CONTROL OF AIRCRAFT POST-CRASH SPILLED FUEL BURNING THROUGH VAPOR-PHASE INERTING

Bernard R. Wright
Belvoir Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510
(512)522-2585

and

Dennis M. Zallen, Ph.D., P.E.
Zallen International Associates
14216 Turner Court N.E.
Albuquerque, New Mexico 87123
(505)299-3025

BACKGROUND

A continuing hazard associated with aircraft is the fuel fire following a survivable crash. No method has been successfully developed for suppression or prevention of the fuel fire immediately after survivable aircraft crash landing. This time is the most critical since there is some time after the crash until ground crews can control the sustained fire to perform rescue. The goal of this project is to identify hazard production and potential concepts for mitigation or elimination of a nearby external fuel fire. Internal aircraft cabin and cargo volumes are not covered in this study.

INITIAL CONCEPTS

In looking at the problem from an overall standpoint, it is noted that a potential fuel fire can be controlled by making the fuel not flammable or by controlling a resultant fire. Making the fuel not flammable could be accomplished aboard the aircraft since an external crew will not be available for some time. However, spilled fuel might also be rendered not flammable.

The fuel tanks could be injected (and mixed using fuel transfer pumps or convective means) with an efficient agent, such as halon, to render the fuel not flammable under pooling conditions. This method may not be the most efficient since enough agent to inert all the fuel would have to be carried aboard, with the resultant weight, even though all the fuel in the tanks might not be released. Similarly, since crash prediction is not possible, enough agent would have to be carried aboard to inert all the fuel carried. The time necessary to accomplish the inertion would need to be investigated.

Another potential method might be to have an annulus around the fuel tanks that would be filled with an agent that would render fuel passing through a rupture as not flammable. This method does not seem advantageous since (a) enough agent to inert all the fuel would be necessary, (b) the mixing process is passive, and (c) all fuel tanks would have to be retrofitted.

Fuel being spilled during crash (trans-crash) movement would not be of major concern since the aircraft would not be involved with that fuel left behind the aircraft (beyond critical distance). It is the fuel nearby and inside the aircraft when the aircraft is at the end of the crash movement, i.e., when the aircraft comes to rest, that **is** of major threat. Therefore, it seems most efficient to treat only the fuel or fire that is external to the aircraft when it comes to rest. This method of treating only the limited fuel after crash would, of course, have to involve (a) a hardened suppression system so that it remains intact after a crash to function **or** (b) a suppression system based on simple mechanics so designed that it releases automatically for some predetermined conditions (glass bulb approach).

It also seems more efficient to treat only the surface of the fuel against fire rather than to inert all the spilled fuel since only the surface of the exposed fuel is vaporized for fueling a fire. Therefore, **an** externally spraying system may provide minimum weight since the quantity of inerting agent necessary to provide the necessary control time may be less than that **required** for inerting all the fuel.

Another similar but more powerful method would use sprays of inerting agent/quantity as differentiated from fire suppression concentrations/rates. This method has been performed with Halon 2402 at increased flow rates. The goal would be to provide fuel surface inertion **or** high bumback resistance over the critical area for a critical time period. When additional fuel is spilled, it would be secured by the upper inertion layer. Quantification studies would need to be accomplished to consider the tradeoffs against suppression quantifies and technical benefits.

Conceptual Small-S e Test Apparatus

The range of concepts presented in the previous section leads to questions about the ability of **an** agent to suppress fire and inert fuel against flammability. For either of these processes, the basic efficacy of the agent(s) would need to be determined. Since the efficacy can be affected by the distribution scheme, which varies according to the application and the agent characteristics, the development of small-scale test apparatuses may need to consider the dismbution and application scheme.

If a liquid/solid agent were to be used to inert the fuel by injection mixing, it would be necessary to know the amount of agent to fuel that would be needed for inertion in order to determine the weight effectiveness. Determining this ratio would involve mixing proportions with standard laboratory apparatus and then testing for ignitability. Since the ignitability of atomized fuel may be different from that of a fuel pool, a fuel/agent spray apparatus would also be required.

If the agent were to be applied for fire suppression external to the aircraft, then this scheme would imply the use of a liquid streaming agent. The weight effectiveness of this type of application could not be determined solely by the standard flooding apparatus (cup burner), but would be strongly influenced by the streaming characteristics (agent properties and node).

