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NUTRIENT, WASTE MANAGEMENT, AND HYGIENE SYSTEMS FOR CHEMICAL PROTECTIVE SUITS

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Systems to supply nutrients, remove metabolic wastes and ensure personal hygiene of troops operating in chemical protective clothing for extended periods were developed and tested. The nutrient system was modeled after earlier feeding systems developed for the U.S. Air Force. It consisted of liquid, semisolid and solid foods packaged in tube dispensers and transferred through a seal/diaphragm on the mask/respirator. The waste management/hygiene systems consisted of waste collection devices and hygiene items stored in pockets on the interior of the protective suit. The suit design allowed the wearer to retract his/her arms into the suit. Collected waste matter was disposed through an air-lock. Results of a field demonstration test showed high user acceptance and only minor functional problems. The systems enabled military armor crews to remain in full chemical protective posture for 54 continuous hours.

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PREFACE

This report is a summary of research undertaken by the authors from 1985 to 1989 at the U.S. Army Natick Research, Development and Engineering Center. The purpose of this program of research was to develop and demonstrate viable systems for feeding, waste management and hygiene of troops wearing full chemical protective ensembles for periods of up to 72 hours.

The systems described herein serve as a major milestone toward the development of a fully integrated protective suit concept that will enable the wearer to live, work and perform combat duties for extended periods of time in a toxic and hostile environment.

Citation of trade names in this report does not constitute official endorsement or approval of the use of such items.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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INTRODUCTION

Current U.S. military chemical protective ensembles do not provide for waste management or nutrient intake other than water. The lack of these life support systems poses serious risks for the soldier fighting in a toxic environment. When the extreme heat stress and perspiration that result from prolonged wear of semipermeable protective garments is combined with the high metabolic demands of combat missions, the result is a significant loss of cellular electrolytes and muscle glycogen depletion over time. Water alone cannot replace these losses and is insufficient to maintain the soldier beyond six hours of MOPP-4 confinement.[1] Moreover, military troops must withhold urination and defecation or risk the resultant psychological distress and microbiological hazard of a fouled suit environment. The latter can lead to performance degradation, loss of morale and mission failure.

Although several published reports have addressed the physiological, perceptual, and psychological problems encountered during wear of industrial and/or military chemical protective clothing and equipment[2-10], the problems of essential nutrient and metabolic support have received only minor attention.[11]

What work exists has developed out of aerospace applications, where, for example, early efforts by the U.S. Air Force led to the development of a through-mask feeding system for high altitude pilots.[12] Subsequent modifications to this concept resulted in the development of the Mercury and Apollo feeding systems for use by astronauts wearing full pressure suits.[13,14] Although NASA currently relies on pressurized cabins and not pressure suits or helmets for individuals consuming food, the through-mask feeding concept still serves as a contingency for space emergencies.

For body waste management, NASA has developed several systems for use with pressurized suits. These include 1) male urine collection systems consisting of external catheters connected to polymeric containment bags, or garments worn inside the suit, 2) female urine collection systems consisting of multilayered undergarments with both conductive and superabsorbent layers, and 3) fecal containment systems consisting of absorbant undergarments that collect and contain fecal matter until the pressure suit is doffed. Although many of these life support concepts were considered for general use in the military, most were found to pose unacceptable psychological demands. As a result, research and development efforts were undertaken to develop systems suitable to military needs.

MATERIALS AND METHODS

NUTRITIONAL SYSTEM DEVELOPMENT

A family of foods, beverages and delivery systems were developed to address the following requirements: (1) that liquid, semisolid and solid foods could be consumed; (2) that the packaging was resistant to nuclear, biological and chemical contaminants; (3) that the foods could be delivered without infiltration of liquid or airborne contaminants; (4) that the system was simple to use and effective, and (5) that the food and beverage items had high user acceptance.

