



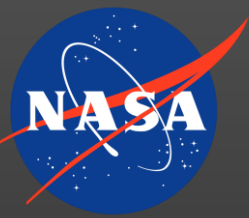
Development of Carbon-Carbon Heat Exchange Tubes for the Nuclear Thermal Propulsion Fuel Element

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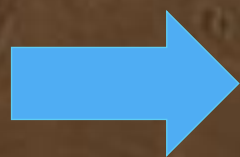


Achieving crewed Mars missions in the 2030s

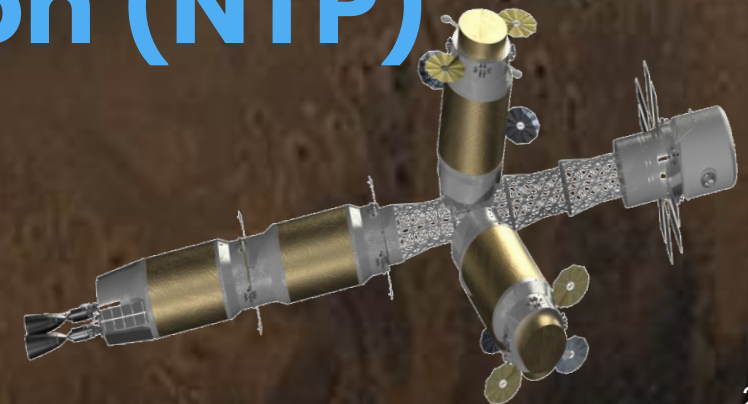
- NASA wants to send the first crewed mission to Mars in 2039
- Goal is to minimize crewed mission duration to ~ two years
- Space Nuclear Propulsion (SNP) Project Office at NASA Marshall Space Flight Center (MSFC) leads technology development efforts for SNP systems in conjunction with the Department of Energy and commercial partners
 - Technology Demonstration Mission funded by NASA Space Technology Mission Directorate (STMD) on fuel and moderator development for the Nuclear Thermal Propulsion (NTP) reactor

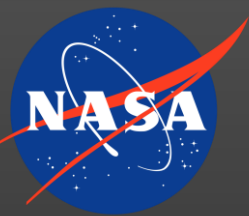
Nuclear Thermal Propulsion (NTP)

