DETONATION RESEARCH TEST FACILITY (DRTF)
RESEARCH PLAN

TEXAS A&M UNIVERSITY
Engineering

Texas A&M Engineering
Experiment Station

THE DRTF RESEARCH PLAN
April 2025

The Detonation Research Test Facility (DRTF) at the Rellis Campus of Texas A&M in Bryan/College Station will be one of the largest facilities in the world to study high-speed reactive flows, fast flames, shocks, and detonations. The cylindrical steel tube is 150 meters long by 2 meters in diameter, with an earth-covered, vented muffler that is 90 meters long by 9 meters wide and high. The DRTF's pressure and optical sensors will observe flame evolution and transition to detonation enhanced by insertable steel baffles.

The DRTF will study the dynamics of explosive events and their flow physics as well as reactions occurring in energetic materials generally. These experiments will help develop ways to avoid, mitigate, enhance, and even control these processes. The DRTF's larger size and improved diagnostics will greatly extend the research done at the Gas Explosions Test Facility used at the Lake Lynn Laboratory from 2008 to 2012.

The DRTF will help solve many of the fundamental problems of detonation (supersonic combustion wave) physics. We can study the effects of system size, obstacle number, obstacle rigidity, and turbulence on flame acceleration, the deflagration-to-detonation transition (DDT), and detonation structure and dynamics. We can observe the pre-detonation (fast flame) reaction zone, the relationship between detonability and flammability limits, and factors affecting detonation reignition. The DRTF will explore fuel detonation, the effects of shocks on dispersed and settled particles, and the application of terrestrial physics to astrophysical phenomena.

DRTF experiments can also help solve many industry-specific safety problems. These include explosions of gaseous fuels and nuclear reactor explosions as well as unintentional inducers of DDT such as industrial structures and other flow obstructions. DRTF experiments can also study structural failure in airframes and engines and help improve devices such as detonation arrestors, detonation-based engines, and scramjets. Basic detonation research such as we propose often goes straight from new fundamental results to many major applications.

DRTF construction was funded by the Chancellor's Research Initiative (CRI), the Governor's University Research Initiative (GURI), the O'Donnell Foundation Professorship, and the Department of Aerospace Engineering. The DRTF is a Texas A&M facility with support from the University, sponsors, and industry.

The DRTFs scientific director, Dr. Elaine S. Oran, is a member of the National Academy of Engineering, the American Academy of Arts and Sciences, and the Royal Academy of Engineering. She is also an Honorary Fellow of the American Institute of Aeronautics and Astronautics and a Fellow of the American Physical Society, the American Society of Mechanical Engineers, the Combustion Institute, and the American Association for the Advancement of Science. She was previously a Senior Scientist at the U.S. Naval Research Laboratory and a Professor at the University of Maryland. Her pioneering work on the numerical simulation of reactive flows and its multidisciplinary applications are internationally recognized. Dr. Oran considered Texas A&M the ideal place to build a world-class detonation facility to ground theory and computation in cutting edge experiments because it has the infrastructure, the financial resources, and, most important, the depth of faculty expertise to make the DRTF a reality.

The DRTFs technical director, Dr. Scott Jackson, is an Associate Professor in the Department of Aerospace Engineering at Texas A&M University (TAMU) and an internationally known expert on high-speed combustion and shock physics. He is active in both the gaseous and condensed phase combustion communities. He has identified new relationships for explosive equations-of-state at extremely high pressures, provided the first thrust measurements and model for pulse-detonation engines, and developed novel measurement methods for shock and detonation processes. He is also building an extensive laboratory of complementary smaller detonation tubes at TAMU. Dr. Jackson is a former Program Chair and now Vice President of the International Colloquium on the Dynamics of Explosions and Reactive Systems (ICDERS) and Colloquium Chair for detonations at the 40th International Combustion Symposium (2024). He was previously a Research Scientist in the Shock and Detonation Physics Group at Los Alamos National Laboratory (LANL) and team leader of LANL's Detonation Physics Team.

