Aluminum and the World Trade Center Disaster

Aluminum was present in two significant forms at the World Trade Center on 9-11:

(i) By far the largest source of aluminum at the WTC was the exterior cladding on WTC 1 & 2. In quantitative terms it may be estimated that 2,000,000 kg of anodized 0.09″ aluminum sheet was used, in the form of 43,600 panels, to cover the façade of each Twin Tower.

(i) The other major source of aluminum at the WTC was the aluminum alloy airframes of the Boeing 767 aircraft that crashed into the Twin Towers on the morning of 9-11. It may be estimated that, on impact, these aircraft weighed about 124,000 kg including fuel; of this weight, 46,000 kg comprised the fuselage and 21,000 kg made up the mass of the wings – all of which were fabricated from aluminum alloys. Modern airframes are invariably constructed from series 2000 aluminum alloys. Alloy 2024 is a typical example containing 93 % Al, 4.5 % Cu, 1.5 % Mg, and 0.5 % each of Mn and Fe. These metallic additions to aluminum lower the melting point of the alloy from a value of 660° C, for pure aluminum, to about 548 ° C for alloy 2024. This relatively low temperature indicates that the fires within the Twin Towers were quite capable of melting at least some of the Boeing 767 aluminum airframe structures remaining in the WTC before its collapse.

But is there any direct evidence for the presence of molten aluminum at the WTC site on 9-11? The answer to this question is an emphatic: "*Yes*!" The formation of molten aluminum in WTC 2 just prior to its collapse was discussed in the well known FEMA and NIST Reports on the performance of the WTC buildings during 9-11. Here are the pertinent references:

FEMA: *World Trade Center Building Performance Study*, Chapter 2, Section 2.2.2.3, page 34:

> "*Just prior to the collapse* (of WTC 2)*, a stream of molten metal - possibly aluminum from the airliner – was seen streaming out of a window opening at the northeast corner* (near the 80th floor level)."

NIST: *Progress Report on the Federal Building and Fire Safety Investigation of the World Trade Center Disaster*, Volume 4, Appendix H, Section H.9, page 43:

> "*Starting around 9:52 a.m., a molten material began to pour from the top of window 80-256 on the north face of WTC 2. The material appears intermittently until the tower collapses at 9:58:59 a.m. The observation of piles of debris in this area combined with the melting point behaviors of the primary alloys used in a Boeing 767 suggest that the material is molten aluminum derived from aircraft debris located on floor 81.*"

Since there were no other metals in the Twin Towers that could melt at the temperatures present in WTC 1 & 2 during 9-11 – i.e. less than 800° C, it must be concluded that molten aluminum was produced in significant quantities from the melting of airframe debris in a least one Twin Tower (WTC 2). However, from the different trajectories of the aircraft strikes on WTC 1 & 2, it appears that the fuselage of the aircraft that struck WTC 2 came to rest closer to an exterior wall than the aircraft that struck WTC 1 which stopped deep inside this building. NIST report that the fires in WTC 2 were *less* active than those observed in WTC 1. In addition, the maximum temperature reached inside the Towers was probably higher for WTC 1 than for WTC 2 because Tower 1 burned for 102 minutes compared to 56 minutes for WTC 2. Given these facts, it is probable that molten aluminum was produced in *both* Towers, but was only observed at one location, namely spilling out of a broken window in WTC 2. It is obviously very difficult to estimate *how much* molten aluminum was produced in either of the Twin Towers during 9-11. However, from the temperature and heat flux estimates reported by NIST, and the mass of aluminum exposed, it is probable that as much as 10,000 kg of molten aluminum formed in each Tower.

<u>The Chemistry of Aluminum</u>

Aluminum exhibits a great affinity for oxygen as shown by the very high heat of formation of aluminum oxide, Al_2O_3:

$$Al + 3/2\ O_2 \rightarrow Al_2O_3\ ;\ \Delta H_f = -\ 1676\ \text{kJ/mol}$$

To quote from the *Kirk-Othmer Encyclopedia of Chemical Technology*:

> "*In dry air at room temperature, this reaction is self limiting, producing a highly impervious film about 5 nm thick, self-healing if scratched, which provides stability in ambient temperature exposures and resistance to corrosion by sea water and other aqueous and chemical solutions*."

