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**Y-12
NATIONAL
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COMPLEX**

**Analysis of Potassium
Superoxide/Kerosene Situation**

J. S. Bullock

**Chemistry and Chemical Engineering
Technical Operations
BWXT Y-12, L.L.C.**

January 16, 2001

MANAGED BY
BWXT Y-12, L.L.C.
FOR THE UNITED STATES
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Analysis of Potassium Superoxide/Kerosene Situation

Introduction

On February 28, 2000, a safety situation came to light within the Y-12 Technical Operations Development Organization involving a potentially explosive combination of potassium superoxide (a strong oxidizer) in contact with kerosene (a combustible hydrocarbon). Inasmuch as this was basically the same combination of materials as that which was implicated in the Y-12 Production accident of December 8, 1999 (except for a nearly inconsequential difference in the molecular weight of the hydrocarbon), there was naturally a great interest in understanding the explosive potential inherent in this situation. Thus, basic information on the quantities of materials was obtained and thermodynamic calculations performed to determine the energies that would probably be released if an explosive event was initiated. Further scenarios were defined involving possible dispersion of the hydrocarbon and subsequent ignition of the dispersion. The energy of this potential event was then related to pressure-surge conditions that might be generated in the room in which the material was stored. In the short-term, these calculations were performed and the results informally communicated to the Development Operations Manager for consideration with respect to evaluating the potential safety hazard and generating an Unresolved Safety Question Determination (USQD) screening submission. This document formally records the analysis described above.

Description of Situation

Three bottles containing potassium metal submerged under a liquid were discovered during a chemical inventory. Two were the original 8-oz vendor bottles; the vendor information indicated that the material had been packaged under kerosene, and there was no evidence that this had been changed from the original material. The metal in these bottles was in the original form of rods of diameter approximately one cm. The original net weight of potassium was 125 grams per bottle, although neither vendor bottle appeared to still contain that much material. These bottles were brown glass, which made detailed examination very difficult, but apparently there was only a dilute slurry of potassium oxide silting the bottom of these bottles. There was no clear indication of the presence of potassium superoxide (KO_2), which has a strong yellow coloration. Lower oxides of potassium that could possibly be present include: K_2O_3 , which is red; K_2O_2 , which is white; and K_2O , which is colorless(or white)¹. The proportions of species that will exist together at equilibrium depend on the elemental ratios of potassium and oxygen. At very low oxygen content, only K_2O is stable. When the elemental ratio of O to K passes 0.5, the amount of K_2O begins to drop and K_2O_2 begins to appear. When the elemental ratio passes 1.0, the amount of K_2O goes to zero, K_2O_2 begins to drop and K_2O_3 begins to appear. When the elemental ratio passes 1.5, the amount of K_2O_2 goes to zero, K_2O_3 begins to drop, and KO_2 begins to appear. When the elemental ratio reaches 2.0, all other oxides are unstable and only KO_2 is present (at equilibrium). This is shown graphically in Figure 1 as calculated by the HSC Chemistry program².

The actual oxide present at equilibrium thus depends critically on the local elemental ratios.

However, the actual species present in any situation also depends on kinetic factors. Since the slurry material appeared to have no yellow or red coloration, it is probably either K_2O or K_2O_2 . The fact that the oxygen content should be low due to the presence of a large excess of K and a presumably low inleakage rate argues for the slurry being composed of K_2O (or the hydroxide).

The third bottle was a 4-oz clear (uncolored) non-vendor glass bottle containing a small amount of potassium in the bottom with an overlayer of what appeared to be kerosene (see Appendix 1). The potassium was not in the form of rods; it had apparently been melted in place and had solidified at an angle to the horizontal. As the melting point of K^3 is $63.25\text{ }^\circ\text{C}$ and the boiling point range of kerosene⁴ is $150\text{-}300\text{ }^\circ\text{C}$, it is highly likely that the melting in place was done under the kerosene cover. The melting may have been done to consolidate more than one small piece of K. While the K presented a shiny surface to the glass vessel wall, the upper surface was irregular as if some dross had remained from the melting operation. Decorating the upper surface at the interface between the K and the kerosene was a layer of a yellow solid which was identified as probably being KO_2 . The total quantity of this KO_2 was conservatively estimated by considering the layer thickness to be 1 mm over the full interface with the kerosene. The area of the interface was calculated as an ellipse of 16 cm^2 using the observed geometry of the solidified melt. Thus, the total estimated volume of the KO_2 was 1.6 cm^3 . Using a density of 2.14 g/cm^3 and a molecular weight of 71.10 g/mole^5 , this volume converts to 3.424 g or 0.048157 moles. Similar geometrical considerations were used (allowing for a dome-shaped vessel bottom) to arrive at a K volume of 8.9 cm^3 . This converts to 7.654 g or 0.195763 moles. The volume of the overlayer of kerosene was estimated at 60 cm^3 . If considered to be only tridecane, with a density of 0.7564 g/cm^3 and a molecular weight of 184.37 g/mole^6 , this volume converts to 45.4 g or 0.2462 moles. A similar 4-oz glass bottle was weighed to determine that the mass of the glass bottle was 120 g .

The clear glass 4-oz bottle and one of the brown glass 8-oz bottles were located in a small flammable material cabinet of free volume about 160 liters. This cabinet is situated in a room with free volume about $6,000\text{ ft}^3$, or $169,900\text{ L}$. The bottle containing the alleged KO_2 as well as the other bottles have been handled and moved without extreme precautions (and without incident) within the last few months, prior to realizing the presence of the KO_2 . The opinion of a material disposal expert⁷ retained by Y-12 to evaluate the Production situation was that in the absence of an initiating event, such as significant mechanical or thermal shock, this material should be stable. Thus, any explosion scenario for the material would in all probability involve handling outside the flammable material cabinet but possibly in the $6,000\text{ ft}^3$ room.

