Technical Meeting on Research Reactor Ageing Management, Refurbishment and Modernization

31 May - 4 June 2021

Supply Fuel Assembly and Commissioning RP-10 Reactor

From Oxide to Silicide

$U_3O_8 \rightarrow U_3Si_2$

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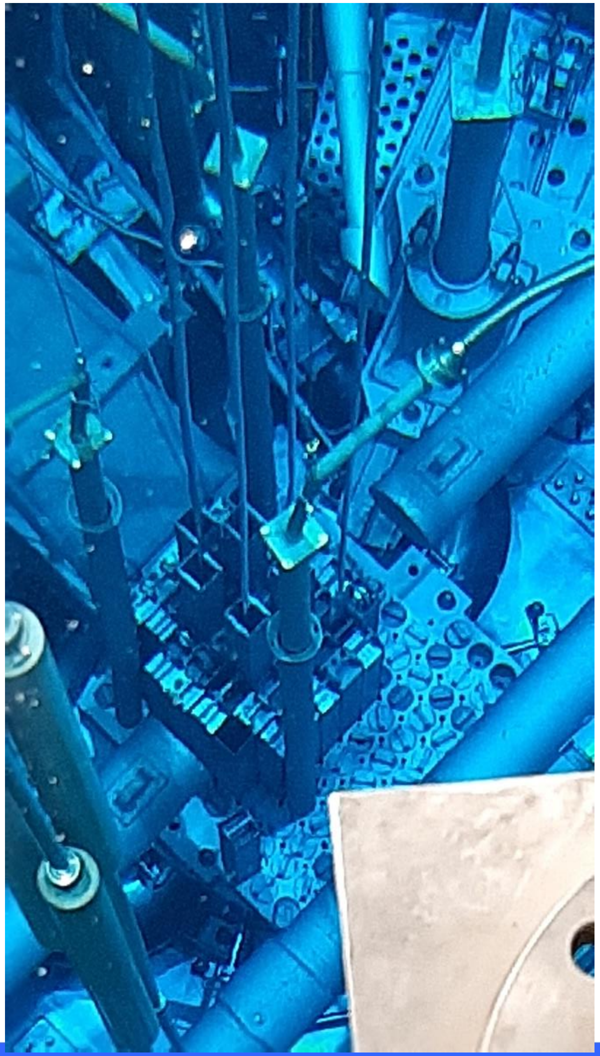
The RP-10 reactor

The RP-10 research reactor is owned by the Peruvian Institute of Nuclear Energy (IPEN: Instituto Peruano de Energia Nuclear), which has been operating since 1988. it is designed to operate at 10 MW of thermal power



SUPPLY OF FUEL ASSEMBLIES FOR RP-10

STAGES OF FUEL ACQUISITION

1. REACTOR FUEL WAS RUNNING OUT
2. PROCEDURES BEGIN TO SUPPLY NEW FUELS
3. FINANCING IS ACHIEVED TO ACQUIRE NEW FUEL
4. THE TECHNICAL CHARACTERISTICS OF THE FUEL ARE DECIDED
5. INITIALLY IT WAS DECIDED TO CONTINUE USING URANIUM OXIDE
6. TECHNICAL COOPERATION IS REQUESTED FROM THE IAEA
7. URANIUM SILICIDE OPTION PROPOSED
8. IT IS DECIDED TO CONSIDER BOTH FUEL OPTIONS.

INTERNATIONAL BIDDING

A technical team was set up at IPEN, and with the advice of an IAEA expert, they developed the technical specifications and plans for the tender.

Technical specifications

U3O8 FA Technical Specification

U3Si2 FA Technical Specification

Drawings

U3O8 FA drawings

U3Si2 FA drawings

These documents were only "valid for bidding"

COMPARATIVE CHART

U_3Si_2 vs U_3O_8

	U3O8	U3Si2
Fuel	**U3O8-Al.**	**U3Si2-Al.**
Type	**MTR.**	**MTR.**
Mass of U235 per plate (g)	**17.5**	**27**
Enrichment of U235 (%)	**19.75**	**19.75**
Density of U (g/cm3)	**2.3**	**4.8**
N° placas		
ECN (plates)	**16**	**17**
ECC (plates)	**12**	**13**
Thermal neutronic flux (n/cm2.s)	**1.47E+14**	**1.82E+14**
Reactivity (ppm)	**5500**	**6200**
Power peak factor	**2.5**	**2.8**
Fuel cycle (days)	**7**	**21**

The IAEA carries out an international bidding, in which the following companies participate, with the following fuel proposals.

