~~CONFIDENTIAL~~

MDH

1

MITRE CONTROL NO.	COPY NO.(S)	CLASS	SP. CTRL	DOC DATE	PROJECT
JSE 82-0254	1W	~~C~~ U		April 1963	JASON

DOCUMENT TITLE

Radiation Escape From a High Altitude Fireball (U)

MITRE

Derived From: DD254, W15P7T-04-C-A203, Dated 1 February 2004 and Multiple Sources

~~Declassify On: OADR~~

13-M-4934

~~CONFIDENTIAL~~

[redacted]

~~CONFIDENTIAL~~

41B 1-1-63

MITRE CONTROL NO. JSE 82W00219
Date 3/82 | Copy 1W

INSTITUTE FOR DEFENSE ANALYSES

JASON DIVISION

Internal Note

RADIATION ESCAPE FROM A HIGH ALTITUDE FIREBALL (U)

~~DECLASSIFY ON: OADR~~

by

Keith A. Brueckner

[redacted]

~~DOWNGRADED AT 12 YEAR INTERVALS; NOT AUTOMATICALLY DECLASSIFIED. DOD DIR 5200.10~~

~~This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Section 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.~~

~~NATIONAL SECURITY INFORMATION Unauthorized Disclosure Subject to Criminal Sanctions~~

~~THIS DOCUMENT REGRADED CONFIDENTIAL AUTHORITY DOD ... BY~~ ... DATE 9-16-75

April 1963

IDA/HQ-63-1421

~~CONFIDENTIAL~~

[redacted]

[redacted]

~~CONFIDENTIAL~~

March 13, 1963

Radiation Escape from a High

Altitude Fireball

by

K. A. Brueckner

Using a previously established model[1] for the reradiation from a high altitude fireball, we found for the energy lost by radiation

$$\frac{Y_R}{Y} = \left(\frac{4}{3}\frac{\pi h_0^3 N_0}{Y}\right)^2 \left[\left(\frac{3}{2}+\frac{1}{4}\alpha\right)\alpha^{1/2} T_0^{3/2}\right]^2 \frac{1}{96}\int_{y_0}^{1}\left[\ln\left(\frac{3-y}{y}\right)\right]^4 (1-y)\,dy \qquad (1$$

with

$$y = e^{-R_+/h_0} \qquad (2$$

and y_0 the value corresponding to the maximum radius. The geometry of the radiating fireball was approximated by a sphere with diameter $D = R_+ + R_-$, with R_+ the distance of upward propagation of the radiation front, and R_- the distance of downward propagation. The condition for 100% efficiency for radiation escape was previously assumed to be

$$\frac{Y_R}{Y} \geq 1 \text{ for } y_0 \to 0 \qquad (3$$

We now investigate another approximation to determine the efficiency for reradiation. We suppose that as energy E_D per atom is trapped in molecular dissociation and is not reradiated sufficiently rapidly to have an appreciable thermal effect. The total energy so trapped is

$$Y_D = \int d r^3\, N(r) E_D \qquad (4$$

1. See Appendix A of Intercept X Working Paper X-19.

~~CONFIDENTIAL~~

[redacted]

We approximate this integral as before by

$$Y_D = \frac{4}{3}\pi \left(\frac{R_+ + R_-}{2}\right)^3 N_0 E_D \, \frac{e^{R_-/h_0} - e^{-R_+/h_0}}{\frac{R_- + R_+}{h_0}} \tag{5}$$

Energy conservation now requires that the reradiation stops when

$$Y_D + Y_R = Y \tag{6}$$

For convenience in evaluating Eq. (6), we introduce the change in variable in Eq. (1)

$$\ln \frac{z - Y}{Y} = s \tag{7}$$

and write

$$\ln \frac{z - Y_0}{Y_0} = a$$
$$\lambda = \frac{4}{3}\pi \lambda_0^3 E_D N_0 / Y \tag{8}$$

We also assume for constants in Eq. (1)

$$\alpha = 2$$
$$T_0 = 4 \text{ ev} \tag{9}$$
$$E_d = 2 \text{ ev}$$

Eq. (6) then becomes

$$1 = 0.75\, Y \lambda^2 \int_0^a ds\, s^Y e^{-s} \frac{1 - e^{-s}}{(1 + e^{-s})^3} \tag{10}$$
$$+ 0.250\, \lambda\, a^2 \frac{1 - e^{-a}}{1 + e^{-a}}$$