Possible Energy Release Scenarios

- 1) Equilibrium conditions with transfer of all enthalpy of reaction to remaining material, including potassium, kerosene and glass bottle.
- 2) Equilibrium conditions with transfer of all enthalpy of reaction to remaining material, including potassium and kerosene.

3) Transient conditions with transfer of all enthalpy of reaction to products of reaction, followed by fragmentation of glass bottle, and dispersion and ignition of remaining kerosene:

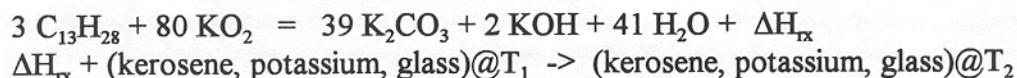
- a) with no recombination reactions in products;
- b) with recombination reactions in products.

4) Transient conditions with transfer of all enthalpy of reaction to products of reaction, followed by fragmentation of glass bottle, dispersion and ignition of remaining kerosene, and heating and ignition of remaining potassium.

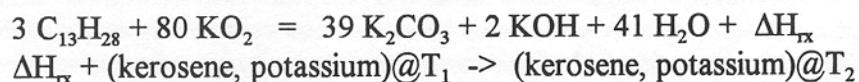
- a) with no recombination reactions in products;
- b) with recombination reactions in products.

There could be a version of Scenario (3) in which the dispersed kerosene is not ignited, but in light of the high local temperature at the reaction site, this seems unlikely. Also, in the succeeding analyses, and considering the boiling point range of kerosene, the distribution of hydrocarbon molecules that could be considered ranges from C_9H_{20} to $C_{17}H_{36}$. The energy release calculations are relatively insensitive to the choice of hydrocarbon, so we will focus on $C_{13}H_{28}$ (tridecane) in the middle of the range as representing the class.

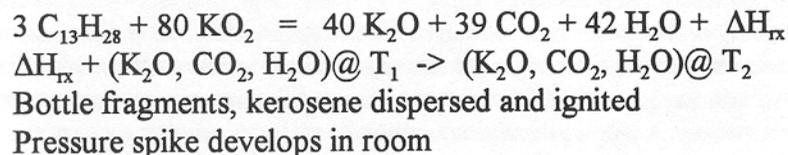
Reactions for Scenario (1):



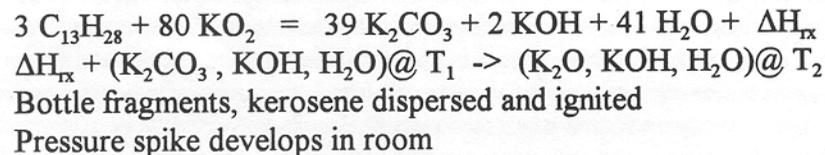
Reactions for Scenario (2):



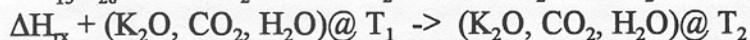
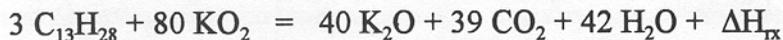
Reactions for Scenario (3a):



Reactions for Scenario (3b):



Reactions for Scenario (4a):

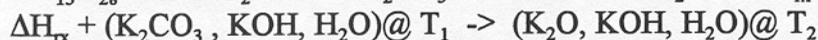


Bottle fragments, kerosene dispersed and ignited

Pressure spike develops in room

Some heat transferred to remaining K which melts then burns

Reactions for Scenario (4b):



Bottle fragments, kerosene dispersed and ignited

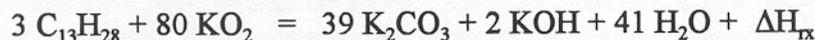
Pressure spike develops in room

Some heat transferred to remaining K which melts then burns

There can be some question as to the nature of explosions resulting from reactions of KO_2 with hydrocarbons. While the total energy releases can be calculated on thermodynamic grounds, this does not answer the question of the rate of propagation of the explosive front. This is important since the result of "low explosive" deflagrations with propagation rates of up to 400 m/s is a pushing effect, whereas "high explosive" detonations with propagation rates of 1,000 to 8,500 m/s exert a shattering effect, due to the supersonic shock wave associated with the explosion⁸. Black gunpowder is a classic example of a low explosive, whereas TNT at 6,942 m/s is a good example of a high explosive. What distinguishes these materials structurally is that, for black powder, on a molecular scale the oxidizing and combusting components are separated and there has to be phase changes and mass transport to bring them together. Whereas, for TNT the oxidizing and combusting components are both part of the same molecule and thus are only angstroms away from each other. One might expect the KO_2 /kerosene mixture to act more like black powder, although probably with a higher propagation rate due to the more intimate contact of the liquid/solid mixture. For reference, TNT releases 1090 cal/gram⁹.

Detailed Analysis of Scenarios

Scenario (1):



The ΔH_{rx} for this reaction as calculated from ΔH_f values¹⁰ at STP is - 7,622,905 cal/mole as written, or - 96,286.3 cal/mole per mole of KO_2 . For the 0.048157 moles of KO_2 we are assuming, this gives a total enthalpy release of 4,588.7 cal. This reduces to a specific enthalpy release for the stoichiometric mixture of 1221 cal/g, which is comparable to and slightly exceeds that for TNT.

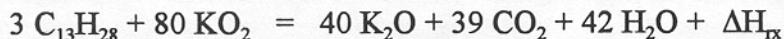
Using a ΔH of melting for K of 558 cal/mole¹¹, Cp values of 7.59 and 72.91 cal/mol*K for K¹² and tridecane¹³ respectively, and 0.19 cal/g*K for the glass container¹⁴, the temperature rise for the system at equilibrium becomes approximately 81 Kelvin degrees, or a final temperature of 106 degrees C. This is the least catastrophic scenario, although not likely in terms of the reaction rate discussion above as well as the low thermal conductivity of tridecane (see Table 1).