For the scheme in which the agent would be used as a suppressant as well as an inertant via spraying, application rate would be a key parameter. Inertion time and burnback resistance over a range of conditions would be key parameters. Fuel pre-use strategies and agents would need to be determined before small-scale apparatus could be determined.

APPROACH

To conveniently discuss the approach for conceptual experimentation, some assumptions will be made that will limit the testing to delineate the important characteristics and parameters. The first assumption is that the fuel will be Jet A with a flash point of approximately 100 °F. In order to accommodate other fuels for the principals to be developed for Jet A, changes would involve the selection properties for the suppressant/inertant agent. Another assumption at this time is that the spilled fuel needs to be secured for a minimum of 3 minutes, which is the unannounced crash fire rescue (CFR) time.

This discussion of approach will encompass the definition of the initial set of scoping tests that will be performed to determine the feasibility and weight effectiveness of the suppressant/inertant agent techniques. Due account will be taken of the application strategies.

Fuel Inerting

The first set of experiments will involve determining the inerting concentrations required to render the fuel nonflammable. This study will provide basic data for inerting, whether it be total or partial fuel inerting. Fuel and agent can be mixed by volume in a laboratory flash using graduated cylinders. The apparatus used for flash-point testing can be used for testing. Most of the work can be performed at standard temperature in order to minimize expenditures for testing basic principles.

Halons and similar substitutes will be used as the agent. Since jet fuel has a distillation range, it will be necessary for weight efficiency to select the agent or mixture of agents so as to provide a nonflammable vapor above the fuel. In an ideal sense, this is mostly a matter of judiciously selecting the agent or agent mixture via boiling point over the operational temperature range. Stated simply, the agent(s) will be selected so that vaporization of the fuel/agent mixture will not yield a flammable vapor mixture above the fuel, since liquid jet fuel bums in the vapor phase at some standoff distance from the liquid surface. The goal of these tests is to investigate experimentally the agent characteristics for optimization of the agent/fuel efficacy. The main parameters are the boiling point, which indicates when the agent will be released from liquid phase, the liquid heat capacity, and the latent heat of vaporization of the agent(s), which indicates how the agent will behave in the fuel/agent mixture.

Almost any halon-type agent can be used for the initial scoping tests to determine the thermal/physical behavior of the fuel/agent mixture. This is thought to be true since all the relatively light-weight freon/CFC/halon-type substances should be readily miscible in jet fuel. However, since there are new restrictions on the use of some CFCs and halons, it will be necessary to investigate halon-type or halon replacements for their efficiency and ozone depletion potential (ODP), in addition to all other parameters of importance as toxicity, conductivity, compatibility, and decomposition.

Surface Inerting

The use of an inerting agent in the fuel may not be the most efficient means to effect fuel inertion. As mentioned earlier, it is only the upper layer of fuel that participates in the process of fire since the fuel must vaporize and mix with gaseous air to form a flammable mixture (fuel/air ratio within the flammability limits). Since the fuel below the surface does not initially participate, then it would seem more efficient to isolate or inert only the fuel surface layer. This process would provide high aircraft-weight effectiveness since the amount of agent required to protect an aircraft is no longer that to inert all the fuel but only that amount necessary to inert the fuel surface layer (which may be flowing and initiating) over some critical area.

Depending on the type and characteristics of the agent, it could be sprayed or flowed onto the fuel external to the aircraft. The agent might float on the surface to form a separation barrier (as does AFFF) between the fuel surface and air, or might mix to form an inerted layer. In the approach in this discussion, halon could be sprayed toward the external fuel for fire suppression, and, under higher application rates (With properly sized droplets), mix with the fuel surface layer to inert it.

The primary test parameter would be the application rate with variations of the droplet/distance criteria Since a single agent with fixed characteristic properties may not provide the most efficient aircraft-weight effectiveness, optimization studies may need to be performed for halon-type agent mixtures to achieve efficient fire suppression over the range of operational conditions and also achieve efficient inertion of the fuel surface.

Enhanced Surface Inerting (H_2O/Surfactant/Halon)

Surface inerting is desirable over total fuel inerting so as to provide high aircraft-weight efficiency. A concern for surface inerting is the movement of the fuel on the ground, which may cause mixing and loss of the inerted layer to the subsurface, thereby exposing a flammable fuel surface. The concept of AFFF is to provide a thin layer of surfactant on the fuel surface to separate it from air. This "light water" concept for AFFF might be employed to keep from losing the halon into the subsurface. Similar to the parameter for foams, the drainage time indicates loss into the subsurface.