CERCA	**Silicide uranium fuel assembly**
INVAP	**Silicide and oxide uranium fuel assembly**
CCHEN	**Silicide and oxide uranium fuel assembly**
BATAN TECK	**Silicide and oxide uranium fuel assembly**

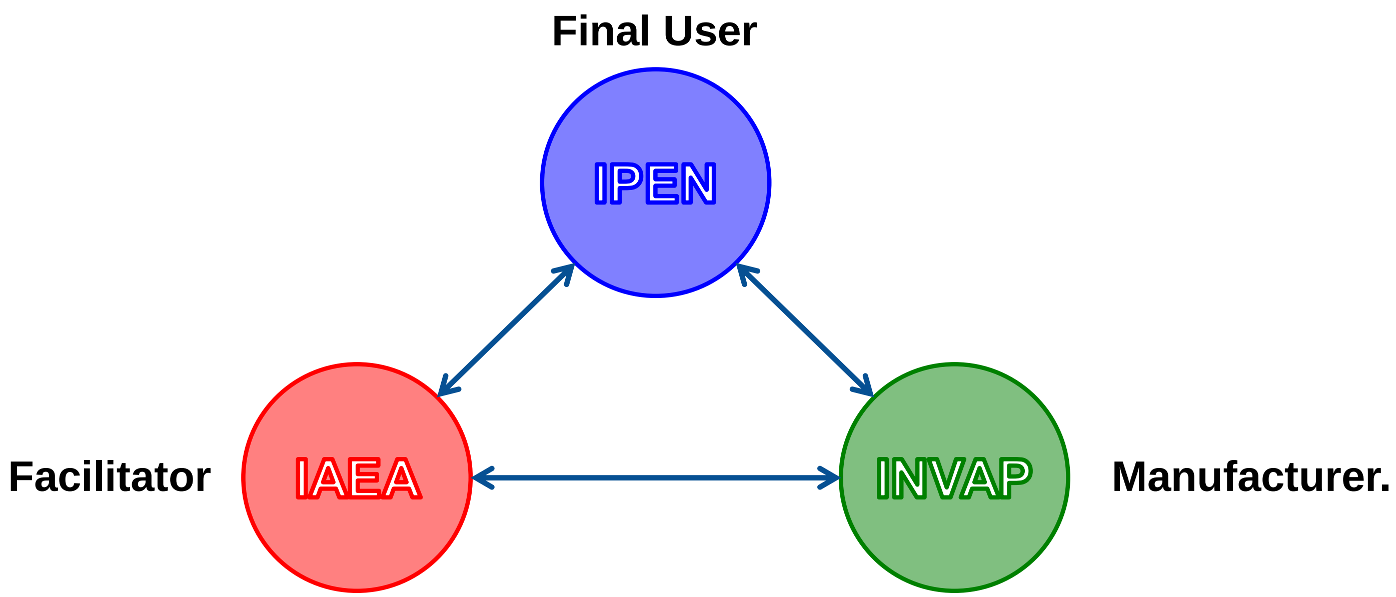
After the technical and economic evaluation, the selected option was **(Marzo 2013)**:

I N V A P
Silicide Uranium

New Fuel Assemblies Project.

Manufacturing Contract.

In **November 2015**, the contract **201505667** was signed between IAEA - INVAP - IPEN to acquire new fuel elements for the RP-10 reactor. This ensured that the reactor would continue to operate and provide service to Peru.



Preparation of Drawing and Technical Specifications valid for manufacturing.

INVAP and CNEA presented modifications to the basic engineering, which were discussed in several teleconferences with the IAEA and IPEN.

Technical Specifications: APPROVED

Manufacturing drawings: APPROVED

IAEA	INVAP	CNEA	IPEN
Frances Marshall	Matías Márquez	Luis Alvarez	Germán Cáceres
Darío Jinchuk		Oswaldo Pedrozo	Alvaro Aguirre

Duration of this stage: **April 2016 to July 2016**

Inspections Made to the Manufacturing Process.

The following inspections were carried out:

Initial Meeting: February 29 to March 04, 2016.

Milestone 1: August 15-19, 2016.

Milestone 2: May 08-12, 2017.

Milestone 3: August 07-11, 2017.

Milestone 4: October 23-27, 2017.

Milestone 5: February 20-22, 2018.

The manufacture was carried out according to the following detail:

- **22 standard Fuel Assemblies (SFA)**
- **07 Control Fuel Assemblies (CFA)**


ECN-016

Reception of Combustible Elements

The fuels were delivered in two shipments:

First Delivery: From 08 to 12 December 2017.

Second Delivery: From March 15 to 19, 2018.