This natural *passivation* of Al, by the rapid formation of a thin film of impervious oxide, may easily be disrupted when Al is heated above its melting point of 660° C, (or ~ 550° C if the Al is alloyed to metals such as Cu or Mg). In its molten state, Al is susceptible to very violent and exothermic reactions with oxygen, even when the oxygen is chemically bound. A well-known example of the reactivity of molten aluminum is the aluminum-water reaction that sometimes occurs with explosive violence when aluminum is cast into a mold unless precautionary measures are taken.

Aluminum ingots are usually formed by "direct chill" casting in which molten aluminum is poured into mold assemblies located in casting pits. These molds and pits are lined with special protective coatings and are cooled by water. Violent explosions sometimes occur when molten aluminum contacts water that may have inadvertently accumulated in the mold or pit.

The nature and causes of molten aluminum-water explosions has been studied in some detail by P.D. Hess and K.J. Brondyke, who published their results in the April 1969 issue of the trade journal *Metal Progress*. These authors show that essentially two types of aluminum-water explosions are possible:

- A "steam explosion" which is caused by the entrapment of water under hot metal. The water is instantaneously changed from liquid to vapor leading to a rapid buildup of pressure. Consider, for example, 1 ml of liquid water at 100° C converted to water vapor at the same temperature. The vapor occupies about 1.7 liters or 1700 times the volume of the liquid, hence the rapid increase in pressure and subsequent explosive expansion of the aluminum-water system. It is noteworthy that "steam explosions" do <u>not</u> involve any chemical reactions; they are nonetheless, potentially quite violent and capable of scattering hot metal particles over a large area.

- A true "chemical" explosion involving exothermic reactions between molten aluminum, water *and* the lining of the pit or mold. Hess and Brondyke (H & K) describe these reactions as "catastrophic" since they invariably blow the container apart and are accompanied by a bright flash of light. H & K's investigations revealed that these violent explosions occurred when coatings of lime, gypsum, rust, or a sludge of aluminum hydroxide where present. Using thermocouple measurements, H & K found that the temperature of the container rose by about 1500° C in a fraction of a second as the explosive reaction took place.

H & K conclude that aluminum, striking the container, reacts with a metal oxide, M-O, and undergoes a so-called <u>*thermite*</u> reaction generating extreme heat. This reaction may be represented by the equation:

$$\mathbf{Al + M{-}O \rightarrow Al{-}O + M + \Delta H}$$

The amount of heat released, measured by ΔH, depends on the difference in the strength of the Al-O bond compared to the M-O bond. With a dissociation energy, D_e, of 512 kJ/mol, the aluminum oxide bond is much stronger than the Fe-O bond, (D_e = 390 kJ/mol), or the Ca-O bond, (D_e = 402 kJ/mol). Comparisons of this sort show that the reaction of Al with iron oxide is one of the most exothermic thermite reactions. However, it is important to note that aluminum undergoes exothermic reactions not only with oxides, but also with *hydroxides*, of which water is a special example. In this case hydrogen gas is produced:

$$\mathbf{Al + {-}O{-}H \rightarrow Al{-}O + H + \Delta H}$$

$$\mathbf{H + H \rightarrow H_2}$$

H & K suggest that the hydrogen released in this reaction contributes to the violence of the explosion involving reactions between molten aluminum, water and a metal oxide or hydroxide.

There is plenty of anecdotal information on the potential for very violent explosions when molten aluminum contacts other materials containing chemically bound oxygen – even something as innocuous as *concrete*! A good example (by B. Davy) is to be found at:

http://astro.umsystem.edu/atm/ARCHIVES/OCT00/msg00433.html

where we read:

"*Pouring molten aluminum in a concrete mold can be VERY DANGEROUS. If the concrete is of normal mix the mold has a very high chance of exploding violently showering you with molten aluminum.*

For those that are interested, it is more than just a steam explosion that can result. The aluminum-water reaction that occurs with molten aluminum is highly exothermic, and will cause the aluminum to detonate with greater energy release than an equivalent weight of TNT. We at the department of Energy became painfully aware of this potential when we realized that the old reactors at Savannah River used metal aluminum fuel and target assemblies. Core meltdown took on a whole new meaning. I also have a friend that worked at the nearby East Alco Aluminum foundry. Everyone there knows that if a crucible full of molten aluminum spills on the concrete floor, they RUN!"

