to employ and/or follow fundamental scientific and engineering principles and practice in the construction, operation and management of its facility.

H. APPLICANT'S FIRE RISK SCENARIO

In its scenario, Applicant assumed a fire in the 38,000 gallon containment area resulting from the rupture of four storage tanks, with emissions rate estimations based upon the calculation of the flame temperature, flame height, flame mass flow, flame residence time, and the destruction and removal efficiency. CD .97 at I-l through I-15 and Attachment 1 to Appendix I. Among the references cited by Applicant in support of its calculations were:

- Ellia, F. 1991. Explosion and Fire Analysis. ***In Risk Assessment and Risk Management for the Chemical Process Industry.*** Greenberg, H. R. and Cramer, J.J., eds. NY; Van Nostrand Reinhold, ("Ellia").
- Ndubizu, C.C., Ramaker, D.E., Tatem, P.A., and Williams, F. W. 1983. ***A Model of Freely Burning Pool Fires.*** Combustion Sci, and Tech. 31: 233-247. ("Ndubizu").
- MacKay, D., and Matsubu, R. S. 1973. ***Evaporation Rates of Liquid Hydrocarbon Spill on Land and Water. Can.*** J. of Chem. Eng. Vol. 51: 434-439. ("MacKay and Matsubu").
- Peters, M.S. 1984. Elementary Chemical Engineering. 2nd Ed. McGraw-Hill,, ("Peters").
- Fang, J. B. Analysis of the Behavior of a Freely Burning Fire in a Quiescent Atmosphere, National Bureau of Standards, February 1973. ("Fang")."

[10] Fang is cited in the Ndubizu reference.

CD .97.

1. Flame and Plume Temperature Estimates

A comparison of flame and plume temperature estimates by Applicant and those from the references provided by Applicant, show the inconsistencies, *infra*:

Flame and Plume Temperature Estimates.

DATA SOURCES	DIAMETER OF FLAME (CM)	FLAMETEMPERATURE (°K)
APPLICANT CD .97 AT I-8	1350	2108
NDUBIZU AT 241 GASOLINE FLAME	15 50 130	1395 1325 1165
NDUBIZU AT 241 GASOLINE PLUME	15 50 130	525 512 562
FANG at figure 4 HEPTANE	1350	FROM 695 TO 1180

As indicated above, the flame temperature estimate of Applicant was 2108 °K for a fire pool of 1350 centimeters diameter. Contrast Ndubizu, where the flame temperatures of gasoline fires of much smaller diameter (15, 50 and 130 centimeters) were observed at a lesser temperature, and where the flame temperature decreased as the pan size increased, to a low of 1165 °K for the combustion zone of the flame. The temperatures in the plume were considerably less at 562 °K.

Using figure 4 of Fang, quoted by Ndubizu, estimates of flame temperature for a heptane fire of 1350 centimeters diameter can be computed. Flame temperatures vary from 695 °K to 1180 °K depending on the position in the flame. As shown below", the temperature profile estimate varies from a low of 596 °K near the surface of the burning pool, up through a hot combustion zone with a maximum temperature of 1180 °K at 14 meters height, and then decreases rapidly at higher elevations. *Id.*

Temp	Height
695 K	34 M
804 K	27 M
918 K	20 M
1180 K	14 M
1102 K	11 M
596 K	approx. 00 M

After checking the references provided by Applicant in its risk assessment document, the Board finds a considerable difference between the flame temperature estimate propounded by Applicant and that of Applicant's references.

"A profile of the flame temperature of a burning pool of heptane, based upon Figure 4 of Fang. The pool radius Y_o was 6.75 meters and the ambient temperature was 293 °K.

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While it may not be a per se rule that Applicant and its cited references indicate the same estimate of flame temperature, it is, however, expected that if there is a twofold difference, an explanation be forthcoming. The information submitted by the Applicant in support of its application is therefore not found to be competent, credible information.

2. Residence Time Calculation Inconsistent Mass Flow

In order to calculate the residence time, Applicant conceptually pictures the fire as a flow of hot gases through a pipe [12]. Applicant's first step in the residence time calculation is to determine the rate of mass flow of hot gases through the hypothetical pipe, which Applicant estimated to be 1,980 lb/hr-ft^2, which is equivalent to 1,388,700 kg/hr. CD 97 at I-8. However, when Applicant calculated the flame temperature, Applicant noted total mass flow as 539,353 kg/hr, (CD .97 at I-6), *not as* 1,388,700 kg/hr.

This inconsistency in mass flows in the calculations of flame temperature and residence time, raises serious doubts regarding the competency and credibility of the Applicant's evidence in support of its application. Consistency of parameter values is one of the most basic requirements

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[12] The scenario assumes the containment area imposes dimensions on the rising plume of heated gases from the waste fuel retained within. The exchange of heat energy from the plume occurs through a film defined by the dimensions of the plume.

To calculate the residence time in the plume, the mass flow rate of the gas is determined by solving the equation (Peters) for heat transfer from turbulent flow inside a circular pipe.