COMMISSIONING OF RP-10

COMMISSIONING OF RP-10

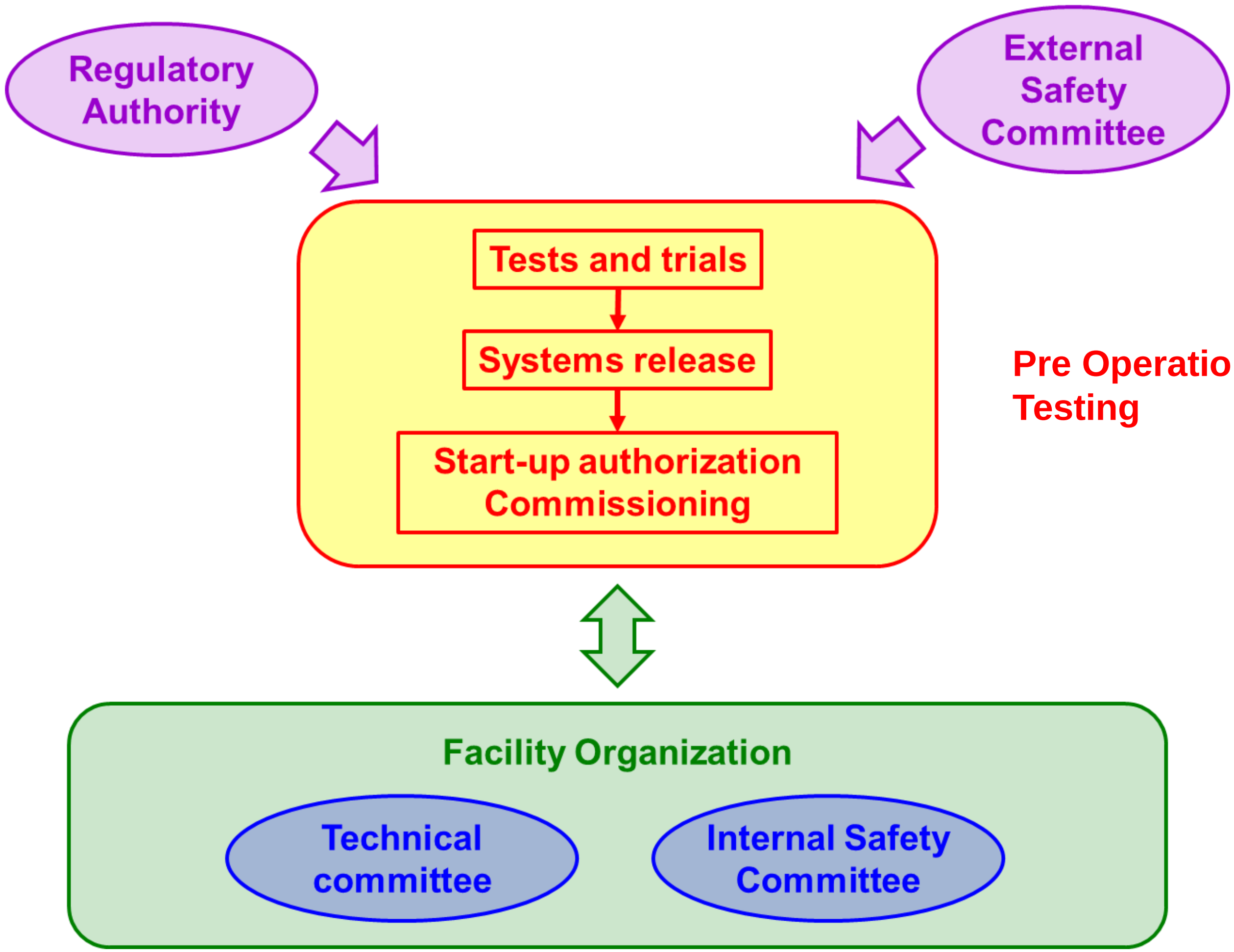
The entry of the fuels assemblies to the reactor core was carried out safely, for that calculations were made and procedures were developed to ensure that the core configurations are safe and operable.

$$U_3O_8 \rightarrow U_3Si_2$$

Calculations **Procedures** **Instructive**

Commissioning Plan

Previous Actions



Pre Operational Testing

Fuel Management

Previous Cores

Core	Reactor Core Assemblies						Initial Reactivity (pcm)
	CFA	SFA	Be	Grap	IB	FCR	
01	5	0	0	0	1	1	-66317
02	5	4	0	0	1	1	-9800
03	5	5	0	0	1	1	-6824
04	5	6	0	0	1	1	-3794
05	5	7	0	0	1	1	-2257
06	5	8	0	0	1	1	-817
07	5	9	0	0	1	1	851

Transient Cores

Core	Reactor Core Assemblies						Initial Reactivity (pcm)
	CFA	SFA	Be	Grap	IB	FCR	
08	5	9	10	9	7	1	6087
09	5	9	19	0	7	1	6043
10	5	10	19	0	8	1	6060
11	5	11	18	0	8	1	5699
12	5	12	19	0	8	1	5993
13	5	13	19	0	8	1	5822
14	5	14	28	0	8	1	6075
15	5	15	28	0	7	1	6124
16	5	16	40	0	8	1	6328

Work Cores

Core	Reactor Core Assemblies						Initial Reactivity (pcm)
	CFA	SFA	Be	Grap	IB	FCR	
17	5	16	40	0	8	1	5921

Commissioning Core

Previous Cores
- N01 5 CFA
- ⋮
- N07 1st Critical Core

Intermediate Cores
- N07A
- ⋮
- N07D

Transient Cores
- N08 Starter Up Core
- N09 Full Beryllium
- ⋮
- N16 Full Power

Work Core
- N17 1st Work Core
- ⋮
- N24 N24

Commissioning Stages

The stages that were considered in the RP-10 program were:

Stage A:

A1) Pre-operational tests before refueling.

A2) Core discharge

Stage B: Fuel load tests, start of criticality

Stage C: Low power tests

Stage D: High power tests.