Occurrence of Thermite Type Compounds at the WTC

If we look at H & K's list of compounds that have the potential to induce "catastrophic explosions" in the presence of molten aluminum, namely, water, lime, gypsum and rust, we see that all of them were present in the Twin Towers during 9-11:

Water:
The Boeing 767 aircraft impacts caused major structural damage over several floors in each Tower. Sprinkler systems were installed in the Twin Towers but apparently failed to operate during the catastrophic events of 9-11. Certainly, however, many plumbing fixtures near the aircraft impact zones would have ruptured and spilled water, especially in washrooms and kitchenettes, but also in office areas where water coolers, coffee makers and drink vending machines would have broken and spilled their contents.

Lime:
Lime is calcium oxide and forms the base for all cements and concretes where it typically constitutes 60 – 67 wt %. (WTC 1 & 2 contained an estimated 48,000,000 kg of concrete per Tower.) The principal binding agent in concrete is calcium silicate hydrate. The water of hydration of this compound, constituting 5 – 7 % of the weight of concrete, is present in the form of H_2O bridges between Ca-O and Si-O layers. This water accounts for much of the chemical bonding that forms between lime and silica during the manufacture of concrete. As previously noted, the combination of water and metal oxide bonding in concrete makes this material very susceptible to explosive reactions in the presence of molten aluminum.

Gypsum:
Gypsum is hydrated calcium sulfate, $CaSO_4.2H_2O$. It is the principal ingredient of wallboard (75 – 90 wt %) but is also used as a binder or filler in fireproofing and insulating materials. Large quantities of gypsum wallboard, typically 5/8-inches thick, were used to enclose exit stairwells and elevator shafts throughout the Twin Towers.

Rust*:*
Rust, which is essentially a mixture of ferric oxides and hydroxides, readily forms on iron or low alloy steels exposed to moist air at ambient temperatures. Post 9-11 photographs of the WTC at ground zero show many rusted steel members in the rubble piles. The iron oxide film thickness measured on selected samples by NIST and FEMA investigators was consistent with the expected level of corrosion of carbon steel after 30 years exposure to the urban/maritime environment of NYC. As shown below, rust may be induced to react violently with aluminum, both in its molten *and solid* state.

Thermite and Related Reactions Involving Aluminum at the WTC on 9-11

1. Low Temperature "Themite Sparking"

A typical "thermite " formulation consists of a mixture of 25 wt. % aluminum metal powder, and 75 wt. % ferric oxide powder. Modern variants add an igniter such as magnesium ribbon, supplemental oxidizing agents such as copper oxide and generally include an inert binder. As we have seen, under appropriate conditions, there is the potential for highly exothermic reactions between aluminum and rust - a mixture of ferric oxide, Fe_2O_3, and ferric hydroxide, $Fe(OH)_3$ - as described by the equations :

$$2Al + Fe_2O_3 = Al_2O_3 + 2Fe \; ; \qquad 2Al + 2Fe(OH)_3 = Al_2O_3 + 2Fe + 3H_2O$$

$$\Delta H = -853.5 \text{ kJ/mole}, \qquad \Delta H = -756.6 \text{ kJ/mole},$$

These *thermite reactions* are used for the welding and cutting of heavy iron and steel sections especially when oxy-acetylene equipment is unavailable. Starting in the 1960s, the European coal mining industry imposed restrictions on the use of aluminum pit-props because of the possibility of thermite reactions induced by impacts between rusty steel and freshly abraded aluminum.

The Colorado School of Mines recently published a report, (No. MT-CWJCR-002-024), entitled "*Feasibility of Thermite Sparking with Impact of Rusted Steel onto Aluminum Coated Steel*." This report shows that intense, thermite-induced, sparking occurs between relatively small (~ 100 gram) aluminum and rusty steel projectiles at impact velocities as low as 12 m/s. In light of these findings there can be no doubt that thermite-enhanced sparking occurred within the Twin Towers when the Boeing 767 aircraft, traveling at about 200 m/s, struck the core columns. This is highly significant because it provides a mechanism for a deflagration-to-detonation transition within the fuel vapor clouds that formed in the Twin Towers immediately after the aircraft impacts. (This topic has been dealt with in greater detail elsewhere.)

