Fission Product & Chemical Energy Releases During Core Melt Events in U-Al Research Reactors

by

R. P. Taleyarkhan
Oak Ridge National Laboratory
Oak Ridge, TN 37831-8045, USA
Tel: 615-576-4735; Fax: 615-574-0740

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This Presentation Will Highlight

- o Analysis & Modeling of Fission Product Releases From Heated Uranium-Aluminum Reactor Fuels

  - UAl (alloy and dispsersion); U_3O_8-Al, U_xSi_y-Al Fuels
  - Modeling of Burnup, Transient & Individual Species Releases
  - Correlation Library Development & Statistics

- o Modeling of Aluminum-Water Ignition

  - Modeling aspects
  - Key predictions and comparisons against data

Key papers summarizing above:

1) R. P. Taleyarkhan, "Analysis & Modeling of Fission Product Release from Heated Uranium -Aluminum Plate Type Reactor Fuels," Nuclear Safety Journal, Vol. 33-1, 1992.
2) S. N. Valenti, V. Georgevich, S. H. Kim and R. P. Taleyarkhan, "The Importance of Fragments Size Distribution on Underwater Aluminum Ignition," Proceedings of ANS, San Francisco, CA (11/93).

Table 1. Salient Aspects of Fission Product Release Experimental Programs

Institution (Researchers)	Fuel Type	Burnup (%)	Ambient	Temperature Range (K)	Heating Time (min)	Principal Species Investigated
HEDL (Woodley et al)	UAl4, U3O8	52	Air, Steam Argon	973 - 1373	2.5	Noble Gases, I, Cs, Te
ORNL (Parker et al)	UAl3	24	Air, Steam Helium	973 - 1373	2, 60	Noble Gases, I, Cs, Te, Ru
(Shibata et al)	Dispersed UAlx	62	Helium	< 973	30	Noble Gases
JAERI (Saito et al)	Fuels Dispersed in Al U3Si2-Al UAl U3Si2-U3Si-Al	23	Air	973 - 1373	60	Noble Gases, I, Cs, Te, Ru