Semisolid Foods. Thirteen shelf-stable, semisolid food items were developed (see Table I). Each was packaged in 162 mL aluminum, enamel-lined tubes (lin. dimen. = 17.1 cm, diam. = 3.8 cm). Each tube of food contained approximately 0.67 MJ of energy. Immediately after filling, open tubes were flushed with superheated steam (232°C to 260°C), crimped and then retorted or pasteurized to ensure shelf stability for up to three years at room temperature. The items were configured into individual 3.35 MJ meal menus, each containing two entrees, one starch, one vegetable and one dessert.[15]

Safe transfer of food from the tubes through a face respirator was accomplished using an 11.2 cm plastic "subsistence transfer unit" (Fig. 1). This unit screwed onto the threaded end

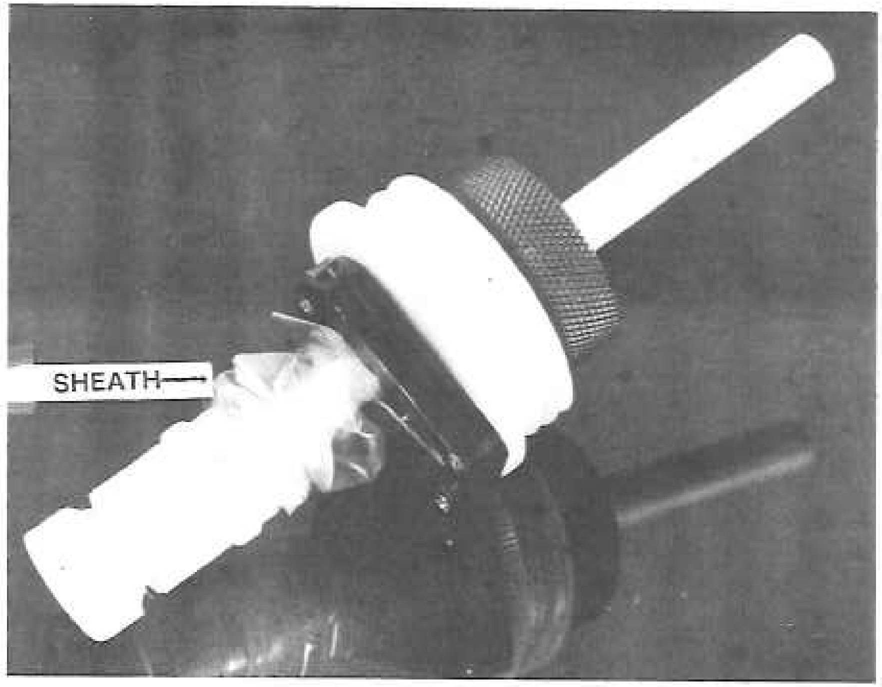

Figure 1. Subsistence transfer unit fully penetrating the seal/diaphragm on the subsistence portal. Note the location of the polymeric sheath after penetration.

of the food tube and was covered with a polymeric sheath that provided protection against contamination of the transfer shaft (inner diameter = 7mm). Penetration of the transfer unit into the subsistence portal on the respirator caused the sheath to tear and fold back upon itself. The subsistence portal (Fig. 1) consisted of a three-piece valve with a self-closing seal/diaphragm to prevent agents from entering the mask while allowing passage of foods and beverages. The portal was mounted on a standard NATO thread adaptor, so as to interface with side ports on NATO protective masks. A slide-cover protected the entrance to the valve when not in use. A seal perforator in the transfer unit allowed the food tubes to be opened only after the transfer unit had penetrated the portal seal/diaphragm, to prevent exposure of the contents to the air. The tube could then be squeezed and the contents consumed.

Fig. 2 shows an individual in full Mission Oriented Protective Posture (MOPP-4) using the feeding system.

Liquid electrolyte replacement beverage. The Office of the Surgeon General of the Army and the National Research Council[1] have estimated that a soldier in MOPP-4 expending a moderate level of activity at 21^{o}C will lose approximately 0.5 mol of sodium over 24 h. To compensate for this loss, electrolyte beverages with an energy content of 0.4 MJ/L, a sodium level of .042 mol/L, and a chloride level of .038 mol/L were developed and tested for physiological efficiency during sustained activity in

Figure 2. Soldier in full MOPP-4 using the nutrient system.

the heat.[16] The beverages were designed to be packaged and consumed in the same manner as the semisolid foods, with an optional 191 mL heat-sealed polymeric tube available. Lemon-lime, raspberry, and orange flavors were developed.

