NUCLEAR PROPULSION TECHNOLOGY

ADVANCED FUELS TECHNOLOGY

WALTER A. STARK, JR.
LOS ALAMOS NATIONAL LABORATORY

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NTP REACTOR & FUEL REQUIREMENTS

REACTOR REQUIREMENTS		FUEL REQUIREMENTS
PERFORMANCE:		
Specific Impulse	>925 sec	Fuel Temperature > 3000K
Thrust-to-Weight	>8	Uranium Loading > 0.8 g/cc
Single Burn Time	1 hr	Thermal & Chemical Stability
Operating Life Time	10 hr	Low Diffusion Rates
Restart s	>10	Thermal Shock Resistance
SAFETY:		
ALARA radiation		FP retention
Large margin to failure		High Melting Point
Redundancy		Robust Fuel Elements
Fast restart		Thermal Shock Resistance

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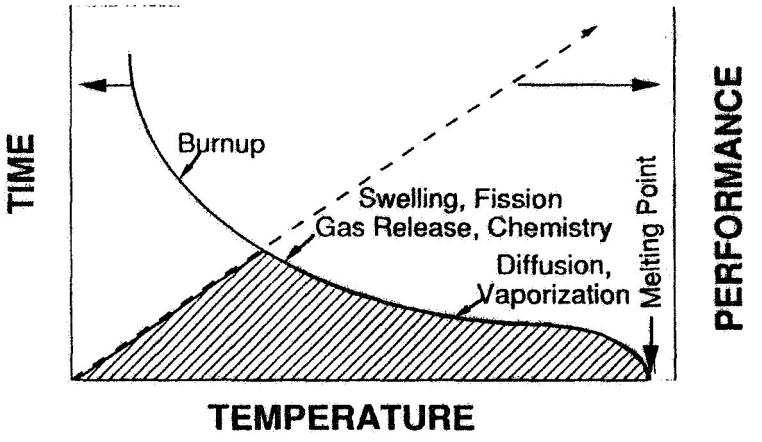
NUCLEAR PROPULSION TRADE-OFFS



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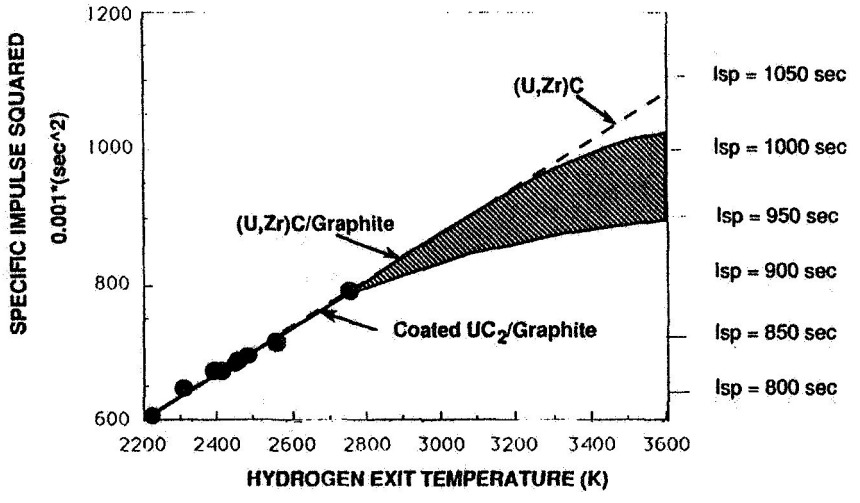
PROPULSION EFFICIENCY AND TEMPERATURE



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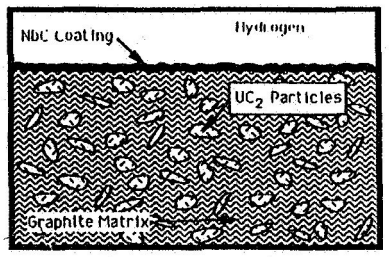
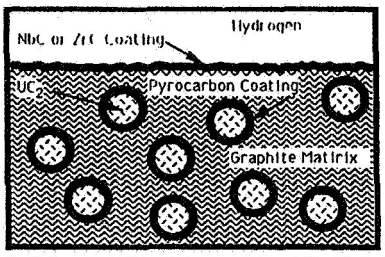
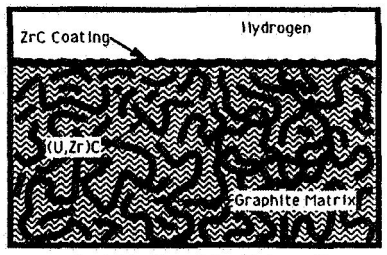
ROVER FUEL TYPES