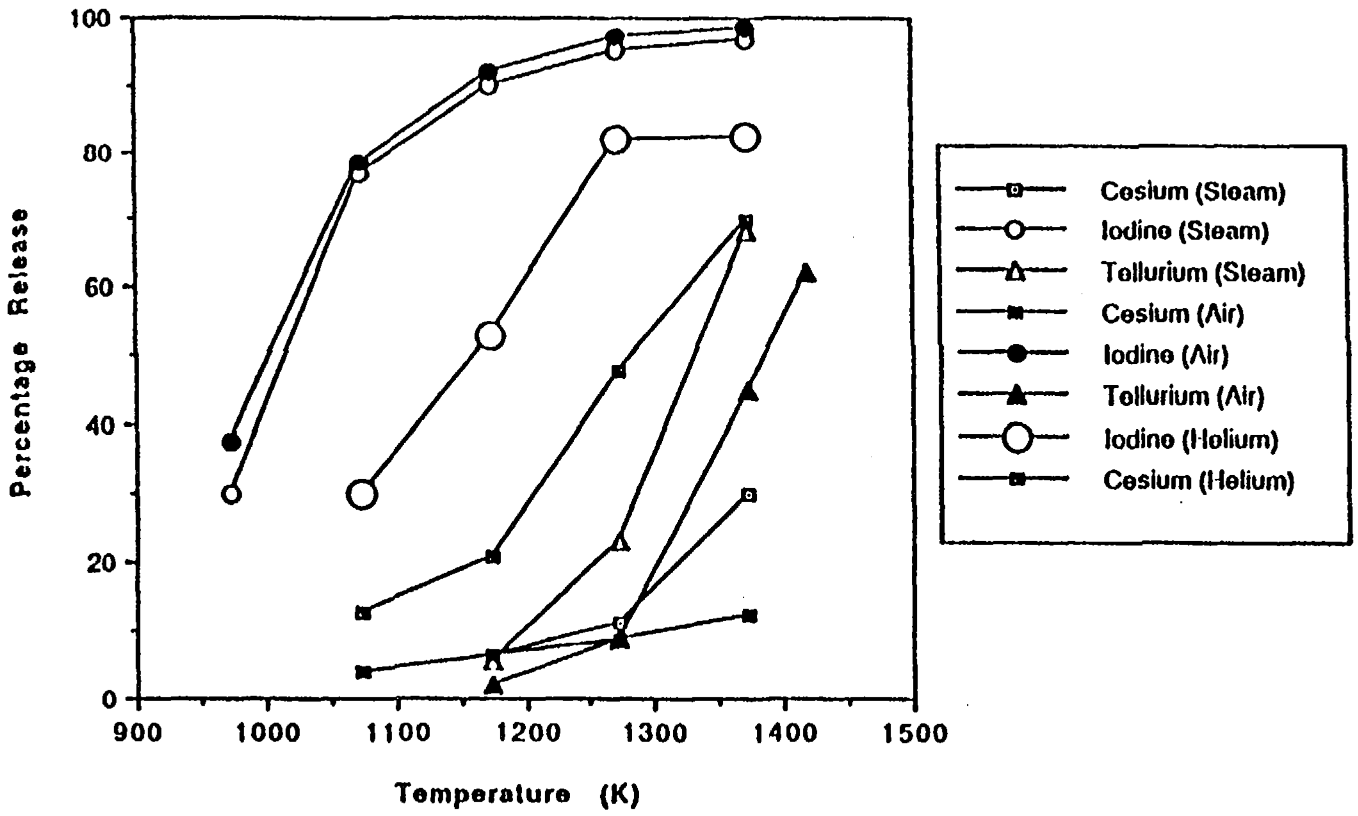


Figure 3. Variation of Volatile Fission Product Releases in Steam, Air, & Helium (ORNL Data)

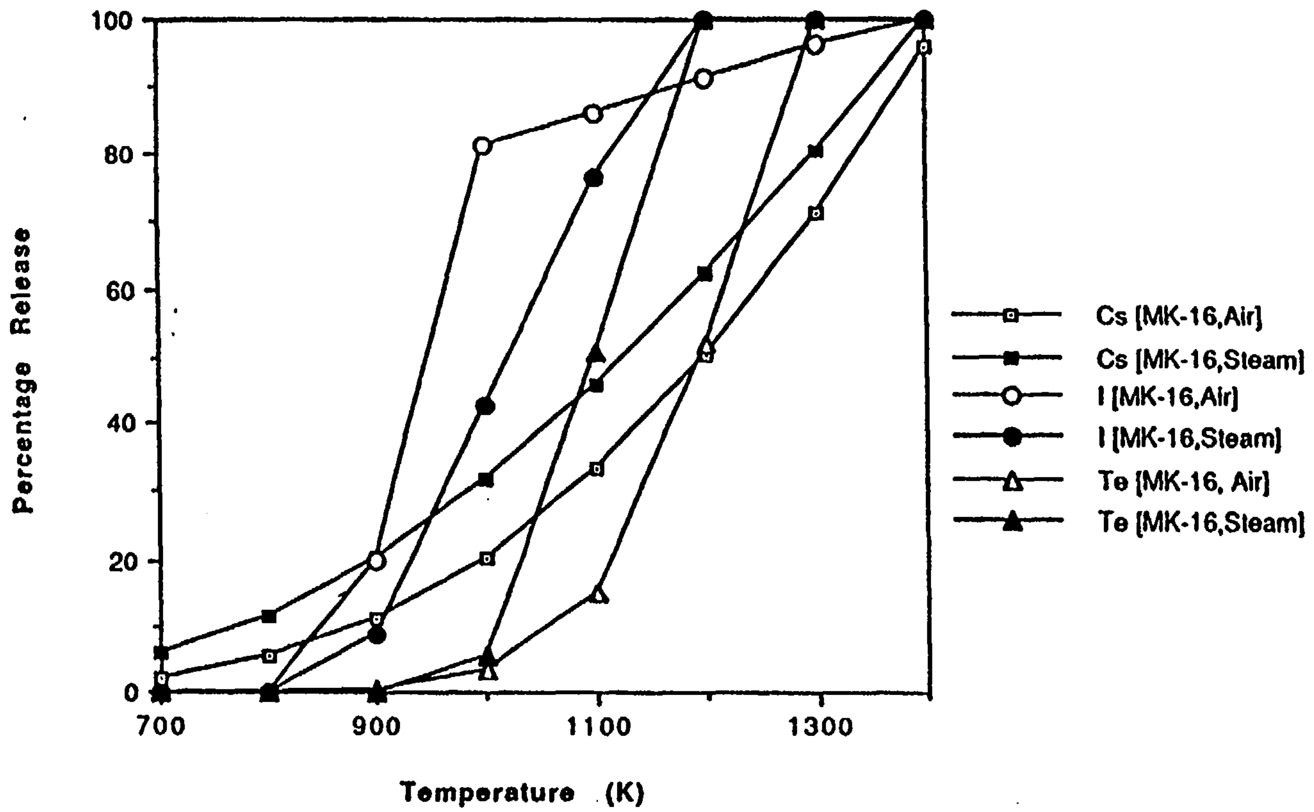


Figure C.16 Variation of Volatile Fission Products in Air & Steam [HEDL Data]