Solid Food. Two solid food items, red licorice and beef jerky, were developed. These were packaged in cylindrical, syringe-dispensers of the same diameter as the transfer unit. The dispensers were inserted through the subsistence portal in the same manner as the transfer units and were protected by polymeric sheaths. The food was dispensed by depressing a plunger located on the end of the dispenser.

Heating System. A heating device, consisting of thermostatically controlled heating elements embedded in a fabric housing or blanket, was developed to warm food for consumption. The device operated on 28V direct current. Up to six food tubes could be placed in the fabric housing at one time and food temperatures of 60°C could be reached in ~25 min.

WASTE MANAGEMENT AND HYGIENE SYSTEM DEVELOPMENT

Systems for within-suit waste management and personal hygiene were developed to integrate with a new, retractable-arm design concept for chemical protective suits. This new design employed gloves that were attached to the suit sleeves by a strap and O-ring arrangement (Fig. 3) and zippered bellows in the axillary areas (Fig. 4) to enable the wearer to withdraw his/her

Figure 3. Test subject unzipping the bellows located under the arms.

Figure 4. Test subject retracting his arms into the suit. Note that the gloves remain attached to the sleeves.

arms into the suit. A similar bellows was designed into the crotch to provide greater freedom of movement during waste management procedures (Fig. 5). Pockets on the interior of the suit provided storage for the waste management and hygiene items, and an airlock in the upper abdominal area allowed collected waste and other items to be transferred to the exterior of the suit (Fig. 6). Jockey briefs, modified with a snap opening in the crotch to allow access to perianal areas, were also developed.

For urinary waste, two kits were developed, one for males and one for females. The kit for males contained a urine collection device (right side, Fig. 7) that consisted of a standard 1000 or 750 mL urinary collection bag (e.g. Intermed, New Foundland, NJ) with an attached latex condom catheter (e.g. TEXAS catheter, Cheeseborough-Ponds, Greenwich, CN). For females, the same collection bag interfaced with an external urethral catheter (left side, Fig. 7). Both collection bags had one-way flutter valves to prevent leakage during use and/or transfer through the air lock. Both were packaged for minimum volume in a rolled configuration (Fig. 7, upper right). Nine devices, sufficient for 72 h, were stored in camouflage pattern fabric pouches (18 x 13 cm) with Velcro closures (Fig. 7, bottom center). Also included in each kit were nine polyethylene (2 mil) 10 x 10 cm self-locking (single track) bags for use as secondary containment bags and one resealable package of 12

Figure 5. Test subject deploying the crotch bellows.

Figure 6. Test subject removing secondary waste containment bag through the airlock.