This approach uses the AFFF concentrate as the carrier to support halon at the upper surface of the fuel. Initial trials would involve the addition of halons with various boiling points around the initial distillation temperature and flash point of the fuel of interest. The mixtures of AFFF concentrate with water and with halon would form the solution for application. It is envisioned that the AFFF bubbles would provide for even (efficient) distribution of the halon/surfactant. The application mixing and the drainage provide for mixing with the upper surface of the fuel to inert it. Temporal measurements of agent concentration above and below the liquid fuel surface would indicate the performance.

The fuel trough could be used as the fuel container with ignition source. The agent mixtures could be flowed and sprayed onto the fuel surface. Testing could be done both with and without fire. Additional experiments should use flowing fuel to investigate the mixing and loss phenomena. Fuel security would be indicated by the agent concentration spatial distribution with time. Fuel security would also be indicated by conducting a bumback test whereby a small area of the trough would be scooped clean of the agent mixture and ignited by a flame to see bum progression against the surface protecting layer. Tests using an initial fire would provide the worse case situation since additional agent would be lost during fire suppression and high heat vaporization. Therefore, necessary application rates would be determined using fire experiments whereas the simpler nonfire tests would be more conveniently used for all the other measurements.

Enhanced Surface Inerting (H_2O/Surfactant)

In the previous approach, halon was added to **AFFF** concentrate as a simple initial trial to induce "light halon-type agent" action to reduce the loss of halon to the subsurface. For comparative purposes, just the AFFF solution should be run. This method will provide a measure of the halon performance in the previous approach.

These tests would be run exactly the same way as the previous approach, which used **H_2O/surfactant/halon** against **fire** and nonfire fuel troughs. *An* additional method that can be used for visualization purposes would be to add a dye to the agent mixture and use a transparent fuel through (pyrex or **quartz)** in order to see the mixing processes.

Enhanced Surface Inerting (Halon/Surfactant)

It may not be necessary nor helpful to use an existing water surfactant mixture to carry the halon. The water may not be an additive providing efficiency. The particular surfactant may not provide the best conditions for the halon to interact with the liquid fuel surface and the vapor above the surface nor to provide desirable release and mixing rates. Therefore, a surfactant should be selected or developed to provide for the optimum performance of the efficient halon. The desirable characteristics would be those determined from the previous tests that would indicate shortcomings and benefits. Again, testing would be performed similarly to the two previous approaches for H_2O/surfactant/halon and H_2O/surfactant. Testing would be performed for a range of surfactants with a range of halons to investigate the best combination for optimal interaction with the fuel surface.

Encapsulated Halon

The approach for encapsulated halon is to provide fuel inertion only under hazardous conditions. The encapsulated halon would provide continuous protection and could be removed by physical means when needed for combustion. However, enough halon would have to be added to be able to inert all the fuel originally taken aboard and that halon would be carried at all times.

Activation by heat from fire will only provide a passive protection system. Another compound might be added to degrade the shell of the capsule, thereby **making** it an active system.

Halon has not been successfully encapsulated for firefighting purposes. Not only does one have to worry about containing the halon without leakage over the entire shipping and flight envelopes, but also to contain the halon when the capsules are mixed with the fuel.

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Prepared by

BERNARD R. WRIGHT
BELVOIR FUELS AND LUBRICANTS RESEARCH FACILITY (SwRI)
P.O. DRAWER 28510
SAN ANTONIO, TEXAS 78228-0510
(512) 522-2585

and

DENNIS M. ZALLEN, PH.D., P.E.
ZALLEN INTERNATIONAL ASSOCIATES
14216 TURNER COURT NE
ALBUQUERQUE, NEW MEXICO 87123
(505) 299-3025