This equation takes on a simpler form in two limits:

$$1 = 0.784 \frac{(\lambda a^3)^2}{48} + 0.124 \lambda a^3 , \quad a \ll 1 \tag{11a}$$

$$1 = 0.784 \lambda^2 \left[24 - (24 + 24a + 12a^2 + 4a^3 + a^4) e^{-a} \right] + 0.240 \lambda a^2 , \quad a \gg 1 \tag{11b}$$

Eq. (11a) can be solved for λa^3, giving

$$\left. \begin{aligned} \lambda a^3 &= 4.84 \\ Y_R/Y &= 40\% \end{aligned} \right\} a \ll 1 \tag{12}$$

This result holds for a yield which is sufficiently small so that containment occurs, i.e., such that

$$Y \ll 0.20 \ \tfrac{4}{3} \pi h_0^3 \epsilon_0 \tag{13}$$

Eq. (11b) has been solved numerically for λ as a function of a, which also gives Y_R/Y as a function of λ. The results are given in Table I and in Fig. (1). The efficiency starts at 40% for low yield and starts to drop at $\lambda^{-1} = Y / \tfrac{4}{3} \pi h_0^3 \epsilon_0 = 1$, falling to 33% at $\lambda^{-1} = 3$, to 15% at $\lambda^{-1} = 10$, and to 3% at $\lambda^{-1} = 25$. Translated to yields and altitudes, the predictions are given in Table II.

These results are indicative of a change in efficiency. Since, however, they are only a model of the process, the quantitative results should not be interpreted too literally!

[redacted]

~~CONFIDENTIAL~~

TABLE I

Variation of λ^{-1} and Y_R/Y with a

a	λ^{-1}	Y_R/T	$\lambda^{-1} Y_R/Y$
1.00	0.415	.395	.164
2.00	1.63	.382	.621
3.00	3.30	.320	1.056
4.00	5.29	.249	1.318
6.00	10.3	.128	1.312
10.00	25.7	.0277	0.712

TABLE II

Variation of Y_R/Y with Altitude

	Y_R/Y			
	40%	33%	15%	3%
100 MT	< 34 km	42 km	51 km	57 km
4 MT	< 57 km	65 km	73 km	80 km

~~CONFIDENTIAL~~

[redacted]

