NEXT-GENERATION

FIRE SUPPRESSION TECHNOLOGY:

STRATEGY FOR A NATIONAL PROGRAM

Department of Defense

Office of the Director
Defense Research and Engineering

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EXECUTIVE SUMMARY

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 during combat operations. Halon 1301 is used for both fire extinguishment and explosion suppression (hereafter referred to collectively as fire suppression) in most weapon systems and mission-critical facilities. Due to its high ozone-depleting potential (ODP), halon was banned from production as of 1 January 1994 by the Copenhagen Amendments to the Montreal Protocol.

Current defense research, development, test, and evaluation (RDT&E) activities are focused on the identification of near-term, environmentally suitable halon alternative technologies--developed by industry--that are either readily available or could enter commercial production in the near future. In general, the outcomes of these activities have demonstrated that near-term alternatives result in solutions that have weight and volume penalties, thus compromising existing system backfit needs. This could have significant operational impact on the Department of Defense (DOD), given that the end of the Cold War has resulted in defense budget reductions, downsizing, and the extension of the in-service lives of fielded weapon systems. Application of near-term alternatives to fielded weapon systems could require DOD weapon system program managers to expend large amounts of funding and time for fire suppression system redesign and reconfiguration.

Meanwhile, other countries are greatly increasing their environmental legislation restrictions--forewarning potential international use restrictions--and one ally of the United States (Australia) has already collected the nation's halon supply and is contemplating its destruction. To ensure supportability of US forces abroad using existing weapon systems, and to preclude any long-term use restriction impacts, a defense technology program to create more optimal next-generation fire suppression processes, techniques, and fluids that, to the maximum extent possible, eliminate dependency on halon 1301 in fielded weapon systems is a prudent course of action. The Next-Generation Fire Suppression Technology Strategy and its supporting Program are designed to satisfy this need.

Experience has shown that the development and examination of new fire suppression technologies is not likely to be brief or easy. The suppressant, its storage support, and delivery system must be of light weight (low mass) and low volume--and compatible with host designs of existing systems. Successful candidates must also perform satisfactorily in a wide variety of tests for the following properties:

- fire suppression efficiency;
- reignition quenching;
- ODP;
- global warming potential (GWP);

- atmospheric lifetime;
- suppressant residue level;
- electrical conductivity;
- corrosivity to metals;
- polymeric materials compatibility;
- stability under long-term storage;
- toxicity of the chemical and its combustion and decomposition products;
- speed of dispersion; and
- safety and occupational health requirements.

The goal of the Next-Generation Fire Suppression Technology Program (NGP) is to develop and demonstrate, by 2004, retrofitable, economically feasible, environmentally-acceptable, and 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. The results will be specifically applicable to fielded weapon systems, and will provide dual-use fire suppression technologies for preserving both life and operational assets.

The research approach consists of six parallel Technical Thrusts embodying 24 separate research elements, which are closely integrated and structured to achieve specific milestones within an eight-year timeframe. The approach was developed collaboratively by government, industry, and academic experts in fire science, the contributing technical disciplines, instrumentation, testing, and current halon 1301-protected weapon systems. The six Technical Thrusts are described below:

1. Risk Assessment and Selection Methodology develops a process for choosing among alternative technologies by applying modern decision-making techniques.

2. Fire Suppression Principles establish the mechanisms of flame extinguishment using detailed experimental studies and computational models leading to new approaches for fire control.

3. Technology Testing Methodologies select, adapt, and develop test methods and instrumentation to obtain data on the effectiveness and properties of new suppression approaches.

4. New Suppression Concepts define new ideas for fire suppression based on chemical and physical principles.

5. Emerging Technology Advancement accelerates to maturity a variety of processes, techniques, and fluids that are currently under development.

6. **Suppression Optimization** develops the knowledge to obtain the highest efficiency of each candidate technology.

NGP research projects encompassing the 24 elements will begin identifying and developing next-generation fire suppression technologies within the first two years of the program, and new knowledge will be added continuously throughout program execution. Investigation of new suppression concepts and ideas will commence in the first year; and, during the next three years, research will transition to the validation of viable fire suppression approaches. At the NGP mid-point (FY 2001) the program focus will shift to suppression optimization; *e.g*., the development of knowledge to obtain the highest efficiency of each candidate technology. The NGP progression is delineated in the major milestones listed below.

- Description and tabulation of the broad classes of model fires to be suppressed by the end of FY 1998.
- Implementation of improved laboratory-scale test methods for measuring the performance, compatibility, and degradation of new suppressants during the fire extinguishment process during FY 1998-1999.
- Selection for further R&D of the first set of new technologies resulting from a broad public solicitation of ideas by the end of FY 1999.
- Completion of a core methodology for DOD program executives/managers to evaluate the impact of selecting alternative fire suppression systems on each weapons system by the end of FY 2001.
- Demonstration of a suite of computer models of the fire suppression processes for creating new suppression approaches and optimizing current ones (based on specific critical physical and chemical principles) by the end of FY 2001.
- Identification of next-generation mist, inert gas generator, and powder technologies by the end of FY 2001.
- Establishment of engineering models for an array of techniques to optimize the use of next-generation fire suppression technologies by the end of FY 2004.
- Demonstration of the effectiveness of a wide variety of new technologies and/or techniques over the period FY 1999-2004.

The NGP will develop and demonstrate next-generation technology alternatives to a level that will enable DOD weapon system managers to make prudent decisions based on cost, risk, schedule, and capability needs. Real-scale validation testing will demonstrate the viability of these technologies for broadly generic applications; however, next-generation technologies will not be developed to the level of application for each specific weapon system.

Required resources for the NGP will be provided by the Military Departments' respective Science and Technology (S&T) programs, the Strategic Environmental Research and Development Program (SERDP), and participating non-DOD government agencies, as well as through collaborative agreements in research partnerships with private sector firms and colleges/universities.

The NGP will be conducted under the guidance and oversight of the Director, Defense Research and Engineering (DDR&E), in accordance with the policy stipulated in DOD Directive 6050.9, Subject: Chlorofluorocarbons (CFCs) and Halons, dated 13 February 1989. This policy requires the DOD Components to conduct research and development (R&D) to identify or develop alternative processes, chemicals, or techniques for functions currently being met by CFCs and halons; the DDR&E to coordinate R&D programs, as appropriate, on alternative chemicals or technologies for fire and explosion suppression; and the Military Departments and Defense Agencies to conduct R&D programs, as needed, to support mission requirements, with emphasis on substitutes for halons.

The NGP is national in scope and may include international collaboration. Program coordination will be provided through the Halon Alternatives R&D Steering Group (HASG). The NGP execution will commence in FY 1997 with five projects to be conducted by the Military Departments and NIST, and four projects by industry and academia. Funding for these projects will be provided primarily by SERDP, with contributions by the performing organizations. In FY 1998, the Military Departments and the SERDP Program Office will plan, program, and budget the necessary S&T program resources required to support their full participation in the NGP.

If successful, the NGP will develop and demonstrate the requisite technologies that will enable the backfit of halon 1301 alternatives into fielded weapon systems, eliminate DOD dependence on a substance no longer in national production, and minimize any readiness impacts that could result if halon 1301 use restrictions are imposed in the future.

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I. INTRODUCTION

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 during combat operations. For the past two decades, halon 1301 has been the agent of choice for fire extinguishment and explosion suppression (hereafter referred to collectively as fire suppression) in both weapon systems and facilities in the Department of Defense (DOD), the private sector, and for other countries' armed forces and domestic needs. Due to its high ozone-depleting potential (ODP), halon was banned from production as of 1 January 1994 by the Copenhagen Amendments to the Montreal Protocol. The national response to the Protocol has been the rapid initiation of research for halon alternatives.

Current defense research, development, test, and evaluation (RDT&E) activities focus on the identification of near-term, environmentally-friendly and user-safe, halon alternative technologies--developed by industry--that are either readily available or could enter commercial production in the near future. In general, the outcomes of these activities have demonstrated that near-term alternatives result in solutions that have weight and volume penalties, thus compromising existing system backfit needs. This could have significant operational impact on the DOD, given that the end of the Cold War has resulted in defense budget reductions, downsizing, and the extension of the in-service lives of fielded weapon systems. Application of near-term alternatives to fielded weapon systems could require DOD weapon system program managers to expend large amounts of funding and time for fire suppression system redesign and reconfiguration.

Meanwhile, other countries are greatly increasing their environmental legislation restrictions--forewarning potential international use restrictions--and one ally of the United States (Australia) has already collected the nation's halon supply and is contemplating destruction. To ensure supportability of US forces abroad using existing weapon systems, and to preclude any long-term halon use restriction impacts, a defense technology program to create more optimal next-generation fire suppression processes, techniques, and fluids that, to the maximum extent possible, eliminate dependency on halon 1301 in fielded weapon systems is a prudent course of action.

The Next-Generation Fire Suppression Technology Strategy, and the supporting Program, are designed to satisfy this need. The potential for success is maximized by bringing together the nation's best researchers in fire suppression and associated technologies, and by leveraging the vital federal and private sector fire suppression RDT&E infrastructure that has been created during the ongoing near-term research program. Next-generation technologies will have dual-use potential, which could satisfy civil fire suppression requirements created by the elimination of halon 1301.

II. DOD HALON 1301 USE

A. Background

Nearly 50 years ago, the U.S. Army directed a program that examined a number of chemicals for their potential in suppressing explosions in occupied spaces of ground armored vehicles. Many of these chemicals were designated "halons," as a contraction for halogenated hydrocarbons. The driving "environmental" factor at that time was inhalation toxicity. Halon 1301 (CF_3Br) emerged from that program as the chemical of choice for total flooding applications. Its use proliferated due to its additional highly regarded properties: high fire suppression efficiency, zero residue, electrical non-conductivity, compact storage, rapid dispersion upon release, and high materials and systems compatibility. Fire protection for most fielded weapons systems has been, in fact, designed around halon capabilities. This, combined with its low storage weight and volume, results in a minimum amount of system engineering required for optimal distribution and design concentration in the development of a broad family of fire suppression systems.

Halon 1301 is used extensively to protect weapon systems and critical mission support facilities from unwanted fires and explosions, often caused by enemy attack. When a fire or explosion is detected, the chemical--which is stored as a pressurized liquid--is released from the storage bottle(s) as a liquid and gas mixture. The liquid fraction is superheated and flashes into the vapor phase. This hastens "total flooding," with the agent rapidly distributing throughout the space. When the concentration of halon 1301 reaches its effective level (typically on the order of 6-7%), the fire is extinguished or the explosion is suppressed. As long as the chemical remains in the atmosphere at inerting concentrations, the fire will not reignite, and the area is protected against additional explosion incidents. This capability is especially valuable during combat. Halon 1301 applications in fielded weapon systems, by Military Department, are listed in Table 1.

Unfortunately, halon 1301's exceptional performance and success over the years have resulted in minimal research into alternative processes, techniques, or fluids for fire suppression. The absence of research on alternatives escalated to an international problem when halon 1301 was found to contribute significantly to stratospheric ozone depletion due to its long lifetime in the troposphere and its ready photodissociation by short wavelength ultraviolet light in the stratosphere, followed by aggressive catalysis of ozone destruction by the bromine moiety. This finding resulted in the Parties to the Montreal Protocol taking action to ban, by law, the commercial production of new halon 1301 as of 1 January 1994. As an interim solution for mission critical applications, the DOD, other government agencies, and private firms have created "banks" of existing and recycled halon 1301 as a temporary means of continuing protection while the aggressive search for viable alternatives proceeds.

Army	Navy	Air Force
Ground Armored Vehicles - crew compartments - engine compartments Aircraft - engine nacelles - APU compartments Maritime Craft Hand-Held Extinguishers - air/ground/maritime Communications Shelters	Shipboard - propulsion machinery - flammable liquid storerooms - fuel pump rooms - emergency generator rooms Aircraft - engine nacelles - dry bays - fuel tanks - crew compartments Ground Armored Vehicles - crew compartments - engine compartments	Aircraft - engine nacelles - dry bays - fuel tanks - weapon bays - cargo bays Facilities Hand-Held Extinguishers

Table 1: Fielded Weapon Systems Applications for Halon 1301

B. National Commitment to Eliminate Ozone-Depleting Substances

The United States is a party to the Montreal Protocol, which initially called for cessation of production of halons and CFCs by the year 2000. Title VI of the U.S. Clean Air Act 1990 Amendments required the regulation of production of halons and CFCs. Citing satellite data, which indicated a more rapid depletion of the ozone layer than previously predicted, President Bush announced on 11 February 1992 that the United States would accelerate its total phaseout of Ozone-Depleting Substance (ODS) production to 1995, and called on the other industrialized nations to accelerate their phaseout. Subsequently, the November 1992 Meeting of the Parties to the Montreal Protocol in Copenhagen agreed to a production phase-out of halons on 1 January 1994 and CFCs by 1 January 1996.