The DRTFs Science and Engineering Team includes leading experts in detonation physics from within Texas A&M and around the country:

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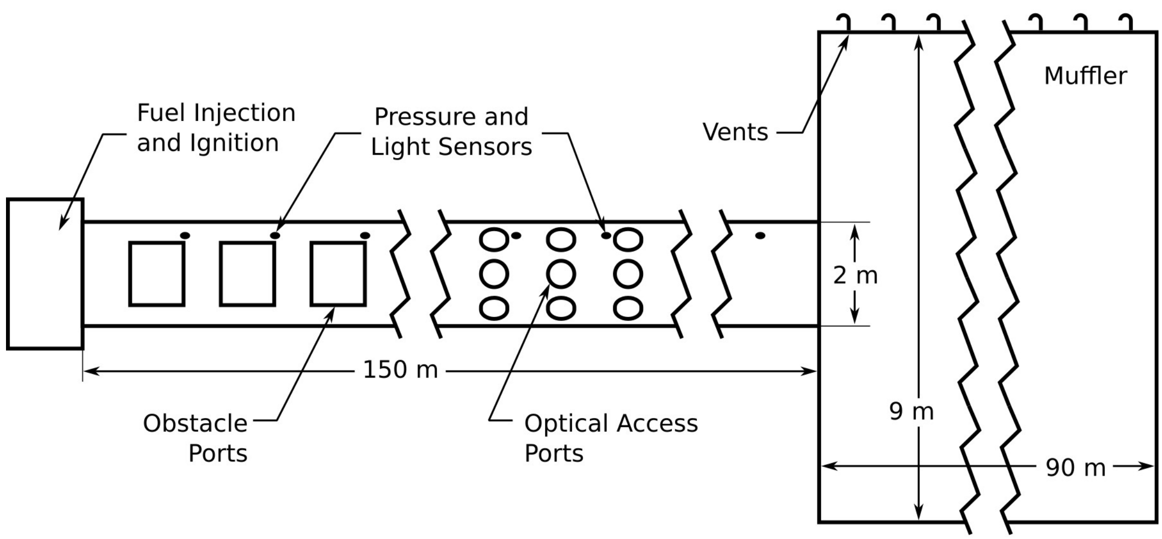

RESEARCH QUESTIONS FOR DRTF EXPERIMENTS

1. Initial Comparison Tests: How do detonations in various methane-air mixtures in the DRTF compare with detonations of the same mixtures in smaller detonation tubes?

2. The Effects of Channel Height on DDT: How does the large DRTF size affect the distance to DDT?

3. The Effects of Turbulence on Flames and Detonations: What are the effects of turbulence on the creation of a turbulent flame, flame acceleration, and DDT?

4. The Effects of Obstacles on Flame Acceleration, DDT, and Detonations and the Effects of Detonations on Obstacles: How do the properties of obstacles affect turbulence production, flame acceleration, and distance to DDT? (Properties here include size, shape, porosity, material composition, and stiffness (e.g. rigidity vs elasticity.))

5. Other Means to Induce DDT: Can tree branches, pipe networks, and industrial structures accelerate flames and induce DDT?

6. Detonation Below the Flammability Limit: Can a detonation sustain itself in a mixture below its flammability limit?

7. Factors Affecting Hydrogen-Methane Detonations: What are the detonation limits in air of natural gas/hydrogen blends, and how do these limits change with possible changes in temperature and pressure?

8. The Pre-Detonation Reaction Zone: What are the structures, dynamics, and interactions of shocks and deflagrations in the pre-detonation reaction zone, and how do these affect the transition to detonation?

9. Detonation Failure and Reignition: What factors influence the natural failure, intentional quenching, and reignition of a detonation?

10. The Effects of Shocks on Dispersed Particles: How does a shock wave or a detonation interact with pre-existing dispersed particles such as nonreactive rock dust and reactive aluminum dust?