Scenario (2):



The total enthalpy release is the same as Scenario (1) (4,588.7 cal), but the glass vessel is not considered to participate in heat absorption. Using the same values for the other parameters, a temperature rise at equilibrium for the K and kerosene only becomes approximately 138 Kelvin degrees, or a final temperature of 163 degrees C. This gets into the lower part of the boiling range for kerosene. Again, this is an unlikely path due to the probable reaction speed and low thermal conductivity of tridecane.

Scenario (3a):



The ΔH_{rx} for this reaction as calculated from ΔH_f values at STP is - 3,896,689 cal/mole as written, or - 48,708.6 cal/mole per mole of KO_2 . For the 0.048157 moles of KO_2 we are assuming, this gives a total enthalpy release of 2,345.7 cal or 9814.4 J.

For this scenario, we are initially considering all the thermal energy to be transferred to the reaction products, generating large temperature and pressure excursions. For the quantities of material present, the amounts of K_2O , CO_2 and H_2O generated are 0.0240785, 0.0234765 and 0.0252824 moles respectively.

To determine the final temperature of these collections of material on absorbing these quantities of heat, the heat capacity of each species has to be put in the form of an equation as a function of temperature; this was done using TableCurve software¹⁵ if the equation was not available in reference literature. Next, the equations have to be integrated from the starting temperature to the final temperature, and all three equations have to be simultaneously solved considering that the total heat load is distributed between the three species; this was done using TKSolver software¹⁶. As an example, the calculations for Scenario 3a are presented here:

$$dH1=m1*(a1*(T-To)+0.5*(b1*1e-3)*(T^2-To^2)+(1/3)*(c1*1e-6)*(T^3-To^3))$$

$$dH2=m2*(a2*(T-To)+0.5*(b2*1e-3)*(T^2-To^2)+(1/3)*(c2*1e-6)*(T^3-To^3))$$

$$dH3=m3*(a3*(T-To)+0.5*(b3*1e-3)*(T^2-To^2)+(1/3)*(c3*1e-6)*(T^3-To^3))$$

$$dH=dH1+dH2+dH3$$

$$\text{moles CO}_2 = m1 = 0.0234765$$

$$\text{moles H}_2\text{O} = m2 = 0.0252824$$

$$\text{moles K}_2\text{O} = m3 = 0.0240785$$

$$\text{total enthalpy} = dH = 2345.7 \text{ cal} = 9814.4 \text{ J}$$

$$\text{starting } T = T_o = 298.2 \text{ K}$$

$$a1 = 32.22 \text{ J}/(\text{mole}\cdot\text{K})$$

$$b1 = 22.18 \text{ J}/(\text{mole}\cdot\text{K}^2)$$

$$c1 = -3.47 \text{ J}/(\text{mole}\cdot\text{K}^3)$$

$$a2 = 30 \text{ J}/(\text{mole}\cdot\text{K})$$

$$b2 = 10.71 \text{ J}/(\text{mole}\cdot\text{K}^2)$$

$$c2 = 0.335 \text{ J}/(\text{mole}\cdot\text{K}^3)$$

$$a3 = 17.455478 \text{ J}/(\text{mole}\cdot\text{K})$$

$$b3 = 0.009687347 \text{ J}/(\text{mole}\cdot\text{K}^2)$$

$$c3 = 0$$

$$\text{final } T = T = 3459.76 \text{ K} = 3186.6^\circ\text{C}$$

For this scenario, from a starting temperature of 25 °C, the final temperature is 3187 °C. It does not appear from literature data on the free energy of formation of K₂O that this species will be stable at this temperature. To be rigorously correct, the enthalpy of dissociation of K₂O should be factored into the calculations, which would lower the total heat available for temperature increases. However, this would require more complexity in the calculations and at this point it is probably useful to not include that point, and to treat K₂O as an ideal gas as will be done for the other products. Thus, the total number of product moles is 0.0728374. From the ideal gas law, PV = nRT, it can be calculated that at a temperature of 3187°C the PV product is 20.68 L*atm. At one atmosphere, this would be a 17-cm-radius fireball. Within the glass bottle, which can be assumed to have a free volume of 40 cc, a pressure of 517 atm/7598 psi would be generated. This should be sufficient to shatter the glass bottle immediately.

The meaning of “immediately” bears some discussion. If we assume that, as a low explosive with a propagation velocity at least as fast as black powder, the propagation velocity is 500 m/s, with a characteristic dimension in the region of the superoxide of 2 cm the total reaction would be over in 4x10⁻⁵ s.

It is also useful to compare the explosive energy, in the quantity of KO_2 -kerosene stoichiometric mixture considered in this analysis, with the energy release for other materials. The highest possible enthalpy release is 4589 calories; the lowest (which has a higher probability of occurring) is 2346 calories. Comparing these values to the enthalpy release for TNT detonation (1090 cal/g), this material is then equivalent to between 2.15 and 4.21 g of TNT. Another comparison might be to the number of handgun cartridges providing equivalent energy. The enthalpy release for nitrocellulose is similar to that for TNT. For the amounts used in, for example, 9-mm cartridges¹⁷, 3.8 and 7.5 cartridges respectively would be equivalent to the two limiting cases.

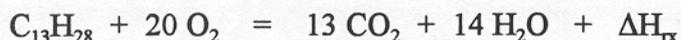
The next aspect to consider is the dispersion and ignition of the kerosene. The dispersion has the aspects of breaking up the kerosene volume into a multitude of small volumes, and transporting the mass of kerosene away from its original location into a larger volume where it is available for ignition. The choice of dimensions may be based on a worst-case scenario, of mixing the dispersed kerosene with a volume of air just equal to that which supplies a stoichiometric amount of oxygen. This happens to be 586 L of air; a combined volume of this 586 L plus the 21 L of the fireball equals an expanded volume of 607 L. If this volume is a hemisphere, which would be the case if the bottle were sitting on the floor or an extended surface, the radius of the hemisphere would be 0.6617 meters. For a uniform distribution of kerosene through the 607 L volume, the mean distance of the mass of kerosene from the center of mass of the kerosene is 0.5250 meters (halfway out on the r^3 scale). Thus, the energy required to so disperse the kerosene is equivalent to the energy required to move it from the center of mass to a hemishell of radius 0.5250 m about the center of mass. Some fraction of the enthalpy release will be converted to (force)*(distance) work in so moving the kerosene.