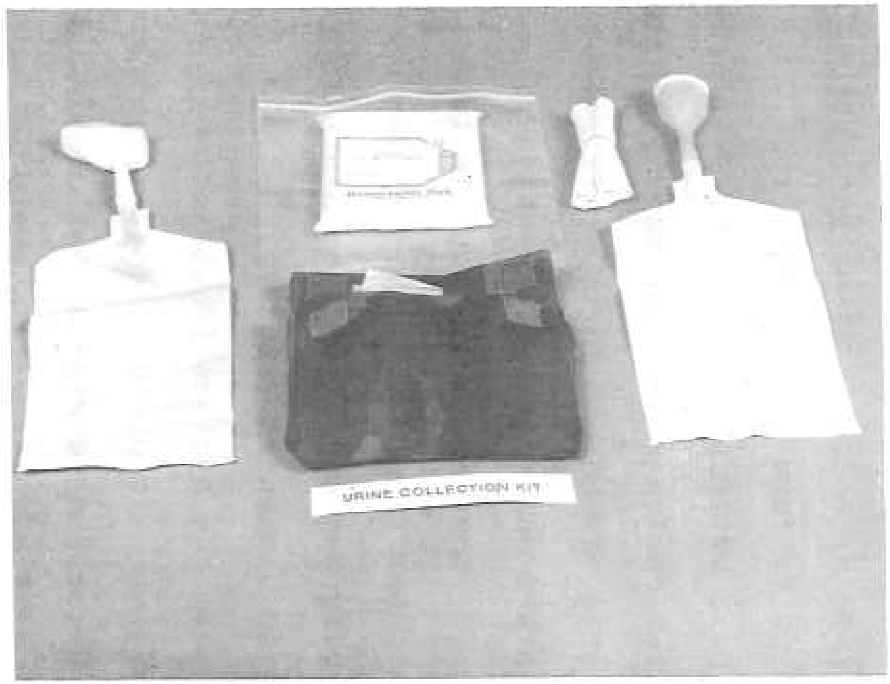

Figure 7. Urine collection kit. Right: male collection bag with condom catheter, Left: female collection bag with external urethral catheter.

moist, hygienic towelettes containing benzalkonium chloride and lanolin (Fig. 7, top center).

For fecal waste, a kit (Fig. 8) was developed consisting of a fecal collection bag (e.g. Hollister Fecal Incontinence Collector, Hollister Inc, Libertyville, IL) with a wide body contoured opening that attached to the perianal area via an adhesive ring (Fig. 8, right). After use, the adhesive ring could be folded up to form an air-tight seal. Six fecal collection devices, sufficient for 72 h, were stored in a fabric pouch of a similar design and of the same dimensions as the urine collection kit (Fig. 8, bottom left). Six self-locking secondary containment bags and one resealable package of moist hygienic towelettes (Fig. 8, top left) were also included.

Dry tissue paper (3 ply, 38 x 43 cm) for waste elimination and for body drying was stored in a separate fabric pouch with an elliptical opening dispenser (Fig. 9).

In addition to the hygiene items included above, a supplementary hygiene kit was developed for general body and facial hygiene before and during MOPP-4 confinement (Fig. 10). This kit included an unscented 14 g stick of antiperspirant containing aluminium zirconium tetrachbrohydrex, a refillable pack of 12 facial astringent pads containing salicylic acid and SD alcohol (acne eruptions are a common result of contact with the butyl rubber surfaces of face respirators), six 0.5 mL single-use tubes of an emollient ointment containing boric acid

Figure 8. Fecal collection kit.

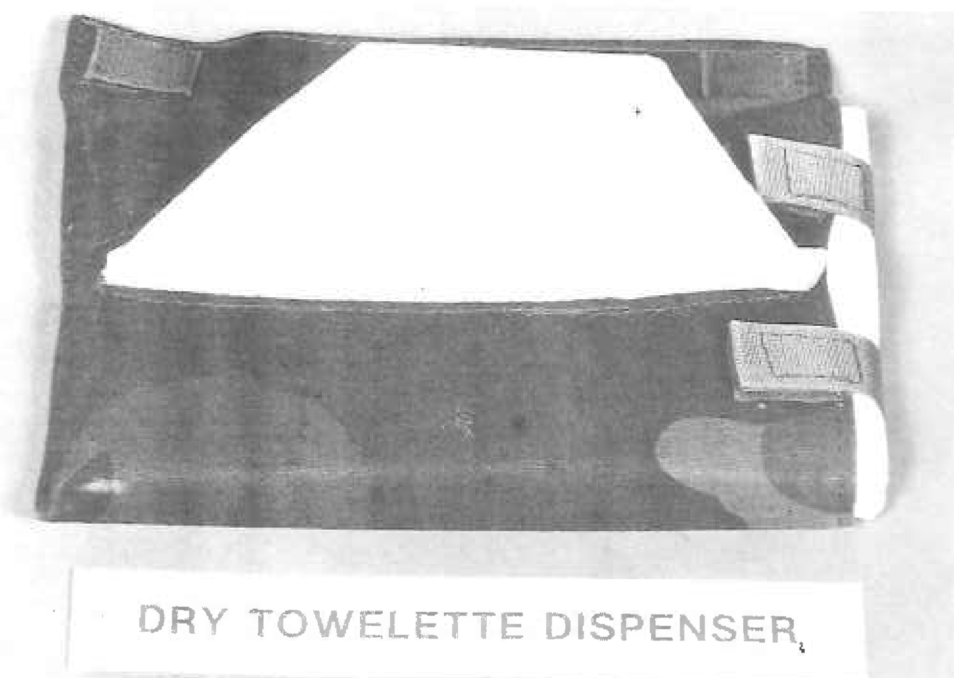

Figure 9. Dry towlette dispenser.