C. Policy

The DOD policy concerning technology efforts aimed at seeking ODS alternatives is delineated in DOD Directive 6050.9, Subject: Chlorofluorocarbons (CFCs) and Halons, dated

13 February 1989. The Directive states that DOD Components "... shall conduct R&D to identify or develop alternate processes, chemicals, or techniques for functions currently being met by CFCs and halons"; that the Director, Defense Research and Engineering (DDR&E) "... shall coordinate R&D programs, as appropriate, on alternative chemicals or technologies for fire and explosion suppression and, if necessary, other CFCs"; and that the Military Departments and Defense Agencies "... shall conduct R&D programs, as needed, to support mission requirements, with emphasis on substitutes for halons." The NGP is consistent with this policy.

III. NEAR-TERM HALON ALTERNATIVE TECHNOLOGY DEVELOPMENT

A. Halon Alternatives R&D Steering Group (HASG)

The Director, Defense Research and Engineering, established the HASG in September 1991 to formulate (and oversee the execution of) an integrated DOD near-term technology strategy and technology development plan to identify suitable alternatives for halons. On the recommendation of the Assistant Secretary of the Navy (Research, Development and Acquisition), the charter of the HASG was expanded to include all ODSs. The HASG is chaired by the Director, Advanced Technology, in the Office of the Director, Defense Research and Engineering (ODDR&E). The HASG also has 2 vice-chairs: the Deputy Director, Operational Test and Evaluation/Live Fire Testing (DDOTE/LFT), Office of the Secretary of Defense; and the Staff Specialist for Survivability, Office of Strategic and Tactical Systems/Air Warfare (ODDS&TS/AW), Office of the Under Secretary of Defense for Acquisition and Technology (OUSD(A&T)).

B. Near-Term Technology Strategy and Technology Development Plan

The HASG formulated the *DOD Technology Strategy For Alternatives To Ozone-Depleting Substances For Weapon Systems Use*, which was approved by the DDR&E on 31 August 1992 to guide the near-term DOD investigation and performance testing of commercially-available and environmentally-acceptable alternatives. The HASG then developed an execution plan, the *DOD Technology Development Plan For Alternatives to Ozone-Depleting Substances For Weapon Systems Use (TDP)*, which was approved by the DDR&E on 28 June 1993 and is updated annually.

The TDP research focuses on identifying commercially available or emerging technology alternatives to halons used in fielded weapon systems. (The TDP also focuses on the identification and qualification of alternatives to CFCs currently used in weapon systems applications for refrigeration and environmental control, and for general and precision cleaning.) The TDP is being executed by the Army, Navy, and Air Force. In general, TDP research goals will be achieved in FY 1996, with the possible exceptions of Army research on alternatives for explosion suppression in occupied compartments of ground armored vehicles, which could continue through FY 1999, and Navy research on alternatives for fire extinguishment in shipboard occupied compartments, which could continue through FY 2001. The Strategy and the TDP together form the cornerstone of the overall DOD near-term response to the impact of the Montreal Protocol on weapon systems.

C. Halon 1301 Alternatives Research

Because establishing initial production capability for a new alternative chemical can take a decade from laboratory synthesis to production in commercially-viable quantities, the search for near-term replacement fluids that could be inserted into current halon 1301 systems has thus far focused on chemicals that are, or imminently will be, available in sufficient commercial production quantities. Research efforts are mainly investigating aliphatic fluorocarbons--analogues of halon 1301, but without the bromine atom. Initially proposed replacement chemicals were offered by companies that already manufacture fluids for fire suppression, or make similar fluids for air conditioning, degreasers, and foam blowing; and were developing replacements for these uses. The emerging candidates were typically limited in chemical scope, some examples being HFC-227ea (C_3HF_7), HFC-134a (CH_2FCF_3), HCFC-124 ($CHFClCF_3$), HFC-125 (CHF_2CF_3), FC-218 (C_3F_8), and halon 13001 (CF_3I).

Many of these chemicals have been examined in the laboratory and at real scale; ***however, none of the current alternative chemicals offer all the properties of halon 1301.*** Nearly all of them are substantially less efficient and will require additional weight allowance and storage volume. In addition, the use of nearly all of them will result in a post-deployment atmosphere containing appreciable concentrations of acid gases; an atmosphere that is not suitable for human occupancy, and which may chemically attack metals, synthetic materials, and electronics.

Because of the unique effectiveness and success of halon 1301, it (like aspirin) has often been specified by name rather than by performance. Its successors thus need new guidelines for approval. Several efforts have been directed at establishing measurement methods and criteria, as well as real-scale performance demonstrations. Because of the diversity of fires types, there is a wide range of possible test procedures. With critical review, some of these methods will be useful for further searching. The Environmental Protection Agency

(EPA) Significant New Alternatives Policy (SNAP) Program has provided a focus for several of these criteria, using "currently accepted practice" to evaluate ODP, atmospheric lifetime, toxicity, and GWP.

D. TDP Research Outcomes

TDP research activities have identified three near-term total flooding technology alternatives to halon 1301. The first is a replacement fluid, HFC-125, which is now undergoing final testing in the development of design equations and criteria for design of aircraft fire extinguishment systems. The second alternative is another fluid, HFC-227ea, which is undergoing final qualification testing. The third alternative is based on inert gas generator technology, which has been extensively tested in specific developmental weapon systems. HFC-125 is currently being considered for use in the engine nacelles of the developmental F-22 and V-22 aircraft. HFC-227ea is being considered for use in the fixed fire suppression systems onboard the lead ship of the new-construction amphibious ship LPD 17, and possibly onboard the new-construction aircraft carrier CVN 76. Inert gas generator technology is being considered for fire suppression applications in two developmental aircraft: the F/A-18 E/F (engine nacelles and dry bay), and the V-22 (dry bay and wing bays).

HFC-125 and HFC-227ea each have volume and weight penalties 2-3 times that of an equivalent extinguishing concentration of halon 1301. Additionally, during suppression they generate significant levels of toxic by-products. New weapon systems have been developed, or are in development, with fire suppression system designs that take into account the associated weight and volume penalties of these total flooding alternatives. But the penalties could negate the possibility of backfitting HFC-125 and/or HFC-227ea into fielded weapon systems due to costly redesign and reconfiguration of installed fire suppression systems, or the negative impact on weapon systems capabilities.

The effectiveness of propellant-generated inert gas technology has been demonstrated in two weapon-system-specific applications (F/A-18 E/F and V-22); however, its effectiveness in suppressing fires in larger weapon system applications (*e.g.*, transport aircraft) is unknown. Fine water mist technology is also being extensively investigated in the TDP for possible applications in aircraft engine nacelles, dry bays, shipboard occupied engineering compartments, ground combat vehicle engine compartments, and maritime craft. Due to the need for a broader science base in these emerging technologies--in order to fully evaluate their potential for wider applications in fielded weapon systems--they will be further investigated in the NGP.

E. Current Fire Suppression System Technology Options

From a weapon system program manager's perspective, the current TDP near-term halon 1301 research activity outcomes offer the three fire suppression options listed below.

1. **Utilize Identified Near-Term Replacements.** This option accepts the penalties associated with the use of HFC-125 and HFC-227ea in fielded, upgraded, developmental, and new weapon systems.

2. **Vintage the Existing Halon System.** Vintaging of an existing halon 1301 fire suppression system is defined as the continued use of halon 1301-based systems until the weapon system is retired or backfitted with an environmentally acceptable and effective alternative. This option entails the protection of a fielded weapon system with banked halon 1301 from the DOD ODS Reserve maintained by the Defense Logistics Agency (DLA).

3. **Cease Fire Protection Altogether.** This approach is being used in the private sector for many computer facilities, where it is less costly to back-up the computer than to provide fire protection.

Overall, each of the above options presents significant trade-off considerations. The use of the near-term alternative technologies or dissimilar fluids, while under investigation, is not always feasible for protecting fielded weapon systems. In many cases, significant re-engineering of the fire suppression system (and the weapon system) may be required to achieve even a marginally acceptable level of protection. The cost of this re-engineering has been estimated at several billion dollars for all fielded weapon systems. For aircraft, use of these near-term technologies will mean increases in take-off gross weight, or decreases in range/payload capability.

The vintaging of fielded weapon systems requires the acquisition community and system operators to depend indefinitely on a substance that is no longer in production, that must be stockpiled to ensure continued availability, and which is subject to market fluctuations in cost and supply. Furthermore, there is no assurance that environmental regulations will indefinitely permit the use of halon 1301; and although vintaging is an acceptable near-term option for some fielded weapon systems (*e.g.,* the A-6, F-16, and several classes of ships and land combat vehicles), it does not constitute a viable DOD long-term strategy for general fire protection in fielded weapon systems.

The abandonment of fire protection altogether may be an acceptable alternative for some computer facilities; however, it is typically not a feasible option for weapon systems. Personnel safety is always of critical importance within DOD, and weapon systems survivability is likewise a high priority.

IV. LOOKING TO THE FUTURE

With the end of the Cold War and the resulting force reductions and budget cuts, the operational lives of fielded weapon systems are being extended and the acquisition of new weapon systems is being stretched out and/or reduced significantly. Fielded weapon systems will continue to be dependent on halon 1301 from the DLA ODS Reserve because of the potentially prohibitive cost and operational impact of backfitting near-term alternatives. A qualitatively different approach from that taken in the TDP is needed to find acceptable alternatives to halon 1301 systems. To do so, it will be necessary to capitalize on the potential creativity in this field. Already, there are a number of other chemicals and alternative suppression technologies being proposed and examined (*e.g.,* powders, misted chemicals, and *in situ* generated chemicals). These require evaluation and development, and additional innovative approaches need to be encouraged.

A. Survey and Requirements

As a first step, a cursory survey was conducted of fires in which the DOD currently uses halon 1301, and which constitute the requirements for fire extinguishment and explosion suppression capabilities in weapon systems. Details of the survey are summarized in Appendix A. The survey *(which does not include all DOD applications)* shows an extremely broad range of fire conditions. The locations vary in size, shape, function, and whether or not they are populated. The fuels are solids, vapors, and liquids; the latter burning as pool fires or sprays. The required time for suppression ranges from hundredths of a second to tens of seconds. In some cases, the agent must be "clean" and in others, not. The hazards to be avoided include harm to people, thermal damage to equipment, post-fire corrosion, loss of visibility, and overpressure. Finding a "one-size-fits-all" fire suppression approach that replaces halon 1301 is highly improbable.

B. Performance Properties

Experience has shown that the development and examination of new fire suppression technologies is not likely to be brief or easy. The suppressant, its storage support and its delivery system must be of light weight (low mass) and low volume--and, to be backfitted into existing systems, compatible with the host design. Successful candidates must also perform satisfactorily in a wide variety of tests for the following properties:

- fire suppression efficiency;
- reignition quenching;
- ODP;
- GWP;
- atmospheric lifetime;
- suppressant residue level;
- electrical conductivity;
- corrosivity to metals;
- polymeric materials compatibility;
- stability under long-term storage;
- toxicity of the chemical and its combustion and decomposition products;
- speed of dispersion; and
- safety and occupational health requirements.

Satisfying this combination of performance characteristic requires a high level of technical expertise, a focused commitment of resources, and a clear sense of direction to find suitable replacements. Fortunately, in the past 50 years there have been major advances in combustion science, sensors, and atmospheric chemistry--so the expertise exists to address these issues. Although there are some next-generation fire suppression projects proposed or already underway within DOD and other government laboratories, they lack focus on a common goal and timeframe.

V. GOAL

The goal of the Next-Generation Fire Suppression Technology Program (NGP) is to develop and demonstrate, by 2004, retrofitable, economically feasible, environmentally-acceptable, and 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. The results will be specifically applicable to fielded weapon systems, and will provide dual-use fire suppression technologies for preserving both life and operational assets.

VI. NEXT-GENERATION PROGRAM APPROACH

The planned research approach is organized into six Technical Thrusts and 24 research elements. In addition to the development and demonstration of new technologies, the integrated nature of this program will result in broader understanding and computer models of the suppression process, as well as a diversity of tested approaches. New ideas generated during validation tests, for instance, will lead to clearer understanding of fire suppression principles and refined testing methods for new suppression technologies. This will, in turn, enable prompt development of further technology should future environmental or weapons systems requirements change.