[redacted] ~~CONFIDENTIAL~~

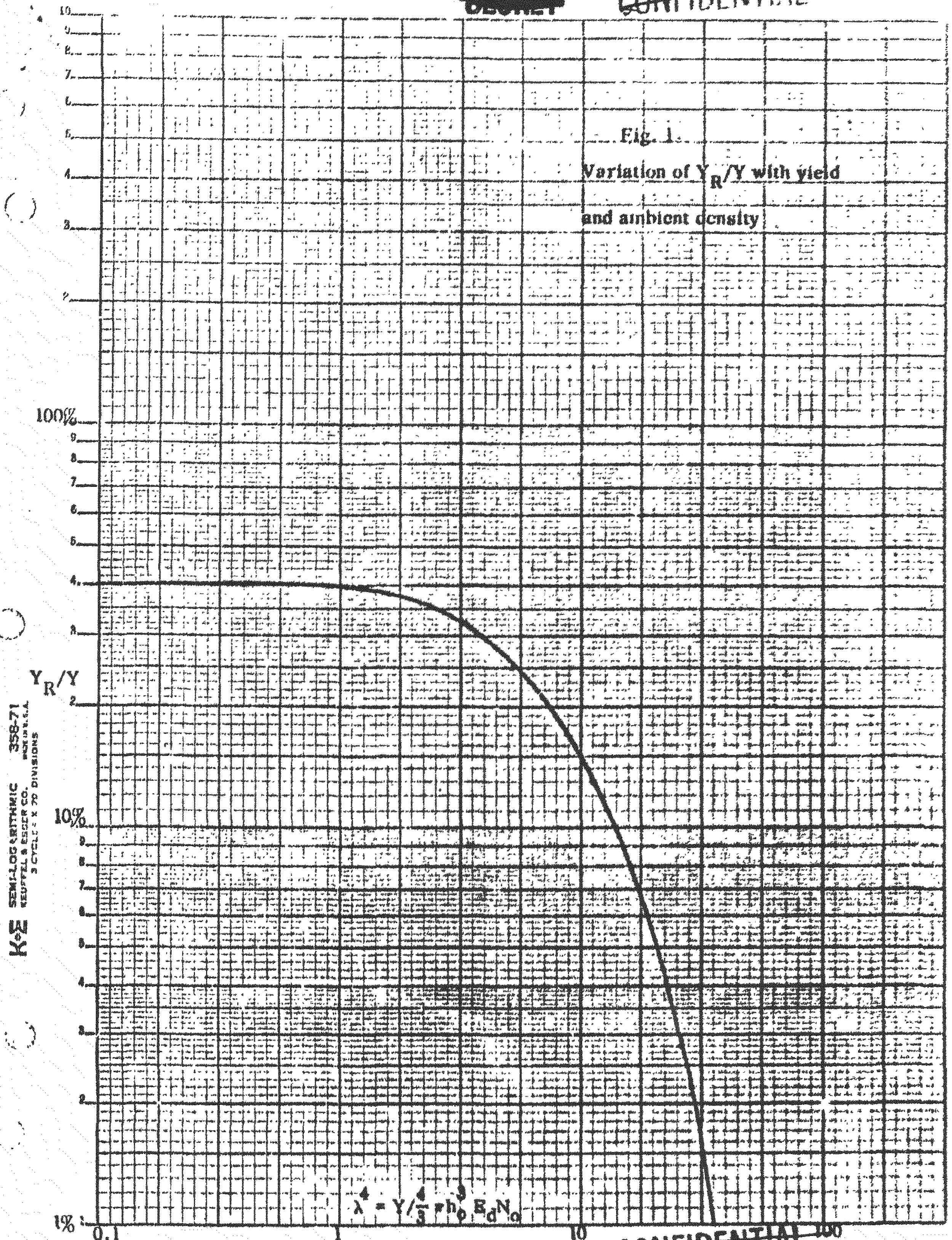


Fig. 1.

Variation of Y_R/Y with yield and ambient density

[redacted] ~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

Radiation Escape from a High altitude Fireball

K. A. Brueckner

Is earlier note available to reference? App. A of [illegible]

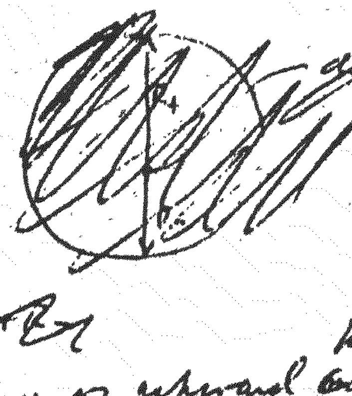
Using a previously established model (1) for the reradiation from a high altitude fireball, we found for the ~~thermal~~ energy lost by radiation

$$\frac{Y_R}{Y} = \left(\frac{\frac{4}{3}\pi h_0^3 N_0}{Y}\right)^2 \left[\left(\frac{3}{2}+\frac{1}{3}\alpha\right)\alpha^{1/2} T_0^{3/2}\right]^2 \frac{1}{96} \int_{y_0}^{1} \left(\ln\frac{1-y}{y_1}\right)^4 (1-y)\,dy \qquad (1)$$

with

$$y = e^{-R_+/h_0} \qquad (2)$$

and y_0 the ~~[illegible]~~ value of ~~[illegible]~~ corresponding to the maximum radius. The geometry of the radiating fireball was approximated ~~[illegible]~~ by a sphere with diameter $D = R_+ + R_-$,



~~$D = R_+ + R_-$~~

with R_+ the distance of upward ~~[illegible]~~ propagation of the radiation front, and R_- the distance of downward propagation.