>900
days



<600
days

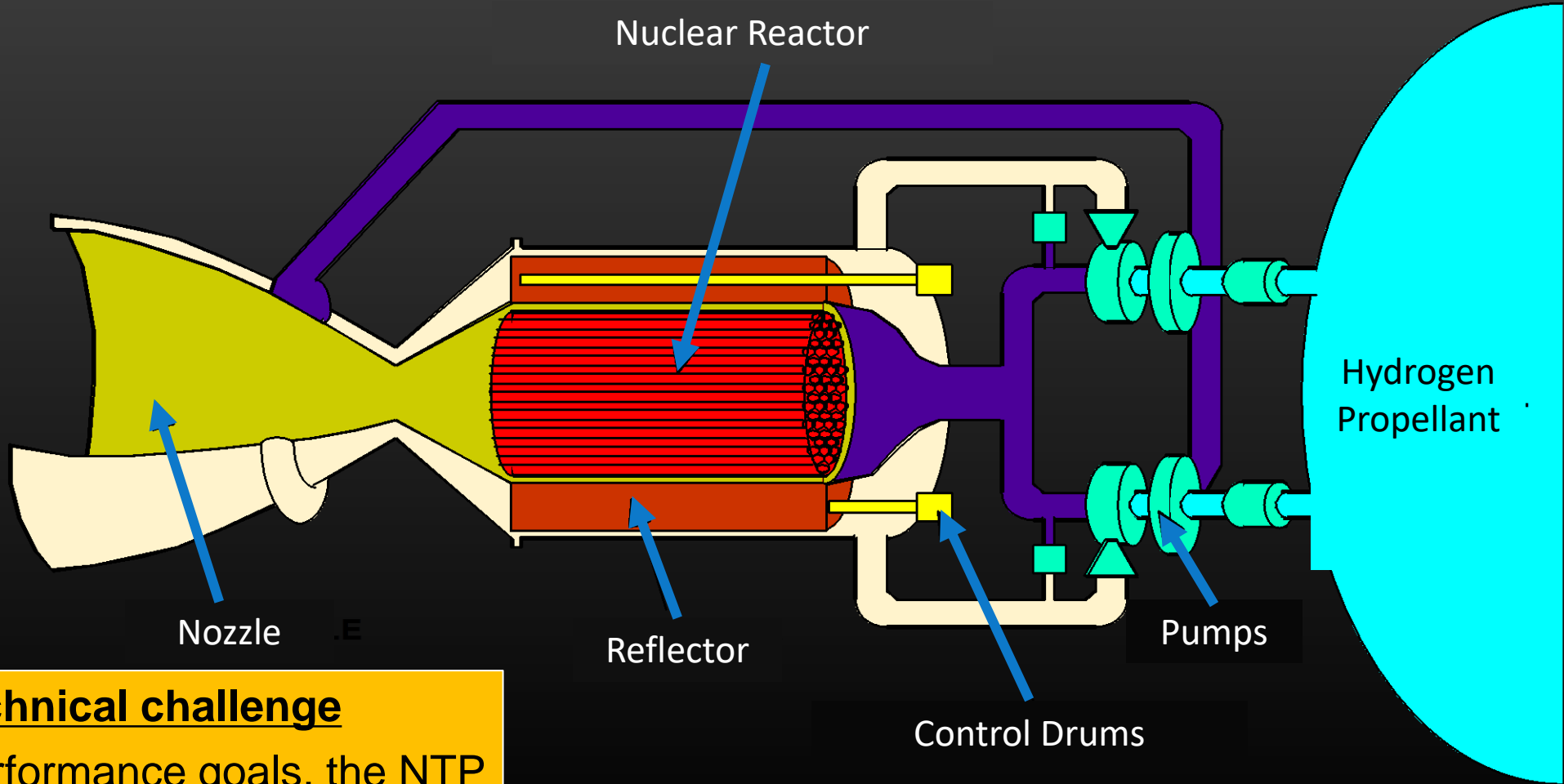




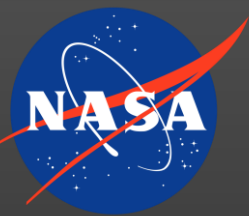
NTP Systems generate high thrust and high specific impulse (Isp)

Thrust is directly related to the thermal power of the reactor:
 $100,000 \text{ N} \approx 450 \text{ MW}_{\text{th}}$
at 900 sec Isp

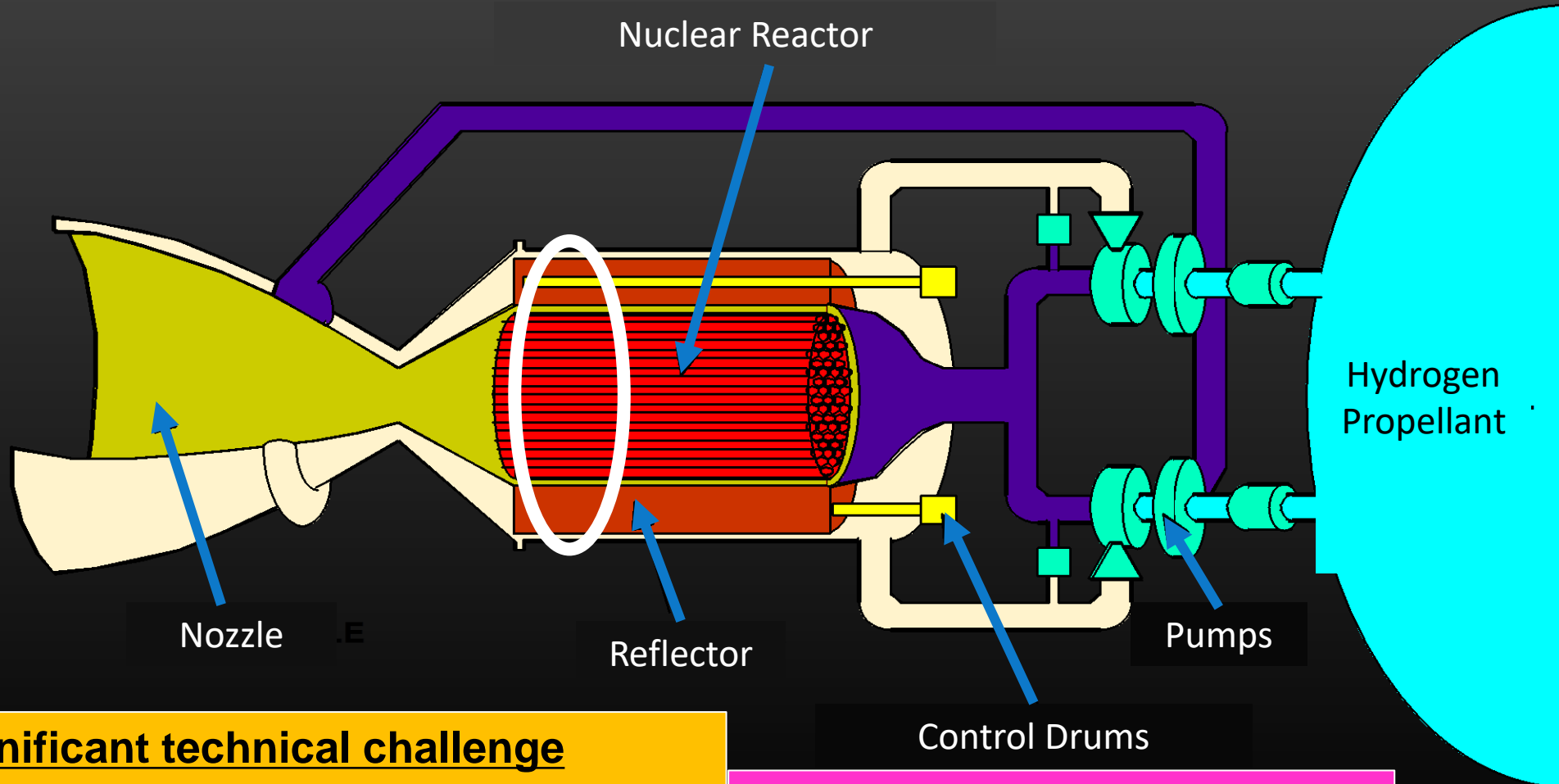
Isp is directly related to exhaust temperature:
900 sec Isp \rightarrow $\sim 2900 \text{ K}$