The energy conversions, $1 \text{ calorie} = 4.184 \text{ Joules} = 0.42665 \text{ Kg}\cdot\text{m}^2\cdot\text{s}^{-2}$, are used to get energy into units incorporating and accessing mass, force, distance, velocity and acceleration in order to estimate the characteristics of dispersion of the kerosene.

It is mere speculation to predict the partition of energy in this case. Without experimental data which are not available to this writer at this time, one can only describe certain possibilities. With that in mind, let us examine the case of 80% of the enthalpy release going to mass transport and 20% going to thermal heating of the products of the reaction. There is also a small amount of energy required to subdivide the kerosene into small particles; to subdivide by a factor of 10^{12} (giving 2.44- μm -radius particles), it only takes 0.43 cal/1.8 J, given a surface energy for tridecane¹⁸ of $2.56 \times 10^{-6} \text{ J}\cdot\text{cm}^{-2}$. If we cause the reaction products to absorb 469.1 cal (20%) as thermal energy, a temperature of 827 °C would be reached; this should be adequate to light off a dispersion of kerosene droplets. This leaves 1876.6 cal available to transport the kerosene into the dispersion volume. This energy is enough to accelerate the 0.04538-kg mass to a velocity of 132.8 m/s at a radius of 0.5250 m, in a time of $3.953 \times 10^{-3} \text{ s}$. Note that this is approximately 100 times as long as the time required to complete the reaction generating the energy driving this dispersal. Note also that the calculated velocity is lower than the speed of sound, which is 340 m/s.

Of course, this is only one reasonable set of results out of many possibilities. In fact, when one compares the total enthalpy release per 9-mm cartridge as mentioned above to the muzzle energy of the bullet fired from a 4-inch barrel, one finds that only about 23% of the energy is converted to useful kinetic energy (although a lot of the remainder does move the surrounding air around, resulting in the usual "bang"). Therefore the partitioning of 80% of the energy to kerosene dispersion may be quite conservative.

Given that, let us calculate the effect of combusting this kerosene fog in air. The reaction is as follows:



As written, ΔH_{rx} for this reaction is -1,957,563 cal/mole tridecane. The amount of kerosene in this calculation is 45.06 g, or 0.2444 moles of tridecane. This is reduced from the original by the amount of tridecane reacted with the KO_2 . Stoichiometric combustion requires 4.888 moles of O_2 and produces 3.17728 moles of CO_2 , 3.42168 moles of H_2O , and an enthalpy release of 478,440 cal. There is of course a large amount (18.66 moles) of N_2 carried along due to the combustion occurring in air. This will absorb the enthalpy release concurrently with the reaction products.

The solution to the equations involving heat deposition into the above materials yields a final temperature of 2146 °C. With the number of moles of material present, the P*V product in the 607-L reaction volume then becomes 5,019.6 L*atm, for a pressure of 8.2696 atm or 121.54 psia. However, the relevant pressure for judging blast effects is the pressure above atmospheric, which would be 106.84 psig. Given the volume of the room, as this pressure relaxes into the full available volume an average pressure of 0.382 psi would be exerted against the room boundaries. This pressure wave would probably travel at the speed of sound. One could also do a dynamic calculation taking into account the distance from the explosion origin to any point and determine the intensity of the pressure wave at that point, using an r^2 attenuation factor. I will not do that in this case, since there is no definition of where in the room the origin might be. If this were to be meaningful, it would also be necessary to take detailed account of the susceptibility of room structures to such pressure waves; I do not have this information.

Scenario (3b):



The ΔH_{rx} for this reaction as calculated from ΔH_f values at STP is - 7,622,905 cal/mole as written, or - 96,286.3 cal/mole per mole of KO_2 . For the 0.048157 moles of KO_2 we are assuming, this gives a total enthalpy release of 4,588.7 cal.

Again, we initially consider that all of the enthalpy release would be transferred to the reaction products as thermal energy. For the materials present, this yields a temperature of 2714 °C. It

appears from reference thermodynamic tables that there may still be about 40 Kcal free energy driving force for the formation of K_2CO_3 at this temperature, so this may be a valid possibility in that respect, although KOH may not be stable. However, whether or not this recombination takes place may be just as much a kinetic question as a thermodynamic one.

If we treat the conversion of 80% of the released energy into (force)*(distance) work as was done for Scenario (3a), then the 20% remaining as thermal energy would heat the reaction products to 830 °C and the remainder would propel the kerosene to the 0.5252-m point in 2.827×10^{-3} s with a final velocity of 185.8 m/s . This is fairly similar to the conditions in Scenario (3a), so the results re pressures developed due to secondary combustion of the kerosene fog may be expected to be fairly similar.

The calculations of pressures developed from kerosene fog combustion yield worst-case values for the pressure wave. If the kerosene is not dispersed uniformly in the combustion volume and not adequately broken up into small particulates, the combustion will proceed slower, which will drag out the development of heat and make the pressure wave lower and longer, which would reduce its effect on the surroundings.

Scenarios (4a) & (4b):

These have been combined due to the similarity of Scenarios (3a) & (3b). The only difference in (4) compared to (3) is the involvement of the K metal in absorbing heat from the initial explosive reaction, and potentially catching fire due to its surface temperature increase. As it happens, the proximity of K metal to the heat-generating site and its high thermal conductivity could conceivably cause a significant perturbation to the results. Table 1 shows the wide disparity in thermal conductivity¹⁹ of the materials present, which will affect their ability to take up thermal energy over short time spans.