The research approach has been developed collaboratively by government, industry, and academia experts in fire science, the contributing technical disciplines, instrumentation, testing, and current halon 1301-protected weapon systems. It builds on the ongoing TDP research activities in fire extinguishment and explosion suppression, incorporating insights gained and emerging innovative technology approaches identified. To encourage continued broad participation in the NGP by industry, academia, and other government agencies, all NGP information on chemicals and systems and their test results will be in the public domain, subject only to limitations on commercially-proprietary technology.

A. Technical Thrusts

1. **Risk Assessment and Selection Methodology** develops a process for research program managers to choose among alternative technologies for each application by applying modern decision-making techniques.

2. **Fire Suppression Principles** establish the mechanisms of flame extinguishment using detailed experimental studies and computational models, leading to new approaches for fire control.

3. **Technology Testing Methodologies** select, adapt, and develop test methods and instrumentation to obtain data on the effectiveness, toxicity, environmental impact, and materials compatibility of new suppressants and their principal degradation products during the fire extinguishment process.

4. **New Suppression Concepts** define new ideas in processes, techniques, and fluids for fire suppression based on chemical and physical principles.

5. **Emerging Technology Advancement** accelerates to maturity a variety of processes, techniques, and fluids that are currently under development.

6. **Suppression Optimization** develops the knowledge to obtain the highest efficiency of each candidate technology.

B. Research Elements

The NGP has 24 research elements--each a critical component of the approach--organized into six Technical Thrusts. Each element will be performed synergistically and, in many cases, concurrently with other elements. The weapon systems information developed in Element 1.a will serve as guiding criteria for what constitutes acceptable retrofit technologies for fielded weapon systems. As technologies emerge, this new knowledge and other relevant information will be used to channel further research. The research elements, described in Appendix B, are listed below by Technical Thrust.

1. Risk Assessment and Selection Criteria

a. Development of Model Fires from DoD Fire Data
b. Ullage Inerting In-Flight Data Collection
c. Relative Benefit Assessment of Fire Protection System Changes

2. Fire Suppression Principles

a. Mechanisms of Ultra-High Efficiency Chemical Suppressants
b. Suppression Dynamics of Fine Droplets and Particles
c. Stabilization of Flames
d. Explosion Inhibition Processes

3. Technology Testing Methodologies

a. Suppression System Effectiveness Screening
b. Agent Compatibility With People, Materials and the Environment
c. Instrumentation for Gaseous Fuels, Oxygen, and Suppressant Concentration Measurements During Suppression of Flames and Explosions

4. New Suppression Concepts

a. Powder-Matrix Systems

b. Evaluation of Highly Effective Chemical Suppressants
c. Super-Effective Thermal Suppressants
d. New and More Effective Fire-Suppression Technologies that are Presently Conceptual

5. Emerging Technology Advancement

a. Liquid Mist Systems
b. Advanced Flame Arresting Foams for Fuel Tank Inerting
c. Active Suppression for Fuel Tank Explosions
d. Advanced Propellant/Additive Development for Gas Generators
e. Enhanced Powder Panels

6. Suppression Optimization

a. Fire Suppressant Dynamics in the Fire Compartment
b. Suppressant Flow Through Piping
c. Mechanism of Unwanted Accelerated Burning
d. Development and Evaluation of Automatically Actuating Pre-Dispersed Agent Storage Containers
e. Full-Scale Optimization of Advanced Fire Suppression Technologies

C. NGP Major Research Milestones

NGP research projects encompassing the 24 elements will begin identifying and developing new fire suppression technologies in FY1997 and establishing ways to determine their effectiveness; new knowledge will be added continuously throughout the program execution. These efforts will soon be accompanied by research to pursue variations on recently proposed fire suppression approaches. At the NGP mid-point (FY2001), the program focus will begin shifting to the development of knowledge to obtain the highest efficiency of each candidate technology and demonstrating the efficacy of the new technologies. The NGP progression is delineated in the major milestones listed below.

- Description and tabulation of the broad classes of model fires to be suppressed by the end of FY 1998.

- Implementation of improved laboratory-scale test methods for measuring the performance, compatibility, and degradation of new suppressants during the fire extinguishment process during FY 1998-1999.

- Selection for further R&D of the first set of new technologies resulting from a broad public solicitation of ideas by the end of FY 1999.

- Completion of a core methodology for DOD program executives/managers to evaluate the impact of selecting alternative fire suppression systems on each weapons system by the end of FY 2001.

- Demonstration of a suite of computer models of the fire suppression processes for creating new suppression approaches and optimizing current ones (based on specific critical physical and chemical principles) by the end of FY 2001.

- Identification of next-generation mist, inert gas generator, and powder technologies by the end of FY 2001.

- Establishment of engineering models for an array of techniques to optimize the use of next-generation fire suppression technologies by the end of FY 2004.

- Demonstration of the effectiveness of a wide variety of new technologies and/or techniques over the period FY 1999-2004.

D. Strategy Evolution

This Strategy is meant to be a "living" document. As presented, it represents the best current thinking for achievement of the program goal and objectives. The goal will remain fixed. Approaches and timelines may be adjusted. As new knowledge emerges, technical efforts will be adjusted accordingly. For example, breakthroughs may find more direct channels toward the conclusion, or complications may necessitate further analysis and research. Further toxicity or real-scale proof testing could be required in the latter years.

E. Success (Exit) Criteria

The NGP will develop and demonstrate next-generation fire suppression technology alternatives to a level that will enable DOD weapon system managers to make prudent decisions based on cost, risk, schedule, and capability needs. Real-scale validation testing will demonstrate the viability of technologies and methods for broadly generic applications; however, new technologies will not be developed to the level of application for each specific weapon system. The NGP technology development process is considered complete when the generic technical know-how exists to design next-generation cost-effective alternatives to halon

1301 systems. In this regard, it is important to note that this effort does not include programs which will ultimately be required to incorporate these alternatives into specific weapon systems. Programs of this nature are beyond the scope of science and technology efforts.

VII. RESOURCES

A. Estimated Funding Summary

The NGP is scheduled to commence in FY 1997 and reach completion by FY 2004.

There are currently ongoing and proposed DOD, industry, and academia activities which could advance the NGP timetable and reduce the estimated costs. Collaborations with these programs--both domestically and internationally--could reduce the funds needed to enable accomplishment of the research goal and objectives by requiring that:

- government organizations whose laboratory capabilities are advanced by participating in this program share setup costs (especially for facilities that will remain after the conclusion of the program);
- laboratories performing similar or related research work cost-share their projects to the extent that these existing efforts relate to proposed activities;
- industrial firms that will find new markets share the costs of performed work in their area (this is especially true for holders of patented or proprietary technologies that are under consideration); and
- other, non-DOD government agencies (including foreign government agencies) provide in-kind support, as their constituencies would benefit from the new fire suppression capabilities.

B. Funding Sources

The NGP will be supported by Military Department Science and Technology (S&T) funds, Strategic Environmental Research and Development Program (SERDP) funds, Other government funds (those from other non-DOD participating government agencies), and collaborative funding by research partners in the private sector. These funding sources are described below.

1. **Military Department S&T Programs.** Military Department S&T programs are used to fund Basic Research (6.1), Exploratory Development (6.2), and Advanced Development (6.3) projects. To eliminate unnecessary duplication, Military Department next-generation fire suppression research projects supported within current S&T budgets are to be incorporated into the NGP Thrust areas by integrating them, as appropriate, with the research elements listed in Appendix B.

2. **SERDP.** SERDP addresses high-priority, defense-mission-related, environmental requirements through basic and applied R&D. (The annual SERDP Program development schedule is shown in Appendix C.) Since halons have been banned from production because of their environmental impact, the search for new fire suppression technology is a DOD environmental requirement. Environmental research is focused on alternative technologies having zero ODP and minimal GWP; therefore, SERDP is a reasonable and appropriate funding source for research on next-generation fire suppression technology.

3. **Other Government Funds.** It is anticipated that non-DOD government agencies, such as the National Institute for Standards and Technology (NIST) and the Department of Energy (DOE), will participate in the NGP. Funds provided for NGP research projects conducted by non-DOD government agencies are categorized as Other government funds.

4. **Cooperative Research.** As designed, this program should quickly begin producing a steady flow of ideas for further development and examination. Those ideas showing promise will be pursued to the point of practical demonstration. To the extent that a given approach is appealing to industry, cooperative research and development agreements (CRADAs) and partnerships will be arranged to facilitate development and demonstration. Cooperative research efforts will also be pursued within the international community.

C. Project Funding

The Military Departments will support their respective research projects with S&T funds, SERDP funds, or a combination of S&T funds and SERDP funds. The NGP and SERDP organizational points-of-contact (POCs) for facilitating the coordination of NGP statements-of-need, project proposals, and project funding, include the HASG Secretariat, the Technical Program Manager (TPM), the SERDP Pollution Prevention Program Manager (PP PM), and the Pollution Prevention Technical Thrust Area Working Group (PP/TTAWG) co-chairs, as depicted in Appendix D. CRADAs with the private sector will be pursued by all performing organizations, as feasible. Additionally, through teaming with other government agencies, tasks within Military Department projects can be accomplished with other government funds, as agreed by the teaming partners.

VIII. TECHNICAL PROGRAM MANAGEMENT

To achieve the NGP goal and objectives, DDR&E will conduct oversight of NGP research projects conducted by the Military Departments, DOD agencies, other government agencies, industry, academia, and, as appropriate, international agencies. This will be accomplished through the HASG. The overall program technical management structure is depicted in Figure 1.

A. Management Organizational Structure

1. **Halon Alternatives R&D Steering Group.** The HASG is responsible for oversight and guidance of the NGP. Established in September 1991 to formulate (and coordinate the execution of) an integrated DOD technology strategy and plan for identifying suitable alternatives for halons, the HASG is chaired by the Director, Advanced Technology, (DDR&E/AT). The HASG has two vice-chairs: the Deputy Director, Operational Test and Evaluation/ Live Fire Testing (DDOTE/LFT), Office of the Secretary of Defense; and the Staff Specialist for Survivability, Office of Strategic and Tactical Systems/Air Warfare (ODDS&TS/AW), Office of the Under Secretary of Defense for Acquisition and Technology (OUSD(A&T)). The HASG includes representation from the Office of the Deputy Under Secretary of Defense for Environmental Security, the Military Departments, DOD Agencies, and liaison personnel from other federal agencies. The current HASG membership will be restructured to increase weapon system user representation, as nominated by the Military Departments.

2. **Technical Coordinating Committee (TCC)**. The TCC is responsible for coordinating the interaction of all thrust areas; reviewing the technical progress of individual research elements; assuring the coherence of the research elements; assessing progress toward the program goal and objectives; appraising the need for changes in technical direction; and coordinating all technical and resource issues at the Technical Thrust level. The TCC consists of the Technical Program Manager (designated as the Chairman) and the Thrust Leaders.

    a. **Technical Program Manager.** The TPM is appointed by the HASG Chairman from nominees submitted by the Military Departments and non-

DOD agencies, and serves at the discretion of the Chairman. The TPM is accountable to the HASG Chairman for the coordination of all NGP technical and resource matters, including program technical direction and progress, achievement of Technical Thrust objectives, and the accomplishment of the NGP goal. The TPM coordinates all NGP Research Elements, Statements-of-Need, solicitations, and broad agency announcements (BAAs), and all NGP project proposal reviews, selections, approvals, and funding. The TPM coordinates all matters pertaining to SERDP-funded NGP Projects with the Office of the SERDP Executive Director.

b. **Thrust Leaders.** Thrust Leaders are appointed by the TPM from nominees submitted by the Army, Navy, Air Force, and other government agencies, with the approval of the HASG Chairman. Thrust Leaders are selected on the basis of their technical expertise in one or more Technical Thrust areas. Thrust Leaders are responsible for formulating and coordinating all NGP Projects within their respective Technical Thrust, drafting Statements-of-Need, reviewing project proposals, recommending proposal selections, and monitoring the execution of all projects in their respective thrust areas.

3. **Thrust Working Groups.** Thrust Leaders may create informal Thrust Working Groups to facilitate coordination of all projects within their particular areas. Thrust Working Groups include NGP research project principal investigators in Army, Navy, and Air Force laboratories and other government laboratories; and principal investigators from industry and academia (as necessary). Thrust Working Groups are chaired by Thrust Leaders.

4. **HASG Secretariat.** The Secretariat is responsible for all HASG administrative matters including scheduling and coordinating HASG meetings (including meeting logistics); preparing all HASG reports and minutes; and supporting the HASG membership, as required. The Secretariat is assisted by the Program Support Office, which provides necessary program and management support to the HASG and the TCC.