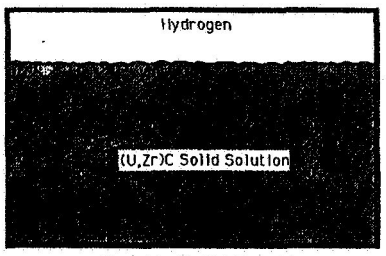
UC_2 Particles/Graphite Matrix



PyC Coated UC_2 Spheres/Graphite Matrix



Carbide/Graphite Composite



Carbide Solid Solution

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URANIUM FUEL COMPOUNDS

Property	UO_2	UC	UC_2	UN	$U_2Zr_{.8}C_{.99}$
Density, g/cc	10.96	13.63	11.68	14.32	8.01
U Density, g/cc	9.66	12.97	10.60	13.52	2.88
Melting Point, K	3100	2775	2710	3035*	3350
Thermal Expansion, 10^{-6} / K (@ 1273 K)	10.1	11.2	12.0	8.9	7.6
Thermal Conductivity, W/cm K (@ 1273K)	0.035	0.23	0.07	0.25	0.3

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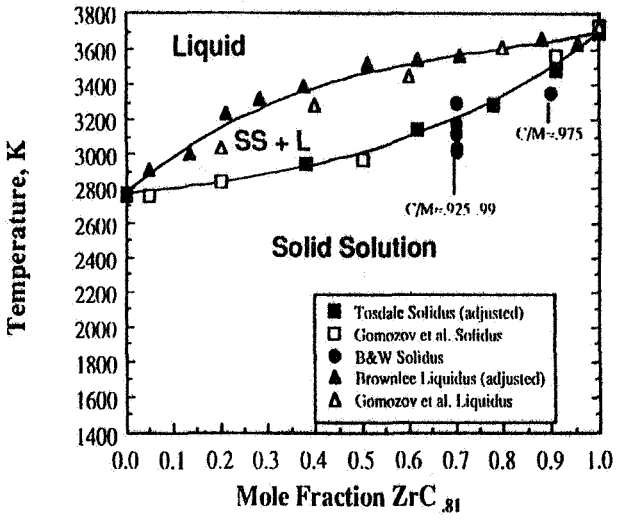
UC-ZrC PSEUDO-BINARY PHASE DIAGRAM



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MAJOR SOURCES OF DATA U-Zr-C PHASE DIAGRAM

Uranium - Carbon Binary
Uranium Carbide - Zirconium Carbide Pseudo-Binary
Uranium Dicarbide - Zirconium Carbide Pseudo-Binary
Zirconium - Carbon Binary
Calculations - Chang Formulation
- Butt and Wallace

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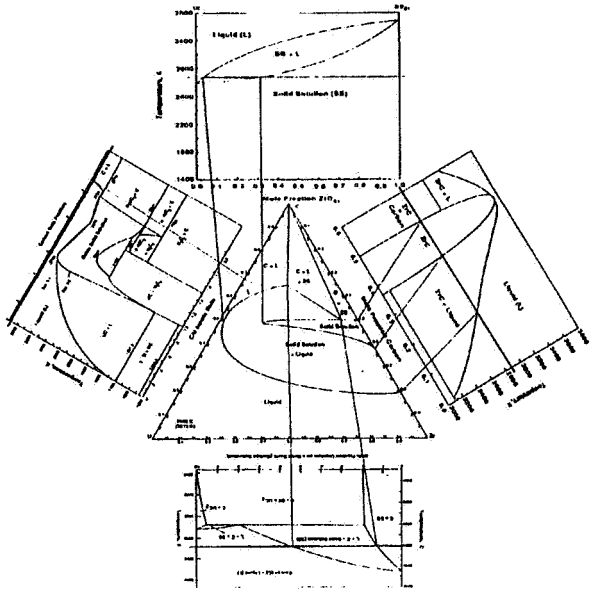
PHASE DIAGRAM "OPTIMIZATION"



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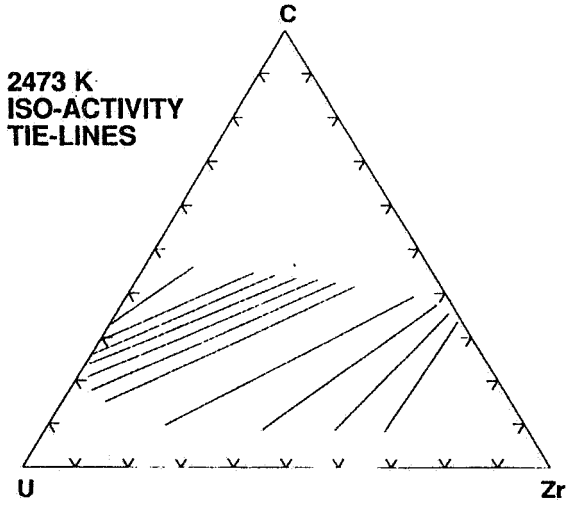
SOLIDUS - LIQUIDUS CALCULATION



