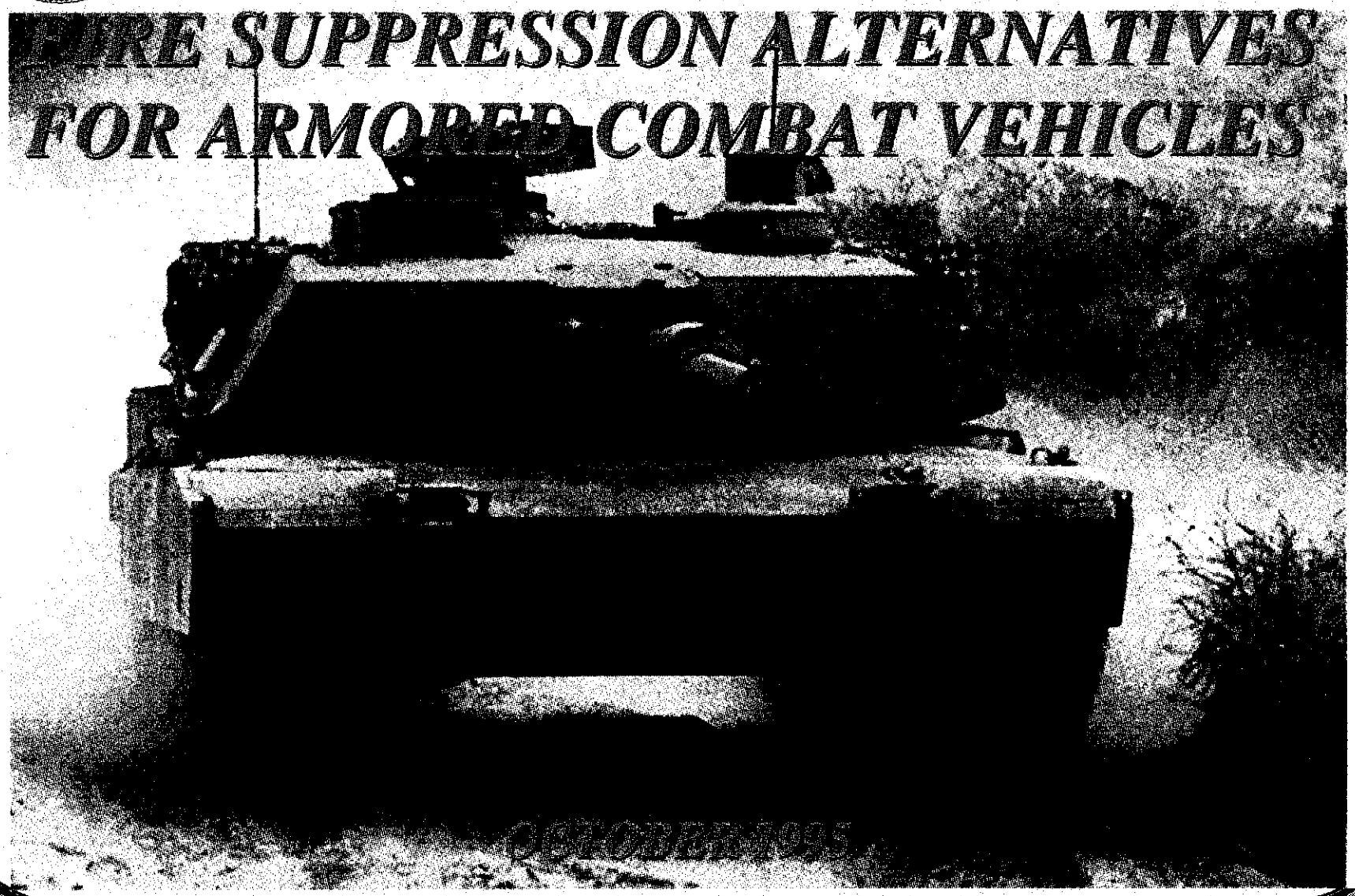
ASB INDEPENDENT ASSESSMENT

FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES



ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

STUDY SPONSOR:

MG Jan A. Van Prooyen
Deputy for Systems Management
OASA(RDA)

STUDY GROUP:

Dr. William E. Snowden
Chairman

Dr. Herbert H. Dobbs

Dr. Richard L. Haley

Dr. James R. Kelsey

Dr. Robert E. Weigle

STAFF ASSISTANT:

LTC Roy J. Seaton
SARD-SC

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

TERMS OF REFERENCE

- **What are the operational requirements for an automatic fire suppression system?**
- **What are the most cost and operationally effective replacement alternatives for Halon 1301 in combat vehicle fire suppression systems?**
- **When can a suitable alternative be ready for insertion into engine compartments? What is the magnitude of the financial requirement?**
- **When can a suitable alternative be ready for insertion into crew compartments? What is the magnitude of the financial requirement?**
- **Given the existing reserve, when will the available supply of Halon 1301 be exhausted?**

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

SUMMARY RESPONSE TO TERMS OF REFERENCE

- **Critical operational requirements for fire suppression systems:**
  - **Minimize vehicle damage, eliminate mobility kills due to engine compartment fires**
  - **Achieve rapid fire/explosion suppression with no injury to crew**
  - **Meet comprehensive set of general requirements for halon alternatives**

- **Several gaseous and powder agents have been identified as potential replacements for Halon 1301 in engine compartments: an affordable alternative should be available soon**

- **Suitable alternative agents for crew compartments have not been identified to date (estimate of financial requirement thus not possible)**

- **Army/DLA halon reserve is critical to maintaining combat readiness and effectiveness well into the next century (Army plan provides for continued halon availability to 2020)**

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

ORIGIN OF THE PROBLEM

- Stratospheric ozone (O_3) depletion caused by catalytic reactions involving chlorine (Cl) and bromine (Br)

$$ClO + ClO + M \rightarrow Cl_2O_2 + M$$

$$Cl_2O_2 + \text{Sunlight} \rightarrow Cl + ClOO$$

$$ClOO + M \rightarrow Cl + O + M$$

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + BrO \rightarrow Br + Cl + O_2$$

$$Cl + O_3 \rightarrow ClO + O_2$$

$$Br + O_3 \rightarrow BrO + O_2$$

- Heterogeneous processes: involve chemical reactions on stratospheric sulfate layer and surfaces of particles comprising polar stratospheric clouds (PSCs)

- Stratospheric Br estimated to be as much as 120X more efficient than Cl in destroying ozone on a per atom basis

Source: Scientific Assessment of Ozone Depletion: 1991
WMO, Global Ozone Research and Monitoring Project - Report No. 25

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

BACKGROUND

- **Montreal Protocol (1987) and later amendments established production phase-out schedules for CFCs and halons known to contribute to stratospheric ozone depletion**

- **Halon 1301 (CF_3Br) has served as an effective fire extinguishment / explosion suppressant in Army armored combat vehicles for several decades; production ended January 1, 1994**

- **Significant Army R&D efforts underway to identify suitable alternative agents for use in engine compartment and crew compartment fire suppression systems**

- **Unique features of Halon 1301: fast acting, mass/volume efficient, not toxic to crew, combat proven**

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

STUDY PLAN

NOV - DEC 94

- Organization
- Document Review
- CSTA Demo

IAG SESSION 1

- Background briefings
- DoD and industry work to develop alternatives to Halon 1301

NMERI site visit

JAN - MAR 95

IAG working sessions

IAG SESSION 2

- Army testing program
- Halon 1301 Reserve
- Proposed new R&D program
- Other topical briefings

IAG SESSION 3

- Visit TACOM
- Developer / User perspective
- Development of findings and recommendations

MAY / JUN 95

- Summarize completed work, findings and recommendations
- Present briefing to study sponsor