11. The Effects of Shocks on Granular Materials: How does a shock wave or a detonation affect dust particles that have the properties of granular materials settled on surfaces?

12. Applications to Astrophysical Phenomena: How can DRTF experiments help explain the physics of astrophysical or cosmological events such as the evolution of stars to supernovae?

Question 1: Initial Questions and Experiments

Note: These initial research experiments will be preceded by safety tests that include progressively increasing zones of a fuel-air mixture within the tube to assure the operational safety of all DRTF components.

Questions to answer include:

How do detonations in various methane-air mixtures in the DRTF compare with detonations of the same mixtures in smaller detonation tubes?

To create a detonation in a specific methane-air mixture, do we need to use obstacles to modify the initial flow field?

More generally, how much energy should be added, and how should it be most effectively added, to a methane-air mixture, to produce a detonation? How lean can we make the mixture and still create a detonation?

These questions may be partially answered by large-scale numerical simulations and by measurements in smaller-scale experiments and extrapolation to the DRTF tube size.

Proposed DRTF Experiments:

Start by igniting very lean methane-air mixtures in the DRTF.

Move gradually to richer mixtures until it is stoichiometric.

Examine what is needed to create a detonation in these mixtures, such as number, placement, and type of obstacles.

These preliminary experiments will lay the groundwork for most subsequent questions such as Question 2 (System Size and Obstacle Placement), Question 6 (Detonations Below the Flammability Limit), and Question 7 (Factors Affecting Hydrogen-Methane Detonations.)

Question 2: Effects of Channel Height on DDT

How does the large DRTF size affect the distance to DDT?

Questions to answer include:

How do the likelihood, timing, and location of DDT scale with system size?

Given a specific fuel-air mixture, how does increasing the number of obstacles affect DDT?

We want to determine the minimum number of obstacles for a specific mixture that allows us to answer a critical question about transition.

How does the relative importance of the contributing physical and chemical factors change as system size changes?

Previously, computations predicted the location of DDT for a range of tube diameters and obstacle placements. The largest simulation predicted a distance to transition for a

3-meter-diameter channel with a stoichiometric methane-air mixture. (This was applicable to coal mine explosions.)

Experiments have measured up to 1-meter-diameter channels. The relative distance to detonation vs tube diameter was effectively linear for tube sizes of up to 1 meter for calculations and simulations. But after 1 meter, the simulated curve was no longer linear, with the relative distance to detonation decreasing. The physical reasons for this predicted downturn are not yet known and need further exploration.

Proposed DRTF Experiments:

One objective is to learn if and why the scaling between channel height and distance to detonation occurs. What controlling physics has changed?

Experiments in the DRTF's 2-meter-width tube can determine whether the measured change in the scaling of the distance to detonation between 1-meter and 2-meter tubes matches simulations. This change in the curve, which is a change in scaling, indicates that something has changed in the controlling physics of the system. The difference between the computed and measured curves can affect our understanding of safety margins in many industrial applications.

First, we determine whether the computed change is real or a computational issue. If it does happen in experiments, one possible answer concerns the role of turbulence in DDT. Does the nature of the turbulence change as system size increases? This issue is addressed in Question 3.

Question 3: Effects of Turbulence on Flames and Detonations

What are the effects of turbulence on the creation of a turbulent flame, on flame acceleration, and on DDT?

The creation and subsequent effects of turbulence on a reacting flow can lead to a detonation in this way:

Fuel accumulates in a portion of a fuel-air mixture with some confinement.

This confined mixture is ignited somewhere (often by a spark) which creates a small flame that moves into unburned background material.

The flame first moves relatively slowly into the unburned material. As it propagates, it expands, pushing like a piston on the downstream unburned gas as the flame releases heat and expands. This process creates acoustic waves and flow instabilities throughout the flow: in the burned gas, at the flame surface, and downstream in unburned gas.

Acoustic waves propagating like a piston downstream of the flame into unburned gas can coalesce into a shock wave. This creates a region between the shock and flame (a shock-flame complex) that has been shock-heated, so it is dense, hot, and high pressure. It is also very turbulent.