2. Molten Aluminum-Themite Reactions

The idea that molten aluminum-thermite reactions may have been involved in the collapse of the Twin Towers is not new. It was first proposed by S. Ashley in an October 2001 article published in *Scientific American*. Ashley noted that the aviation fuel fires in the Twin Towers burned sufficiently hot to melt and *even ignite* the airliners' aluminum airframe structures. Aluminum, could then have added to the conflagrations. Hot molten aluminum could have seeped down into the floor systems, doing significant damage. Aluminum melts into burning 'goblet puddles' that would pool around depressions, such as beam joints, service openings in the floor, stairwells and so forth. The goblets are white hot, burning at an estimated 1800 degrees Celsius. At this temperature, the water of hydration in the concrete is vaporized and consumed by the aluminum. This evolves hydrogen gas that burns. Aluminum burning in concrete produces a calcium oxide/silicate slag covered by a white aluminum oxide ash, all of which serve to insulate and contain the aluminum puddle. This keeps the metal hot and burning.

Our present study of the propensity of molten aluminum to react violently with common structural materials not only supports, but extends the above scenario. Thus, in addition to the action of molten aluminum on concrete discussed by Ashley, we have referenced studies showing that mixtures of water, gypsum and rust are also capable of violent reactions with molten aluminum. Gypsum wallboard was used throughout the Twin Towers and was reported to have fallen off and blocked many stairwells. Rust was present on all the structural steel. Molten aluminum reacts with these substances by grabbing the oxygen and releasing flammable hydrogen. It may be calculated that the energy released by the chemical conversion of the molten aluminum produced in the Twin Towers was about 10^{12} Joules or *comparable to the potential energy released by the collapse of the Towers!*

Based on the known properties of molten aluminum in the presence of hydrated oxides in concrete, gypsum and rust we propose the following sequence of events involving aluminum reactions, brought down the Twin Towers on 9-11:

- Boeing 767 aircraft separately strike WTC 1 & 2 and flaming wreckage becomes lodged in the upper floors of each Tower.
- Combustibles, such as office furniture, paper and plastic, start to burn, fuelled by at least 10,00 liters of kerosene, and the temperature in the impact zone begins to rise.
- After about 30 minutes, the fires subside, but black smoke continues to pour out of both Towers showing that the fires are not “out”, but “smoldering”.
- After about 40 minutes, parts of the airframe in WTC 2 approached the critical temperature range of 500 - 550° C where aluminum alloys starts to soften and melt.
- At 50 minutes, molten aluminum forms and starts to flow from the airframe in WTC 2.
- The molten aluminum re-ignites some of the smoldering fires and rapidly burns through other combustible materials that survived the initial conflagration. Molten aluminum also falls onto fractured concrete, gypsum and rusted steel surfaces inducing violent thermite explosions, dispersing globules of molten metal and igniting new fires.

• The extreme heat generated by the molten aluminum rapidly weakens already damaged steel columns and trusses in the impact zone causing local slumping and partial collapse.
• The remains of the semi-molten airframe fall to the floor below and mix with fresh combustible material, air, water, thermite reagents (crushed concrete, gypsum, rust), and sections of aluminum cladding from the Tower's façade, initiating more explosions.
• This sequence of events is now repeated in a rapidly accelerating, and increasingly violent cascade of destruction. Gravity adds momentum to the downward acceleration of the mass of debris and WTC 2 collapses in less than 16 seconds.
• The burning aluminum remaining at the end of the collapse glows brightly for a moment and illuminates the rising clouds of smoke and dust at ground zero.
• About 25 minutes later, the temperature of the aircraft wreckage in WTC 1 reaches the critical 500 - 550° C range where molten aluminum starts to flow. The sequence of events observed in WTC 2 is repeated in WTC 1 and a second global collapse ensues.