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

INFORMATION SESSION 1

- DoD Technology Development Plan for Alternatives to Ozone-Depleting Substances
- Army ODC Elimination Program Overview
- The Army Halon 1301 Reserve
- Requirements for Fire and Explosion Suppression Systems in Ground Combat Vehicles
- Navy Halon 1301 Alternatives Program for Aircraft Applications
- Fire Suppression Alternatives: Research and Applications (NRL)
- Halon 1301 Alternatives for Aircraft Applications (Navy)
- Halon 1301 Alternatives for Use in Manned Facilities (Air Force)
- Industry Work to Develop Alternatives to Halon 1301
  (DuPont, 3M, Great Lakes Chemical)
- Testing and Evaluation of Fire Suppression Agents for Combat Vehicles (SBRC)
- Status of Alternative Technologies and NFPA 2001 (Hughes Associates)

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

INFORMATION SESSION 2

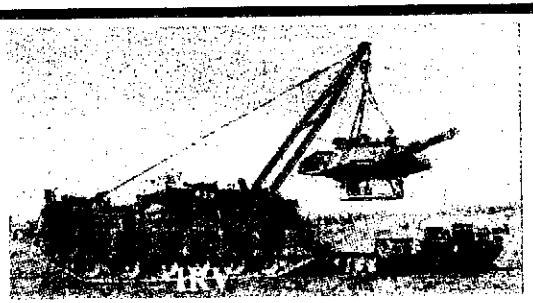
- Replacement of Halon 1301: Toxicity Evaluation Strategy (Army)
- EPA Analysis of Halon Substitutes
- Advanced Agent Development (New Mexico Engineering Research Institute)
- Next-Generation Fire Suppression Technology: Proposed DoD Research Plan
- The Army Ground Combat Vehicle Halon Substitutes Test Program
- Evaluation of Fire Suppression Alternative for Ground Combat Vehicles: An International Perspective (Kidde-Graviner Ltd., UK)
- Design and Performance of Fire Suppression Systems for Ground Combat Vehicles (Pacific Scientific)
- Fire Suppression Systems for Current and Future Ground Combat Vehicles (GD/LSD)
- Non-Halon Based Fire Suppression System Issues: BFV and AGS (UDLP)
- The Army Halon 1301 Reserve: Detailed Discussion
- DLA Acquisition and Management of the DoD ODS Reserve

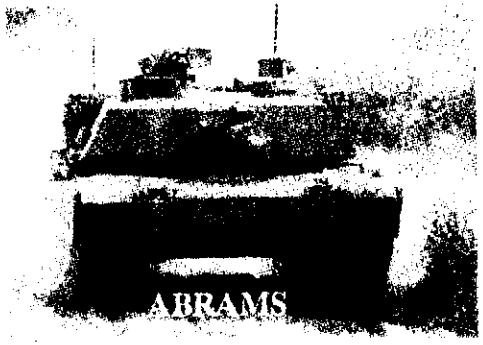
ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

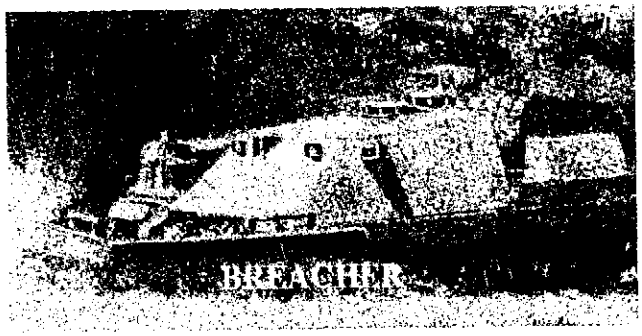
INFORMATION SESSION 3 (TARDEC)