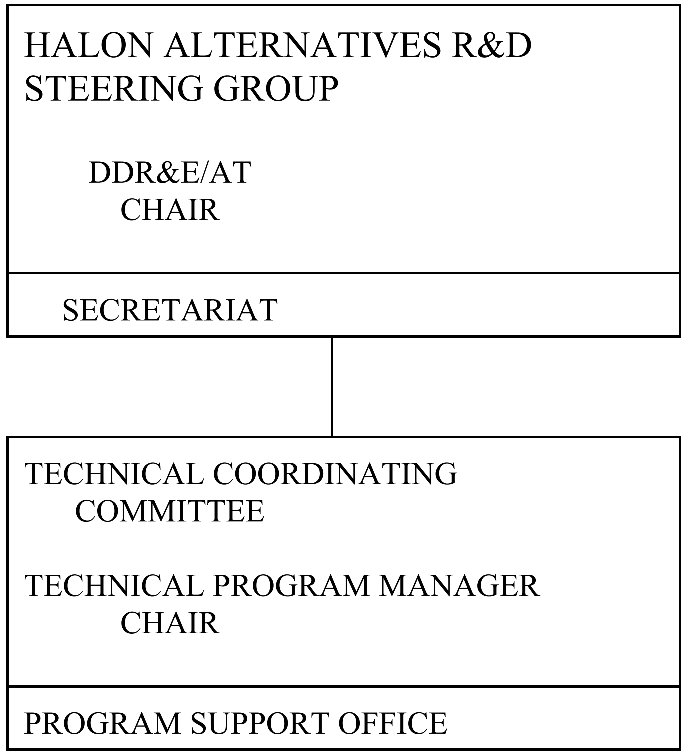

Figure 1: Program Technical Management Organization

B. Program Coordination and Review

The NGP is supported by an efficient and effective methodology for technical program coordination and review. It is expected that as many as 50 professionals and 20 organizations will be involved during the course of the program. The preferred operation will involve the best technical experts making extensive use of capabilities within the government laboratories. There is immense value in obtaining the broadest spectrum of new ideas. Therefore, technical coordination and cross-pollination of work in progress is essential. The following mechanisms will be used to promote technical interactions and the flow of information to sponsors, overseers, and potential customers as well as program oversight and coordination:

1. **Semi-Annual HASG Meetings.** The HASG reviews NGP plans and progress at its semi-annual meetings conducted in the May and October timeframes. The TPM presents technical briefings to the HASG concerning proposed NGP Statements-of-Need, recommended NGP Project Proposals, status of on-going NGP Projects, and the annual NGP Plan.

2. **SERDP Organization Annual Project Review.** On-going SERDP-funded NGP Projects are reviewed annually by the SERDP organization, usually in May.

3. **Annual NGP Research Meeting**. An annual NGP Research Meeting is convened in the May or October timeframe to provide a peer review and user feedback on the ongoing research. Coordinated by the TPM, the Research Meeting is attended by Thrust Leaders, program managers, principal investigators, weapon systems managers, HASG members, and other interested parties. Presentations will summarize overall progress achieved during the preceding fiscal year, and future plans in each Technical Thrust and Research Element.

4. **Quarterly Progress Reports.** Quarterly progress reports are prepared by all principal investigators or grantees/contractors, in accordance with SERDP procedures, and submitted to the TPM. SERDP-funded NGP Projects will also be reported quarterly to the SERDP Executive Director in accordance with SERDP procedures. The technical content of these reports will promptly be made accessible electronically to all NGP participants in order to promote a more rapid flow of information among them.

IX. PROGRAM EXECUTION

NGP execution will be characterized by rigorous application of scientific and engineering principles within a framework of integrated research thrusts and focused scientific and technical investigations. Progress will be measured through the attainment of specific milestones associated with the NGP Research Elements, which map the path for development of next-generation technologies.

The entire program will be reviewed annually by the TCC to ensure that the work is focused and on track, recommend any warranted corrections in the funded tasks, identify the priority new-starts for the following year, and make changes in the remaining Research Elements resulting from new findings. Program execution will be reviewed semi-annually by the HASG and the TCC to ensure that all in-progress and planned NGP research projects support user needs and are consistent with the guiding principles of the baseline Research Element 1.a. These reviews may result in the acceleration, re-scoping, or the cancellation of some research elements and/or projects.

A. Participants

Program execution will involve a variety of participants, as listed below:

- ODDR&E;
- DDOTE/LFT;
- ODDS&TS/AW;
- Army, Navy, and Air Force research sponsors, laboratories, and field activities;
- other government organizations (e.g., NIST, DOE laboratories, foreign governments);
- private sector companies (both small and large businesses);
- colleges and universities;
- designated federal government contracting agency (CA) (for contracting support);
- the HASG;
- the TCC;
- NGP Project principal investigators; and
- the SERDP organization, including the Council, Executive Director, Scientific Advisory Board (SAB), Executive Working Group (EWG), PP PM, and the PP/TTAWG.

B. Execution Process

The NGP will be executed through research projects proposed by the Military Departments and other federal government agencies in response to Research Element Statements-of-Need developed by the TCC. SERDP-funded projects will be coordinated through the HASG and approved by the SERDP Council. Non-SERDP funded projects will be approved through the HASG. Selected Research Element Statements-of-Need will be solicited among industry and academia by SERDP and the CA through the Commerce Business Daily. Proposals accepted from industry and academia will be incorporated into the NGP supporting programs of the Military Departments or other participating federal government agencies. More details on the execution process are provided in Appendices C and D.

X. INITIATION OF THE NGP

A. FY 1997 NGP New-Start Projects

Due to the urgency of the need to find alternatives to halon 1301, the NGP will commence in FY 1997 with nine projects and transition to full program execution commencing in FY 1998. In October 1995, the HASG Chairman submitted the FY97 NGP Portfolio to the SERDP Executive Director for consideration in the FY 1997 SERDP Program. SERDP solicited six NGP Statements-of-Need among government agencies in January 1996. Proposals received were evaluated by the PP/TTWAG and the TCC, resulting in the selection of five Directed NGP New-Start projects. SERDP also solicited one Statement-of-Need to industry and academia through a Broad Agency Announcement by the CA in March 1996. Proposals received were evaluated by the TCC and the PP/TTWAG, resulting in the selection of four projects. In May 1996, the nine proposed FY97 NGP New-Start Projects, scheduled to commence in October 1996, were coordinated with the HASG and forwarded to the Executive Director by the HASG Chairman.

B. Integration of NGP Research Element Funding Needs and TDP Activities

The NGP Research Element funding needs will be integrated into the SERDP Plan beginning in FY 1997, and into Military Department S&T program plans beginning in FY 1998. Commencing in FY98, the Military Departments will plan, program, and budget the necessary S&T program resources required to support their full participation in the NGP. All TDP halon 1301 alternatives research activities will be reviewed by the HASG in FY97 with the objective of integrating all next-generation efforts into the NGP in FY98, as appropriate. To this end, the Military Departments will review and assess their ongoing or planned halon 1301 next-generation alternatives research activities, both within and outside the TDP, and technically align these efforts to conform to the goal, technical objectives, and resource requirements of the NGP commencing in FY98. This will mitigate duplication of effort, facilitate a coordinated approach among all the Military Departments, and ensure that all Military Department halon 1301 alternatives research efforts are consistent with DOD priorities and support the NGP goal.

XI. ACHIEVING THE NGP GOAL--PROSPECTS AND PAYOFF

A. Prospects

Although there is a moderate degree of risk in this research, prospects for achieving the program goal are excellent for three reasons:

1. There are scientific indications that new chemical compounds may potentially have the same effectiveness as halon 1301. There are no scientific principles that prevent a chemical from being as effective as, or more effective than, halon 1301 in quenching combustion. Alkaline powders, metallics, and iodine-containing compounds, for example, have all been shown to inhibit combustion and suppress flames at mass-loadings near or below those required for halon 1301. Even water, if properly applied, can be demonstrated to be more effective on a kilogram-for-kilogram basis than halon 1301. The majority of the vast number of isomers, homologues, and bonding arrangements within other potential families of chemicals were not examined in the rapid search for near-term alternatives.

2. Through a greater understanding of fire suppression principles, it may be possible to develop compounds that are as effective as halon 1301, and to develop new suppression concepts. Better laboratory scale screening tools are required to adequately investigate the fire suppression phenomena of new chemical compounds or suppression concepts. The current tools were developed for halons and near-term alternatives, and are not suitable for dealing with the heavier, high boiling point compounds that will be investigated in the NGP. These new tools will provide insights required for better understanding of flame extinguishment and fire suppression mechanisms, leading to the development of new combustion models required for effective investigation of new compounds and suppression concepts. (The new screening tools will also enable the optimization of emerging alternative technologies now under development and testing in the TDP; *e.g.*, water mists and inert gas generators.) The expertise to develop these screening tools, suppression mechanisms, combustion models, and testing methodologies is available in government laboratories, industry, and academia.

3. Maximizing the fire suppression efficiency of new delivery concepts may result in system solutions that are as effective as halon-based systems, even though the compounds may be less effective. Also, newly emerging technologies are already known to exist, but need further optimization. These include gas generator systems, explosively-released water mists, and intelligent control of fluid motion in a protected space. The large number of options, each of which by itself containing some drawbacks, suggests that synergy could follow the invocation of combinations of processes, techniques, and fluids. Ideas for novel delivery schemes are being explored which could greatly enhance the performance of any particular compound and, thus, its probability of success.

The prospects for successfully achieving the goal are greatly enhanced by the NGP technical management team, a highly skilled and experienced group of scientists and engineers. The TCC will marshal a strong government, industry, and academia research effort with built-in provisions to ensure the lateral exchange of experimental and theoretical information among scientists, and the vertical transfer of information from engineers to the bench scientists and back. This coordination will allow rapid appraisal of ideas and direct the development process onto winning technologies, precluding time and resource-consuming dead-end investigations or non-relevant tangential efforts. The technical team efforts will be subject to highly effective program oversight and progress assessment by resource sponsors and users on the HASG, ensuring that the NGP stays on track and achieves its goal and objectives with minimum expenditure of resources and time.

B. Payoff

If successful, the NGP will develop and demonstrate the requisite technologies that will enable the backfit of halon 1301 alternatives into fielded weapon systems, eliminate DOD dependence on a substance no longer in national production, and minimize any readiness impacts that could result if halon 1301 use restrictions are imposed in the future.

APPENDIX A: MILITARY DEPARTMENT FIRE AND EXPLOSION SURVEY

SURVEY FORM AND TABULATION OF FIRE TYPES

SURVEY FORM: FIRE AND EXPLOSION SCENARIO DESCRIPTION --HALON 1301 REPLACEMENT

BRIEF DESCRIPTION OF FIRE/EXPLOSION SCENARIO:____

____

____

IS THIS APPLICATION A RETROFIT? _______ A NEW SYSTEM? _______

FUEL(S) (INCLUDING P,T RANGES):____

____

IGNITION SOURCE(S):____

OUTCOME TO BE AVOIDED:____

TIME FRAME FOR DETECTION:____

TIME FRAME DURING WHICH SUPPRESSION MUST OCCUR:____

ARE PEOPLE PRESENT DURING SUPPRESSION?____

CAN THEY LEAVE DURING THE FIRE? ________________________AFTER SUPPRESSION? ___________________

IS A CLEAN AGENT NEEDED? ______

CANNOT WORK WITH MIST ____, GASEOUS ____, POWDER ____ AGENT. WHY?

WHAT ARE POSSIBLE POST-FIRE LIMITATIONS TO BE AVOIDED?