3. Aluminum Reactions in the Rubble Pile

Remarkably, our story of the deadly role played by aluminum in the WTC disaster is not quite over because aluminum has one more chemical trick to perform in the rubble pile. The WTC rubble pile was a veritable stew of materials including body parts mixed with pulverized concrete, gypsum, glass fiber, vermiculite, chrysotile asbestos, mineral wool and glass as well as paper, plastic, copper wire and large sections of steel and aluminum.

Two factors should be considered in evaluating this mix of materials. First, because of the way it was formed amid fires and explosions, *the rubble pile was very hot*. In fact it is probable that some molten aluminum made its way into the rubble pile. As previously noted, molten aluminum burning on contact with concrete produces a calcium oxide/silicate slag covered by a white aluminum oxide ash which serves to insulate and contain the aluminum puddle, keeping it hot and burning…..

There is evidence that the WTC rubble pile was not just hot, but on fire, and it stayed that way for a long time. See for example Jonathan Beard's article in the December 2001 issue of *New Scientist*:

Ground Zero's fires still burning

Almost 12 weeks after the terrorist atrocity at New York's World Trade Center, there is at least one fire still burning in the rubble - it is the longest-burning structural fire in history. Deputy Chief Charles Blaich of the New York City Fire Department would not predict when the last fire might be extinguished. But compared to the situation at the end of September, when aerial thermal images showed the whole of Ground Zero to be a hot spot, conditions today are much safer for the workers clearing the rubble.

We will consider how the rubble pile could be on fire many days after 9-11 in a moment, but first we must discuss the second important factor controlling the chemistry of the rubble pile, namely *the presence of water*. The basement of the Twin Towers was severely damaged on 9-11 and flooded with water from sewer lines, fresh domestic water lines, steam pipes and condensate returns. Just days after 9-11, millions of gallons of water had already flowed into WTC basement floors and was being pumped out at a rate of about 3,000 gallons per minute. In the days and weeks following 9-11 water was continuously percolating through the rubble piles from firefighters' hoses and rainfall. Ironically, the WTC site was sprayed with water mainly to keep dust levels down during cleanup operations, rather than extinguish fires.

The US Geological Survey has measured the properties of water exposed to WTC dust and debris (See pubs.usgs.gov/of/2001) These so-called "WTC leach solutions" are invariably very alkaline with pH ~ 10. Chemical analysis has shown up to 700 μg/liter of Al dissolved in the leach water. The USGS researchers concluded that: "*Of all the metals in the WTC dust, aluminum is leached in greatest amounts*".

The dissolution of aluminum in the WTC rubble pile water is readily explained by the well-known corrosion reaction:

$$Al + H_2O + OH^- \rightarrow AlO_2^- + 3/2\ H_2$$

What is most significant about this reaction is that aluminum enters solution as the aluminate ion, AlO_2^-, <u>*with the release of 3/2 moles of gaseous hydrogen*</u>. That this type of reaction occurred in the WTC rubble pile should not be surprising since hydrogen production reactions have been reported in similar environments involving aluminum in contact with water and cementitious materials. Thus the Pacific Northwest National Laboratory recently published a report entitled: "*Potential for Generation of Flammable Mixtures of Hydrogen from Aluminum-Grout Interaction in the K Basin During Basin Grouting.*" (See PNNL Report No. 15156 by S.M. Short and B.M. Parker, issued April 2005.) In the introduction to this report we read:

"*This evaluation was performed to assess the potential impact of imbedding equipment and debris within a layer of grout to provide shielding and to fix contamination. The presence of aluminum in the form of empty canisters, identification tags or other hardware will lead to the generation of hydrogen as high pH grout contacts and reacts with the aluminum metal.*"

The authors go on to explain that hydrogen generation from grouted aluminum occurs due to the reaction of aluminum with hydroxide ion from $Ca(OH)_2$ present in the pore water of the grout. Measurements at 50° C showed a maximum hydrogen gas generation rate of about 5 cm^3/min for an aluminum coupon with an area of about 20 cm^2 exposed to a saturated solution of calcium hydroxide.