- PEO-ASM Overview
  - Heavy Assault Bridge (HAB)
  - Breacher
  - Improved Recovery Vehicle (IRV)
- Current PEO-ASM Systems
  - M1 Abrams
  - M2/M3/MLRS
- Future Systems
  - Armored Gun System (AGS)
- Non PEO-ASM Systems
  - M992 FAASV (Field Artillery Ammunition Supply Vehicle)
  - FOX
  - M9 ACE
- Logistics and Support Issues
- Vehicle Inspections (M1, M2/M3)

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES







ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

ARMY COMBAT VEHICLE FIRE SUPPRESSION AGENTS

Vehicle	Number	Engine compartment	Crew compartment
Abrams	7538	Halon 1301	Halon 1301
Bradley	6727	Halon 1301	Halon 1301
MLRS	921	Halon 1301	(None)
FAASV	789	Halon 1301	Halon 1301
PALADIN	824	Halon 1301	Halon (handheld)
M9ACE	580	Halon 1301	Halon (handheld)
IRV	346	CO_2	Halon 1301
FOX	113	Halon 1211	Halon (handheld)
AGS	237	Sodium Bicarbonate	Halon 1301
HAB	358	PGA	Halon 1301
BREACHER	382	PGA	Halon 1301

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

GENERAL REQUIREMENTS FOR HALON ALTERNATIVES

- **Zero ODP** (to ensure long-term availability), **Low GWP** (very short atmospheric lifetime)
- **Commercially Available and Manufacturable** (in bulk at reasonable cost)
- **Materials Compatability** (with O-rings, hoses, valves, metals, etc., used in FS systems)
- **Chemical Stability** (stable under long-term storage conditions)
- **Environmentally Safe** (in compliance with comprehensive ES&H regulations)
- **Non-Corrosive** (with respect to materials used in FS systems and strorage containers)
- **Toxicity lower than for halons**
- **Effective explosion suppressant in confined spaces**
- **Effective over wide temperature range (-40 to 150 ^{o}F)**
- **Electrically non-conducting**
- **Minimal weight and volume penalties relative to Halon 1301**
- **"Drop in" utility in existing FS systems**

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

FSS REQUIREMENTS: ENGINE COMPARTMENTS

- **Protect the vehicle: minimize damage associated with engine compartment fires**
- **Extinguish fires using agent producing no adverse impacts on crew and ground support troops in close proximity**
- **Must be effective against both bilge fires and fuel spray fires**
  - **Required extinguishment time vehicle-design dependent (typically ≤ 15 second desired)**
- **Affordable / implementable / cost-effective**

Near-Term Solution Emerging

Eliminate mobility kill due to engine compartment fires

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

POTENTIAL ALTERNATIVES

- **Gaseous Agents:** HCFCs, HBFCs, HFCs, PFCs, & FICs
- **Dry Powder:** e. g., Sodium Bicarbonate
- **Wet Powder:** PGA (gelled hydrocarbon / chemical suspension)
- **Water mist technology**
- **Inert gas mixtures**

POWSUS Envirogel™

HFC-125 (CHF_2CF_3)
or
HFC-134a (CH_2FCF_3)
+
Ammonium Polyphosphate
or
Monoammonium Phosphate
+
Gelling agent

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

ARMY ENGINE COMPARTMENT TEST PROGRAM

- Three-phase program to evaluate alternative agents
  - Phase I: Candidate agent screening test (modified M60A3 test fixture)
  - Phase II: Transition phase (testing in M60A3 with operating engine)
  - Phase III: Testing in other vehicles (M1, M2/M3, MLRS, etc.)
- Phase I (Jun 94 - Aug 95): Four (4) agents selected for further testing
  - FM-200 (HFC-227ea; Great Lakes Chemical Corp.)
  - FE-36 (HFC-236fa; DuPont Fluoroproducts)
  - Dessikarb (Sodium Bicarbonate; Kidde Graviner)
  - Envirogel^{TM} (Gelled HFC/Powder; POWSUS INC.)
- Significant general observation: Distribution system design is critical and must consider engine compartment geometry and air flow
  - Complicates agent evaluation / selection process and portends potential performance variations in different combat vehicles