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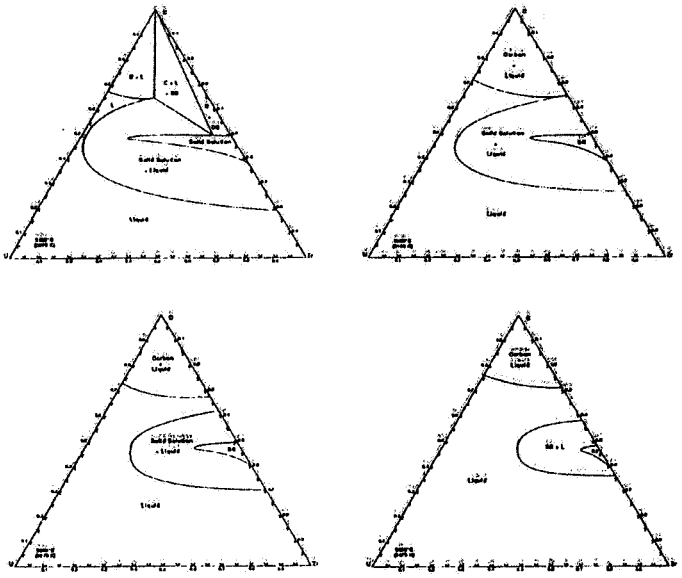
U-Zr-C ISOTHERMAL SECTIONS



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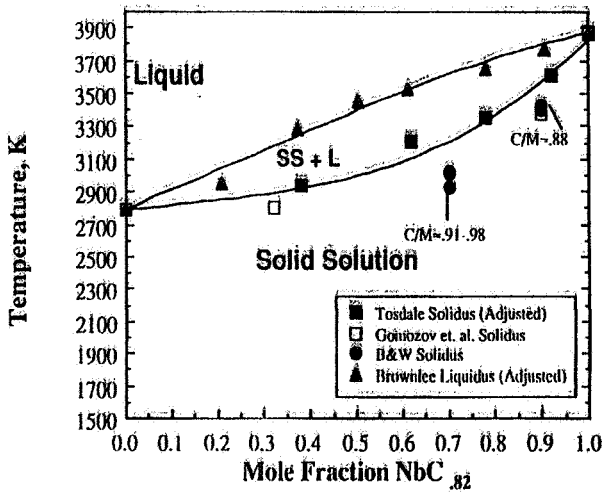
UC-NbC PSEUDO-BINARY PHASE DIAGRAM



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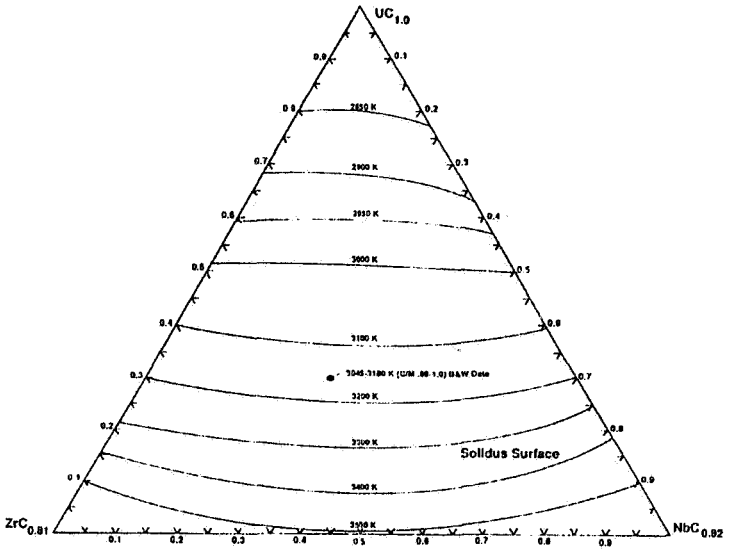
UC-NbC-ZrC PSEUDO TERNARY SYSTEM