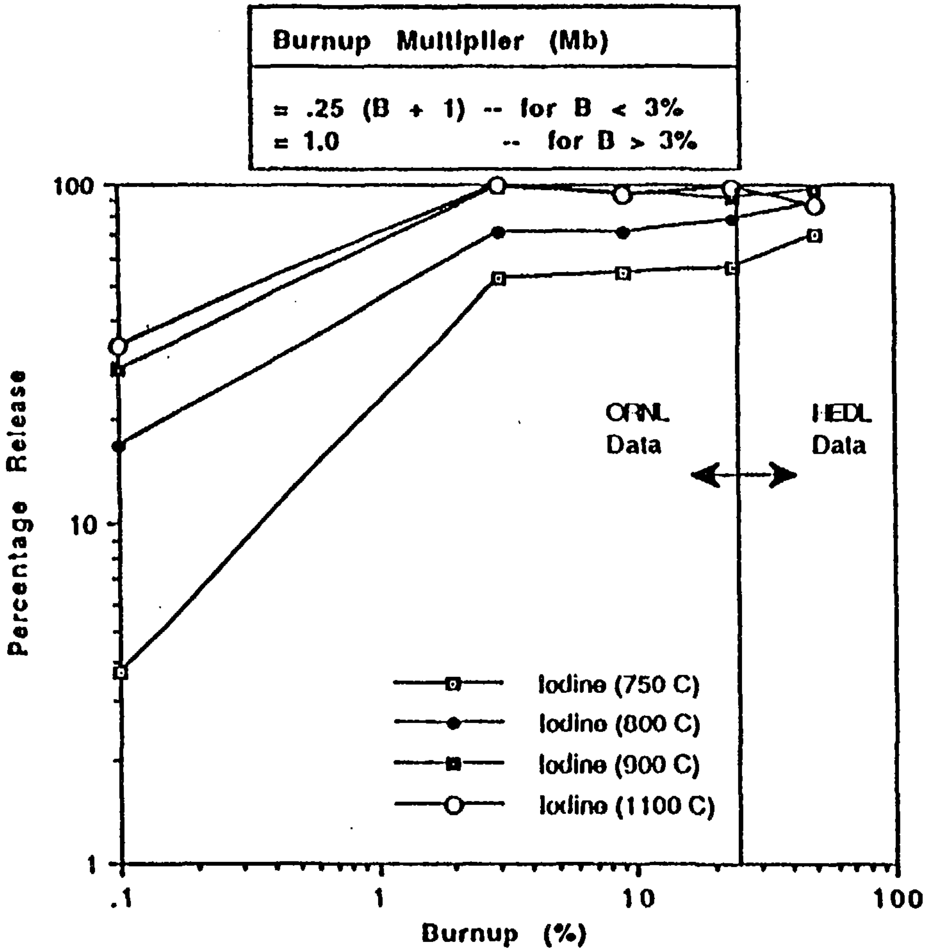
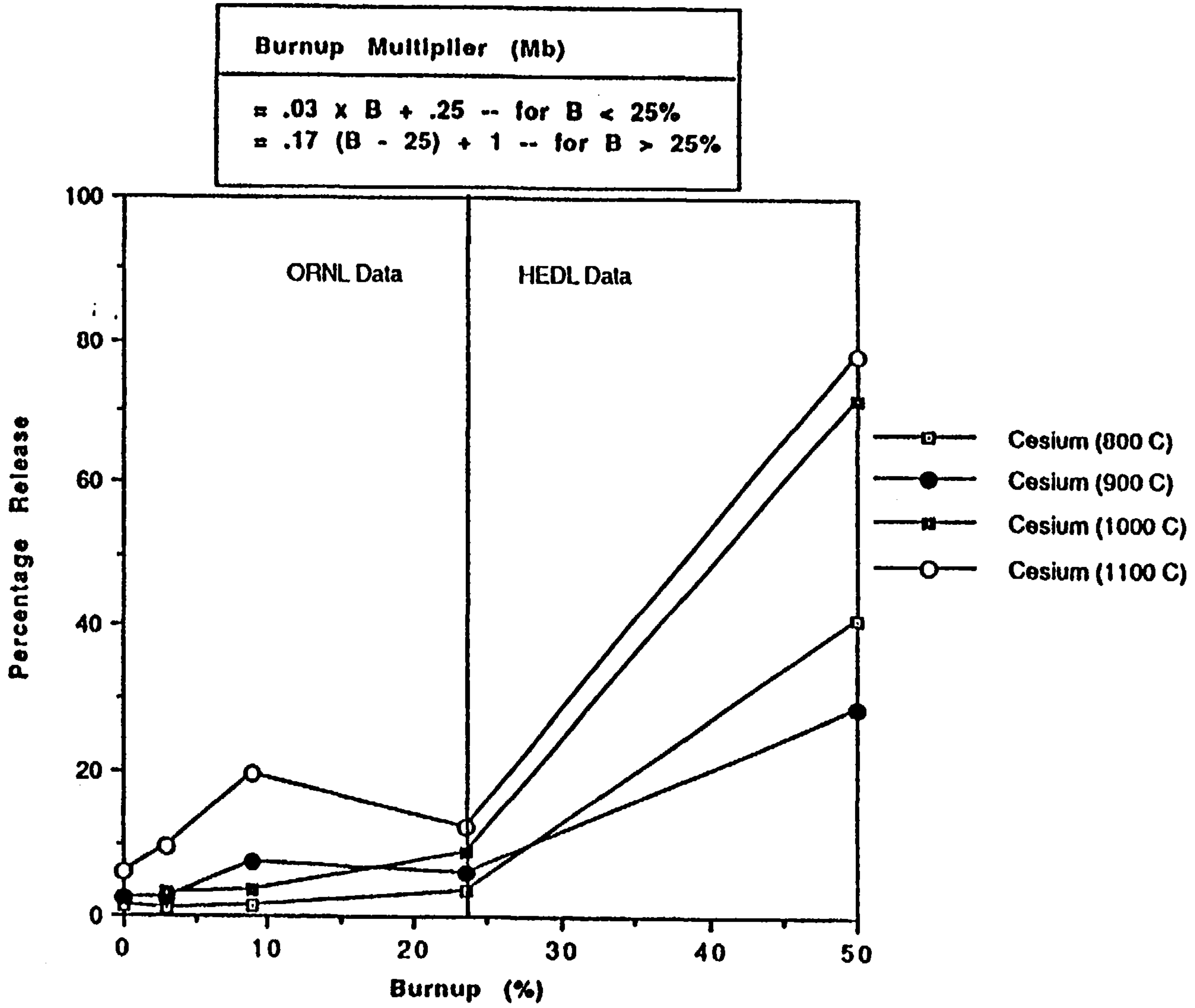