CORROSION ___ LOSS OF VISIBILITY ___ TOXIC ATMOSPHERE ___

RE-FLASH ___ OTHER (SPECIFY)____

IS A SECOND-SHOT CAPABILITY NECESSARY? YES ________ NO _______

ACCEPTABLE VOLUME INCREASE OVER HALON 1301 STORAGE?_____________________________%

ACCEPTABLE WEIGHT INCREASE OVER HALON 1301 STORAGE?_____________________________%

MUST PRESENT DISTRIBUTION SYSTEM BE USED? YES ______NO ______

YEAR FOR NEEDING TO KNOW NEW AGENT/SYSTEM: ________________________

YOUR NAME:________________________________ PHONE:________________________FAX_____________________

ADDRESS:____
PEOPLE CONSULTED/AFFILIATIONS:____

Service	Facility	Fire Type	Location	Fuel(s)	Suppr. Time	Fixed/ Hand-Held	Occupied At T_{ext}?
Army	watercraft	fuel spray	engine room machinery space	diesel fuel lube/hydraulic oil	≈ 10 s	F?	N
Army	watercraft	≈ pool fire	paint locker	paints & solvents	≈ 10 s	F	N
Army	aircraft	fuel spray	engine	JP-4 or JP-8	seconds	F	N
Army	aircraft	stack fire	aux. power unit exhaust	JP-4 or JP-8	seconds?	F?	N?
Army	helicopter	turbine jet fire	engine nacelle	JP-4 or JP-8	≈ 5 s	F,H?	N
Army	ground vehicle	explosion	crew compartment	solid propellant	≈ 0.1 s	F	Y
Army	ground vehicle	mist explosion	crew compartment	JP-8	≈ 0.2 s	F	Y
Army	ground vehicle	explosion	ammo compartment	solid propellant	< 5 s	F	N
Tri-service	aircraft	explosion	dry bay	JP-8, hydr. fluid	≈ 10 ms	F	N
Tri-service	aircraft	turbine jet fire	engine nacelle	JP-4, JP-8	≈ 5 s	F	N
USAF	aircraft	electrical	compartment	plastics	< 30 s	H	Y
USAF	aircraft	wall fire	cargo bay	plastics	≈ 5 m	F (→H)	Y
USAF	ground	pool/wall fires	rooms	paper, plastics, chemicals	< 5 m	F	Y
USAF	engine test	spray/pool fires?	room	JP-4 & JP-8	< 1 m	F	Y
Navy	ship	spray/pool fires	machinery space	diesel fuel lube oil	< 1 m?	F	Y
Navy	aircraft	fuel spray	engine	JP-4,5,8	seconds	F	Y
Navy	aircraft	fuel spray	crew compartment	JP-4,5,8, hydrolic	<30s	H	Y
Navy	aircraft	electrical	crew compartment	insulation/plastics	<30s	H	Y
Navy	aircraft	turbine jet fire	engine nacelle	JP-4,5,8	10-20s	F	N
Navy	aircraft	rapid growth	dry bay	JP-4,5,8	app.50ms	F	N

Hazards include re-flash, over pressure, post-fire corrosion, and loss of visibility & toxic atmosphere (manned compartments)

Table A-1: Tabulation of Fire Types (July 11, 1994)

APPENDIX B: RESEARCH ELEMENTS

1. Risk Assessment and Selection Criteria

1.a. Development of Model Fires from DoD Fire Data (24 months; begin in FY 1997)

Objective:	Characterization of the nature, frequency, consequences (including personnel injuries), and severity of fires previously and currently attacked using halon 1301; tabulation of failures in deployment and/or suppression; extension of this description to include weapons systems in the pipeline (and new hazards due to advanced component materials) for which halon 1301 is intended; identification of the nature of halon 1301 system in each weapon system, the limitations presented for retrofit with a new fire suppression technology, and limits of acceptable damage and threats to people; use of these analyses to construct a small set of representative (model) fires and a retrofit qualification template for other elements in the Program.
Rationale:	Development of appropriate new technologies requires knowledge of the fires of concern and the characteristics and limitations of the systems they will replace or into which they will be fit. No in-depth survey of real-life fuel flows and conditions has been done, including the effects of pressure drop during release, although for fires involving disgorging liquid fuels, the fuel type, flow type and rate, and droplet size can have a dramatic effect on fire intensity and suppression results.
Approach:	A preliminary survey was conducted as a basis for formulating this plan. A more detailed survey of data bases and the weapons systems operators will produce more definitive information about the fire types and fuel flows in already-deployed systems. Experts on systems in the pipeline will be interviewed to identify similarities or significant differences. The results will be analyzed and reduced to a minimal number of model fires to focus the research tasks. As needed, lab- and full-scale tests will determine the effect of fuel flow on suppressant needs. The descriptions of the environments of the current systems will serve as boundary conditions for the new technologies to be developed in subsequent Elements.
Products:	Report (a) describing the halon 1301 systems, including limitations for alternative technologies, (b) tabulating characteristics of fires to be defended against, (c) the fuel flow characteristics during such fires and their impact on suppressant requirements, and (d) describing a small number of model fires.

1.b. Ullage Inerting In-Flight Data Collection (24 months; begin in FY 1998)

Objective:	Obtain accurate data on in-flight ullage conditions on which to base a valid fire protection strategy.
Rationale:	Fuel tank protection schemes have been designed and fielded without verification of the hypothesized ullage conditions in flight. The fuel tank environment may never reach the worst-case, stoichiometric conditions. Prior programs to install measurement devices on-board aircraft to measure in-flight conditions have failed to accomplish the task. New or modified current devices are needed to measure accurately and remotely, endure the flight environment, and potentially be used by pilots to control when inertant is released. **NOTE**: there may be additional fire scenarios needing this type of analysis.
Approach:	Current measurement technologies (including the new equivalence ratio meter) and their accuracy will be assessed. Ground tests will be performed to assure capability, and afterward ruggedization and packaging for the aircraft environment will be completed. Arrange with services for test bed aircraft and install measurement equipment. Collect data through a range of flight scenarios.
Products:	Assessment of proper fuel/air conditions needing protection based on accurate ullage fuel concentration data and other conditions in flight throughout the flight envelope.

1.c. Relative Benefit Assessment of Fire Protection System Changes (Begin in FY 1998, continuing)

Objective:	Develop means to evaluate the relative desirability of potentially effective changes to fire protection systems and changes in fire suppression procedures that would enhance the efficiency of the suppression process.
Rationale:	There are potentially high and variable costs associated with the differing changes from the features of the conventional halon 1301 fire extinguishing system. Quantification of modification costs and identification of decision-affecting considerations (*e.g.*, materials compatibility, weight, volume, toxicity, environmental impact) increases the odds of identifying a satisfactory solution. Initial studies may also show where the most payoff in technology research may be found early. Traditional fire response protocols for halon 1301 use will be revisited as new suppression technologies are considered.
Approach:	A panel of specialists in and manufacturers of weapon systems logistics will be convened to determine ultimate life cycle costs, assess the impacts of modifying different parameters of suppression systems, and analyze the fire incidence reports (Element 1.a) to determine positive and negative features of the current response procedures. The last includes evaluation of time from fire initiation to fire detection, and extinguishant release, discharge and transport times. Techniques such as influence diagrams will be used to integrate the compiled knowledge. Recommendations for areas for best exploitation will be prepared. Alternative technologies will be appraised as they are proposed.
Products:	Methodology for assessing the ultimate impact each change in suppression system parameters have upon the effectiveness and cost of the entire weapons system; recommended changes in fire suppression protocols.

2. Fire Suppression Principles

2.a. Mechanisms of Ultra-High Efficiency Chemical Suppressants (60 months; begin in FY 1997)

Objective:	Determine how chemicals that are as or more efficient than halon 1301 quench flames characteristic of those identified in Thrust 1. This entails differentiating between chemical and physical effects, heterogeneous and homogeneous chemistry, etc.
Rationale:	Understanding how the flame propagation processes can best be stopped will lead to identifying chemicals with the appropriate properties.
Approach:	Quantify flame quenching properties of a range of identified "superagents" for various fuels, laboratory burners (laminar and turbulent), and flame strain rates. For a few select representative chemicals, measure flame temperatures, and species concentration profiles (including flame-suppression-effective by-products of the suppressant) as the flames undergo extinction. Determine the rates of those key reactions not yet published. Construct a computer model of the chemical extinction process. Determine how these effective chemicals work.
Products:	Identification of the most vulnerable steps in flame propagation chemistry; key properties of fluid, aerosol, or particulate chemicals that have high impact on those steps; flame chemistry model for appraising further candidate chemicals.

2.b. Suppression Dynamics of Fine Droplets and Particles (60 months; begin in FY 1997)

Objective:	Obtain the data and understanding required to engineer improved heterogeneous agent dispersion systems with enhanced fire-extinction capability.
Rationale:	Knowledge of how small droplets and particles (1-100 µm) interact with burning surfaces at different temperatures and with flames is needed for identifying, evaluating, and optimizing suppression systems employing droplets or particles.
Approach:	Conduct experiments to determine whether small droplets or particles (the latter dependent on the outcome of Element 1.a) reach the surface of burning fuels. If so, develop a predictive model for the impact and spread of small droplets on surfaces. This would be tested using data from single droplet impact experiments as well as experiments to examine the impingement of a mist on a burning surface. Develop information on the transport and degradation of small particles and droplets in flames.
Products:	A validated model of the dominant suppression process(es) of small particles and aerosols. Within the flame, this includes physical and chemical effects; at the burning surface, impact and spread of small droplets as a function of aerosol/particle size and velocity and surface characteristics and correlations for the heat transfer rate.

2.c. Stabilization of Flames (24 months; begin in FY 1997)

Objective:	Understanding of the extent to which flame stabilization can impact the observed effect of a suppressant.
Rationale:	In complex geometries, the stability of the flame may be a dominant factor affecting fire suppression. The flame stabilizes either on a bluff body, in a recirculation zone or where steady-state conditions are reached in space that can support stable combustion. Thus, the capability to extinguish the fire may rest substantially upon decoupling the fire physically or otherwise from its stabilized position and preventing its reattachment. Were flame stabilization better understood, better techniques for ultimately extinguishing the fire, including non-traditional means, may be discovered.
Approach:	Building on current knowledge, appropriate lab-scale burners will be modified to include flame-stabilizing geometries. Further testing may be performed at real scale with instrumentation to characterize the airflow/flame conditions (Element 3.c). Bench-scale simulators may be necessary to understand fundamentals of the interaction. This includes turbulent spray burners and basic research apparatus for bluff body studies. Techniques based upon these studies can be demonstrated at real scale.
Products:	Reports documenting understanding of the effects of flame stability, instability and bluff body effects on fires, and techniques to utilize the behavior to extinguish fires more effectively.

2.d. Explosion Inhibition Processes (48 months; begin in FY 1998)

Objective:	Develop basis for "designing" explosion inhibitors.
Rationale:	Explosions are the most sudden (and often most critical) threats quenched by halon 1301. The criteria for stopping high-speed flames are different from those for buoyant flames.
Approach:	Review existing models of explosion propagation and inhibition, select the most appropriate, and develop for current purposes. Select appropriate laboratory combustor(s) and measure shock velocities, pressure ratios and combustion wave speeds in inhibited fuel air mixtures. Develop relative performance measures for different suppression approaches, including aerosols and powders. Use data to verify and improve model. Variants of this type of work are underway at a number of research institutions and can be leveraged.
Products:	Verified model of extinction of deflagrations; performance metrics for explosion 0quenchers.

3. Technology Testing Methodologies

3.a. Suppression System Effectiveness Screening (42 months; begin in FY 1997)

Objective:	Select, adapt, or develop test methods to obtain inexpensive fire suppression efficiency information on a diversity of suppression technologies.
Rationale: Approach:	It is expected that numerous approaches to fire suppression will emerge, involving multiple chemicals and other features. The means are needed to obtain accurate relative performance data (a) among variations on each approach and (b) among approaches. In addition, reignition of fuels and hydraulic fluids at temperatures that can occur on the surfaces of engines has been shown to be a dominant event in dictating the quantities of agent required for suppression. Conduct workshop to identify the best current suppression effectiveness screens for each agent class and fire type (Element 1.a). Several laboratories have developed laboratory scale methods for some types of agents and some fire types and some hot surface conditions. Each of the chosen methods should be identified as appropriate as is, needing significant adaptation for continued use, or needing replacement during this program. Those in the latter two categories would be pursued further. Conduct a round-robin of methods as needed to enable multi-lab use of methods.
Products:	Techniques for estimating suppression technology performance; apparatus documentation for replication by other laboratories.