~~We now modify these results~~

~~If Y_R/Y near [illegible] the result for 40-50 are [illegible]~~

~~CONFIDENTIAL~~

The condition for this 100% efficiency for thermal radiation escape was previously assumed to be

$$\frac{Y_R}{Y} \geq 1 \text{ for } y_0 \to 0 \qquad (3$$

We now ~~ex~~ investigate another approximation methodology to determine the efficiency for reradiation. We suppose that an energy E_D per atom is trapped in molecular dissociation and is not reradiated sufficiently to have an appreciable thermal effect. ~~[illegible]~~ The total energy so trapped is

$$Y_D = \int d\vec{r}\, N(r)\, E_D \qquad (4$$

we approximate this integral as before by

$$Y_D = \frac{4}{3}\pi \left(\frac{R_+ + R_-}{2}\right)^3 N_0 E_D \frac{e^{-R_-/h_0} - e^{-R_+/h_0}}{\frac{R_- + R_+}{h_0}} \qquad (5$$

$$= \frac{4}{3}\pi N_0 E_D \left(\ln \frac{2-y_0}{y_0}\right)^2 \frac{(1-y_0)}{4}$$

with $y_0 = e^{-R_+/h_0}$ delete

Energy conservation now requires that the reradiation stops when

$$Y_D + Y_R = Y \qquad (6$$

For convenience in evaluating Eq.(6), we introduce the change in variable in Eq.(1)

$$\ln \frac{z-4}{4} = s \qquad (7$$

and write

$$\ln \frac{z-40}{40} = a$$
$$\lambda = \frac{4}{3} \pi h \rho_0^3 N_0 \Gamma_d / Y \qquad (8$$

We also assume for constants in Eq.(1)

$$\alpha = 2$$
$$T_0 = 4 \text{ ev} \qquad (9$$
$$E_d = 2 \text{ ev}$$

Eq.(6) then becomes

$$1 = 0.784 \lambda^2 \int_0^a ds \; s^4 e^{-s} \frac{(1-e^{-s})}{(1+e^{-s})^3}$$

$$+ 0.250 \lambda \; a^2 \frac{1-e^{-a}}{1+e^{-a}} \qquad (10$$

This equation takes on a simpler form in two limits:

$$1 = 0.784 \frac{(\lambda a^3)^2}{48} + 0.125 \lambda a^3 \quad ; a \ll 1 \qquad (11a$$

$$= 0.784 \lambda^2 \left[24 - (24 + 24a + 12a^2 + 4a^3 + a^4) e^{-a} \right] \qquad (11b$$
$$+ 0.250 \lambda a^2 \quad , a \gtrsim 1$$

Eq.(11a) can be solved for λa^3, giving

$$\lambda a^3 = 4.94 \quad a \ll 1$$
$$Y_F / Y = 40\% \qquad (12$$

This result holds for a yield which is sufficiently small ...

that containment occurs, i.e. such that

$$Y \ll 0.20\left(\tfrac{4}{3}\pi h_0^3 E_0\right) \qquad (15$$

Eq. (11b) has been solved numerically for λ as a function of a, which also gives Y_R/Y as a function of λ. The results are given in Table I and in Fig (1). The efficiency starts at 40% for low yield and starts to drop at $\lambda^{-1} = Y/\frac{4}{3}\pi h_0^3 N_0 E_0 = 1$, falling to 33% at $\lambda^{-1} = 3$, to 15% at $\lambda^{-1} = 10$, and to 3% at $\lambda^{-1} = 25$. Translated to yields and altitudes, the predictions are given in Table II.

These results are indicative of a change in efficiency. Since, however, they are only a model of the process, the quantitative results should not be interpreted too literally!

~~CONFIDENTIAL~~

Table I — Variation of λ^{-1} and Y_R/Y with a

a	λ^{-1}	Y_R/Y	$\lambda^{-1} Y_R/Y$
1.00	0.415	.395	.164
2.00	1.63	.382	.621
3.00	3.30	.320	1.056
4.00	5.29	.249	1.318
6.00	10.3	.128	1.312
10.00	25.7	.0277	0.712

Table II

Variation of Y_R/Y with altitude

	Y_R/Y			
	40%	33%	15%	3%
100 MT	< 34 km	42 km	51 km	57 km
4 MT	< 57 km	64 km	73 km	80 km

~~CONFIDENTIAL~~