CD .97 at I-8.

of credible engineering calculations. Inconsistency of parameter values was not discussed by Applicant in CD .97. In this case, the lack of credibility and competency is seen as Applicant's calculation requires one fire to have two mass flow rates at a given time, which is not physically possible.

More formally stated, the Board finds that this inconsistency of mass flow between the calculations of flame temperature and residence time is unacceptable, and reflects poor engineering judgement.

Furthermore, the Applicant's calculations violate the law of the conservation of matter which may be stated as follows: the total mass of materials entering a system in a fixed period of time must equal the mass of all materials leaving, plus any accumulation that has taken place. Peters at 8 and 9.

In the heat and mass balance of the flame temperature calculation, as set forth in tables of CD. 97, at 6 and Attachment 1 to Appendix I, the mass of materials entering the fire was balanced with the mass of materials leaving the fire. There was no accumulation factor.

However, when Applicant proceeded to the residence time calculation (CD .97 at I-S), the rate of mass of gas flowing through a hypothetical pipe is calculated. For the law of the conservation of matter to be satisfied, in the residence time calculation, the mass of matter entering the

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hypothetical pipe must equal the mass flowing through the pipe. The only discussion in CD .97 regarding the rate of mass entering the flame is found in the flame temperature calculation where the rate of fuel and air entering the flame are specified. CD .97 at I-6. As was previously noted, this flow rate was much less than Applicant's flow rate within the hypothetical pipe.

The Board finds that a violation of a principle as fundamental as the law of conservation of matter raises serious doubts regarding the competency and credibility of Applicant's evidence in support of its application.

3. *The* Use of Inconsistent Mass Flows is a Major Departure from the Methods of Applicant's References, Ndubizu and Fang

A major point in Applicant's reference, Ndubizu, was that all of the equations written to model a fire must be satisfied by a common set of values for each of the variables determined by the calculation. [13,14] This is in sharp contrast with Applicant's inconsistency in the value of

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[13] Ndubizu at 238 states:

> The current computer code was written such that only three equations [Eqs. (1), (2), and (12)] in the set are actually solved with Powell's algorithm for the three unknowns m_v, T_f, and T_p. However, at each iteration current values of m_v, T_f, and T_p are used to evaluate the rest of the equations. This is equivalent to solving these equations exactly at each iteration.

In Ndubizu's paper a total of 33 equations were solved simultaneously. Those equations included mass flow into the fire, mass flow of gasses out of the fire, flame temperature, plume temperature, flame height, and other parameters.

"See. also Fang, cited by Ndubizu, where in all equations written to model a fire were satisfied by a common set of values for each of the variables determined by the calculation.

parameters as different equations are solved.

The Board finds that such an abrupt departure from the methods of Applicant's references, without any discussion of why Applicant chose to disagree with Applicant's references, is a demonstration of the lack of competency and credibility of Applicant's evidence offered in support of its application. It is concluded that Applicant does not appreciate the importance of the basic concepts of consistency of parameter values and conservation of matter which were carefully followed in the Applicant's references.

4. Confusion Regarding the Definitions of Heat Transfer and Coefficient of Heat Transfer

When Applicant computed mass flow through a hypothetical pipe as a step in the flame residence time calculation, Board staff observed that Applicant demonstrated a lack of understanding of elementary concepts in heat transfer. Applicant's calculation of mass flow through a hypothetical pipe is stated as:

> The efficiency of combustion is generally taken to be a combination of temperature, turbulence and flame residence time. For the waste fuel fire, the residence time was calculated by considering the principles of convective heat transfer.
>
> The conceptual scenario assumes the containment area imposes dimensions on the rising plume of heated gases from the waste fuel retained within it. The exchange of heat energy from the plume occurs through a film defined by the dimensions of the plume.

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To calculate the residence time in the plume, the mass flow rate of the gas is calculated by solving the equation (Peters 1984) for heat transfer from turbulent flow inside a circular pipe:

$$h = \frac{0.0144C_p*G^{0.8}}{D^{0.2}} \qquad (10)$$

where:

h	=	gas-film coefficient of heat transfer,
C_p	=	heat capacity of air at constant pressure (Btu/lb-°F),
G	=	mass flow rate of gas ($lb/hr\text{-}ft^2$), and
D	=	equivalent diameter of spill (ft).

For free natural convection of gases, the equivalent expression is (Peters at 143):

$$h = k(dt)^{0.25} \qquad (11)$$

where:

dt	=	temperature difference between the plume and ambient air (°F), and
k	=	constant, depending on plume geometry ($0.27/D^{0.25}$,

Equations 10 and 11 may be combined and solved for the mass flow rate (G).

CD .97 at I-8 and I-9

The Board finds that external (natural convection) and internal (forced convection) heat-transfers coefficients for the flame cannot, in general, be equated. In fact, as will be shown later, this will result in a violation of the first law of thermodynamics. The procedure used for calculating G from equations (10) and (11) indicate a gross incompetence in performing heat-transfer calculations, and raised serious doubts regarding competency and credibility of Applicant's