This shock-flame complex is a turbulent intermediate state in which hot spots (small regions with very high ignition probabilities) can lead to a detonation. The turbulence is not in an equilibrium state and is not easily characterized or defined.

Questions to answer include:

When there is a flame in a turbulent flow, such as exists in a shock-flame complex, what happens to the flame and what happens to the turbulence?

Does the type of turbulence in the shock-flame complex affect DDT or the development of hot spots?

Does the type of turbulence change with system size?

What is the nature of the turbulence in the shock-flame complex, and how does it change as the system evolves towards detonation?

Do large and small scales in a turbulent flow influence each other directly, and not only through an orderly cascade through intermediate scales?

Proposed DRTF Experiments:

Initial experiments will coordinate with simulations to isolate and define the structures of the shock-flame complex. Lasers, pressure sensors, and light sensors will focus on the turbulent flow field to capture background fluctuations and DDT.

Note: Prior experiments for Question 1 (Initial Comparison Tests) and Question 2 (System Size and Obstacle Placement) may lay the groundwork for these experiments. Also, these Turbulence experiments may inform the experiments on explosions of gaseous fuels in most of the following questions.

Question 4: The Effects of Obstacles on Flame Acceleration, DDT and Detonations and the Effects of Detonations on Obstacles

How do the properties of obstacles affect turbulence production, flame acceleration, and distance to DDT? (Properties here include size, shape, porosity, material composition and stiffness (e.g., rigidity vs elasticity).

Inversely, how does the passage of detonations affect obstacles with varying properties?

These are serious problems in large-scale explosions, such as the flames and detonations that occurred in the vapor cloud explosion in Buncefield, UK (2005).

Other factors in shock-obstacle interactions, such as the number of obstacles and their congestion (packing tightness), are discussed in other questions in this research plan.

Questions to answer include:

How do various types of obstacles, such as baffles or grates of varying porosity, affect turbulence, flames, and DDT?

How does varying the stiffness of obstacles affect turbulence, flames, and DDT?

What are the effects of shocks and detonations on objects that play important roles in society's infrastructure and objects that play an important role in forefront research?

Proposed DRTF experiments on the effects of obstacle type and rigidity include:

Replace solid thick-steel baffles with grates of varying porosity (size, spacing, etc., of holes).

Replace solid thick-steel baffles with baffles that will break or deform.

In each case, follow the development of the flow and record whether detonation occurs and, if so, the distance to detonation.

Replacing solid steel baffles with materials which, when destroyed, add to or detract from the energy of the flow, such as particulates or fragments created by the shock waves, is discussed in Questions 10 and 11.

Proposed experiments on the effects of shocks and detonations on solid objects include placing these objects in front of a detonation in the DRTF:

-Objects one hopes will remain substantially unchanged, such as the heavy steel baffles used previously to create interactions in the pre-detonation zone. -Objects one hopes would not fracture or shatter, such as gas pipes or concrete building materials. -Objects one hopes would not bend, such as the steel structural supports of buildings. -Objects one hopes would not degrade medically, such as a brain in a helmet or lungs in a chest. -Objects that ablate, such as substances that might make useful new microparticles. -Models of objects that might be subjected to detonations, such as vehicles, buildings, etc.

Question 5: Other Means to Induce DDT

Can tree branches, pipe networks, and industrial structures accelerate flames and induce DDT?

Questions to answer include:

How do the surroundings of a facility affect the likelihood that a fuel vapor cloud created around the facility will transition to detonation?

How do a facility's internal structures affect the likelihood that a fuel vapor cloud created inside the facility will transition to detonation?

How might increasing the complexity of an external or internal environment (such as pipes, walls, grated walkways, or trees) surrounding or within a facility (such as a petrochemical plant, a nuclear power plant, a hydrogen refilling station, or a hydrogen-powered home) increase the likelihood of a catastrophic accident?