Table 1 - Thermal Conductivity Data for Materials in Proximity to the Initial Reaction

Material	Thermal Conductivity κ w $cm^{-1} K^{-1}$	κ/κ_{max}
K metal (solid)	1.023	1.000
K metal (liquid)	0.532	0.520
Glass	0.01046	0.010225
$C_{13}H_{28}$ (tridecane)	0.001333	0.001303

The tridecane has such a low thermal conductivity that during the milliseconds of the process as already described, the amount of sensible heat taken up by tridecane liquid is relatively trivial. The glass is not in direct contact with most of the reacting KO_2 layer, so its involvement should be very small. In contrast, K metal could have a significant effect. The program HEATING²⁰ was

used to examine the effect of putting a high-temperature heat source next to a K surface initially at 25 °C. Figure 2 illustrates the K temperature as a function of depth into the surface, for a series of times at intervals of 0.1 millisecond up to a maximum of 1.0 ms. The discontinuity near the depth axis reflects melting of the K. For higher source temperatures (2000 and 3000 K), a second discontinuity reflecting K vaporization is seen (see Figures 3 & 4 for the 2000 & 3000 K cases). For the 1000 K case, at the 1 ms point, melting has progressed into the surface to a depth of 0.055 cm. For the 2000 K case, melting has gone somewhat deeper and vaporization has progressed to a depth of 0.015 cm. This simulation has a simplification which makes it somewhat unrealistic - namely, that no cooling of the source is included. However, even significant cooling would probably still allow ignition of the K surface in air to occur, unless the temperature was quenched sufficiently prior to re-aeration of the surface region. So this is still somewhat of an open question pending more comprehensive analyses (which could be done with HEATING), or experiments.

The question of how much of the enthalpy-release heat would be taken up by the K is important to understanding how much energy is available to disperse the kerosene. The data for heat flux at each time interval used to plot Figure 2, given in Table 2, was integrated with respect to time.

Table 2 - Heat Flux into K vs Time for the Case of Source T = 1000C

Elapsed Time (s)	Instantaneous Flux (W*cm ⁻²)
.0001	166,851.0
.0002	126,037.0
.0003	105,270.0
.0004	92,228.0
.0005	83,071.2
.0006	76,187.6
.0007	70,770.2
.0008	66,364.5
.0009	62,690.7
.0010	59,566.6
Average =	90,903.68
Total fluence for 1 ms =	90.90 J/cm ² (or 21.73 cal/cm ²)

The energy uptake for the total 1-ms interval is then 21.73 cal cm⁻². This then begs the question

of how much K surface is actually in contact with the KO_2 -kerosene mixture. That area is probably less than the total 16 cm^2 assumed in estimating the amount of KO_2 present. If we call this contact area 10 cm^2 , then the total loss of heat to the K would be about 217 cal. This still leaves, in the scenario with the lowest enthalpy release, more than 90% of the energy available before this correction, or 2129 cal. Therefore, although dispersion in this case would be slightly less vigorous, it should still occur.

Ignition of the K and the dispersed kerosene seems highly probable. To really determine the most probable event description, it would be necessary to simultaneously solve for the temperature-dependant KO_2 -kerosene reaction enthalpy, the temperature of the reaction products, and the heat absorption/temperature rise of the K. It would be further necessary to simulate the mass transport of oxygen back into the reaction zone and its correlation with transient temperature changes to determine what can be ignited when. If it is already known, for the Y-12 Production accident with KO_2 -mineral oil, that a mineral oil cloud did ignite, then that would be useful data to guide judgements of what is possible.

Conclusions

A general picture of the processes that could occur in an initiated KO_2 -kerosene reaction with excess kerosene and in contact with K metal has been created. A worst-case estimate of explosion of the dispersed kerosene overlayer has also been created, with a probable value of average pressure surge in the current storage room of less than 0.4 psi. More probable scenarios would put the peak value of pressure surge somewhat lower, with ignition of the K metal and burning of the excess kerosene at a rate between smooth burning and a slow deflagration. The enthalpy release from the combustion of kerosene in this situation (478,440 cal) is much larger than that for the reaction between KO_2 and kerosene (between 2346 and 4589 cal). Thus, kerosene combustion is potentially much more significant than the KO_2 reaction and may provide 99.05 to 99.51% of the total energy of possible explosions. Hence, there is a good reason to separate bulk amounts of flammable or combustible hydrocarbons from explosive material. For this case, in the limit that absolutely all hydrocarbons were removed from the system, there should no longer be an explosive hazard.