3.b. Agent Compatibility With People, Materials and the Environment (24 months; begin in FY 1998)

Objective:	Select, adapt, or develop test methods to obtain data on the toxicity, environmental impact, and materials compatibility of new suppressants and their principal degradation products during the fire extinguishment process.
Rationale:	As new, effective agents are identified, acceptable methods are needed to determine other key indicators of their acceptability
Approach:	Conduct a workshop with experts in these areas of testing, leading to selection of the best current means for obtaining each type of data. There are three basic types of fire suppression agents likely to be proposed: volatile agents, particulates, and mists, contingent on the outcome of Element 1.a. For particulates and mists, the agent might consist of both a volatile and non-volatile component. The methods should be useful for each of these types. As appropriate, the methods should be applied to the agent's byproducts formed during suppression as well. For the toxicity of chemicals that may be used in occupied spaces, follow EPA approval format as a minimal testing strategy, and obtain consensus on tests for new forms of suppressants. As needed, develop appropriate toxicology technology to obtain toxicology-driven agent release concentrations appropriate to the hazard of fire situations. For environmental effects, non-volatile components should create only cleanup problems. [ii] For volatile components, data is needed to determine the atmospheric lifetimes of the compound itself and its volatile reaction products. This requires the measurement or estimation of: reaction rate constants, primarily with OH; photolysis cross sections; infra-reed cross sections; Henry's Law constants and hydrolysis rates. It is also necessary to review the capability of the 2-D atmospheric models used to determine the lifetime and accumulation of material in the atmosphere, the ODP and GWP, as well as the 3-D models needed to evaluate species with lifetimes less than a few months. Note that if the compound contains atoms other than C,H,O,N, or halogens, chemical kinetic additions to the models may be needed. [iii] For compatibility with storage container materials, data would be obtained for each weapons system to determine the thermal exposure for the stored suppression system, as well as any other external forces that might affect the agent's endurance. NIST has developed a set of tests for assessing potential degradation of metals and elastomers in the presence of a fluid suppressant and degradation of the fluid itself. Protocols are needed for similar testing of solid suppressants (*e.g.*, powders), both dry and moist. Reactive chemicals need to be assessed for their own integrity. The thermal degradation methods should be useful for determining the stability of agents that impact on hot surfaces during fire suppression as well. [iv] The impact of the agent and it's combustion by-products on downstream weapons system materials needs to be determined under appropriate thermal and moisture conditions. Each of the methods should be identified as appropriate as is, needing significant adaptation for continued use, or needing replacement during this program. Those in the latter two categories would be pursued further.
Products:	Methods for obtaining performance measures of the key properties of new agents.

3.c. Instrumentation for Gaseous Fuels, Oxygen, and Suppressant Concentration Measurements During Suppression of Flames and Explosions (72 months, begin in FY 1998)

Objective:	Develop measurement methods needed for characterization of suppression performance and for determining combustion conditions in laboratory-scale apparatus; instrument the existing full-scale fire suppression testing facilities, as needed, making them research-capable and usable for certification.
Rationale:	Data on, *e.g.*, the concentrations of the principal species, mixing behavior, and velocities are essential to understanding why one alternative behaves differently than another and to validating hypotheses of the reasons for good/poor flame suppression performance. There are limited techniques available for making the measurements on the fast time scale needed for many of the key fire types. While data on other flame species and agent breakdown products (which may be the active suppressant) would be valuable, a program of this size does not justify the additional expense. Additional instrumentation will be needed in order to get excellent performance measurements from large-scale facilities. Moreover, when anomalous behavior is observed in full-scale tests, there are insufficient data from which to derive explanations. Additional measurements are also needed to use these facility for experimental verification of laboratory experiments and computational models.
Approach:	Identify the key flame species and properties and key suppressants (as they are identified as promising and in conjunction with Element 1.a) to be examined, review the literature to identify optimal techniques, and adapt to this context. (Capitalize on combustion and particle/aerosol diagnostic research ongoing at a number of laboratories that can be redirected to this application.) Convene panel of experts to identify critical variables to be measured during intermediate- and full-scale tests (esp. Thrust 6). Adapt lab-scale instrumentation as appropriate, design and fabricate access, purchase and install instruments.
Products:	Instruments suitable for measuring fuel/air ratios, agent concentrations, particle size distributions, number densities, composition, velocities, and radiant flux as a function of time and space in laboratory and, as needed, full-scale suppression experiments.

4. New Suppression Concepts

4.a. Powder-Matrix Systems (84 months; begin in FY 1998)

Objective:	Investigate the concept of an agent dissolved in an inert polymeric or inorganic matrix with the specific property that it will be released rapidly at a temperature near or below the ignition point of the combustible mixture.
Rationale:	Many possible fire suppressants cannot be used due to their atmospheric consequences or toxic properties. Further, in any fire situation, much more of the suppressant is used than needed to put out a fire. This approach would only release the amount of chemical needed to quench the fire and then only in the immediate vicinity of the flames. This Element would not be funded if the results of Element 1.a discourage the use of agents that leave residues.
Approach:	Survey current capabilities. Identify potential substrates and determine how much agent a given particle can hold using experiences from gas chromatography matrixes. Develop surface treatments that would increase holding capacity and increase the release temperature. Evaluate the potential for using polymer substrates, including building the suppressant into the polymer itself. Determine how rapidly the agent can be released through heat and mass transfer calculations with experimental verification. Work with EPA to ensure consideration of environmental concerns. Test chemicals for effectiveness and compatibility using methods described under Thrust 3.
Products:	New approach, with specific chemicals, for suppressing fires where cleanliness is not essential.

4.b. Evaluation of Highly Effective Chemical Suppressants (72 months; begin in FY 1998)

Objective:	Identify and evaluate the full range of chemically active suppressants that are as or more effective than CF_3Br and sufficiently low in toxicity and environmental impact.
Rationale:	Exploratory studies have shown that several families of compounds are at least as efficient as halon 1301 as flame inhibitors and have zero ozone depletion potential (ODP), *e.g.*, organometallics and phosphonitrilics. Although some are too toxic, others are potentially non-toxic and may have desirable chemical and physical properties.
Approach:	Using the principles emerging from Element 2.a, new ideas arising from Element 4.e, the findings from Element 1.a, and the fundamental chemistries of these families, develop a list of candidates with high flame suppression efficiency and low toxicity. Synthesize new chemicals as necessary. Perform extinguishment and flame structure experiments on strained diffusion flames to verify or adapt principles. Perform post-flame analyses to identify potential by-products. Run screening tests from Elements 3.a and 3.b for suppression effectiveness, toxic potency, environmental impact, and residue to estimate acceptability.
Products:	A list of promising compounds with pertinent information on their physical and chemical properties, suppression efficiency, toxicity, storage stability, and breakdown products and their properties and toxicities.

4.c. Super-Effective Thermal Suppressants (60 months; begin in FY 1997)

Objective:	Determine whether there are practical physical suppressants of efficiency comparable to halon 1301.
Rationale:	There may be materials that have very high heats of phase transition and undergo these transitions at temperatures and over time scales such that they can effectively extract heat from fires leading to suppression. Such materials may be pure materials, *e.g.*, silicates, or dissolved aqueous solids, *e.g.*, salt solutions, which evaporate to leave small salt crystals. Such materials have the potential for equaling the effectiveness of halon 1301 with zero ODP.
Approach:	Survey the chemical literature and perform thermochemical calculations to identify potential candidates that also met the requirements identified under Element 1.a. Examine such chemicals in diffusion flames to verify concepts and suggest further candidates. Conduct appropriate testing from Thrust 3 on best performing candidates.`
Products:	Set of high efficiency fire extinguishing agents.

4.d. New and More Effective Fire-Suppression Technologies that are Presently Conceptual (48 months; begin in FY 1997)

Objective:	Introduce new and innovative approaches to fire suppression at the onset of the next-generation halon replacement program.
Rationale:	There are additional and diverse new ideas that merit screening. Subject to the boundaries set under Element 1.a, the best of these should be examined to see if further research is needed to develop their full potential for the Program.
Approach:	Conduct one or more RFPs for novel ideas. Provide up to 1-year support for worthy proposals (to include proof-of-concept demonstration), refer the successful results to the testing facilities, and continue support for those with promise. Convene a workshop on flame suppression to stimulate additional thinking.
Products:	New classes of high efficiency fire extinguishing agents and technologies.

5. Emerging Technology Advancement

5.a. Liquid Mist Systems (72 months; begin in FY 1998)

Objective:	Improve small droplet suppression systems.
Rationale:	Some systematic testing of water mist systems has demonstrated their potential. Other fluids or additives should be considered as well, including blends of high and low volatility components. Issues remain regarding the speed of deployment, dispersal around clutter, and sound level in occupied spaces.
Approach:	Identify possible candidates in conjunction with Elements 1.a and 2.b. Perform bench-scale suppression experiments to screen candidates. For mixtures, examine the influence of fluid composition, droplet velocity, and droplet size on the droplet evaporation rate and the delay time for the droplet to burst and release the trapped volatiles within. Consider using propellant-generated gases as a dispersing mechanism. Conduct real-scale tests to identify additional factors affecting effectiveness. If effectiveness is comparable to halon 1301, then perform other tests developed in Thrust 3 and then proceed to mid-scale tests for optimizing storage and dispersion conditions, deployment speed and distribution around clutter. Determine whether this approach is fruitful for preventing ammunition fires. There are a number of research and testing efforts underway that will benefit this effort.
Products:	Enhancements for mist suppression technology; new high efficiency fire extinguishing agents.

5.b. Advanced Flame Arresting Foams for Fuel Tank Inerting (30 months; begin in FY 2002)

Objective:	Develop advanced foams that are lighter, retain little to no fuel, do not degrade or statically discharge, and offer acceptable explosion suppression at weight and volume levels equivalent to current halon 1301 fuel protection systems.
Rationale:	Foams were adapted from auto racing for aircraft during the Southeast Asia conflict, when many aircraft were lost due to fuel tank explosions. Although very successful, a loss in range due to fuel retention was observed, and foam degradation and static discharges were also problems that were moderately addressed in modest research programs in the 70s and 80s. The substantial penalties that persisted led to aircraft such as the F-16 opting for halon 1301 inerting systems over foam due to lower life-cycle penalties. Dry-bay foam has also been used successfully in limited aircraft such as the A-10 in Desert Storm.
Approach:	Delineate the improvements needed to equal the safety afforded by halon 1301. These may include density, heat capacity, pore size and structure, and surface tension. Request samples of complying materials. Stimulate foam manufacturers to develop improved versions. Perform live fire tests, sustained fuel exposure tests and static discharge tests. Work with the F-16 Program Office's 4-5 year effort to find a replacement for its halon inerting system.
Products:	New foam technology.

5.c. Active Suppression for Fuel Tank Explosions (24 months; begin in FY 2002)

Objective:	Determine the viability of previously-developed alternative systems, such as the LFE (Linear Fire Extinguisher), PRESS (Parker Reactive Explosion Suppression System), Walter Kidde Canister System, NIBB (Nitrogen Inflated Ballistic Bladder).
Rationale:	Several alternative systems were developed by the Navy and Air Force in the 1980s and showed potential in full-scale tests. Implementation of these systems was aborted due to nagging operational questions or limitations on research funding to proceed with development.
Approach:	The systems mentioned above will be reanalyzed along with recent data. If needed, additional research will be performed in association with pertinent system manufacturers, and real-scale explosion testing will take place at existing facilities. The manufacturers will, at their discretion and expense, develop the systems to withstand the aircraft fuel tank environment, minimize maintenance impact and system initial and support costs.
Products:	Improved alternative systems.

5.d. Advanced Propellant/Additive Development for Gas Generators (60 months; begin in FY 1998)

Objective:	Develop new types of chemically-generated gaseous suppressants.
Rationale:	Proposed and theorized techniques using solid propellants for gas generation to extinguish fires have been in existence for decades. [Such devices are the means for the rapid inflation of automobile air bags.] Preliminary results from Navy-sponsored research, development and testing and Air Force-sponsored research are very promising, with system weight in some cases approximating halon 1301 systems. Gas generator extinguishers primarily suppress a fire by the high concentration of inert gas enhanced by the high specific volume achieved by the very hot gas. Navy and Air Force tests indicate that the extinguisher is also blowing out the fire. Further, the strong gas momentum may be primarily in a linear direction, and extinguishing obstructed fires may prove difficult. In addition, it was shown that filtered systems and gas/liquid "hybrids" could in some instances prove more effective than conventional all-propellant systems. Mechanistic hypotheses remain to be checked.
Approach:	This work would begin with a literature search for alternative, less exothermic (or even endothermic) propellant chemistry and gas/liquid hybrids, identifying candidates for study, consistent with the results of Element 1.a. Samples of these would be synthesized, along with additives (which can even add solid brominated products that can be vaporized and released, then condense back to solid form after release to prevent atmospheric uptake), for evaluation in both small- and full-scale tests. Hybrid systems that employ high-boiling liquid agents, with the propellant both vaporizing and propelling the liquid, would also be evaluated. All three services have efforts underway which would synergize with this effort. To the extent that new suppressants are generated, they would be tested for toxicity and compatibility as in Thrust 3.
Products:	New solid propellant gas generators and an understanding of the fundamentals of their behavior.