It is highly probable that environmental complexity contributes to the likelihood of a vapor clouds transition to DDT. Among many examples, a flame passing through the trees around Buncefield's fuel storage facility caused DDT, and the walking grates at other plants present similar hazards. Environmental complexity has been observed, simulated, and reproduced on a small scale, but full-scale experiments are obviously too dangerous.

Proposed DRTF Experiments:

Attempt to reproduce real-world conditions by sub-section experiments, such as by placing real-world size walking grates or metal models of tree branches across the DRTF.

Attempt to reproduce real-world conditions by miniaturization, such as by placing a doll house of the external pipe structure of a petrochemical plant across the DRTF.

Attempt to deduce real-world conditions from prior analogous DRTF experiments involving object placement and complexity.

Question 6: Detonation Below the Flammability Limit

Can a detonation sustain itself in a mixture below its flammability limit?

Questions to answer include:

How close to the flame-propagation limit can a detonation be initiated and propagate? Can a detonation propagate below this flammability limit?

A detonation (a supersonic combustion wave) or a flame can arise in mixtures of an explosive gas and air only within their respective lean and rich limits. One difference is that flammability limits as now defined do not depend on system size. Detonation limits have been observed to approach flammability limits for large, lean mixtures of natural gas and air, but have not been observed to extend to leaner limits. For example, a gas-phase detonation may not propagate in a system that is too small because keeping it going requires the multidimensional shock system that allows constant reignition at the detonation front. Using a larger system will extend the detonation limits to leaner limits.

What indicates that a detonation below the flammability limit might be possible?

Elements of the physics that drive a flame are different from the physics that drive a detonation. These differences may indicate that much of the controlling flame physics is not important for detonation physics. In addition, while it is generally assumed that a detonation cannot exist below the flammability limit, and maintaining such a detonation might be difficult, there is no consistent reason or proof why it cannot happen.

Can we make it happen?

Small-scale experiments for natural gas show detonation limits well within flammability limits. Experiments in the previously existing Lake Lynn 1-meter detonation tube, however, showed detonation limits closely approaching flammability limits. A larger tube, such as the 2-meter DRTF, might show that the detonation limits overlap, or are even below, the flammability limits. First, we need to show that it can happen. Then, if it can happen, we can show how to make it happen under various conditions.

Proposed DRTF Experiments:

These experiments could begin with natural gas/air explosive mixtures similar to those in prior smaller-scale experiments. Now, however, the detonation is initiated with obstacles.

If this system is physically too small to produce a detonation below the flammability limit, experiments could move on to mixtures of hydrogen and natural gas in air.

If there is a detonation below the flammability limit, it will change our fundamental understanding of how detonations can form and propagate.

It could also change our understanding of how supernovae can ignite and propagate. This alone would be a fundamental conceptual change. It could also lead to a changed understanding of how galaxies form, of the nature of dark matter & dark energy, and, possibly, the origin of the universe.

It could also change the regulation definitions of what constitutes a detonation-safe system. The rules for designing and maintaining such systems might need to be reconsidered in industrial systems such as mining, natural gas storage & transportation, chemical plant safety, and grain silos.

A detonation below the flammability limit could also lead to a wider scope for defining detonability in detonation-based engines and for power generation.

Question 7: Factors Affecting Hydrogen-Methane Detonations

What are the detonation limits in air of natural gas/hydrogen blends, and how do these limits change with possible changes in temperature and pressure?

This refers to both the proportion of hydrogen added to methane and to the dilution of this mixture in air. These are important because as a methane/hydrogen blend dissipates, or as the temperature rises, the hydrogen can diffuse faster, and react more quickly, than the methane, changing the stoichiometry and the effective limits.

Questions to answer include:

How do we quantify the danger and what parameters can be used to either compute or measure the danger?