BACKGROUND

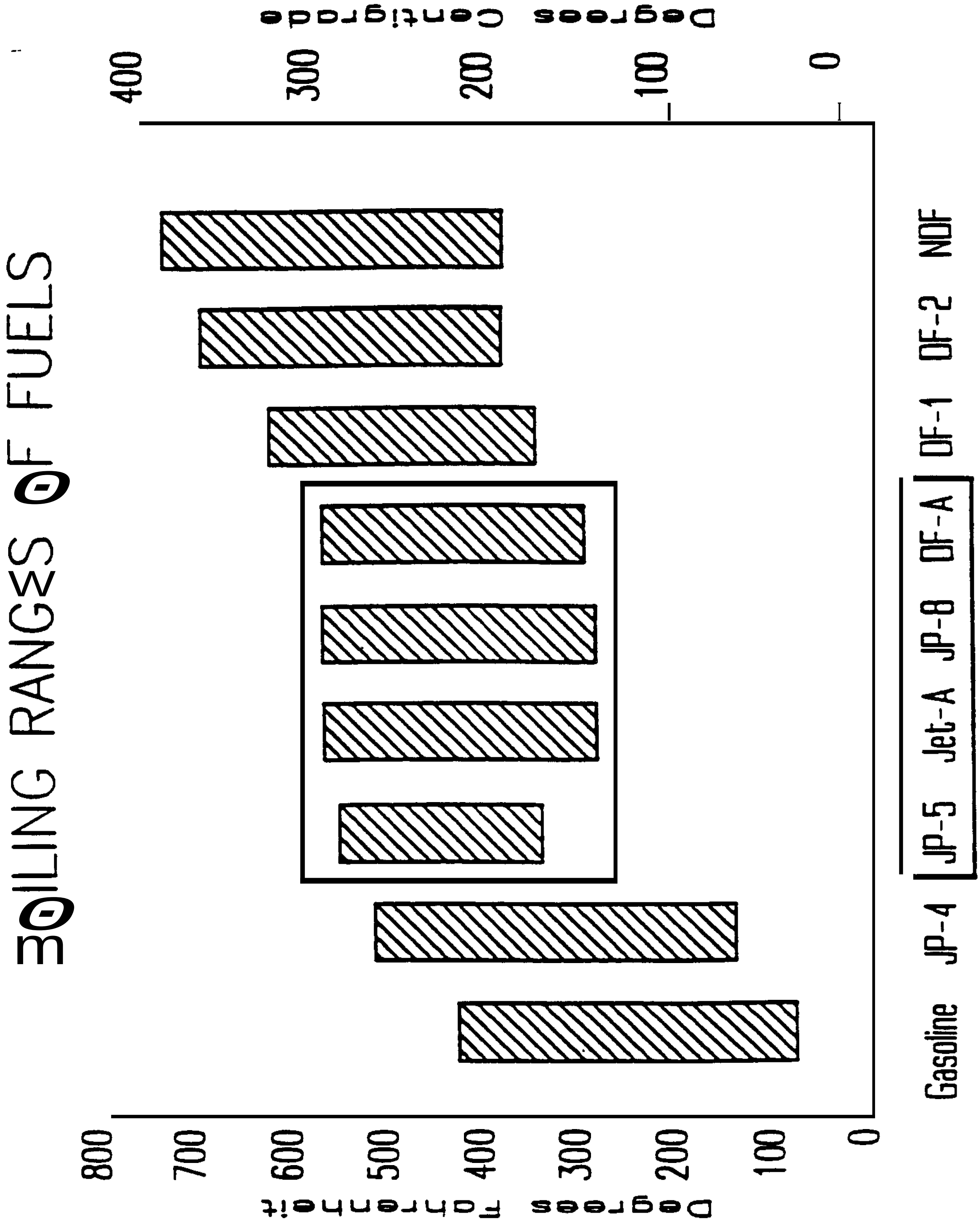
PRIOR RESEARCH FOCUSED ON TOTAL FUEL TREATMENT INCLUDING:

1. OIL-IN-WATER SEMISOLID GELS
2. ANTIMISTING AGENTS
3. WATER-IN-OIL MICROEMULSIONS

FLAMMABILITY HAZARD ASSESSMENT

I. FLUID/EXPOSURE PARAMETERS (SPRAYS AND POOLS)

- FLUID CHEMICAL AND PHYSICAL PROPERTIES
- FLUID SYSTEMS PRESSURE
- FL ID FLOW RATES
- FLUID SYSTEMS TEMPERATURES
- AIR VELOCITY AND DIRECTION
- AIR TEMPERATURE
- REPEATABILITY OF ATOMIZING NOZZLE
- REPEATABILITY AND INTENSITY OF IGNITION SOURCE