Figure C.13 Variation of Iodine Release From UAl Alloy Fuel With Burnup



Burnup Multiplier (Mb)

= .03 x B + .25 -- for B < 25%

= .17 (B - 25) + 1 -- for B > 25%

Figure C.12 Variation of Cesium Release From UAl Alloy Fuel With Burnup

TRANSIENT FISSION PRODUCT RELEASE

- NONE OF THE EXPERIMENTAL PROGRAMS STUDIED TRANSIENT EFFECTS
- STUDY OF ORNL DATA FOR UAL ALLOY FUEL INDICATED A UNIQUE & SIGNIFICANT DEPENDENCE OF RELEASE AMOUNTS WITH HEATING TIME
- IMPACT OF USING CONVENTIONAL CORSOR MODELING APPROACH
  - $R(t) = 1 - \exp(-kt)$ -- (rate constant 'k' based upon data taken over a certain time frame
  - Study to Evaluate Potential Inaccuracies in Using CORSOR Approach

TRANSIENT FISSION PRODUCT RELEASE

PRELIMINARY CONCLUSIONS

- Using Conventional CORSOR Approach
  - can give rise to significant over- or under-predictions
  - should be used carefully in codes such as MELCOR, CONTAIN, etc.

- Different Approach is Necessary for Capturing Time Dependence
  - Necessity of Additional Data for Guidance and/or Confirmation

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PRACTICAL CONSIDERATIONS

- Can Have Significant Impact On:
  - Evaluation of Delayed Release Effects
  - Evaluation of Core Melt Progression Phenomena (e.g., Structural Ablation)
  - Debris Coolability & Dispersion
  - Molten Core Concrete Interaction