Some things we know and don't know about the dangers and parameters: -We have computational data, and some limited small-scale experimental data, on methane detonability, but not a full understanding of large-scale detonability, and there are few parametric studies for hydrogen or blends. -We need to relate current computational, theoretical, and smaller-than-DRTF experimental studies to decide how to approach the first DRTF experiments. -We do not know how important even a 20-30 degree F temperature change can be. -Both absolute and relative detonability limits have some temperature and pressure dependence, but we do not know these or their interdependence. - Prior disasters indicate that hydrogen ignition can be catastrophic. -When leaked propane was ignited by a train-generated spark in Siberia, hundreds of people were killed and much land was destroyed. This could happen with a methane/hydrogen mixture. - Hydrogen leaks were responsible for much of the damage in Chernobyl, and also in Fukushima, where there were two (possibly three) hydrogen detonations. -Similar explosions can occur with modern pipelines in industrial, commercial, and residential situations.

How do the distance and time to detonation decrease with increasing amounts of hydrogen added to methane?

How do the distance and time to detonation for each of these mixtures compare with simulations?

This will indicate how the danger level increases for each type of change, and for a combination of the two changes.

Once summer operational safety is determined, can we use the wide variation in Texas summer and winter temperatures to estimate the dangers of industrial temperature swings?

Proposed DRTF Experiments:

Find the minimal amount of hydrogen needed for an unobstructed detonation by starting with a stoichiometric methane/air mixture, which will not detonate in the DRTF.

Then replace small amounts of methane with equal small amounts of hydrogen.

At some point of increasing replacement, establish a mixture that will detonate unobstructed, thus defining the limit.

Compare this defined limit with the effects of adding various obstructions at equal and lower amounts of hydrogen.

Question 8: The Pre-Detonation Reaction Zone

What are the structures, dynamics, and interactions of shocks and deflagrations in the pre-detonation reaction zone, and how do these affect transition to detonation?

In the process leading to DDT, hot spots and detonations can form in a transition region between the leading shock wave and the turbulent flame. The shock and flame are loosely coupled, unlike a detonation in which the shocks and reaction zones are very close. This loosely coupled region is called a shock-flame complex or a fast flame.

Questions to answer include:

When, how, and under what physical conditions in the pre-detonation reaction zone do detonations occur?

How does detonation initiation change as we change a mixture from stoichiometric to the lean limit?

Detonations are fairly well understood for mixtures at or near stoichiometric, but less well understood for mixtures closer to the lean limit. As the lean limit approaches, isolated detonation regions can occur that are extremely powerful in small areas for short lengths of time. Localized, strong (perhaps megabars in pressure) transverse detonations can generate very strong shock waves that may be more dangerous than in stoichiometric mixtures, and perhaps cause more damage than the leading detonation.

Proposed DRTF Experiments:

Use laser diagnostics to create Schlieren movies of large, extended transverse detonations in the pre-detonation zone.

Focus on the ignition of hot spots to observe their effect on detonation initiation, especially as to changes from stoichiometric to lean mixtures.

Hot spot ignitions in regimes of high temperature and pressure can be caused by turbulence, flame-turbulence interaction, and localized shock focusing, which may cause powerful transverse detonations. This was observed at Lake Lynn. The DRTF may show how this happens more clearly, and may show more powerful detonations, because we will observe a larger reaction zone with better diagnostics.

Question 9: Detonation Failure and Reignition

What factors influence the natural failure, intentional quenching, and reignition of a detonation?

This is a broad question. It requires understanding the interactions of flames, shocks, and detonations, as well as putting them into the context of their surroundings in a broad range of conditions and settings. Sub-questions to answer include:

Are there universal criteria or scaling laws that can be derived, or even postulated, to answer the main question? What conditions influence whether a failed unconfined detonation will reignite? What conditions influence whether a failed confined detonation will reignite? What are the effects of passing through an opening or over obstacles?

Stopping a Detonation

It is extremely difficult to stop a detonation once it starts if combustible materials remain in its path. Shocks generated in a detonation persist after a detonation stops and tend to reignite the combustible material. When a detonation is failing, it leaves behind a flame and a leading shock. This complex of a turbulent flame and a strong shock is very dangerous. This is important because detonations are the most violent form of energy release, generating forces that persistently change everything around them. While the residual blast (shock wave) from an explosion dies out, a propagating detonation, with continuous energy release at the front, combined with shock structures created by the detonation, usually continues until the fuel runs out or the detonation is otherwise stopped.