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

FSS REQUIREMENTS: CREW COMPARTMENTS

- **Protect the crew (P - T - t - Toxicity)**
  - **Non-toxic agent**
  - **Non-toxic byproducts**
  - **No second-degree burns**
  - **Limit lung / ear / eye damage**

Explosion Suppression Most Critical Problem

- **Protect the vehicle: maintain battlefield operability**
  - **Non-conductive agent**
  - **Non-corrosive agent**

No Potential Near-Term Solution Identified

- **Affordable / implementable / cost-effective**

Fire-out time is not the most significant measure of agent / FSS effectiveness

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

ARMY HALON 1301 RESERVE

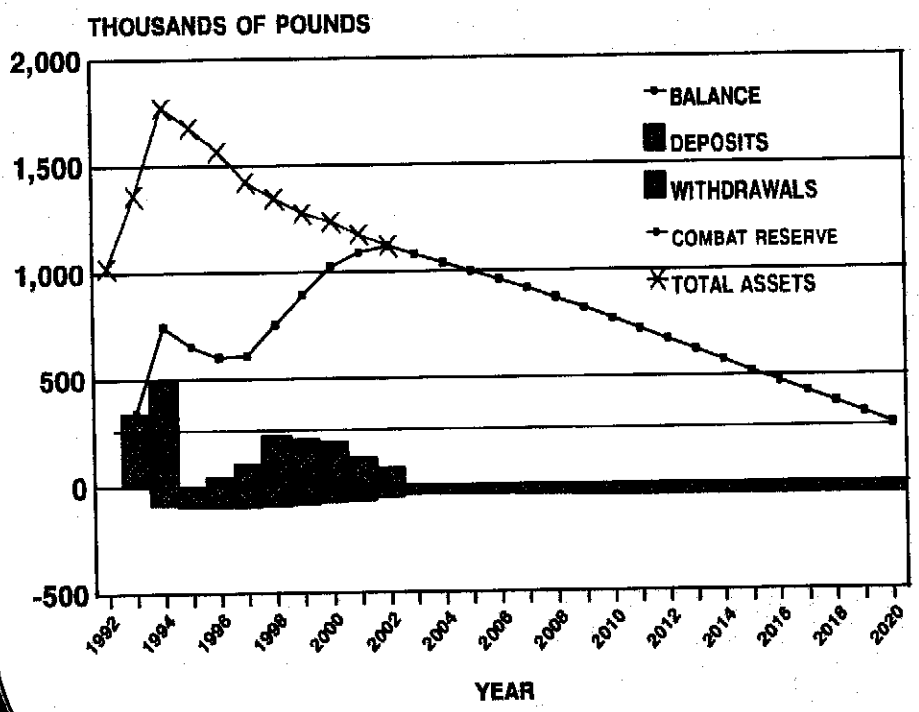
- Critical element of Army response to halon production ban: enables continuing use of Halon 1301 in crew compartments to 2020 (provided continued critical use allowed)
- Reserve adequacy linked to Army plans for engine compartment FSS retrofits and viability of Halon 1301 recovery from other facilities, as well as Army ability to respond to procurement opportunities on the open market
- Without Halon 1301 additions from planned retrofits (and contributions from other recycling efforts), diminished Halon 1301 reserve could compromise combat readiness as early as 2008
- Solutions to overall agent replacement problem for crew compartments:
  - Unwavering Army commitment to continued use of Halon 1301 in crew compartments
  - Intensified RDT&E effort to identify acceptable alternatives