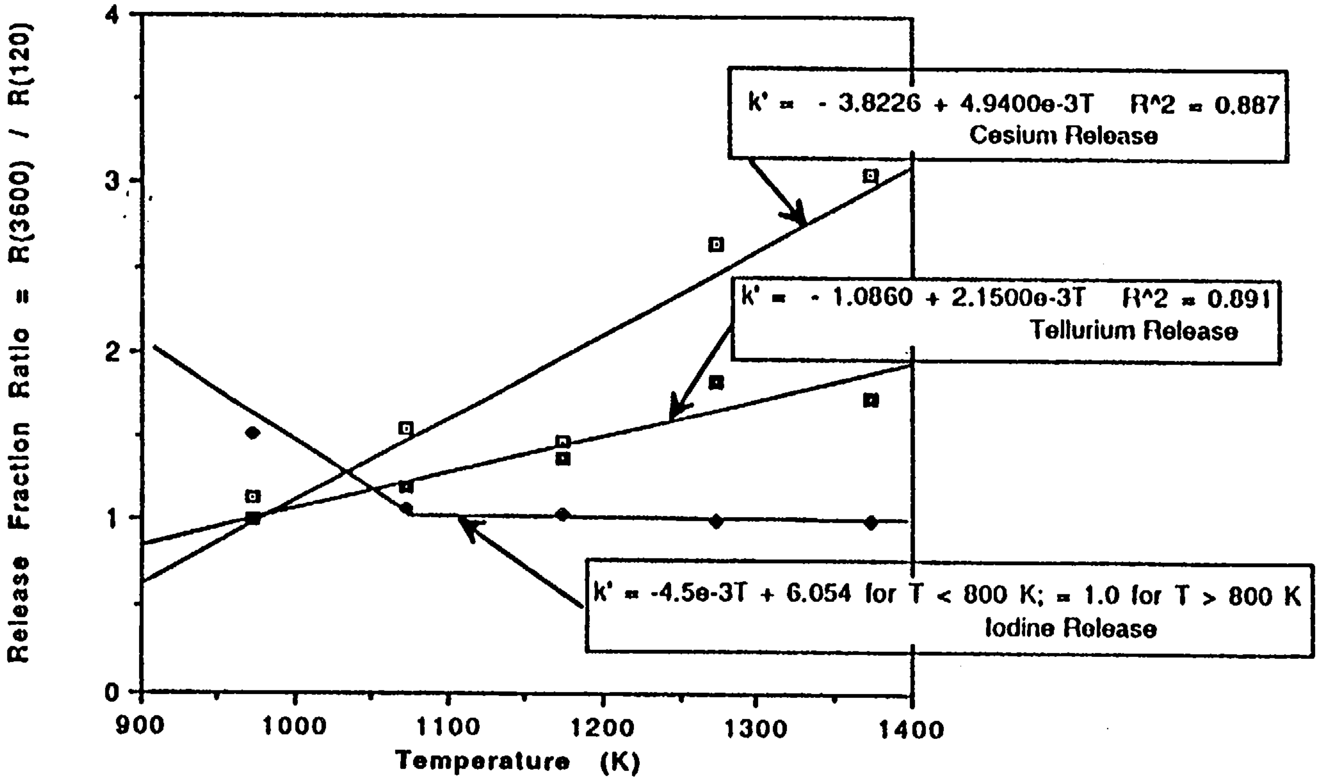

Figure 1. Variation of Ratio of Releases (60 min. to 2 min.) vs Temperature

GENERAL FORM OF CORRELATION

- FOR EACH FUEL TYPE & INDIVIDUAL FISSION PRODUCT SPECIES
  - R(t, T, Bu, Ambient) = f1(Bu, T) x f2(Ambient) x R(t, T)
  - f1(Bu, T) = Burnup Dependent Function
  - f2(Ambient) = Ambient Dependent Function or Multiplier
  - $$R(t,T) = \begin{cases} R(120,T) \text{ -- for } T< 120s \\ R(120,T) + R(120,T) \times [k'(T) - 1.0] \times (t-120)/3480 \text{ -- for } t>120s \end{cases}$$
  - k'(T) = R(3600,T) / R(120,T)

- ASSUMPTION
  - In the Absence of Prototypical Data Time and Temperature Dependence as Observed for UAl Alloy Fuel in Air Would be the Same for Other UAl Reactor Fuels and Different Ambient Conditions