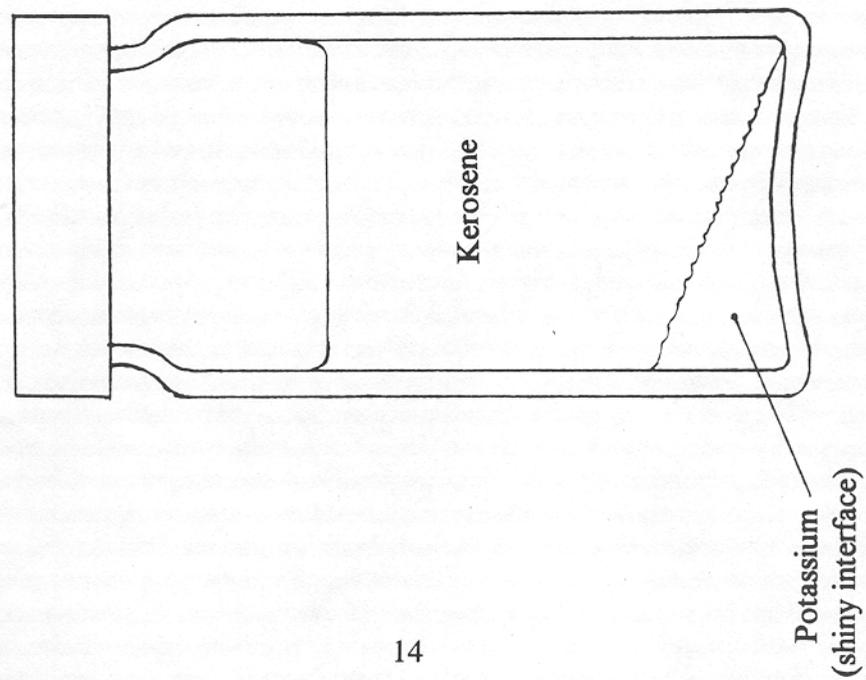
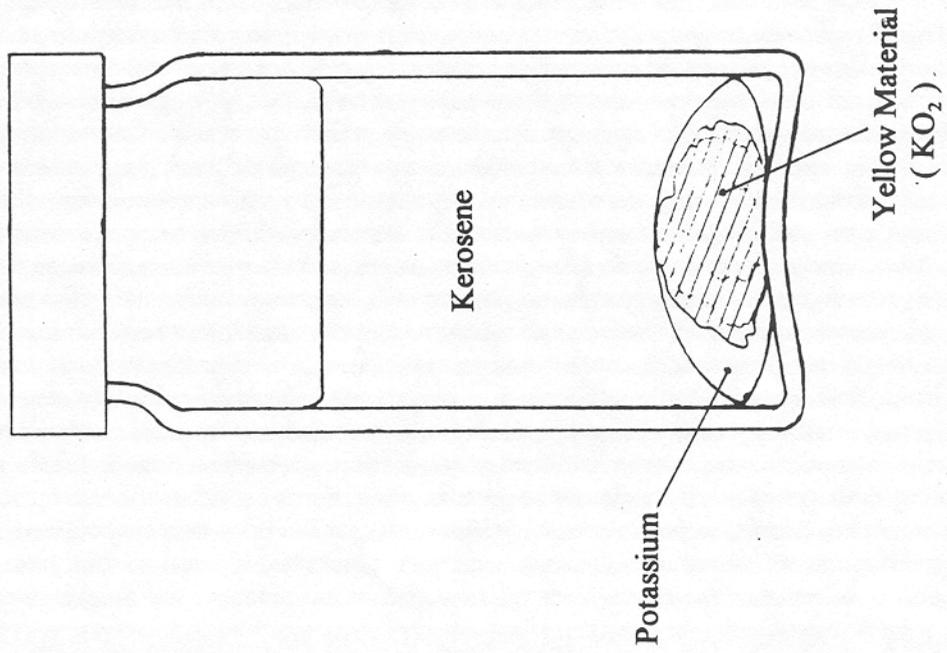
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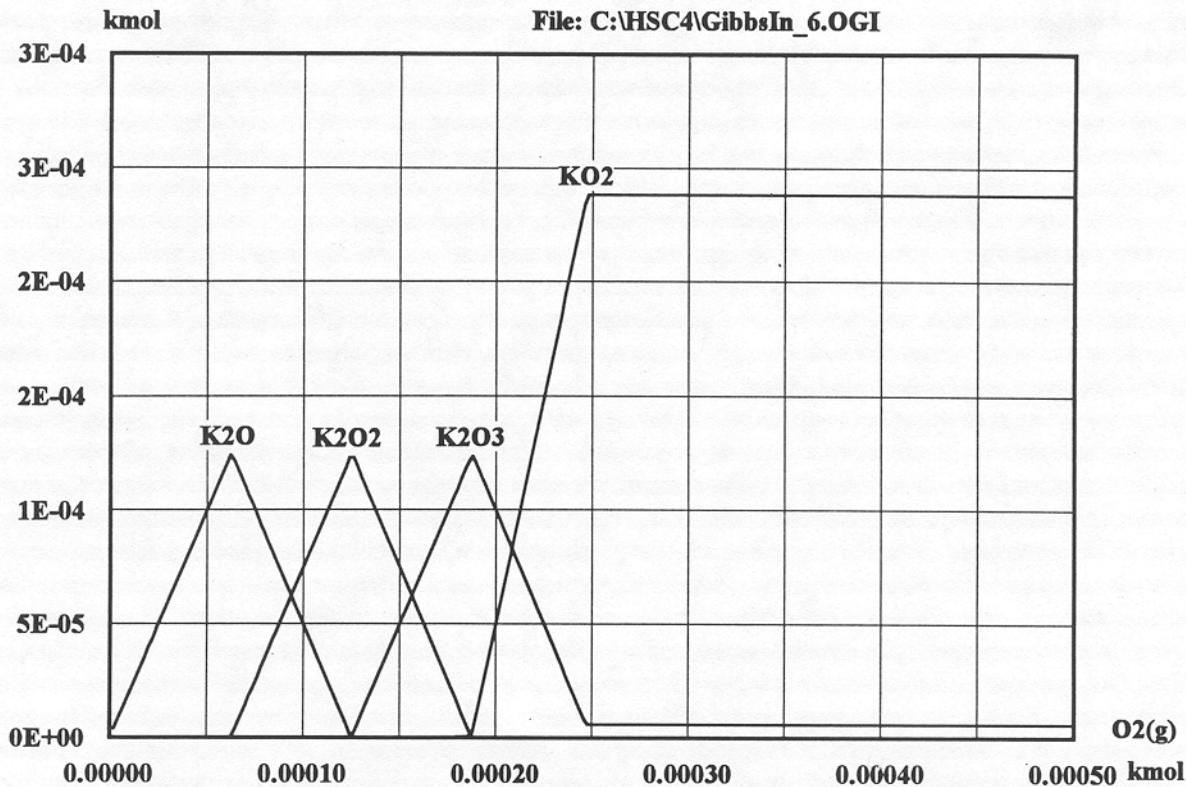
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Appendix Figure 1 - Two Views of 4-Oz Clear Bottle Containing Potassium and Kerosene