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

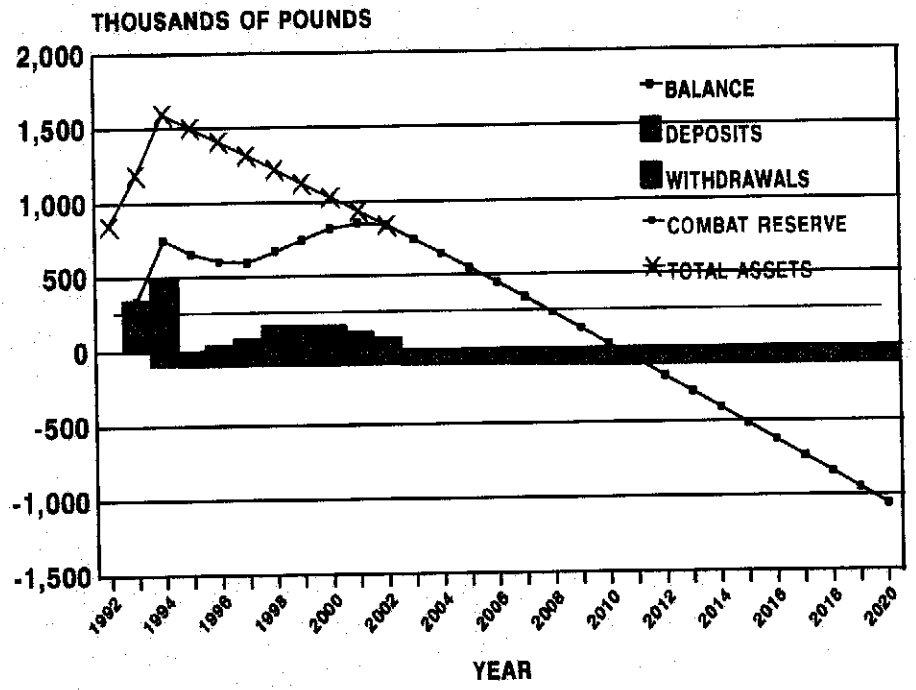
ARMY HALON 1301 RESERVE

- CRITICAL TO MAINTAINING COMBAT READINESS AND EFFECTIVENESS -

WITH
ENGINE COMPARTMENT RETROFIT



WITHOUT
ENGINE COMPARTMENT RETROFIT



ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

ENGINE COMPARTMENT FSS RETROFIT COST ESTIMATES

- Cost estimates associated with retrofit of fire suppression systems in engine compartments made by considering three alternative agent types:
  - Advanced gaseous agents (e.g., FM-200, FE-36)
  - Powders (e.g., sodium bicarbonate, PGA - Envirogel^{TM})
  - Carbon Dioxide (CO_2)
- Cost estimates considered 3 major cost categories:
  - Development Costs (RDT&E): for design, testing and evaluation, and redesign of vehicle fire supression system components
  - Procurement + Retrofit Costs (PAA): for new/modified hardware (total kit costs + spares) and retrofit labor
  - Sustainment (O&M): for operating and maintaining the fire suppression system and support equipment over its useful life
- Cost estimates based on Abrams, Bradley, MLRS, and FAASV vehicles only (>90 % of ground combat vehicle fleet using Halon 1301 as FSS agent)

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

COST ESTIMATE CATEGORIES
(TARDEC / SYSTEMS ENGINEERING)

- **Development (RDT&E)**
  - **Design development, evaluation, testing and redesign for system components**
  - **Prototype fabrication, engineering and logistics support, program management**
- **Procurement + Retrofit (PAA)**
  - **All system hardware (kits + initial spares)**
  - **Labor for retrofit kit installation plus TDY expenses**
  - **Transportation, system engineering, training, support equipment, inspection**
  - **Initial consumables, recurring engineering, quality assurance, documentation**
  - **Technical documentation, program management**
- **Sustainment (O&M)**
  - **Comprehensive life-cycle system operating and maintenance costs**
  - **Includes refilling and replacement/repair/overhaul of bottles and valves**
  - **Most difficult costs to estimate (based on experience with Halon system)**