Using this result and other quantitative data related to the rate of corrosion of aluminum in alkali media at temperatures up to 100° C, it is possible to estimate that tens of thousands of liters of hydrogen gas were released, *per day*, into the WTC rubble pile immediately after 9-11. Because of the presence of hot smoldering debris and localized fires at ground zero, this hydrogen would have burnt and contributed to the heat generation that kept the WTC rubble pile hot and cooking for months after 9-11.

Summary and Conclusions

In this article I take a close look at the role of aluminum in the World Trade Center (WTC) disaster of September 11th, 2001. Metallic aluminum was present in the WTC on 9-11 not only as the familiar shiny cladding on the façade of the Twin Towers, but also as a major component of the Boeing aircraft that penetrated deep into the cores of these buildings. The article first reviews what is known about the physical condition of aluminum in the Twin Towers before, during and after the terror attacks and discusses the evidence for the formation of molten aluminum from the heat of the fires. It is concluded that as much as 10,000 kg of molten aluminum flowed from the Boeing 767 airframes lodged in the upper floors of the Towers prior to their collapse.

The chemistry of molten aluminum has also been reviewed and the corrosive and highly reactive nature of this material highlighted. It is shown that molten aluminum readily undergoes violent explosive thermite reactions when dropped into slurries of lime, gypsum or rust – materials that were present in great abundance in the impact zones of WTC 1 & 2, a place where fires raged and aluminum was being heated above its 550° C melting point on the morning of 9-11.

Based on these findings it is proposed that the formation of molten aluminum in the Twin Towers just before their collapse, accounts for most of the startling and controversial observations that accompanied the spectacular destruction of these massive structures. It is suggested that molten aluminum initiated the global collapse of each Tower by burning through key structural supports in the impact zones. Molten aluminum-thermite reactions could explain the rapid intensification of the fires and the many detonations seen and heard moments before and during the collapse of each Tower. Molten aluminum-thermite explosions - reactions that are quite capable of shattering ceramic or metal molds during aluminum casting - would help to explain the much-debated pulverization of the WTC concrete. And, remarkably, the production and combustion of hydrogen gas by reactions of hot aluminum with high pH water at ground zero, explains why the WTC rubble pile continued to burn for so long.

It is indeed ironic that the progressive collapse of the Twin Towers has prompted many 9-11 researchers to reach the erroneous conclusion that deliberately placed thermite "cutter charges" *must* have been used to bring down these buildings. The findings outlined in this article show the underlying reasons for this misconception. Simply put, thermite-induced reactions *were* largely responsible for the destruction of the Twin Towers on that terrible September day in New York City – but the fatal damage was not from deliberately planted thermite charges. Molten aluminum was the culprit, and the true terrorist!

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Addendum

1. Some relevant information about the combustion of H_2:

   H_2 is highly flammable over a concentration range from 4 to 75 % - the 2nd widest range of any common flammable gas. With such a wide flammability range it is easily ignited. The flame from burning H_2 has a very high heat content – its flame temperature is over 2000° C. *H_2 burns with an almost invisible flame*.

2. One of the best videos of the collapse of WTC 1 was taken by Rick Siegel, at a location in Jersey City, looking east across the Hudson River. It is important to view it as the full screen version available on the letsroll911.org forum page. The letsroll911 post begins as follows:

   "Please watch this clip. Look inside and all over the collapse plume of WTC1, the North Tower. You will notice a series of flashes inside the plume going off. The thing that is really interesting is the flashes seem to be very bright in the dark plume. You can see it on from the top to the bottom. From left to right. Especially at about the height of WTC7. Concentrate on that area of the plume."

   Having viewed this clip many times, the flashes are indeed quite obvious, but the claim that they are "demolition charges" is not supported by the visual evidence. I would expect deliberately placed charges to be in horizontal rows that would be fired in a regular and systematic fashion. The flashes visible in the video are widespread and *completely random* , both in placement and in timing. This is completely consistent with the thermite sparking theory developed in my "Aluminum in the WTC" article. The aluminum in this instance could have been molten droplets showering over the collapsing structure or cold cladding sections (perhaps still attached to the exterior steel columns), striking rust covered steel columns as they fall to ground zero.