BOILING RANGES OF FUELS
Degrees Centigrade
400
300
200
100
0
Degrees Fahrenheit
800
700
600
500
400
300
200
100
0
Gasoline
JP-4
JP-5
Jet-A
JP-8
DF-A
DF-1
DF-2
NDF

Comparison of Gravity, Distillation, and True Vapor Pressure at Various Temperatures*

Sample	Gravity, °API	D 86 Distillation, °F							D 2889, True Vapor Pressure (TVP), at °F, psia			
		IBP	10%	30%	50%	70%	90%	FBP	200	300	400	500
A) JP-8(1)	45.1	342	371	393	410	430	462	504	1.2	6	21	57
B) JP-8(1)	49.3	304	332	348	366	392	429	482	2	9	31	82
A) 1-D Diesel(2)	42.2	393	412	431	450	480	510	542	<1	1.5	11	35
B) 1-D Diesel(2)	39.9	262	379	400	421	445	473	508	2.5	10	29	70
A) 2-D Diesel(2)	31.7	456	509	528	548	577	607	648	<1	<	2.8	10
B) 2-D Diesel(2)	32.4	315	418	461	503	545	587	631	1.1	5	17	44
A) JP-4(3)	54.6	152	232	263	295	368	441	501	18	55	130	250
B) JP-4(3)	53.1	79	163	215	268	321	375	479	[illegible]	110	230	400

*A and B samples are maximum and minimum values from each survey.

(1) Current JP-8 worldwide fuels data base, 59 samples.

(2) Summary for 1-D and 2-D Fuels, 1985, NIPER.

(3) Inspection data for Aviation Turbine Fuels, 1985, NIPER.

FLAME INHIBITION EFFICACY OF HALONS DETERMINED BY FLASH POINT

Halon Description	Halon Formula	Halon Boiling Point, °C	No-Flash Halon Conc., wt%	Halon Vapor Pressure, mm Hg
Carbon Tetrachloride	CCl,	76.8	10.39	41.2
Methylene Chloride	CH_2Cl_2	40.5	6.25	138.0
Bromochloromethane	CH_2ClBr	68.0	2.1 3	13.4
Dibromomethane	CH_2Br_2	98.2	2.29	4.1
1,1,2-Trichloro-1,2,2-Trifluoroethane	$ClCF_2CFCl_2$	47.5	3.39	28.8
Ethyl Bromide	C_2H_5Br	38.4	2.21	42.7
Trichloroethylene	$ClCH = CCl_2$	85.7	36.25	115.2
Chloroform	CHCl,	61.3	8.1 **3**	67.0
Bromochloro-trifluoroethane	$CHClBrCF_3$	50.2	2.0	14.80
Dichloro-trifluoroethane	$CHCl_2CF_3$	24.0	2.0	44.33

FLAME THROUGH PROPAGATION TEST RESULTS

Fuel	D 93 Flash Point. °F (°C)	Fuel Test Temp., °F (°C)	Time to Propagation	Propagation Rate, In./Second
Jet A-1	113 (45)	75 (24)	3 Min	1.3
JP-5	146 (63)	75 (24)	>5 Min	Did Not Propagate
DF-2	148 (64)	75 (24)	>5 Min	Did Not Propagate
Jet A-1		125 (51)	11 Sec	2.5
JP-5		125 (51)	>5 Min	Did Not Propagate
DF-2		125 (51)	>5 Min	Did Not Propagate
Jet A-1		170 (77)	Instantaneous	Instantaneous
JP-5		170 (77)	18.5 Sec	2.5
DF-2		170 (77)	1 Min 53 Sec	1.02
Jet A-1		--	--	--
JP-5		205 (96)	1 Sec	1.6
DF-2		205 (96)	41 Sec	1.0

SUMMARY

- FINALIZE STRATEGY FOR AGENT APPLICATION
  - BLENDING WITH FUEL
  - SPRAY INERTANTS OVER FUEL SURFACE
  - INERT AREA AROUND PLANE (CRITICAL DISTANCE)
  - FUSELAGE SURFACE COOLING
- FINALIZE CONCEPTS FOR AGENT DISPERSAL
  - AGENT ENCAPSULATION
  - ENHANCED SURFACE INERTING (H_2O/SURFACTANT/HALON)
  - ENHANCED SURFACE INERTING (H_2O/SURFACTANT)
  - ENHANCED SURFACE INERTING (HALON/SURFACTANT)