ETAPA PREVIA DESMONTAR	Descarga del núcleo final				
Actividad	Dias	S1	S2	S3	S4
Reflectores	0.5				
Elementos normales	1				
Elementos de control	0.5				
Detectores	2				
Ref. Procedimiento descarga					
Total:	4				
ETAPA A PRUEBAS	Antes de la carga				
Sistemas	3				
Ref. Anexo I					
Total:	3				
ETAPA B	Primer núcleo crítico				
Aproximación a crítico	3				
Exceso reactividad	1.5				
Estimación de potencia	0.5				
Ref. Anexo II					
Total:	5				
ETAPA C	Primer núcleo transitorio (baja potencia)				
Aproximación a crítico	1				
Exceso reactividad	1				
Calibración de sistema de control	1.5				
Determinación del margen de parada	0.5				
Determinación del flujo neutrónico EECC	4				
Determinación del factor de pico axial	1				
Determinación de coeficientes de reactividad	1				
Determinación flujo principales facilidades (cajas irradiacion, SN)	3				
Ref. Anexo III					
Total:	10				
ETAPA D	Primer núcleo transitorio (alta potencia)				
Determinacion de flujo facilidades	1				
Calibración en potencia por balance térmico	3				
Determinación coeficiente reactividad	1				
Ref. Anexo III					
Total:	5				

Stage A1

IPEN	FORMULARIO LISTADO DE PRUEBAS PRE OPERACIONALES DE LA PUESTA EN SERVICIO	Código: RENU-CTPS-FR-002 Versión: 01 Vigente desde: 10/07/2019 Página: 1 de 1

Fecha: 06.09.19 Etapa: A1

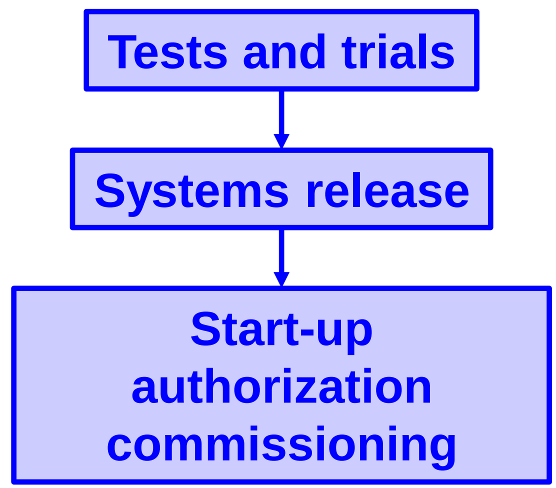
ITEM	NOMBRE DEL SISTEMA	RESPONSABLE	SITUACIÓN ACTUAL
A4	Instrumentación nuclear	Eisenk Benancio	Operativo
A5	Paneles sinópticos	Eisenk Benancio	Operativo
A6	Instrumentación convencional	Eisenk Benancio	Operativo
A7	Puesta en marcha del sistema de ventilación	Rodión Santivañez	Operativo
A8	Tablero del sistema secundario (TS)	Rodión Santivañez	Operativo
A9	Tablero del sistema primario (TP)	Rodión Santivañez	Operativo
A10	Tablero de boca de tanque (TBT)	Rodión Santivañez	Operativo
A11	Grupo electrógeno del RP-10	Rodión Santivañez	Operativo
A12	Tableros de compresores (TC), tablero de mantenimiento mecánico (TMM), y tablero de horno (TH)	Rodión Santivañez	Operativo
A13	Tablero de tensión estabilizada de s.c. (TTE)	Rodión Santivañez	Operativo con restricciones (*)
A14	Tableros de tensión estabilizada de laboratorios (TTE 1 al 3)	Rodión Santivañez	Operativo
A15	Sistema de enclavamiento de puertas y semáforos	Dionisio Canaza	Operativo
A16	Sistema de señalización de evacuación	Edgar Ovalle	Fuera de Servicio (**)
A17	Sistemas de energía eléctrica del RP-10	Rodión Santivañez	Operativo
A18	Sistema de emergencia II (UPS)	Rodión Santivañez	Operativo
A19	Tablero de consola en sala de control de PPR (TCSC)	Rodión Santivañez	Fuera de servicio (***)
A20	Sistema de tableros general (TG) emergencia (TG) y consola de sala de control (TSC)	Dionisio Canaza	Operativo
A21	Sistema de purificación de agua al reactor	Iván Babiche	Operativo
A22	Sistema de efluentes activos	Iván Babiche	Operativo
A23	Sistema de colchón caliente	Iván Babiche	Operativo
A24	Sistema secundario	Roberto Giol	Operativo
A25	Sistema primario	Roberto Giol	Operativo
A26	Tanque principal-componentes internos	Agustín Urcía	Operativo
A27	Pileta auxiliar y canal de comunicación	Agustín Urcía	Operativo
A28	Tanque principal - componentes externos	Agustín Urcía	Operativo
A29	Compresores RP-10	Rocío Solís	Operativo
A30	Estructuras y mecanismos clase "A"	Rolando Arrieta	Operativo
A31	Estructuras y mecanismos clases B y C	Rolando Arrieta	Operativo
A32	Sistema de provisión de agua al reactor	Iván Babiche	Operativo

(*) Se informó que una de las tres fuentes de rectificación ferro-resonante del tablero presenta condensadores con inconvenientes.
(**) Los letreros luminosos con la palabra "SALIDA" se encuentran fuera de servicio.
(***) Perteneciente al Sistema neumático de envío de muestras entre el RP-10 y la PPR, el cual se encuentra fuera de servicio

Elaborado por : ____________________ Firma: ____________________

Pre Operational Testing

Pre-operational tests of the systems associated with the operation of the reactor.