3. Prof. S. Jones at BYU has recently tested the reactivity of molten aluminum towards materials such as rusted steel and concrete. (See his Feb, 2006, article at: Scholarsfor911truth.org). While his results are interesting, Prof. Jones has *not* conducted anything close to the tests I suggested. Ironically, Prof. Jones quotes from an e-mail I wrote to him on January 26th 2006, where I outline the type of test that would settle the question of the role of molten aluminum in the WTC collapse:

   "*I suspect our different views will* never *be resolved by discussion alone. I therefore suggest an experimental resolution: The NIST fire tests, which were designed to simulate the conditions in WTC 1 & 2 after the aircraft impacts, should be repeated in a more realistic environment that includes shredded aluminum alloy 2024, crushed concrete and gypsum, water, rusted steel, aviation fuel, plastics, etc.... Then I want to see two things happen: (i) The fires melt the aluminum, and (ii) The molten aluminum ignites violent, explosive reactions*."

In spite of what I suggested in my January e-mail, namely simulations that reproduce conditions in the WTC fires and would thus be an acceptable test of my claims, Prof. Jones carries out two entirely different experiments:

(i) Molten aluminum was poured onto a section of clean, dry, rusted steel.
(ii) Molten aluminum was poured onto a clean, dry, concrete block.

Because there were no violent reactions in these two tests, Prof. Jones concludes that my hypothesis is invalid! This conclusion is reached in spite of the fact that gypsum was not even tested, and none of the materials were pre-heated or crushed.

Of all the parameters not duplicated in Prof. Jones' experiments I would argue that the crushing of the materials is one of the most important. Why? It is a well-known fact that solid-state reaction rates depend on the *surface area* of the reactants. A one kilogram block of concrete has a surface area of about 0.06 m^2. The surface area of one kilogram of concrete crushed to 60 μm particles has a surface area calculated as follows:

$$\text{Surface area of 1 kg of crushed concrete} = (6 \times 60 \times 60 \times 10^{-12}\ m^2) / (3.24 \times 10^{-10}\ kg)$$

$$= 67\ m^2$$

Crushed (pulverized) materials are <u>much</u> more reactive than solid blocks of material…..

In conclusion I would say that Prof. Jones is, of course, entitled to his opinion, but I would argue that his "simulation" lacks most of the key conditions that were present in the WTC impact zones on 9-11, namely prolonged fires ignited by aviation fuel, sustained by burning plastics, paper, furniture, etc, that directly heated water, aluminum and rusted steel in the presence of <u>*crushed*</u> concrete and gypsum. I challenge Prof. Jones to repeat his tests under these conditions and publish the results.

F. R. Greening
Feb 20th, 2006

<u>Update April 7th, 2006</u>:

In the past few months there has been considerable discussion on Internet forums concerning the molten metal that began to pour from window 80-256 on the north face of WTC 2 moments before the collapse of this building. (See page 1 of this author's *Aluminum and the World Trade Center Disaster* report.)

An interesting feature of the videos and still photographs of this event is the bright yellow glow *inside* WTC 2 from what appears to be the source of the molten metal. The color and intensity of this glowing ball shows that something was burning at a very high temperature - perhaps as high as 1100° C. Such a temperature is well beyond the 800 - 900° range of flame temperatures attainable in typical solid or liquid hydrocarbon-fuelled fires. This has led some researchers to invoke the inevitable " pre-placed thermite incendiaries" as the cause of the bright yellow glow. However, rather than jump to this conclusion, we offer below an alternative, less-conspiratorial, explanation of this phenomenon:

Localized Oxygen-Enhanced Fires in WTC 2

Information available on U.S. FAA websites, and confirmed in the NIST NCSTAR 1-5 report, indicate that the Boeing 767 aircraft involved in the 9-11 impacts on the WTC Towers carried a number of oxygen cylinders *and* oxygen generators. A NASA report by T. L. Reynolds, (No. NASA/CR-2001-210903, issued in May 2001), discusses Onboard Oxygen Gas Generating Systems, or OBOGS, and other sources of breathable oxygen on aircraft:

> "*Oxygen systems, as they are currently designed for use on commercial transport aircraft, include passenger oxygen for use in the event of a sudden loss of cabin pressure (provided by either compressed oxygen or solid chemical oxygen generators) and gaseous oxygen for use by the flight deck crew. There is also portable gaseous oxygen available for medical use and for protective breathing equipment. The use of oxygen on commercial aircraft, required by FAA regulations, does pose a potential fire safety hazard because of the extremely high gas combustion temperatures that can be produced by combustible materials burning in either pure or oxygen-enriched air environments. This is true of any oxygen system in any environment.*"

The standard oxygen cylinder carried on all U.S. commercial aircraft contains 3200 liters of O_2 stored at 1850 psi when full. Details of the over-pressure relief of these cylinders are provided in a FAA report by T. R. Marker et al., (No. DOT/FAA/AR-TN98/29):

> "*Different types of pressure relief devices are used for storing breathable oxygen. There are two types of rupturing relief valves, a frangible disc that will fail under excessive pressure (typically 2500 psi) and a thermal disc that will fail when the temperature exceeds 165°F or 225°F, depending on the type. The rupture disc pressure relief device is the only type used on gaseous oxygen cylinders for crew and passenger breathing systems on commercial transport aircraft..... Ironically, the rupture disc type pressure relief devices pose a more serious concern in a fire environment because, with these relief devices, it is possible for the entire contents of the oxygen cylinder to be discharged at elevated temperatures.*"

Marker's report describes studies showing that rupture disc failure occurs within 15 minutes for cylinders exposed to temperatures as low as 200° C.

The standard chemical oxygen generator used in the OBOGS on commercial aircraft consists of a small metal canister equipped with a spring-loaded striker. When activated, a "candle" of sodium chlorate and additives such as barium peroxide undergoes spontaneous thermal decomposition releasing oxygen gas. The OBOGS units installed on most Boeing aircraft contain about 250 grams of $NaClO_3$ per canister that generate about 50 liters of O_2 in 12 minutes – an amount of oxygen considered sufficient to supply two passengers during an emergency descent.

NIST report that the Boeing 767s involved in the 9-11 impacts on the WTC Towers carried about 100 canisters per aircraft; each canister capable of 12-minute oxygen generation for a total of 5000 liters of O_2 per aircraft; the canisters were located in compartments above the passenger seats. Researcher D. Blake, in a study of the response of aircraft oxygen generators to elevated temperatures, (See report No. DOT/FAA/AR-TN03/35), found that the lowest temperature for self-activation of a generator canister was 315° C. Other tests conducted by Blake showed that more than 80 % of generator canisters heated to 370° C activated during an hour of heating.

Based on the experimental data presented above it appears quite probable that a significant portion of the oxygen carried by the two aircraft that hit the Twin Towers was released *prior to* the collapse of these buildings. Experimental data also show that gas cylinders undergo acute release of oxygen at much *lower temperatures* than the chemical generators onboard the aircraft. Furthermore, the chemical generators release oxygen in 50-liter increments involving many locations in the aircraft cabin, while the bottled gas supply would be released in one 3200-liter pulse at the front-end of the aircraft fuselage where the cylinder is wall-mounted.

In one of the tests described by Marker, 600 liters of oxygen was released into a cargo container where a small fire had been deliberately set. The initial discharge of oxygen caused a very violent combustion reaction that ripped open, and subsequently destroyed, the container. Other data from fire tests in oxygen-enriched environments show that cellulose-based materials such as wood, cardboard and paper, burn almost four times faster in air enriched to 40 vol % O_2. This increased combustion rate induces a comparable increase in the heat flux from the burning material and results in flame temperatures as much as 600° C higher than the flame for the same material burning in air – thus flame temperatures up to 1500° C are possible.

Based on the calculated trajectory of UA Flight 175 *inside WTC 2*, the forward cabin area of the aircraft ploughed into floors 80 to 82 of the northeast corner of the building. Thus the 3200-liter oxygen cylinder carried in the crew compartment of Flight 175 came to rest precisely in the area where the bright yellow glow was to later appear. As many videos show, about 50 minutes after impact, fires were well established in localized areas of the northeast corner of WTC 2 – these fires would have gradually heated the entire forward fuselage to temperatures in excess of 200° C. We therefore suggest that the intense yellow glow seen moments before the collapse of WTC 2 was caused by the discharge of the onboard oxygen cylinder and the subsequent enhancement of the pre-existing fires.