Temperature: 298.150 K
 Pressure: 1.000 bar
 Raw Materials: kmol
 K: 2.5000E-04
 O₂(g): 2.0000E-06

Figure 1 - Output of the HSC Chemistry program showing compounds in the K - O system

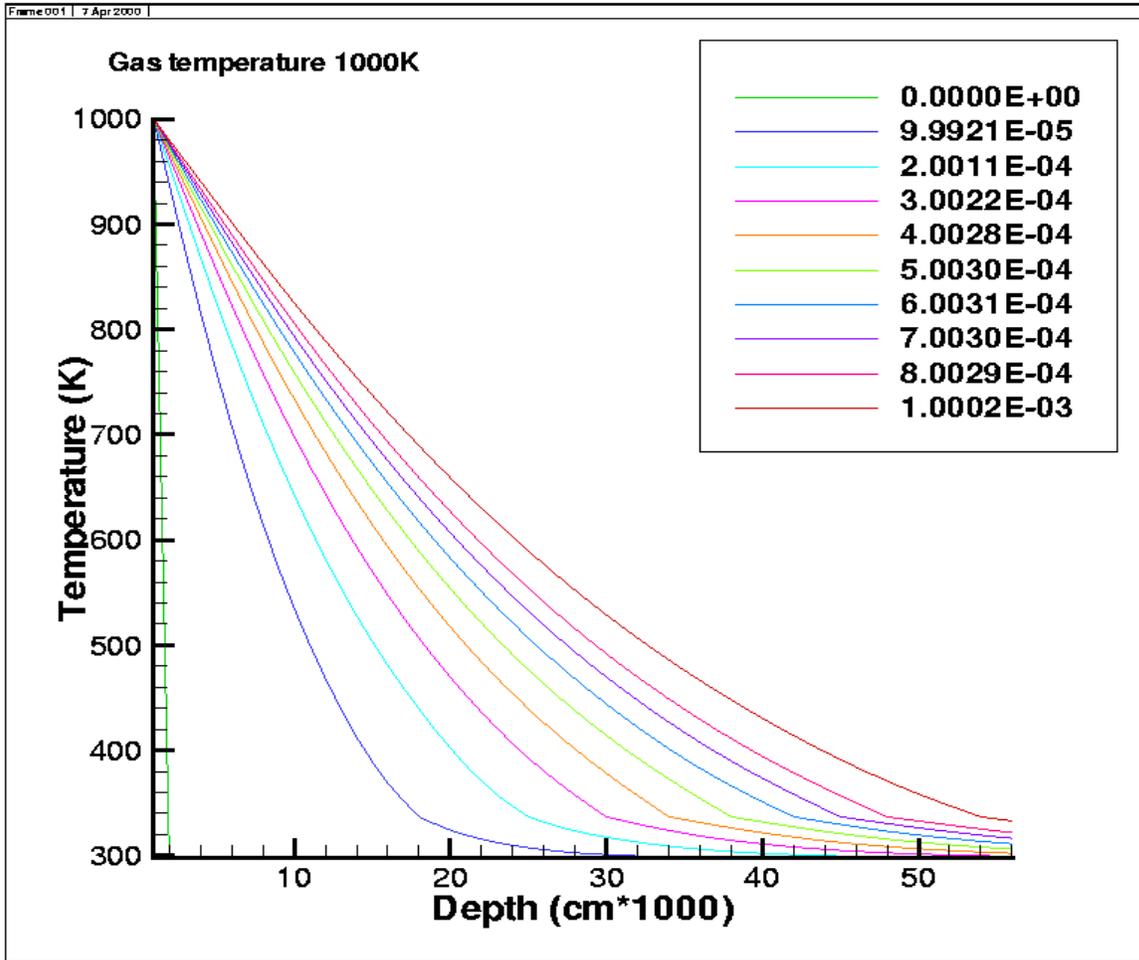


Figure 2 - Output of HEATING showing temperature-depth-time profile for K metal for 1000K