The four basic ways a detonation might possibly be stopped are to: 1. Stop the flame so the detonation doesn't start in the first place. 2. Damp the leading shock wave directly and mechanically. 3. Remove the fuel after the detonation starts, which leaves a residual blast that dies out. 4. Pull energy out of the system, which kills off the structure of the front by killing the transverse waves within it. This might be done through energy losses to the boundary, such as by heat dissipation through the walls.

Reigniting a Detonation

As examples, a failed unconfined detonation may be more likely to reignite when: Background shocks are strong or plentiful. The gas properties, such as temperature, pressure, and stoichiometry, support reignition. There are obstructions with the right size, shape, and composition. There are obstructions with openings of the right size and number.

A failing confined detonation that passes through an opening or over obstacles may be more likely to reignite when: The gas properties, such as temperature, pressure, and stoichiometry, support reignition. The opening size or space above the obstacles is large enough relative to the confinement size. The opening size or space above the obstacles is large enough. (But this is system dependent.) The number and spacing of obstacles support reignition. (But this has not yet been studied systematically.) Boundary-layer conditions enhance reignition.

Proposed DRTF Experiments:

Most of these experiments vary obstacle height, opening sizes within obstacles, gas selection, and gas mixture composition to compare the results of smaller quenching and reignition experiments to the larger DRTF:

Put arrays of current detonation arresters (and maybe one custom-built large-scale arrester) into the DRTF in various configurations and use optical diagnostics to observe the flow to see what might quench or reignite a large detonation with the large cell sizes possible in this large tube.

Arrestors of various sizes, porosities, and spacing (or surrogate arrestors) will give the effect of varying opening sizes.

Compare these results to smaller experiments, current commercial applications, and computations.

To simulate unconfined reignition: This will be difficult in the DRTF, but perhaps we could use layers of inert gasses, baffles of different sizes, and methods of creating large heat losses.

To observe boundary layer effects: Use layers of inert gasses to create varying boundary conditions or use harder limits, but this will not be among our early experiments.

Specific experiments and configurations can be defined as results evolve.

Question 10: Effects of Shocks on Dispersed Particles

How does a shock wave or a detonation interact with pre-existing dispersed particles such as nonreactive rock dust and reactive aluminum dust?

There are many kinds of particles, including: -Pre-existing and those created by shock interactions with surroundings. -Dispersed (discussed here) and settled as granular materials within a density gradient (discussed in Question 11) -Inert (like rock dust) and reactive (like aluminum or coal dust, powdered sugar, or cornstarch) -Large and small, with a wide range from microns to inches, or, in an astrophysical context, kilometers. -Dense and porous.

The background conditions of pre-existing, dispersed particles may be dynamic (in a fluid) or have variations in particle density. Solid particles, whether inert or reactive, can interact with each other and with their background.

When reactive particles or the background gas are heated and compressed as, for example, by a shock wave, the particles can volatilize, creating a local gradient of gas and air. This reactive gas mixed with air can then ignite. Radiation from the burning particles might change the dynamics of the interaction.

When a shock wave passes through dispersed particles in air or in another gas, particles of different sizes and densities separate into groups, and the particles can be broken mechanically or fused at high temperatures and pressures.

Industrial facilities where reactive particles can create explosions and detonations include coal mines, sugar and grain storage facilities, and power plants with organic or nuclear fuels. All the effects of gas phase DDT plus the particle effects and interactions can occur. That is, shocks may disperse granular materials which then interact with igniting particles to create the conditions for a detonation.

An existing gas phase detonation may encounter extremely reactive particles and rapidly heat and compress them, causing a secondary detonation. Shocks and detonations lift and disperse dust, potentially leading to an intensified shock or a dust detonation.