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

ENGINE COMPARTMENT FSS RETROFIT COSTS

	ALTERNATIVE AGENTS		
DEVELOPMENT (RDT&E)	**GAS**	**POWDER**	**CO_2**
M1 ABRAMS	9.20	11.30	12.40
M2/M3 BRADLEY	3.70	4.40	4.40
MLRS	3.00	3.70	3.70
FAASV	2.14	1.59	2.69
TOTAL	18.04	20.99	23.19
PROCUREMENT + RETROFIT (PAA)			
M1 ABRAMS	36.20	71.30	129.70
M2/M3 BRADLEY	26.90	43.50	38.40
MLRS	5.00	7.60	6.50
FAASV	3.23	8.31	9.94
TOTAL	71.33	130.71	184.54
(CONSTANT FY95 $M) TOTAL COST	89.37	151.70	207.73

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

SUSTAINMENT COSTS

COSTS PER YEAR (O&M)	ALTERNATIVE AGENTS			
	HALON	GAS	POWDER	CO_2
M1 ABRAMS	1.14	0.91	0.49	1.75
BRADLEY / MLRS	0.38	0.36	0.27	0.77
FAASV	0.41	0.15	0.26	0.41
TOTAL	1.93	1.42	1.02	2.93

(CONSTANT FY95 $M)

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

GROUND COMBAT VEHICLE FUNDING
ARMY FY97 BES

(WTCV / $K)
(FY97 BES /AUG 95)

		FY94	FY95	FY96	FY97	FY98	FY99	FY00	TOTAL
GA0700	M1 ABRAMS			* 2,490	17,825	16,297	20,261	0	* 56,873
GA0925	MODS < 2M			154	1,095	1,095	0	0	2,344
GA8010	FAASV PIP			2,968	* 2,008	1,480	334	0	* 6,790
GZ2400	BRADLEY/MLRS			5,949	8,956	2,991	0	0	17,896
TOTAL		4,132	7,103	11,561	29,884	21,863	20,595	0	* 95,138

* During FY97 POM to Budget (FY97 BES), GA0700 line was reduced by $25,332 for FY96 and GA8010 line was reduced by $2,968 for FY97 to reflect current requirements.

ASB INDEPENDENT ASSESSMENT OF FIRE SUPPRESSION ALTERNATIVES FOR ARMORED COMBAT VEHICLES

KEY FINDINGS AND RECOMMENDATIONS

- **Retrofit solutions for Engine Compartments are near-at-hand**
  - **Army testing of identified alternative gaseous and powder agents should be accelerated to enable FY97/FY98 startup of retrofit programs**
  - **Common solution should be adopted for all Army ground combat vehicles**
  - **Budgeted resources (FY96 - FY00) are sufficient to cover estimated costs associated with engine compartment retrofit efforts**
- **No suitable alternative agents for Crew Compartments identified to date**
  - **Army should make strong commitment to continue use of Halon 1301 in crew compartments as its sole critical application to promote crew survivability**
  - **Army Halon 1301 reserve should be maintained at levels required to support combat vehicle needs at least to the year 2020**
  - **Aggressive RDT&E program to identify effective new agents should be established to provide a safety net against possible worldwide ban of all Halon 1301 use (linked to DoD Next-Generation Fire Suppression Technology Program)**

DoD NEXT-GENERATION FIRE SUPPRESSION TECHNOLOGY PROGRAM

- **New program being formulated within OSD/ODDRE to address fundamental issues pertaining to fire suppression and develop effective alternatives to Halon 1301**
- **<u>Stated goal</u>: to develop and demonstrate - by 2004 - environmentally friendly, user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by Halon 1301 systems in aircraft, ships, land combat vehicles, and critical mission support facilities, with results applicable to both new and existing systems**
- **Includes six thrust areas:**
  - **Risk Assessment and Selection Methodology**
  - **Fire Suppression Principles**
  - **Technology Testing methodologies**
  - **New Suppression Concepts**
  - **Emerging Technology Advancement**
  - **Suppression Optimization**
- **Planned cooperative effort: DoD, other Federal agencies (NIST), industry, academia**