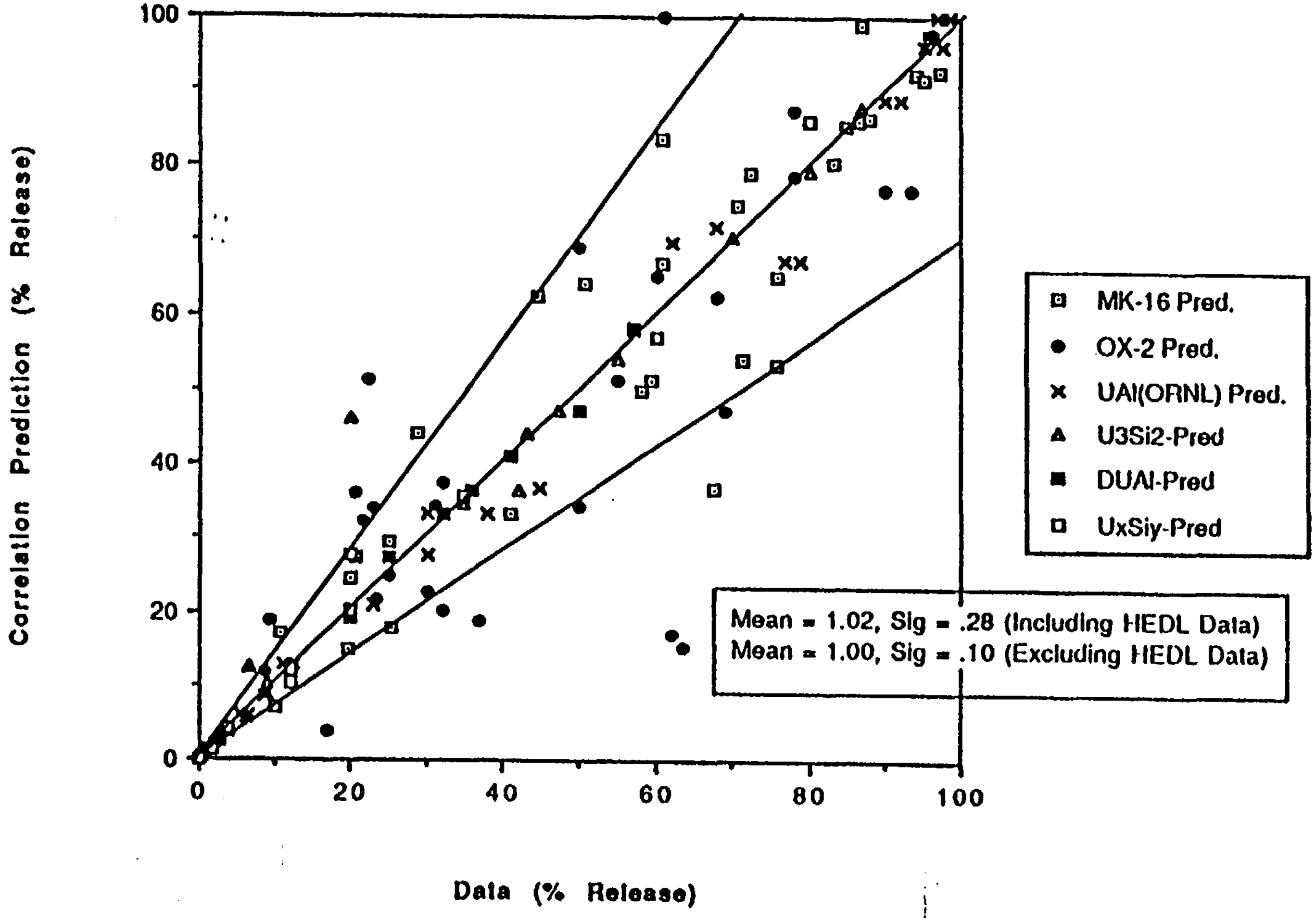

Figure C.74 Variation of Suggested Form (Combination) Correlation Predictions vs. Experimental Data (Overall Statistics)

SUMMARY & CONCLUSION

- AVAILABLE UAL-FUEL FISSION PRODUCT RELEASE DATA ANALYZED
  - Extensive Library of Correlations Developed For Predicting Releases Which May Vary With Time, Burnup, Ambient, & Fuel-Type Subject To Certain Assumptions
  - Correlations Developed In Various Forms For U-AL (Dispersed/Alloy), U_3O_8-AL (Dispersed) and Dispersed U_3Si_2-AL, & U_3Si-Al Fuels
  - Overall Statistics Quite Favorable

    (Mean = 1.0/1.04, Sig = .10/.28 - Excluding/Including HEDL Data)

- UNRESOLVED ISSUES & DATA NEEDS FOR BEST-ESTIMATE ANALYSES OF REACTORS USING U_3Si_2-AL FUEL

- COOPERATIVE EFFORTS
  - JAERI/ORNL Joint Development Program
  - Interactions With Other Programs
  - Integration With Other Safety & Design Issues