Stage A2: Fuel Unloading U_3O_8

Downloading the kernel components
- Discharge of U3O8 fuels
- Reflector discharge
- Fission chamber movement
- Natural background measurements.

Date:
September 10, 2019

Core 0

	A	B	C	D	E	F	G	H	I	J
1										
2			CF							
3							CF			
4					CI					
5										
6										
7					CF					
8										
9										
10										

Stage B: U_3Si_2 fuel entry to the core

According to the fuel management provided in the commissioning plan, the uranium silicide fuels enter the reactor.
This stage begins with the core configuration 01 and ends with the core configuration 07

Date:
September 11 to 16, 2019

Core 01

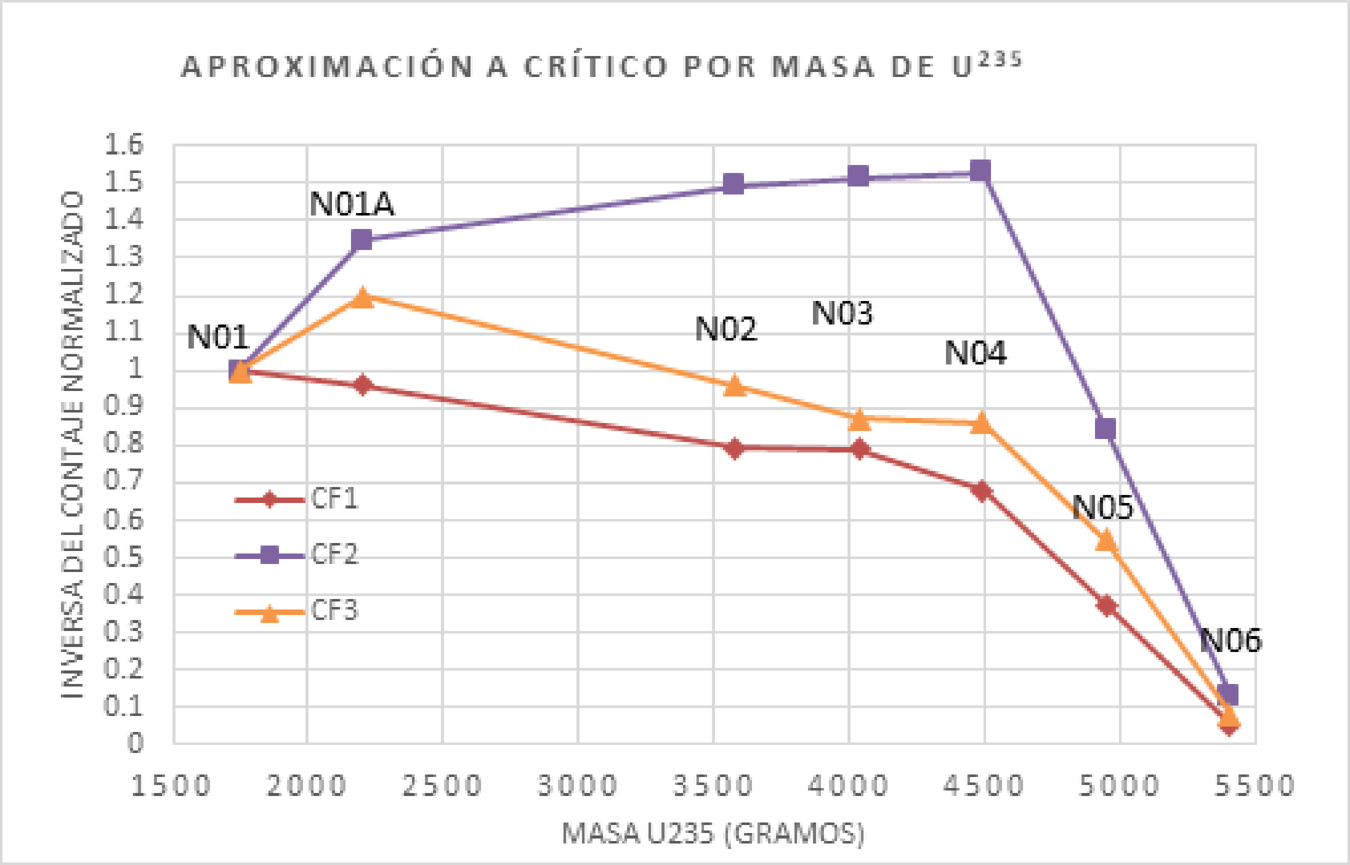
	A	B	C	D	E	F	G	H	I	J
1										
2			CF		ECC-001					
3				ECC-003		ECC-004	CF			
4					CI					
5				ECC-006		ECC-007				
6										
7					CF					
8										
9										
10										