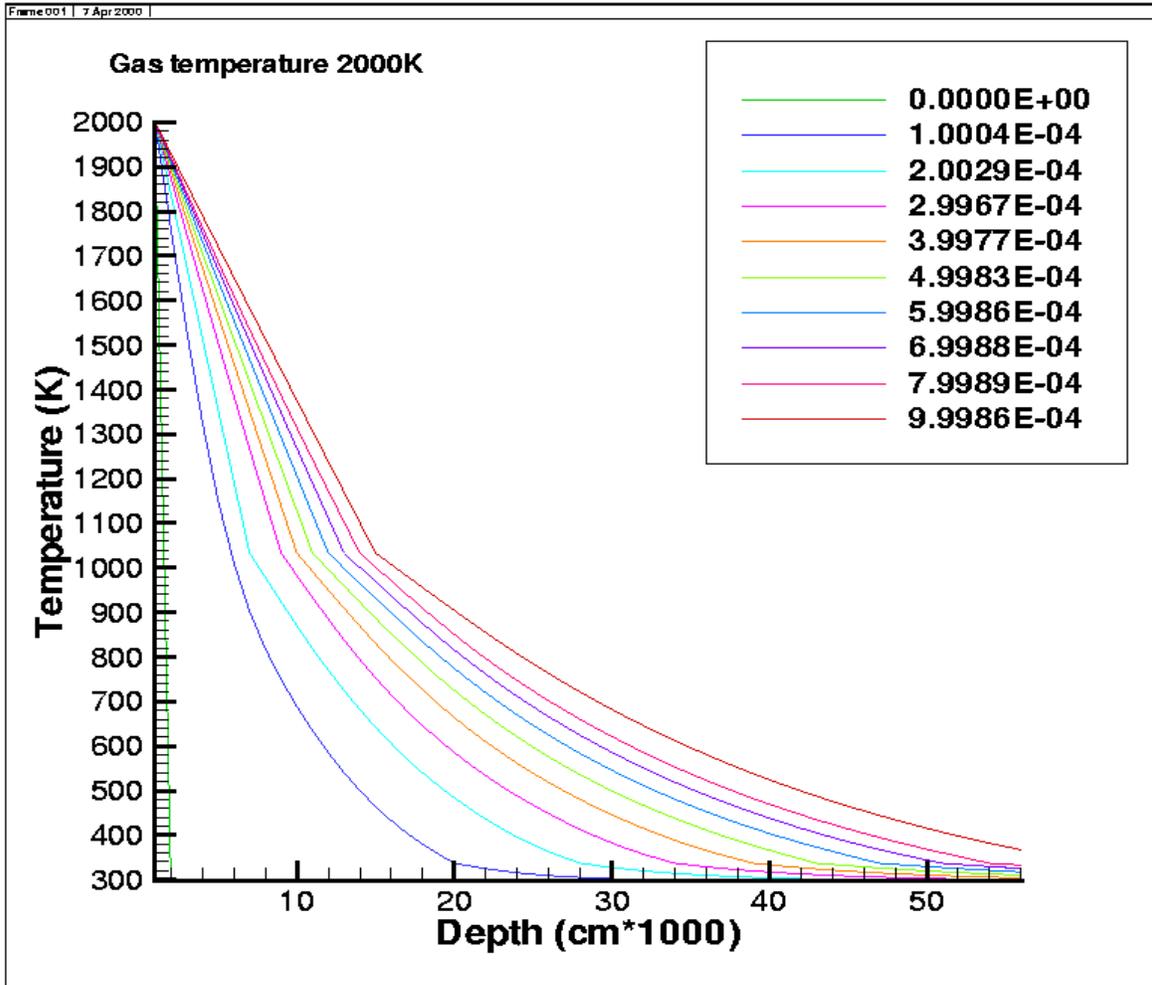


Figure 3 - Output of HEATING showing temperature-depth-time profile for K metal for 2000K

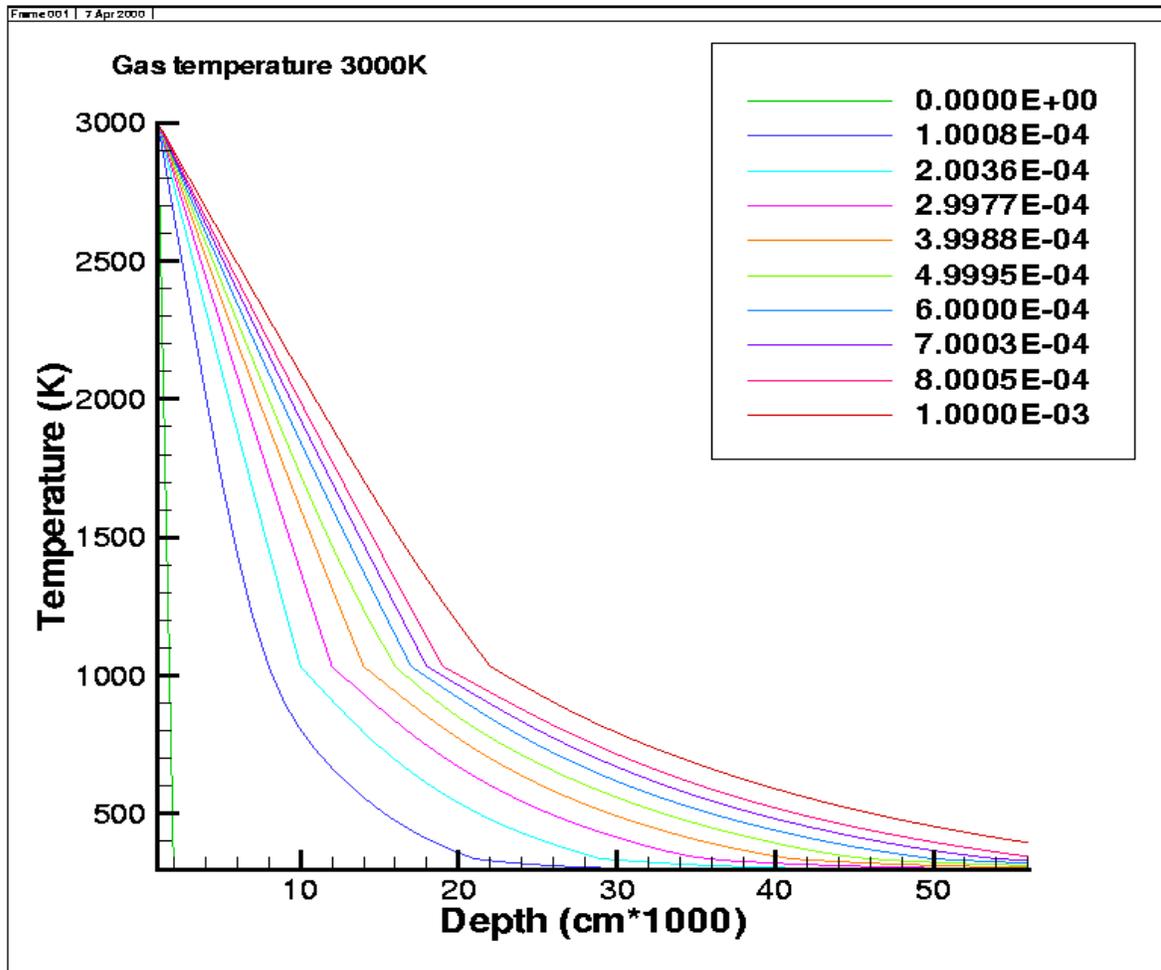


Figure 4 - Output of Heating showing temperature-depth-time profile for K metal for 3000K

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