Significant technical challenge
To meet propulsion performance goals, the NTP reactor operates at very high temperatures



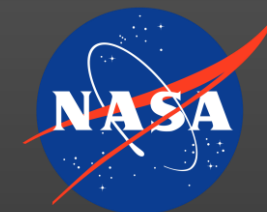
Temperatures in the nuclear reactor limit material choices



Significant technical challenge

To meet propulsion performance goals, the NTP reactor operates at very high temperatures

= a materials problem!



Limited material choices in the 2900 K temperature range

1																	2		
H																	He		
3	4											5	6	7	8	9	10		
Li	Be											B	C	N	O	F	Ne		
11	12											13	14	15	16	17	18		
Na	Mg											Al	Si	P	S	Cl	Ar		
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54		
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
55	56			72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
Cs	Ba			Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
87	88			104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	
Fr	Ra			Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og	
				57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	
													Dy	Ho	Er	Tm	Yb	Lu	
				98	99	100	101	102	103										
														Cf	Es	Fm	Md	No	Lr

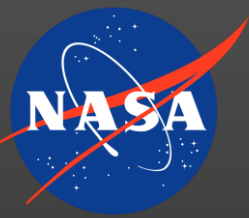
- Refractory Metals
- Historically used in nuclear applications
 - High temperature capable
 - Manufacturability issues
 - H₂ embrittlement issues

Carbon-carbon (C/C)

- Typically used in hypersonics
- High temperature capable
- Low coefficient of thermal expansion (CTE)
- H₂ corrosion without protective coating at high temperatures

For NTP specific applications, we also must consider:

- Neutron absorption cross-section (desire low)
- Hydrogen reactivity (desire low)
- Manufacturing complex geometry (small diameter tube)



Manufacturing carbon-carbon (C/C) heat exchange tubes is a challenging task



Small diameter tubes, high-aspect ratio

- 0.125-in. outer diameter
- 0.010-in. to 0.015 in. wall thickness
- 40-in. length

*figure not to scale (10X scale)



High operating temperature (2900 K)

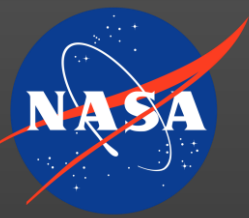
High operating pressure (1000 psi)



Hot, flowing hydrogen environment will corrode C/C unless protected by a coating



Thermal cyclical loading due to multiple start/stops during lifetime



Current status of manufacturing C/C tubes and coating development efforts



- Commercial manufacturer producing C/C tubes of varying lengths
- Structural testing as part of design cycle to inform next iteration
- Non-destructive characterization



- Coefficient of thermal expansion mismatch concerns between C/C tube and carbide coating
- Finite element modelling of tube and coating to understand thermal stresses



- Development of a hermetic, carbide coating
- Investigating chemical vapor deposition techniques
- Modelling hydrogen flow over coating materials
- Experimental testing at MSFC Compact Fuel Element Environmental Test facility



- Experimental testing of coated C/C samples to understand thermal cycling impact
- Non-destructive characterization of damage post thermal cycling



Questions?

C/C tube development activities are ongoing, and we look forward to sharing updates at the next NETS conference

For more information, please contact:
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