Proposed DRTF Experiments:

Drive a shock or detonation through dispersed nonreacting particles to observe the effects of changing pressures and densities.

Do the same with dispersed reactive particles to observe changes in particle properties and radiation effects

Compare these results to numerical simulations.

Additional experiments will create gradients of particles in air to compare with calculations.

Multiphase systems are hard to compute and understand. Needed inputs are often unclear. Everything done will add to the knowledge base.

Question 11: Effects of Shocks on Granular Materials

How does a shock wave or a detonation affect dust particles that have the properties of granular materials settled on surfaces?

A granular material consists of particles packed closely, but with interstitial gas. Granular materials' packing fractions range from about .2 to about .8 by volume.

When a shock interacts with a granular material, waves are transmitted, reflected, or rarefied. The shock can create compression waves in these materials, disperse particles behind the shock and, if the particles are reactive, strengthen the original shock and create a secondary detonation.

Experiments are needed that can be tested progressively against models.

Proposed DRTF Experiments:

Propagate shocks over layers of inert particles, then over layers of reactive particles.

Vary shock strength, particle size, particle reactivity, packing fractions, and layer height.

Propagate detonations over layers of inert particles to observe possible damping effects.

Propagate detonations through layers of reactive particles to look for novel effects such as particle distribution at high temperatures and pressures.

Note: Basic properties of break-up and fusing should be first evaluated in smaller experiments as inputs to understanding DRTF-scale experiments.

Question 12: Applications to Astrophysical Phenomena

How can DRTF-scale experiments help explain astrophysical and cosmological events such as the evolution of stars to supernovae?

Astrophysics has many important and unexplained phenomena involving fluid physics, nuclear reactions, plasma and particle physics, and other fundamental processes and their interactions. Experiments in the DRTF can help explore these phenomena. This has already been demonstrated by the application of basic combustion concepts to astrophysical flames, detonations, and nuclear reactions.

Of course, its not possible to study events on astrophysical scales or with astrophysical materials in the DRTF, but we can do analog experiments with terrestrial gasses to understand basic mechanisms. Analog experiments then require asking the right questions to translate results from scale and material differences. Many terrestrial nonequilibrium turbulence effects apply to large scale astrophysical phenomena, and many of the large, carbon-based molecules that form on earth also form outside stars.

Questions to answer include:

Can a layered detonation of helium on a carbon-oxygen core contribute to a dwarf star's transition to a supernova?

Can a white dwarf star explode without internal obstacles or additional mass to trigger it?

What are the minimum fluctuations of temperature, pressure, and carbon percentage in a carbon/oxygen white dwarf star that might trigger the energy release of thermonuclear reactions?

Many of the prior questions in this DRTF Research Plan apply directly to these questions. For example, we need to know: -The behavior of lean and rich systems (Questions 1 and 2) -The effects of obstacles on DDT and detonations (Question 4) -The behavior of turbulent flames, detonations, and shock-flame complexes (Questions 3 and 8) -We also need simplified reaction models of thermonuclear systems -And Question 6, which explores the relation between detonation limits and flammability limits, could change our understanding of supernova explosions.

Proposed DRTF Experiments:

To use DRTF experiments to help understand fundamental astrophysical phenomena such as supernova, it is important to find appropriate surrogate fuels to use in the experiments. In general, these includes hydrogen and the light hydrocarbons (e.g., methane, ethane, propane) and multistage fuels which include mixtures of these.

As one example, to study the ways in which helium layers can ignite carbon-oxygen material and make it detonate, we need to layer fuels with large differences in detonation cell size to model the rich carbon-oxygen in the outer layers of a star and the lean helium layers outside the star. Once we resolve the detonation cell structure in these materials, we can then calculate how the layers interact.

Other important experiments include detonation and flame propagation in turbulent reacting flows in gradients of temperature, density, pressure, and fuel mixtures. We could also consider detonation propagation in multilevel fuels, so that the first fuel must be consumed before the second fuel begins to burn.

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