Core 07

	A	B	C	D	E	F	G	H	I	J
1										
2			CF	ECN-010	ECC-001	ECN-012				
3				ECC-003	ECN-001	ECC-004	CF			
4				ECN-003	CI	ECN-005				
5				ECC-006	ECN-007	ECC-007				
6				ECN-017	ECN-015	ECN-019				
7					CF					
8										
9										
10										

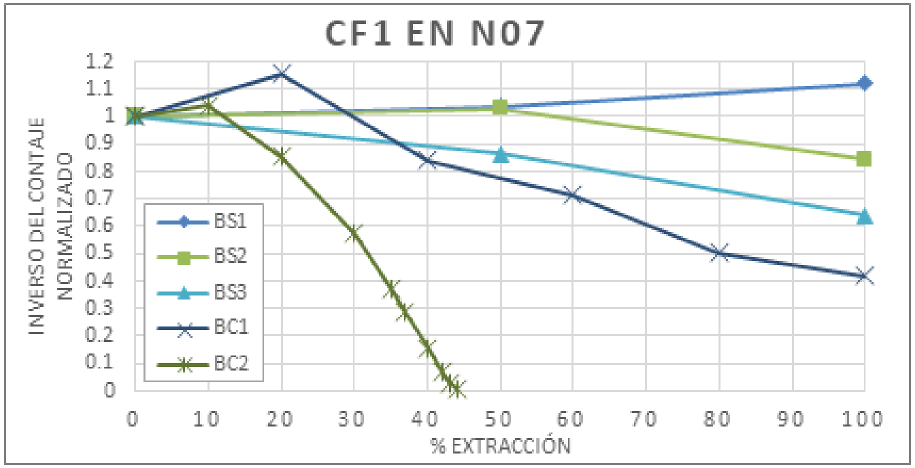