ORNL

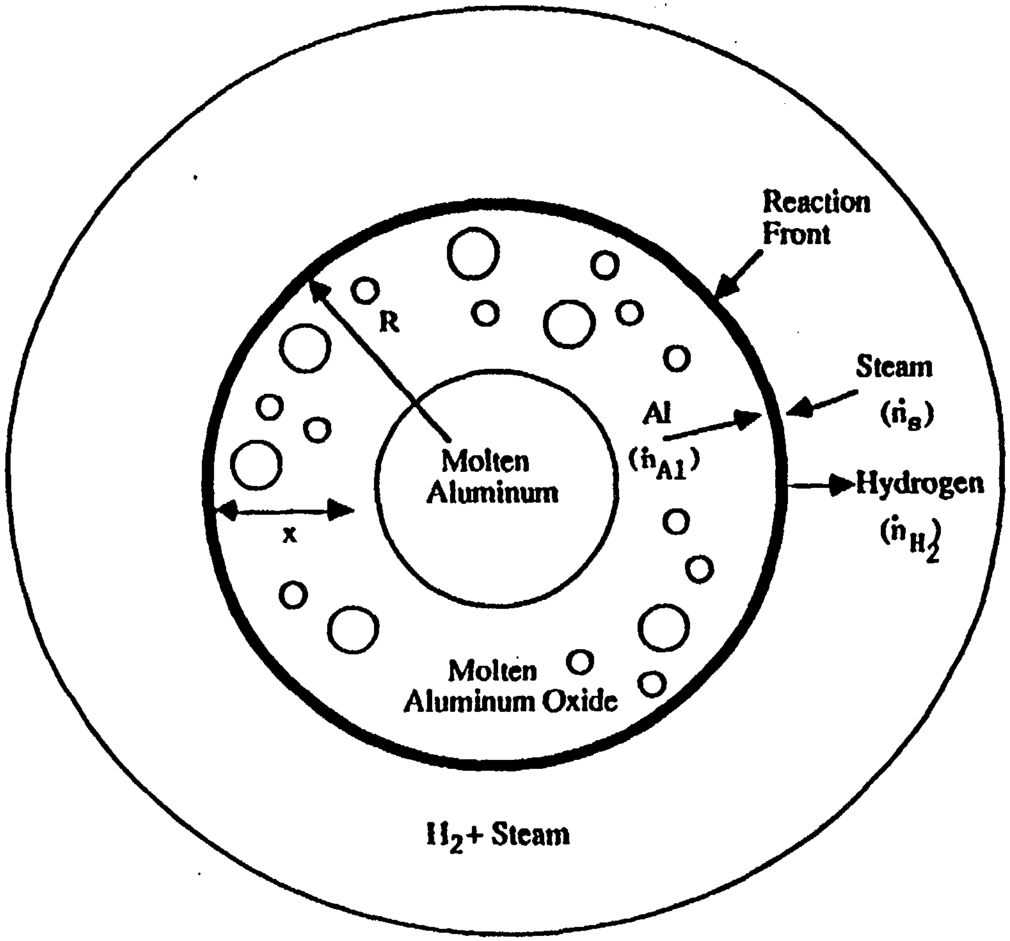

Figure 1. Molten Aluminum Droplet Model.

ORNL MODEL INCLUDES:

- ALUMINUM MASS BALANCE
- ALUMINUM OXIDE MASS BALANCE
- ALUMINUM ENERGY EQUATION
- ALUMINUM OXIDE ENERGY EQUATION
- DROPLET MOMENTUM EQUATION
- 2 CRYSTALLIZATION RATE EQUATIONS
- EXTENT OF REACTION CALCULATION

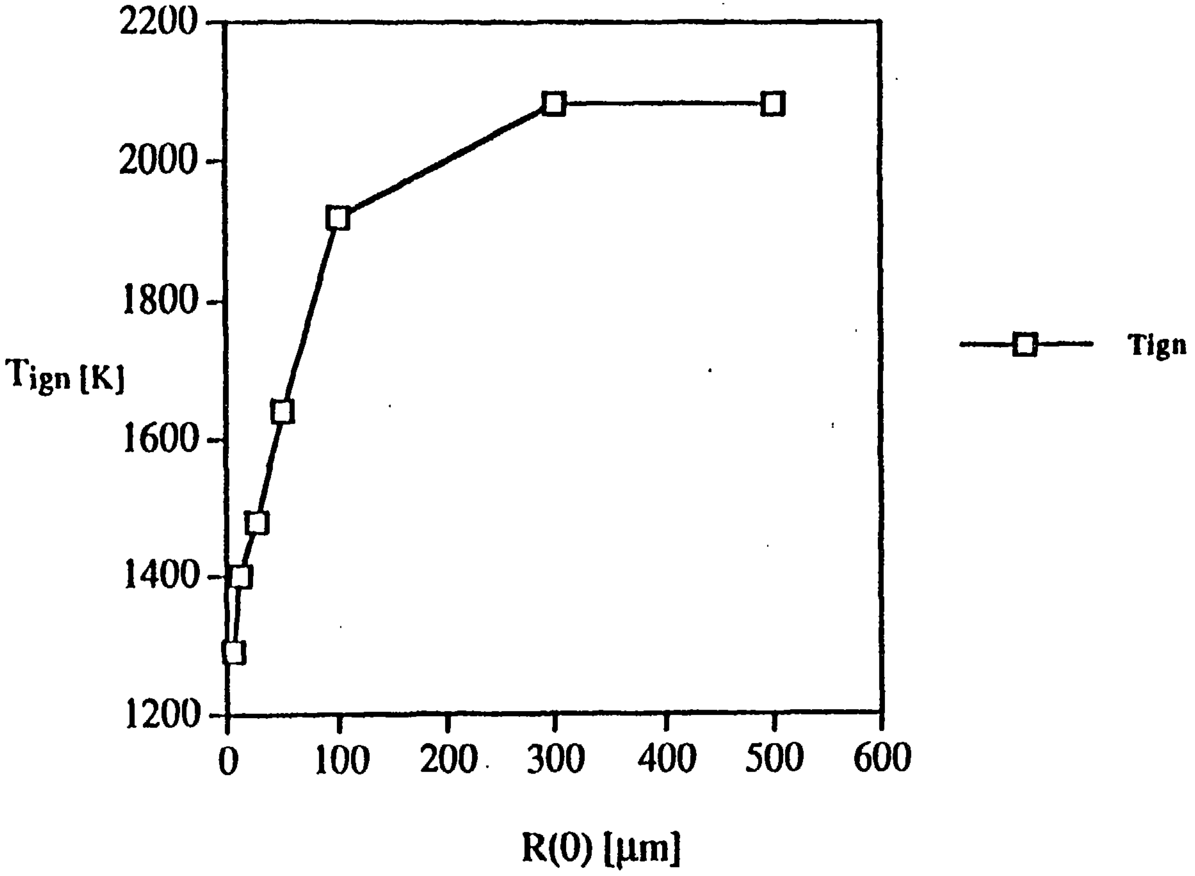

Figure 10. Ignition Curve (P_∞=10 MPa, v_∞=22 m/s).