Figure 10. Supplemental hygiene kit.

(5%) and lanolin to ease chafing and drying of skin, six 0.3 mL single-use containers of eyedrop solution containing phenylphrine HCI and polyvinyl alcohol to reduce the potential for conjunctivitis, one resealable package of hygienic towelettes and three secondary containment bags.

To address the hygiene needs of menstruating female troops, a feminine hygiene kit was developed (Fig. 11). This kit consisted of 12 sanitary napkins, (e.g., Always, Slender For Teens, Thin Maxi-Pads; Proctor and Gamble, Cincinnati, OH) stored in a separate fabric pouch with 12 secondary containment bags and one resealable package of towlettes.

VALIDATION TESTING

Numerous human factors and item acceptance tests were conducted with civilian and military test subjects during development of the nutrition and waste management systems. However, in order to assess the systems under actual use conditions, a 72 h operational demonstration of the essential components of these systems was conducted with military subjects operating a prototype command post vehicle in a simulated chemical warfare scenario.[17] Six male crewmen wore the advanced chemical protective suit shown in Figs. 3 to 6 with an air-cooled microclimate conditioning vest and ventilated face mask (P^3I XM42s). Maximum ambient daytime temperatures were 24-27^{o}C.

The crew operated the vehicle as a battery fire direction

Figure 11. Female hygiene kit.

and control center operating in an NBC environment (external and internal vehicle environments assumed to be toxic) for 72 continuous hours. The crew followed a computer-driven mission sequence. All crewmen were physiologically monitored and observed by remote camera to ensure safety and conformance to the continuous MOPP-4 requirement. Crewmen were supplied food and electrolyte beverage (in optional polymeric tubes) for 72 h and were allowed to eat ad libitum. At each meal subjects evaluated the acceptance of the food items using a 9-point hedonic scale[18] and completed a questionnaire addressing the human factors of the feeding system. Crewmen were also supplied urine and fecal collection kits (without fabric storage pouches and with standard issue toilet paper instead of the dry tissue dispenser) to last 72 h. Supplementary hygiene kits were not provided, as they were not available at the time of the test. Crewmen completed written questionnaires concerning the human factors aspects of the suit and waste management/hygiene items and participated in a structured group interview at the end of the test.

RESULTS AND DISCUSSION

Four of the six crewmen were able to remain completely encapsulated within their chemical protective clothing for 54 hours and 37 minutes. The decision to remove crewmembers from the test was based on medical reasons unrelated to the nutritional or waste management systems. All crewmembers reported feeling well-nourished and reported no gastrointestinal or other symptoms attributable to failures of either the advanced feeding system or the within-suit waste management/hygiene systems.

USER ACCEPTANCE OF FOOD ITEMS

Mean acceptance ratings across subjects and meals for the food and beverage items are shown in Table I. Ratings of the semisolid food items were high, with some notable exceptions. Fruit and dessert items scored highest, while entree items varied considerably. Lowest acceptance was found for sweet potatoes, but this is a relatively low preference item, even for conventional preparation methods.

Subjects reported that the semisolid food entrees needed more spice, and that "they all seemed to taste alike after a while." In the operational test, the crews consumed from three-quarters to all of the food in each tube. The majority of the crew reported that they felt they would be able to eat these products for a week or more while in continuous MOPP-4 confinement. In terms of improvements, the addition of soups, more fruits and starches, and breakfast items was suggested.

The fruit-flavored electrolyte beverages consistently scored high on the 9-point rating scale. Increasing the intensity of fruit flavor and cooling the beverages were deemed necessary to further increase user acceptance.