Approach to Critical

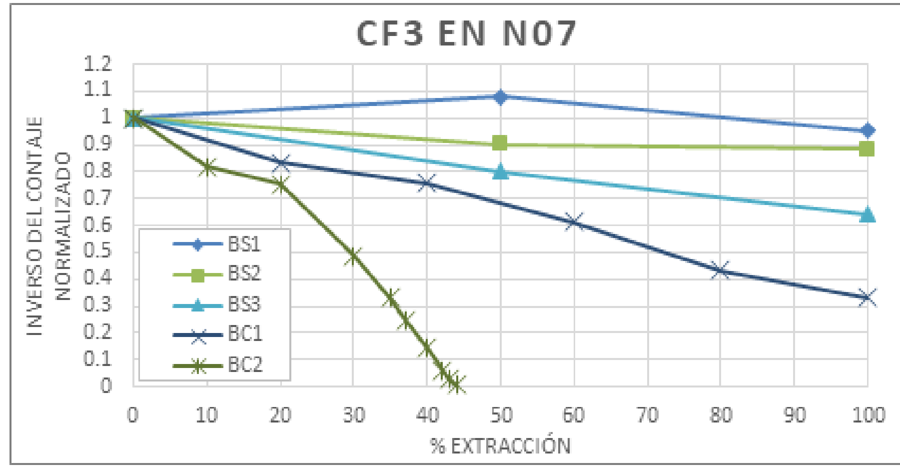
Approach to critical per uranium mass

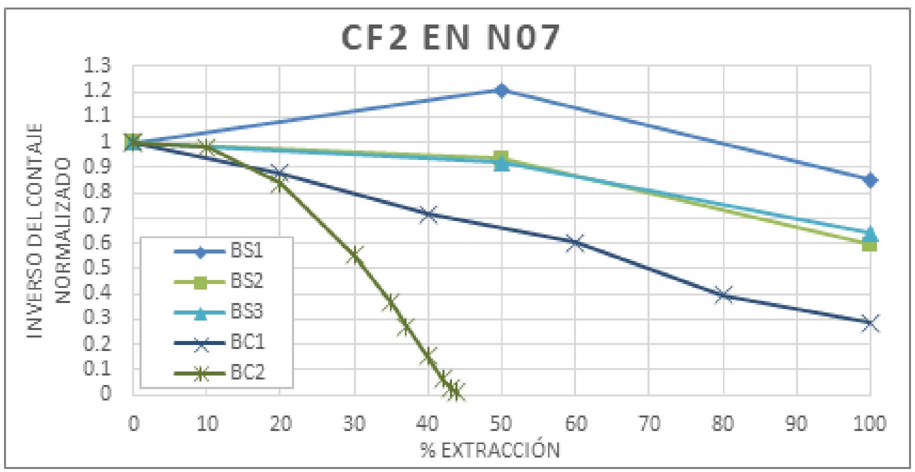


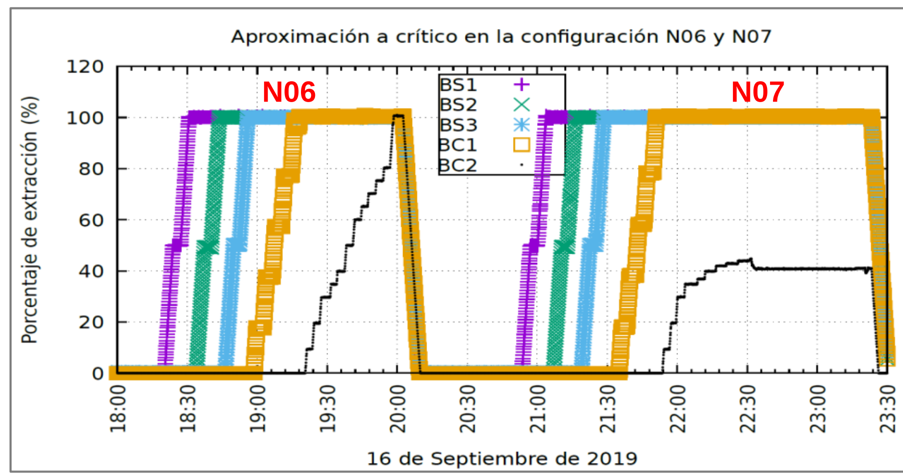
Approach to Critical

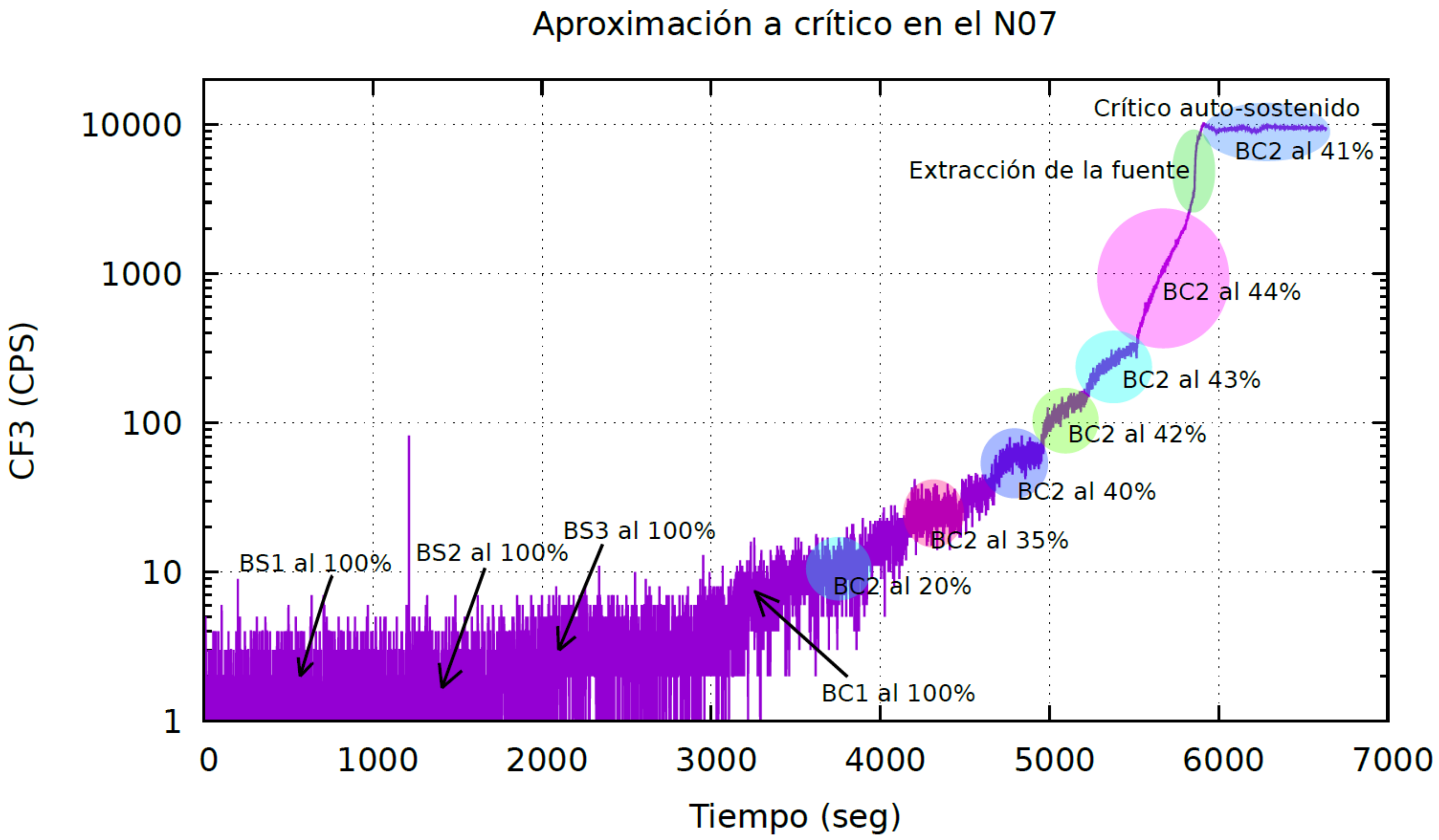
Approach to critical by control rod position