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MELTING POINT EXPERIMENTS

SAMPLE FABRICATION
- **COMPOSITION**
- **FABRICATION**

MEASUREMENT

ANALYSIS

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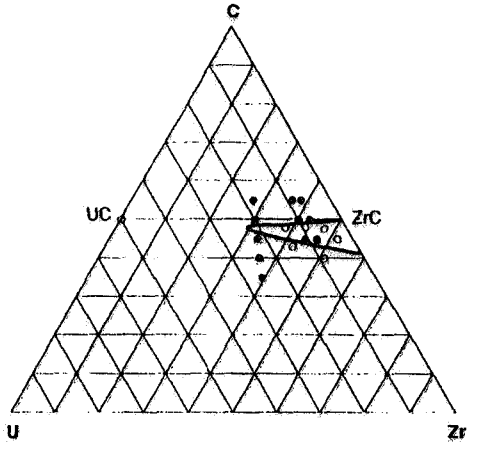
PRELIMINARY MELT POINT COMPOSITIONS



U-Zr-C Ternary Diagram
3273 K ISOTHERMAL SECTION

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SAMPLE FABRICATION TECHNIQUES

COLD PRESS, REDUCE, AND SINTER

ARC MELT

COMBUSTION SYNTHESIS

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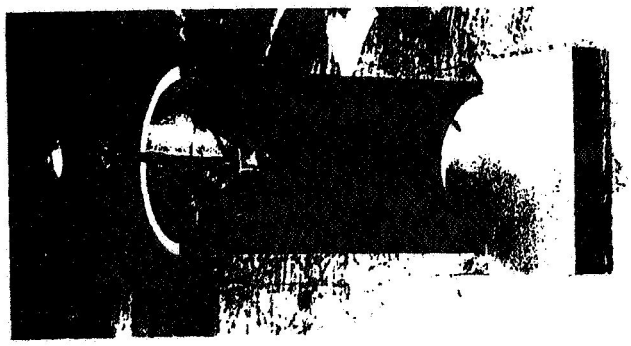
Meltpoint Setup



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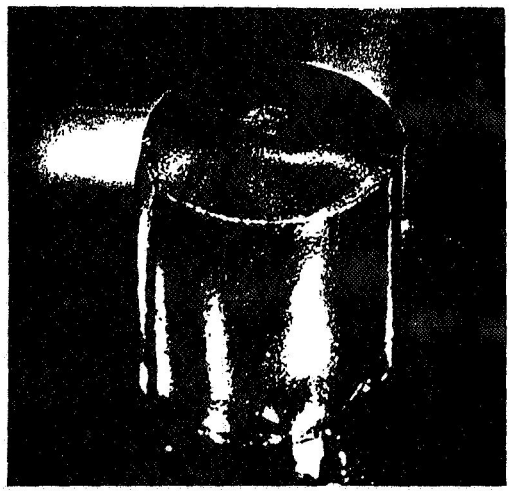
Post-Melt Sample



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MEASURED MELT POINT COMPARISON

Composition	Observed Melt Pt., K	Literature Value, K	Variance, K
$UC_{1.0}$	2806	2793	+13
$UC_{1.4}$	2633	2673	-40
$U_{.4}Zr_{.6}C_{1.2}$	2683	2673	+10
$U_{.4}Zr_{.6}C_{1.2}$	2655	2673	-18

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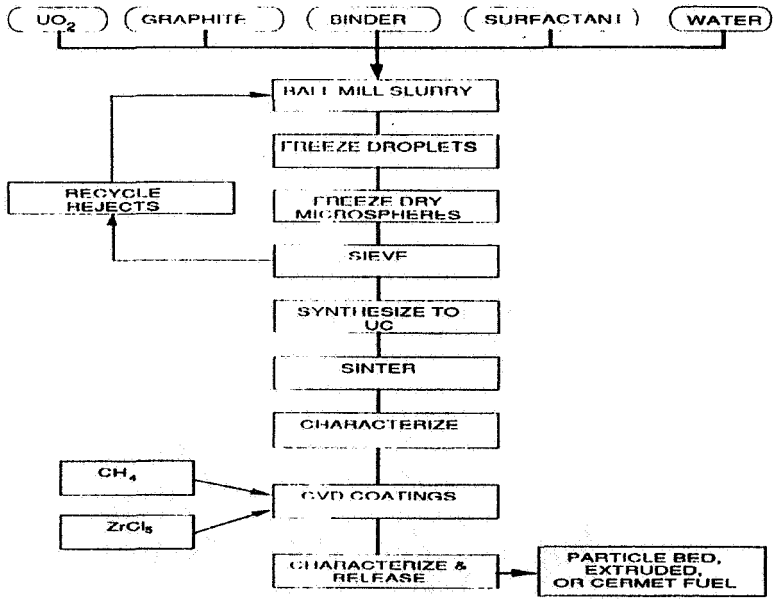
CRYOCHEMICAL FUEL PROCESSING



