these insults and their effects on the individual's ability to escape or continue to perform his mission.

b. Helicopters have portable Halon 1301 extinguishers for use in the cabin, and engine fire extinguishing systems. Fixed engine systems could also allow extinguishant to bleed into the cabin space due to its close proximity. Determination of the effect of the agent and its decomposition would need to be evaluated due to the peak performance required for helicopter control.

c. Cargo bays, such as the C-5A cargo bay, have a total flood extinguishing systems. Often there are crewmembers in this area which would experience exposure to the agent and its decomposition.

d. The Navy has total flood systems in the engine and machine rooms onboard ships. Again, the effects of the decomposed agent and its mixing with the byproducts of the fire would affect the engine room operators and subsequent firefighters sent in to verify the extinguishment.

e. Maintenance personnel could be exposed particularly to the clean agent, during its installation, replacement, demilitarization, banking, recycling, and destruction. Investigations of the effects of release of existing fire extinguishing agents to maintenance personnel have been performed recently by McDonnell Douglas Aerospace (MDA) for one aircraft platform. ORCA could be developed after considering MDA's findings to evaluate the effects to maintenance personnel on their ability to perform their required tasks.

f. Another application exists for mission critical facilities, such as missile command centers. There are extinguishing systems in mission critical facilities for use in the event that there is an electrical fire which might result from burning insulation, sparking, arcing, or other events at the facility. Personnel present must be at their peak performance and can only evacuate as a last resort. Their exposure to the clean extinguishant, its decomposed byproducts, and burning insulation and other materials might be harmful and therefore impede their performance. ORCA could be used to determine their required tasks, and the allowable exposure to these insults before evacuation would be necessary.

MILITARY APPLICATIONS

By end of 1997, ORCA will have a library of 18 representative combat occupations: Infantry (completed), combat engineer, combat operations control specialist, AH-64 Apache Pilot, artilleryman, medical care provider, C-130 Hercules Pilot, combat pilot (jet fixed wing), EOD Technician, Light armored Vehicle Crewman, seaman, shipboard propulsion technician, Firefighter radar operator, installation security specialist, damage control specialist, ammunition specialist, radioman, motor transport operator, and five generic missions: infantry assault (land warrior), infantry defense (land warrior), fixed-wing aircraft--returning to base, seaman--damage control, and NATO/UN peacekeeping force.

COMMERCIAL APPLICATIONS

During a structure-based fire event, firefighters may be exposed to fire, toxic fumes, blast overpressure (including possible explosions), and penetration (glass fragments, debris, explosive materials, collapsing structure,etc.). These insults may cause restriction in mobility, not only to perform the task at hand, but also to allow safe egress. Exposure to fire may cause burns to the individuals, in spite of their protective clothing. Exposure to toxic fumes may also occur, in spite of protective masks. Smoke might also be an obstruction during evacuation.

It can be visualized that the tasks of the firefighters could be implemented into ORCA. The required tasks of firefighters for various scenarios would need to be determined as well as their required ability to perform those tasks.

TASKS NOW UNDERWAY

- Development of an unbiased methodology using ORCA to evaluate new fire extinguishants based on the compatibility of the agents with people.
- Applying this methodology to the different weapon systems and mission-critical facilities.
- Incorporating compatibility data for existing extinguishants and newly developed extinguishants (when they become available).

EXPECTATIONS OF THE PROJECT

The expected outcomes from this project include: an evaluation methodology of the effects of the new extinguishants on military personnel and their ability to perform their required missions for the various weapon systems and mission critical facilities; as well as concentration threshold standards for the new extinguishants based upon the platform application. It is expected that the technology gleaned from this program can be transferred to: museums, libraries, computer rooms (commercial), commercial transportation industry (aircraft, vehicles, mass transit), nuclear/power facilities, and telecommunication facilities, etc.

SURVIAC AND ORCA

Once the model is completely developed (with all insults incorporated by the end of 1997, and release scheduled for May 1998), it is proposed (by JTCG/ME & AS Crew Casualty Working Group) that it will be maintained by the Survivability/Vulnerability Information Analysis Center (SURVIAC). SURVIAC maintains libraries, computer models, methodologies and databases, and disseminates information and models to the user community. This includes government and industry personnel involved in weapon system research development, procurement, concept analysis, mission planning and combat operations. SURVIAC's technical focus—non-nuclear survivability and lethality—encompasses such threats as conventional weapons, directed energy weapons and chemical/biological weapons, and targets that include a broad range of US and foreign aeronautical and surface systems, including ships.

REFERENCES

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2. Coleman, K., 1997, "Derivation of Crew Task Requirements for the Operational-Requirements-based Casualty Assessment (ORCA) Model", TASC, Inc., Presented at the Live Fire Test & Evaluation Conference, Livermore, California, January 15, 1997.