Table I. Acceptance ratings of food/beverage items developed for use with nutrient delivery system. Data were obtained during the field validation test.

Food/Beverage Item	Acceptance Ratings*
Turkey/Gravy	6.8 ± (1.3)
Buttered Corn	5.3 ± (1.2)
Sweet Potatoes	2.7 ± (2.1)
Apple Pie	7.2 ± (2.1)
Beef/Gravy	6.2 ± (1.9)
Strawberry Pudding	7.5 ± (0.6)
Chicken-Ala-King	7.3 ± (0.5)
Pears	8.0 ± (1.2)
Red Licorice	6.6 ± (2.2)
Beef Jerkey	7.3 ± (1.5)
Lemon-Lime Beverage	5.8 ± (2.1)
Raspberry Beverage	5.7 ± (1.6)
Orange Beverage	5.8 ± (1.6)

* Values are means ± S.D.

The two solid food items had high acceptance and comments of subjects suggested that the availability of solid food is important to avoid sensory-specific satiety to the texture of the semisolid food items.

<u>HUMAN FACTORS OF NUTRIENT SYSTEM</u>

The major human factors problem identified by subjects was difficulty in properly aligning the subsistence transfer unit with the subsistence portal. Proper alignment required that the food tube and transfer unit be held perpendicular to the cheek. In the operational test, this frequently required that a fellow crewmember assist in the alignment. A possible solution is relocation of the subsistence portal closer to the midline of the face. A secondary problem was the force required to push the transfer unit through the subsistence portal. On occasion, the applied force required to penetrate the portal ruptured the crimp seal on the bottom of the semisolid food tube. In the future, use of heat-sealed retortable polymeric tubes in lieu of the aluminum crimped tube would eliminate this problem.

No problems were reported with the beverage tubes and subjects had no problem drinking the contents of the tubes. The solid food was easily consumed from the dispenser and no discomfort occurred during chewing as a result of friction with the sides of the mask. Subjects reported that a greater volume of solid food should be packaged into each dispensing unit, and efforts are underway to do so.

WASTE MANAGEMENT/HYGIENE SYSTEMS

All of the crewmembers successfully used the urine collection system with no spillage of waste inside the suit. However, subjects observed that the exigencies of a combat scenario forced them to delay urination until absolutely necessary. This resulted in voluminous and forceful voids and some minor splash-back, because the inlet aperture on the urine collection bag was not large enough to handle the rate of flow. In addition, the 750 mL bag was too small to accommodate the larger voids. The 1000 mL bag is now being adopted.

Three crewmen used the fecal collection system during the test, but only one voided. The latter individual used the system with no spillage or problems of note, although the total time required to complete the waste management procedure was long (~ 35 min.). This was due partly to his lack of experience (crewmen received only 3 h of training prior to the test) and partly to excessive precautions to ensure against error. Results show that a systematic training program in the use of the waste management procedures is needed to reduce the time required to perform these procedures in MOPP-4.

Although modifications are being made to further improve the waste management systems, it is clear that the current concept has removed the last technical barrier to maintaining a soldier in MOPP-4 for periods of time up to 72 h. Expansion of the effort is planned to further develop the waste management system and supplementary hygiene kit as components of an advanced integrated protective suit being designed to provide protection against multiple battlefield threats. A recent laboratory evaluation has already demonstrated functional compatibility of the developed waste management and hygiene items with the first prototype of this advanced protective ensemble. A comprehensive technical demonstration of the integrated protective suit concept is being planned. It will include a field test of a next-generation waste management/hygiene system to assess its impact on soldier morale, comfort and performance under extended and simulated NBC combat conditions.

CONCLUSIONS

The field demonstration marked the first time that military troops collected and disposed of their body wastes while in MOPP-4 without compromising the integrity of their protective posture. The 54 and one-half hours that they remained in chemical protective suits was a new duration record for this type of scenario. Without these new life-support systems, this duration record would not have been possible. The nutrition and waste management systems that were developed have significant potential for application by private industry or other government agencies who employ personnel in hazardous duties that require them to remain in protective clothing ensembles for extended time periods.

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