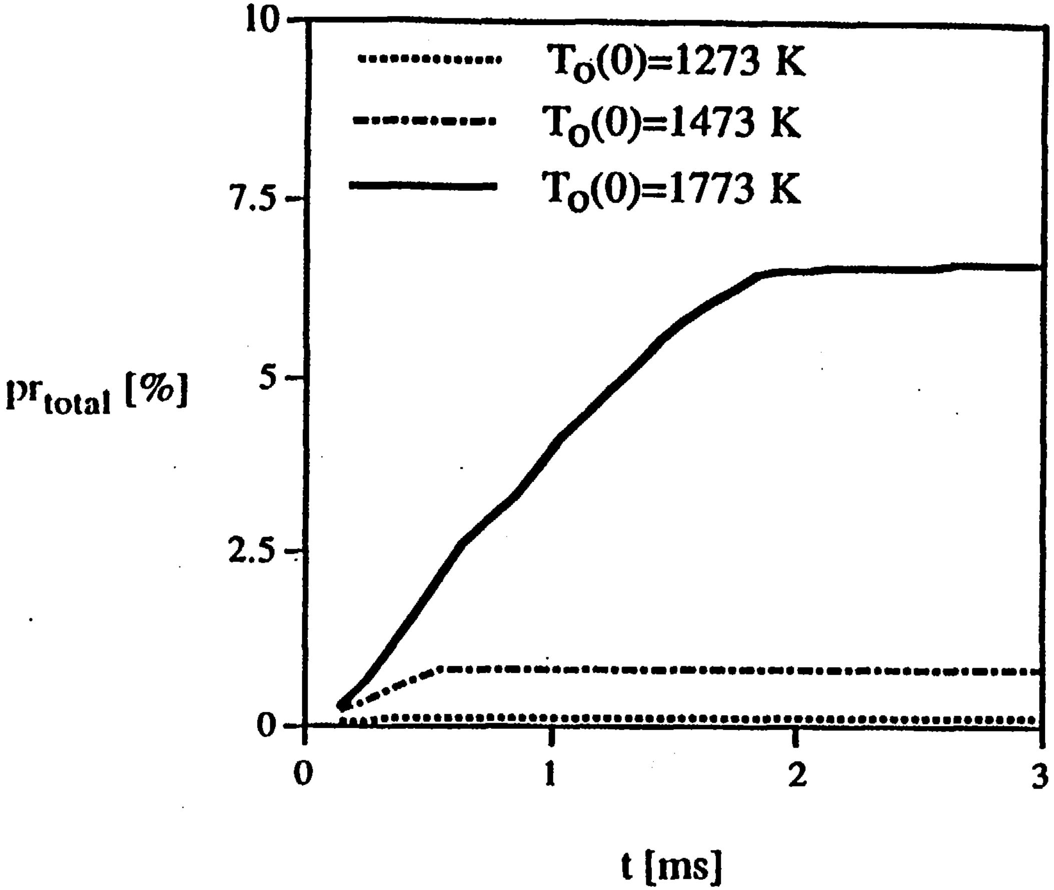

Figure 15. Total Extent of Reaction Predicted for Nelson's Experiments [4]
(P_∞=10 MPa, v_∞=22 m/s,σ_{fs}=0.49 N/m).

NELSON'S DROPLET EXPERIMENT

- SMALL-SCALE ALUMINUM/WATER EXPERIMENTS
- FOR LOW TEMPERATURES: THERMAL-TYPE INTERACTIONS OCCUR WITH BUBBLE COLLAPSE
- FOR THERMAL CASES (1273 K, 1473 K), NELSON ESTIMATED A RELATIVE VELOCITY OF 22 M/S.
- IGNITION-TYPE INTERACTION OCCURRED FOR 1773 K, WHEREIN 3 TO 6 % OF AL PARTICIPATED IN THE EXPLOSION.
- DEBRIS SIZE DISTRIBUTION WAS MEASURED.

CONCLUSIONS

- IMPORTANCE OF CAPTURING FRAGMENT SIZE DISTRIBUTION WAS DEMONSTRATED.
- RESULTS AGREE WITH NELSON'S OBSERVATIONS FOR ONSET OF IGNITION.
- EXTENT OF REACTION PREDICTED AGREES VERY WELL WITH NELSON'S OBSERVATIONS.
- THE NEED TO DEVELOP AN APPROPRIATE FRAGMENTATION MODEL WAS EVIDENT.
- EXTENSION TO LARGE-SCALE EXPLOSIONS REQUIRES FURTHER RESEARCH (ONGOING).