5.e. Enhanced Powder Panels (36 months; begin FY 1999)

Objective:	Advance protection against penetrating shells in those applications where halon 1301 is currently used in conjunction with powder panels.
Rationale:	Powder panels provide passive, lightweight, effective fire protection against ballistic impact, which release powder into the fire zone to inert the space before the adjoining fuel spills into the space and is ignited by incendiaries. Preliminary results with simple powders were impressive. Cleanup remains a concern. Powder panels add weight based upon the surface area of the fuel wall/fire zone interface, as opposed to the volume of the fire zone, so the relative benefit of the panels are dependent upon the configuration of the particular bay. Recent testing of conventional panels showed promise for final implementation, but they are in essence the same design that has existed for decades.
Approach:	An in-depth study of the mechanisms of ballistic penetration and behavior, and the nature of dry bay fires, will first be conducted. Features necessary for successful use of powder panels will be identified, and requirements for integration into aircraft structure will also be assembled. New designs of panels and new powders will be tested in small- and full-scale facilities. Evaluations of operational suitability such as vibration, shock and temperature resistance will also be performed. Make use of the current Army program in this area.
Products:	Enhancements to current powder panel technologies.

6. Suppression Optimization

6.a. Fire Suppressant Dynamics in the Fire Compartment (48 months; begin in FY 2001)

Objective:	Develop understanding of the interaction between the suppressant flow, the fire field, and the concentration needed for extinguishment, leading to providing the technology base needed to develop physical injection systems that are uniquely relevant to advanced fire suppression methods, such as flashing injection, mist generation, and gas-generator product injection.
Rationale:	Because of the high efficiency of halon 1301 and the absence of alternatives, little has been done to optimize delivery system engineering. Furthermore, flow fields dramatically affect fires and their suppression. This is further complicated if the fire's combustion products are re-entrained into the flames, and a directional flow can prematurely sweep the agent from the fire vicinity, leading to a need for more suppressant and inviting re-ignition of residual hot fuel. Moreover, recent experiments have shown that significantly enhanced agent dispersion can result from improvements in the suppressant delivery system and that obstacles can discriminate against some types of suppressants. These considerations are especially important for less effective agents and for those fire types that must be suppressed in fractions of a second. A general-purpose technology needs to be developed.
Approach:	This project requires a combination of modeling and experimentation for each of the model fires developed under Element 1.a. Experiments will develop systematic data on the rate of delivery and degree of dispersion of the suppressant, mixing patterns, and gas phase flow fields for several important, generic and realistically obstructed fire suppressant scenario applications (Element 2.c). As needed, additional data will complement prior data on agent concentration needs for extinction as a function of the flow field, strain rates, etc. New instrumentation from Element 3.c will facilitate obtaining the key concentration and flow field information from these experiments. The results of the experimentation will be incorporated in 3-D computational fluid dynamic (CFD) calculations for a variety of fires, agent injection rates, flow patterns, and nozzle locations/design. The combustion chemistry will be simplified to reduce the computational burden. The results of the computations will be assessed using full-scale tests, which will be obtained by piggy-backing on other programs. Reanalysis of the Tri-Service/FAA Halon Replacement Program statistical data, including differentiating independent effects of variables and quantifying the magnitude of the effects under different conditions will assist in the design of the full-scale tests.
Products:	Design information on the penetration, the rate of production and the nature of the injected gas, liquid or solid suppressant. Documented computer simulations of the effect of fire-induced and external flow fields on suppressant concentration distribution and the amount of agent needed for suppression that will accelerate the currently-lengthy suppression system development process, permit the optimization of candidate designs, and incorporate quantitatively into the design process the results of the detailed studies of physical and chemical phenomena developed elsewhere in this program. Engineering design tools (either in the form of data correlations or simple mathematical models) to optimize nozzle placement. Guidance for how to test alternative suppression technologies at full scale and how to rank their relative performance.

6.b. Suppressant Flow Through Piping (24 months; begin in FY 1998)

Objective:	Develop and validate calculation methods for flow in pipes of single-and 2-phase fluids with widely varying physical properties and flow conditions.
Rationale:	New generation fire suppression agents have different physical properties from water and halon 1301. The equations in commercially developed "black box" calculation programs based on halon 1301 may not be suitable for fluids with different densities, boiling points, viscosities, critical behavior and transitions, and other properties. Equations used to calculate friction losses in piping flowing water may include simplifying assumptions about the "normal" ranges of temperature and pressures encountered in piping systems. New water-mist systems may operate in regions of high flow rate, higher turbulence and smaller diameter piping than previously considered. There is, therefore, a need to re-visit flow modeling to ensure inclusion of all properties. The solution codes should be non-proprietary, and made available to all researchers and engineers.
Approach:	Survey and evaluate existing public and proprietary codes to identify the optimal starting point. Modify as needed to include friction losses, discharge pressures and flow rates in piping, including terms for all physical fluid mechanical properties. [Consider gaseous suppression agents, liquids, and dry powder distribution piping, as determined by Element 1.a.] Determine the set of agent properties needed for the model(s) so that unknown values can be estimated or measured. Conduct laboratory tests to validate the computer solutions to the equations for gaseous agents involving 2-phase flow and for water under a wide range of temperatures and pressures. Produce a model usable by project engineers.
Products:	Validated computer code for calculating single- and two-phase flow in pipes, for fluids of diverse physical properties. Laboratory data on flow rates, pressure losses, discharge pressures of agent flow in pipes, empirical friction coefficients, Reynolds numbers, etc., for water and other suppression system fluids in pipes, under the needed range of pressures and flow velocities.

6.c. Mechanism of Unwanted Accelerated Burning (36 months; begin in FY 1999)

Objective:	Characterization of the mechanisms responsible for the enhanced burning which is sometimes observed when fire extinguishing agents are first applied to flames.
Rationale:	Application of some agents to flames is observed to accelerate burning momentarily or to enhance combustion at low concentrations under certain conditions, but to retard it at higher concentrations.
Approach:	Compile results of laboratory studies and practical observations, leading to guidance on the conditions under which accelerated burning occurs for agents likely to meet the performance criteria under Element 1.a. Adapt appropriate laboratory burners to determine if the source of acceleration is physical (*e.g.*, enhancing fire air entrainment or fuel vaporization) or chemical. Pursue intermediate-scale testing as appropriate to verify phenomena and determine scaling effects. Perform kinetic evaluation of accelerated systems as needed. If warranted, a modeling element would be added or element 6.a would be enhanced.
Products:	Tabulation of test conditions to be replicated (if accelerated burning is a concern for that type of fire) and real-scale conditions to be avoided.

6.d. Development and Evaluation of Automatically Actuating Pre-Dispersed Agent Storage Containers (48 months; begin in FY 2001)

Objective:	Develop new technology for minimizing the quantity of agent needed, while enhancing the delivery efficiency.
Rationale:	It would be advantageous to locate agent storage containers in the immediate vicinity of the equipment they are protecting. These would actuate automatically in response to a fire and discharge agent over a limited area encompassing the protected equipment and personnel. Ideally the container would be flexible so as to allow it to be draped over or around critical equipment perhaps as an outer layer or blanket. Fire exposure or other release signals could actuate a fusible plug or raise the vapor pressure so that a relief device would actuate to discharge the agent. The advantages of this type of system are that it would eliminate costs for piping (design, installation and inspection as well as material costs), and would reduce the required amount of agent since only part of the enclosure volume would have to be protected.
Approach:	Determine from Element 1.a for which, if any, applications this technology is applicable. Build on existing materials and thermodynamic data to build a prototype. Test in reduced-scale compartments. Coordinate with Elements 5.d, 5.e, and 6.a. Partner with commercial firms for further development.
Products:	Usage, design and performance criteria for new technology. Prototype device(s).

6.e. Full-Scale Optimization of Advanced Fire Suppression Technologies (60 months; begin in FY 2000)

Objectives:	Obtain full-scale verification of the factors affecting suppression performance; demonstrate the effectiveness of selected new fire suppression technologies.
Rationale:	Full-scale testing is needed to examine the optimization variables, to verify the predictions from the models of fire suppression performance, and to know which factors need further research emphasis. Such testing is also needed to verify the efficacy of new technologies developed under this program.
Approach:	The services have each generated quantities of performance data, mostly on halocarbon fluid suppressants. These data will have to suffice in the near term as the bases for evaluating laboratory-scale apparatus and computational models. Upon completion of any upgrades from Element 3.c, panels of experts will recommend initial technologies and models to be examined. Final performance testing would include fire suppression effectiveness and speed, residue effects, and an evaluation of impact on personnel egress.
Products:	Verification of the effectiveness of new fire suppression technologies and the implementation factors that affect suppression efficiency.

APPENDIX C: SERDP AND NGP ANNUAL DEVELOPMENT SCHEDULES

I. ANNUAL SERDP PROGRAM AND NGP PLAN DEVELOPMENT SCHEDULES

The annual SERDP Program development schedule is illustrated at Attachment 1 for FY 1997. The annual NGP Plan development schedule is shown at Attachment 2. The sequence of events in the NGP Plan development schedule is keyed to the sequence of events in the SERDP Program development schedule. Development of the (CFY+1) NGP Plan and the (CFY+2) NGP Portfolio commence in July. After the SERDP Council approves the (CFY+1) SERDP-funded NGP New Start Projects in September, the (CFY+1) NGP Plan is approved by the HASG Chairman in October, and published in October/November.

FY97 SERDP PROGRAM DEVELOPMENT SCHEDULE

Council approved FY96 Program and FY97 Strategic Guidance

Ex Dir releases FY96 funds to performers

SAB reviews appropriate ongoing projects and new starts

TTAWGs submit draft FY97 Program with statements of need for proposed new starts to Ex Dir

Ex Dir submits draft FY97 Program with statements of need for proposed new starts to EWG

EWG meets to approve draft FY97 Program with proposed new starts

29 AUG 1995 — 24-26 OCT — 20 NOV — 30 NOV — 11 DEC — 3 JAN 1996 — 6-7 FEB

Ex Dir solicits proposals for new starts. Proposals due to Ex Dir NLT 30 March

SAB reviews approporate ongoing projects

FY95 SAB Report and FY Annual Report/5-Yr SIP to Congress

FY97 new start proposals due to Ex Dir from EWG members

Ex Dir and TTAWGs hold annual IPRs including oral presentations of top ranking proposals

TTAWGs submit final proposal evaluation results to Ex Dir

TTAWGs submit final recommended FY97 Program and FY98 Strategic Guidance to Ex Dir

16 MAR — 30 MAR — 1 APR - 31 MAY — 30 JUN — 9-11 JUL — 17 JUL — 8-10 AUG

SAB reviews appropriate ongoing projects and proposed new starts

Ex.Dir. submits final recommended FY97 SERDP Plan and FY98 Strategic

SAB reviews remaining projects

EWG meets to approve final recommended FY97 SERDP Plan

Council meets to approve FY97 Program and FY98 Strategic Guidance

Release FY97 funds to performers

Hold Annual SERDP Symposium

Dates are approximate

ATTACHMENT 1

APPENDIX D: NGP EXECUTION PROCESS

I. NGP EXECUTION PROCESS

The NGP execution process is comprised of 10 sub processes conducted annually within each fiscal year cycle. These sub processes consist of tasks and decisions required to formulate and approve statements-of-need, solicit proposals, evaluate and rank proposals, approve and fund proposals as new-start government projects, and to contract with industry and academia as necessary. The 10 sub processes are described in the following sections, beginning with a definition of terms used in the execution process.

A. Definition of Terms

The following definitions are provided for clarity in discussing the NGP execution sub processes.

- **NGP Research Element** is a body of scientific or technical investigations conducted in support of a Technical Thrust. It contains an objective, rationale, approach, and a description of the output products.

- **NGP Research Element Statement-of-Need** is a summary statement of the specific nature and scope of a particular research project based on a Research Element. It is the vehicle for soliciting project proposals for a given Research Element.

- **(CFY+1) NGP Portfolio** is the compilation of all the NGP Research Element Statements-of-Need to be addressed in the fiscal year following the current fiscal year (CFY+1). The Statements-of-Need are allocated to two categories: Designated Project Statements-of-Need and Industry/Academia Project Statements-of-Need.

- **NGP Project** is any research project supporting the objective of an NGP Research Element.

- **NGP Designated Project** is a research project conducted by a Military Department or another federal government organization (*i.e.*, NIST, DOE) a research project conducted by a private sector industrial firm or a college/university under a contract with a Military Department or other federal government organization, which supports the technical objective(s) of an NGP Research Element.

- **NGP Industry/Academia Project** is a research project conducted by a private sector industrial firm or a college/university, and supporting the objective of an NGP Research Element.

- **NGP Foreign Project** is a collaborative research project conducted and funded by a foreign government organization, and supporting the objective of an NGP Research Element.

- **NGP Project Proposal** is a proposal submitted in response to an NGP Statement-of-Need or Broad Agency Announcement (BAA).

