Carbon – Plutonium – Rhodium

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Introduction

The C-Pu-Rh system is of interest because of its links with the fission products when plutonium carbides are used as fuel in nuclear reactors [1970Hai]. Studies were made of the ternary systems comprising the most important actinides (Th, U and Pu), and many of the U- and Pu- systems had perovskite phases of the filled Cu_3Au structure. The latter structures are important because they are found in both irradiated oxide [1968Bra] and carbide [1970Bra] fast reactor conditions. The experimental studies of the system are listed in Table 1.

Binary Systems

The C-Rh and Pu-Rh binary systems are taken from [Mas2]. The C-Pu phase diagram from [Mas2] has been amended and is given in Fig. 1. The αPuC_2 compound shown in the phase diagram given in [Mas2] is omitted from Fig. 1, as according to [1970Gre], the phase is metastable. This compound does not appear in any of the earlier versions of the phase diagram. As well as the six polymorphs of Pu, there are eight intermetallic Pu-Rh compounds, three C-Pu intermetallic compounds, and no miscibility between C and Rh.

Solid Phases

The solid phases are given in Table 2. To date, no true ternary compounds have been reported, only an extension of the (Pu) and $PuRh_3$ phases into the ternary system [1975Hai, 1975Hol, 1977Hol, 1980Hol, 1984Hol1, 1984Hol2].

Isothermal Sections

In a review and assessment, [1984Hol1, 1984Hol2] gave an isothermal section at 1200°C showing no true ternary phases, but an extension of $PuRh_3$ as $PuRh_3C_{1-x}$. This was redrawn from [1975Hai] and [1980Hol] (Fig. 2). A partial isothermal section for 1300°C was given by [1977Hol]. The phase equilibria shown are virtually identical to those given for the same region at 1200°C. A tentative isothermal section at 800°C is shown in Fig. 3 taken from [1975Hai]. Alterations were made to the isothermal sections to ensure agreement with the accepted binary systems.

References

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Table 1: Investigations of the C-Pu-Rh Phase Relations, Structures and Thermodynamics

Reference	Method/Experimental Technique	Temperature/Composition/Phase Range Studied
[1975Hai]	XRD, ceramography and EMPA of arc-melted samples, homogenized between 800 and 1250°C for up to 750 h	Isothermal section at 800°C
[1977Hol]	XRD of arc melted samples, homogenized at 1300°C	Rh rich alloys. Partial isothermal section at 1300°C
[1982Hol]	Arc-melted sample, annealed for 40 h at 1200°C. Metallography, atom probe and XRD	20Pu-60Rh-20C (at.%)

Table 2: Crystallographic Data of Solid Phases

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(C)	*hP*4 $P6_3/mmc$ C (graphite)	a = 246.12 c = 670.9	at 25°C [Mas2]
(εPu) 640 - 483	*cI*2 $Im\bar{3}m$ W	a = 363.43	[Mas2]
(δ'Pu) 483 - 463	*tI*2 *I*4/*mmm* In	a = 332.61 c = 446.30	[Mas2]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
(δPu) 463 - 320	*cF*4 $Fm\bar{3}m$ Cu	*a* = 463.71	[Mas2]
(γPu) 320 - 215	*oF*8 *Fddd* γPu	*a* = 315.87 *b* = 576.82 *c* = 1016.2	[Mas2]
(βPu) 215 - 125	*mC*34 *C*2/*m* βPu	*a* = 928.4 *b* = 1046.3 *c* = 785.9	[Mas2]
(αPu) < 125	*mP*16 $P2_1/m$ αPu	*a* = 618.3 *b* = 482.2 *c* = 1096.3	at 25°C [Mas2]
(Rh)	*cF*4 $Fm\bar{3}m$ Cu	*a* = 380.32 *a* = 380.3	at 25°C [Mas2] [1980Hol]
Pu_3C_2 < 575	-	-	-
PuC < ~1654	*cF*8 $Fm\bar{3}m$ NaCl	*a* = 497.25	[Mas2], [V-C2]
Pu_2C_3 ≲ 2050	*cI*40 $I\bar{4}3d$ Pu_2C_3	*a* = 813.2 *a* = 813.5	isotope ^{239}Pu [V-C2] isotope ^{240}Pu [V-C2]
βPuC_2 2350 - 1660	-	*a* = 569.6	[Mas2], [V-C2]
αPuC_2 < 1660	*tI*6 *I*4/*mmm* CaC_2	*a* = 363.0 *c* = 609.4	metastable [1970Gre], [V-C2]
Pu_2Rh < 940	-	-	[Mas2]
Pu_5Rh_3 < 980	*tP*32 *P*4/*ncc* Pu_5Rh_3	*a* = 1094.1 *c* = 602.03	[Mas2], [V-C2]
$Pu_{31}Rh_{20}$ < 1020?	*tI*204 *I*4/*mcm* $Pu_{31}Rh_{20}$	*a* = 1107.6 ± 0.4 *c* = 3693.3 ± 0.12	[Mas2], [V-C2]
Pu_5Rh_4 < 1180	*oP*36 *Pnma* Sm_5Ge_4	*a* = 726.3 *b* = 1448.0 *c* = 746.4	[Mas2], [V-C2]