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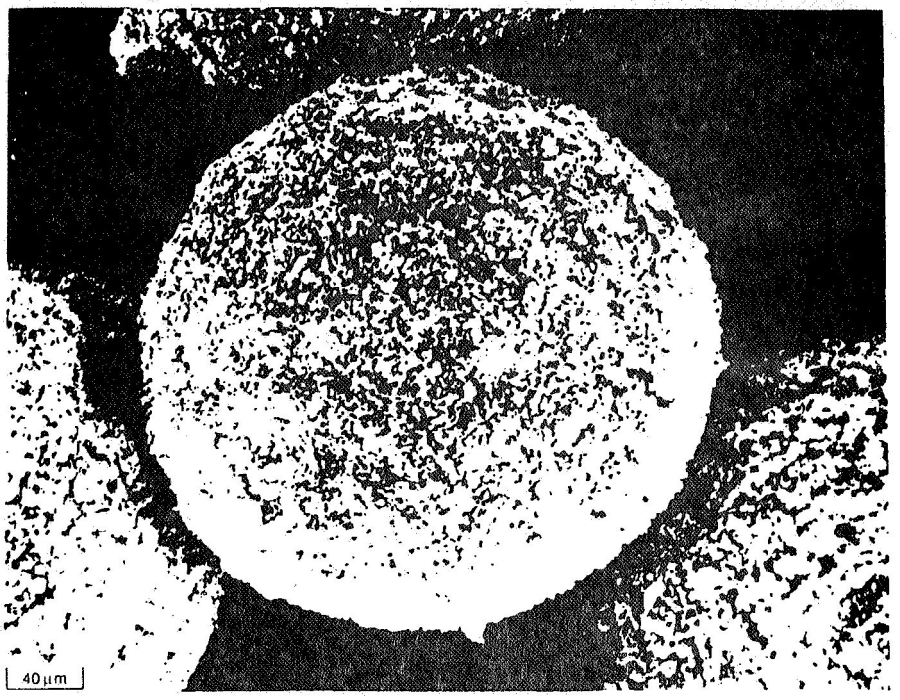
UO_2 + C MICROSPHERE AFTER FREEZE DRYING ≈500X



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SINTERED UC_2 MICROSPHERES

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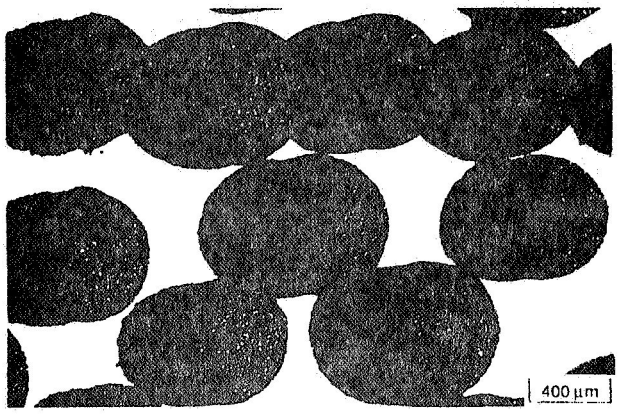
SINTERED $(U_{0.1}Zr_{0.9})C$ MICROSPHERES



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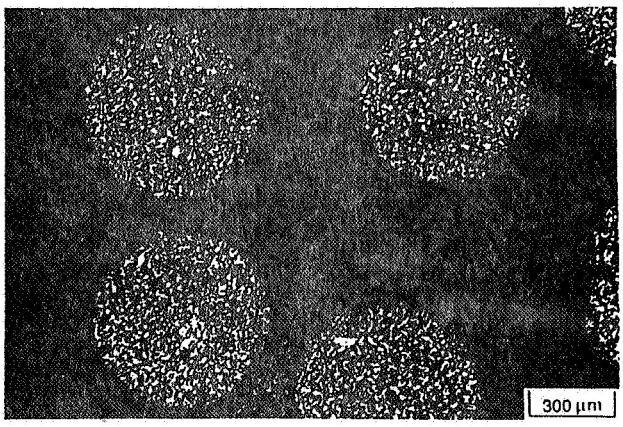
CROSS-SECTION OF SINTERED MIXED CARBIDE MICROSPHERES



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CRYOCHEMICAL SPHERE FORMING ADVANTAGES

- Process is composed of a few simple steps
- Applicable to a variety of nuclear fuel concepts
- Porosity is likely a controllable variable
- Spheres >1000 μm diameter appear possible
- Rejected spheres are easily reused
- Re-using process fluids minimizes wastes

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