- **(CFY+1) NGP New-Start Project** is an NGP Project to be initiated in the fiscal year following the current fiscal year.

- **(CFY+1) SERDP NGP New-Start Project** is an NGP Project to be initiated in the fiscal year following the current fiscal year, and funded in part or in full by SERDP.

- **NGP White Paper** is a document addressing an NGP Industry/Academia Research Element Statement-of-Need. It is used, as desired, by the Military Departments, DOD agencies, or other federal government agencies to request that an NGP Industry/Academia Research Element Statement-of-Need be changed to an NGP Designated Research Element Statement-of-Need, and provides the appropriate justification. A White Paper includes a description of the unique government organizational capabilities (personnel and facilities) and resources (manpower and funding) that would justify sole-source performance by a government organization. White Papers are limited to three pages in length and must be submitted to the TPM five working days prior to presentation of the draft Portfolio to the HASG.

- **NGP Plan** is a document consisting of all ongoing, new-start, planned, and completed NGP Projects, and all Research Elements not yet solicited for NGP Project Proposals. It is developed by the TPM, through the TCC, coordinated with the HASG, and approved by the HASG Chairman. The Plan structure is based on the six Technical Thrusts. Each Thrust includes all NGP Projects pertaining to its respective Research Elements. The NGP Plan is updated, revised, and published annually, incorporating the approved (CFY +1) NGP New-Start Projects.

B. Sub Processes

The program execution process consists of 10 sub processes as described in the following paragraphs.

1. **Development of the (CFY+1) NGP Portfolio.** This sub process is accomplished by the TPM, through the TCC, and includes the following tasks:

    a. determining the Research Elements to be addressed in CFY+1;

b. developing the estimated funding needs of the (CFY+1) Research Elements;

c. drafting and coordinating the corresponding (CFY+1) Research Element Statements-of-Need;

d. allocating the (CFY+1) Research Element Statements-of-Need into two categories: NGP Designated Project Statements-of-Need and NGP Industry/Academia Project Statements-of-Need. (The allocation of Statements-of-Need into these two categories will adhere to the SERDP principle of competition in the award of all projects, as feasible);

e. integrating and prioritizing the (CFY+1) Research Elements and corresponding (CFY+1) Statements-of-Need into a draft (CFY+1) NGP Portfolio;

f. distributing the draft (CFY+1) NGP Portfolio to the Military Departments and other federal government organizations for coordination;

g. reviewing and resolving White Papers submitted by federal government organizations; and

h. incorporating White Paper decisions into the draft (CFY+1) NGP Portfolio, as appropriate.

2. **HASG Coordination and Approval of the (CFY+1) NGP Portfolio.** This sub process includes the following tasks:

a. briefing the draft (CFY+1) NGP Portfolio and White Papers to the HASG by the TPM;

b. coordinating the draft (CFY+1) NGP Portfolio within the HASG by the TPM;

c. approving the (CFY+1) NGP Portfolio by the HASG Chairman; and

d. forwarding the (CFY+1) NGP Portfolio to the SERDP Executive Director by the HASG Chairman.

3. **SERDP Review of the (CFY+1) NGP Portfolio.** The SERDP Executive Director will review the (CFY+1) NGP Portfolio and determine the

appropriateness of SERDP funding for each proposed (CFY+1) Research Element and corresponding Statement-of-Need. The review sub process includes the following tasks:

a. reviewing all (CFY+1) NGP Research Elements and corresponding (CFY+1) Statements-of-Need by the PP/TTAWG and PP PM, in coordination with the TPM;

b. identifying the (CFY+1) NGP Research Element Statements-of-Need to be considered for the (CFY+1) SERDP Program by the PP/TTAWG and PP PM, in coordination with the TPM;

c. compiling and rank ordering all Pollution Prevention Pillar Statements-of-Need recommended for the (CFY+1) SERDP Program and forwarding to the Executive Director by the PP/TTWAG Co-Chairs, in coordination with the TPM; and

d. forwarding the Pollution Prevention Pillar Statements-of-Need recommended for the (CFY+1) SERDP Program to the EWG by the SERDP Executive Director.

4. **Solicitation of (CFY+1) NGP Project Proposals.** The sub process for soliciting proposals addressing the (CFY+1) NGP Designated Project Statements-of-Need and NGP Industry/Academia Project Statements-of-Need includes the following tasks:

a. forwarding all NGP Industry/Academia Project Statements-of-Need to the CA by the SERDP Executive Director, through the TPM;

b. issuing a call for proposals, through the EWG, to the Military Departments and other federal government agencies for (CFY+1) NGP Designated Project Statements-of-Need to be funded in part or entirely by SERDP, by the SERDP Executive Director;

c. issuing a call for proposals by the TPM, through the HASG Secretariat, to the Military Departments and other federal government agencies for (CFY+1) NGP Designated Project Statements-of-Need not funded by SERDP;

d. publishing a call for proposals or a BAA in the Commerce Business Daily addressing (CFY+1) NGP Industry/Academia Project Statements-of-Need by the CA;

e. receiving all (CFY+1) NGP Designated Project proposals seeking SERDP funding (in part or in full) by the SERDP Office;

f. receiving all (CFY+1) NGP Industry/Academia Project proposals by the CA; and

g. receiving all (CFY+1) NGP Designated Project proposals not seeking SERDP funding by the TPM.

5. **Evaluation and Selection of Acceptable (CFY+1) NGP Industry/Academia Project Proposals.** The TPM will create and chair a Source Selection Evaluation Panel (SSEP) composed of at least 3 evaluators, normally members of the TCC, the SERDP PP/TTAWG, and/or other selected reviewers, as designated by the SSEP Chairman. The SSEP is responsible for evaluating, ranking, and recommending acceptable (CFY+1) NGP Industry/ Academia Project proposals. The TPM will present the recommended proposals to the HASG for coordination. These proposals will be then be forwarded to the SERDP Executive Director by the HASG Chairman. The PP/TTWAG and the SSEP will select a subset of the acceptable proposals for award which will construct a balanced program, meeting the needs of the NGP. These proposals will then be reviewed by the SERDP Scientific Advisory Board as proposed SERDP new-starts. NGP Industry/Academia Project proposals which are subsequently approved as (CFY+1) SERDP NGP New-Start Projects will be integrated into the NGP program of a Military Department or other participating federal government organization during the contractual process. This will be accomplished by the designation of a Contracting Officer's Technical Representative (COTR) from the respective Military Department or government organization, coordinated by the TPM through the TCC and the PP PM. The NGP Industry/Academia Project proposal evaluation and selection sub process includes the following tasks and decisions:

a. forwarding all (CFY+1) NGP Industry/Academia Project proposals to the TPM by the CA;

b. creation of a SSEP by the TPM;

c. coordinating the distribution of all (CFY+1) NGP Industry/Academia proposals to the SSEP by the TPM;

d. evaluating and ranking all proposals and recommending acceptable proposals on the basis of responsiveness, demonstrated capabilities, quality, cost, and collaborative funding, by the SSEP;

e. briefing the recommended (CFY+1) NGP Industry/Academia proposals as proposed (CFY+1) NGP New-Start Projects to the HASG by the TPM, and showing their linkage to an NGP Designated Project;

f. coordinating the recommended proposals as proposed (CFY+1) NGP New-Start Projects with the HASG by the TPM; and

g. forwarding the recommended (CFY+1) NGP Industry/Academia proposals as proposed (CFY+1) NGP New-Start Projects to the SERDP Executive Director by the HASG Chairman.

6. **Evaluation and Selection of Acceptable (CFY+1) NGP Designated Project Proposals.** The sub process for evaluating (CFY+1) NGP Designated Project proposals received and selecting acceptable proposals includes the following tasks and decisions:

a. forwarding all (CFY+1) NGP Designated Project proposals seeking SERDP funding to the PP/TTAWG and TPM by the SERDP Executive Director;

b. evaluating all (CFY+1) NGP Designated Project proposals seeking SERDP funding by the PP/TTAWG and the TCC, as coordinated by the TPM and the PP PM;

c. evaluating all (CFY+1) NGP Designated Project proposals not seeking SERDP funding by the TCC, as coordinated by the TPM;

d. recommending acceptable SERDP-funded (CFY+1) NGP Designated Project proposals on the basis of responsiveness, demonstrated capabilities, quality, cost, and funding contribution (or collaborative funding) by the TCC, as coordinated by the TPM;

e. recommending acceptable non-SERDP-funded (CFY+1) NGP Designated Project proposals on the basis of responsiveness, demonstrated capabilities, quality, cost, and funding contribution (or collaborative funding) by the TCC, as coordinated by the TPM; and

f. rank ordering of acceptable (CFY+1) NGP Designated Project proposals (both SERDP-funded and non-SERDP-funded) as proposed (CFY+1) NGP Designated New-Start Projects by the TPM, through the TCC.

7. **HASG Coordination and Approval of Proposed (CFY+1) NGP Designated New-Start Projects.** The sub process for HASG coordination and approval of Proposed (CFY+1) NGP Designated New-Start Projects consists of the following tasks and decisions:

   a. briefing the proposed (CFY+1) NGP New-Start Projects to the HASG by the TPM;

   b. coordinating the proposed (CFY+1) NGP New-Start Projects within the HASG by the TPM;

   c. approving non-SERDP-funded (CFY+1) NGP New-Start Projects by the HASG Chairman; and

   d. forwarding by the HASG Chairman proposed (CFY+1) NGP New-Start Projects to the SERDP Executive Director for funding as (CFY+1) SERDP new-start projects.

   [**NOTE:** Included for information only to the SERDP Executive Director is the identification of approved non-SERDP-funded (CFY+1) NGP New-Start Projects.]

8. **SERDP Approval of (CFY+1) NGP New-Start Projects**. The (CFY+1) SERDP Program consists of (CFY+1) SERDP new starts and ongoing SERDP projects. (CFY+1) NGP New-Start Projects include NGP Designated Projects and NGP Industry/Academia Projects. The sub process for reviewing and approving proposed (CFY+1) NGP New-Start Projects as SERDP new-starts consists of the following tasks and decisions:

   a. briefing the proposed (CFY+1) SERDP NGP New-Start Projects to the PP/TTAWG by the TPM;

   b. integrating and prioritizing the proposed (CFY+1) SERDP NGP New-Start Projects into the overall SERDP Pollution Prevention Pillar list of proposed (CFY+1) SERDP new-starts by the PP/TTAWG, in coordination with the TPM and the PP PM;

c. compiling and forwarding a list of recommended (CFY+1) SERDP new-starts to the SERDP Executive Director by the PP/TTAWG Co-Chairs, in coordination with the TPM and the PP PM;

d. reviewing the recommended (CFY+1) SERDP new-starts (and all on-going projects over $900K in annual SERDP funding) by the SAB;

e. reviewing the recommended (CFY+1) SERDP Program by the EWG;

f. approving the (CFY+1) SERDP Program by the SERDP Council; and

g. notifying the HASG Chairman of all approved SERDP-funded NGP Projects [both ongoing SERDP-funded NGP Projects and (CFY+1) SERDP NGP New-Start Projects] by the SERDP Executive Director.

9. Implementation of Approved (CFY+1) NGP Designated New-Start Projects. Following the approval of (CFY+1) NGP Designated New-Start Projects, funds for all new and ongoing projects are distributed by the Resource Sponsors as follows:

a. SERDP funds are distributed directly to the performing organizations as expeditiously as possible after they have been appropriated, by the SERDP Executive Director; and

b. S &T and/or Other Government funds are distributed to the performing organizations through normal government channels.

10. Contracting of Approved (CFY+1) NGP Industry/Academia New-Start Projects. The CA will provide contracting support for NGP Industry/Academia New-Start Projects solicited by the CA in sub process 4 above. The sub processes for contracting these projects includes the following tasks:

a. transmitting the approved (CFY+1) NGP Industry/Academia New-Start Projects and authorized SERDP funds to the CA by the SERDP Executive Director;

b. designation of a COTR by the TPM; and

c. executing a contract for each funded (CFY+1) NGP Industry/Academia New-Start Project by the CA .

C. Prevention of Conflicts of Interest

In view of the fact that members of the TCC could potentially be assigned to a Source Selection Panel to evaluate NGP Designated Project proposals in which they have a direct interest, the TPM will take appropriate precautions to preclude possible conflicts of interest in the source selection process. Conflict of interest issues concerning NGP Designated Project proposals that cannot be resolved by the TPM will be referred to the HASG Chairman. The TPM will also take necessary precautions to preclude possible conflicts of interest in the evaluation and selection of NGP Industry/Academia proposals, in accordance with Source Selection Plans approved by the contracting agency contracts management office director and the Executive Director, SERDP.