Phase/ Temperature Range [°C]	Pearson Symbol/ Space Group/ Prototype	Lattice Parameters [pm]	Comments/References
PuRh < 1300	-	-	[Mas2]
Pu_3Rh_4 < 1310	-	-	[Mas2]
$PuRh_2$ < 1340	*cF*24 $Fd\bar{3}m$ $MgCu_2$	*a* = 748.8	[1961Mul], [V-C2]
$PuRh_3C_{1-x}$	*cP*4 $Pm\bar{3}m$ $CaTiO_2$	*a*= 409.8 *a* = 498.0	at $PuRh_3C$, 1200°C [1975Hai] [1984Hol1, 1984Hol2] possibly misquoting [1975Hai] $0 < x < 1$
$PuRh_3$ < 1495	*cP*4 $Pm\bar{3}m$ Cu_3Au	*a* = 400.9 to 404.0 *a* = 404.0	[1961Mul], [V-C2] [1980Hol]

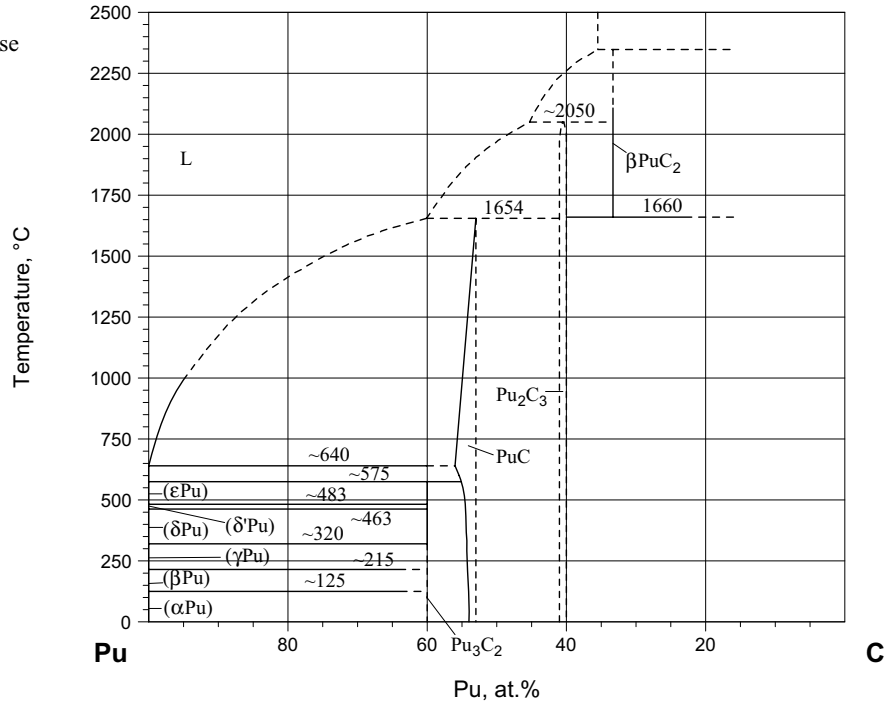

Fig. 1: C-Pu-Rh. Amended C-Pu phase diagram

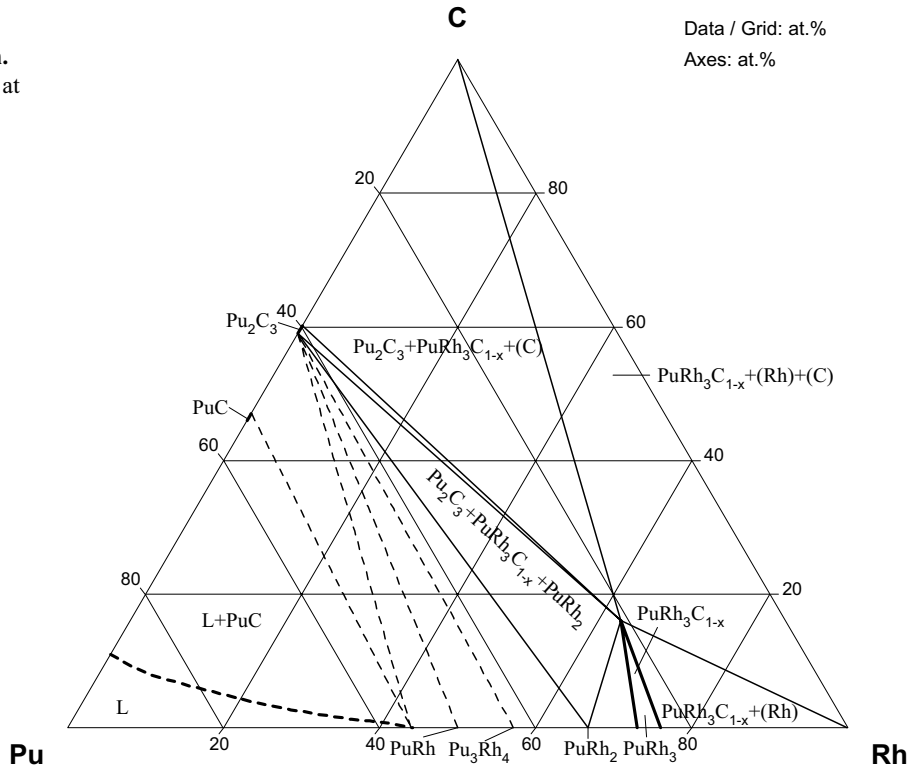

Fig. 2: C-Pu-Rh. Isothermal section at 1200°C

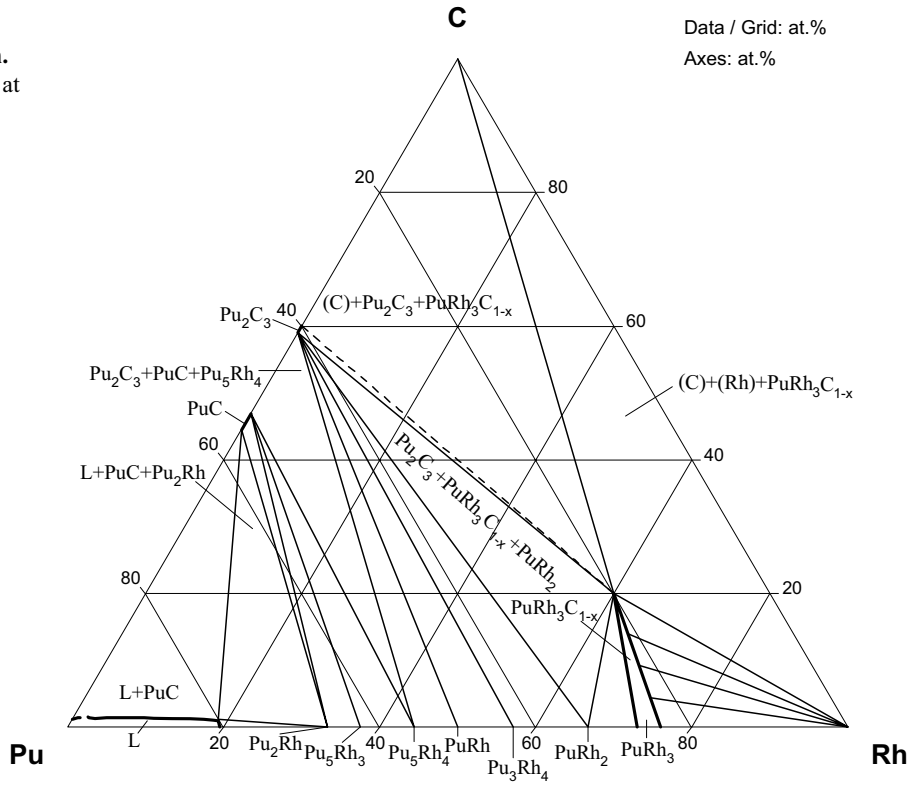

Fig. 3: C-Pu-Rh. Isothermal section at 800°C