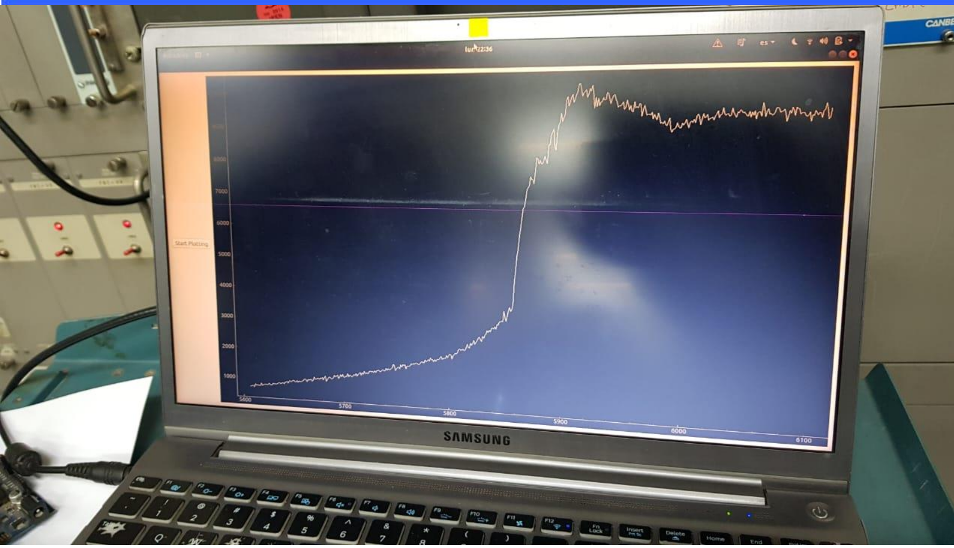







Aproximación a crítico en el N07
CF3 (CPS)
Tiempo (seg)
10000
1000
100
10
1
0
1000
2000
3000
4000
5000
6000
7000
Crítico auto-sostenido
BC2 al 41%
Extracción de la fuente
BC2 al 44%
BC2 al 43%
BC2 al 42%
BC2 al 40%
BC2 al 35%
BC2 al 20%
BC1 al 100%
BS1 al 100%
BS2 al 100%
BS3 al 100%

Approach to Critical



Reactor in critical state

Date: **September 16, 2019**

Time: **22:31**

Control rod position:

BS1 = 100%

BS2 = 100%

BS3 = 100%

BC1 = 100%

BC2 = 40.9%

5 CFA

9 SFA

Core 07

	A	B	C	D	E	F	G	H	I	J
1										
2			CF	ECN-010	ECC-001	ECN-012				
3				ECC-003	ECN-001	ECC-004	CF			
4				ECN-003	CI	ECN-005				
5				ECC-006	ECN-007	ECC-007				
6				ECN-017	ECN-015	ECN-019				
7					CF					
8										
9										
10										

Stage C: Heading to the Starter Up Core

Core 07

	A	B	C	D	E	F	G	H	I	J
1										
2			CF	ECN-010	ECC-001	ECN-012				
3				ECC-003	ECN-001	ECC-004	CF			
4				ECN-003	CI	ECN-005				
5				ECC-006	ECN-007	ECC-007				
6				ECN-017	ECN-015	ECN-019				
7					CF					
8										
9										
10										

Core 07A

	A	B	C	D	E	F	G	H	I	J
1										
2			CF	ECN-010	ECC-001	ECN-012				
3				ECC-003	ECN-001	ECC-004	CF			
4			GR	ECN-003	CI	ECN-005				
5				ECC-006	ECN-007	ECC-007				
6				ECN-017	ECN-015	ECN-019				
7					CF					
8										
9										
10										

Core 07B

	A	B	C	D	E	F	G	H	I	J
1										
2			CF	ECN-010	ECC-001	ECN-012				
3				ECC-003	ECN-001	ECC-004	CF			
4			BE	ECN-003	CI	ECN-005				
5				ECC-006	ECN-007	ECC-007				
6				ECN-017	ECN-015	ECN-019				
7					CF					
8										
9										
10										

Stage C: Heading to the Starter Up Core

Core 07

	A	B	C	D	E	F	G	H	I	J
1										
2			CF	ECN-010	ECC-001	ECN-012				
3				ECC-003	ECN-001	ECC-004	CF			
4				ECN-003	CI	ECN-005				
5				ECC-006	ECN-007	ECC-007				
6				ECN-017	ECN-015	ECN-019				
7					CF					
8										
9										
10										

Core 07C

	A	B	C	D	E	F	G	H	I	J
1				BE	BE	BE				
2		CF		ECN-010	ECC-001	ECN-012		CF		
3			CI	ECC-003	ECN-001	ECC-004	CI			
4			CI	ECN-003	CI	ECN-005	CI			
5			CI	ECC-006	ECN-007	ECC-007	CI			
6				ECN-017	ECN-015	ECN-019				
7					BE					
8				CF						
9										
10										

Core 07D

	A	B	C	D	E	F	G	H	I	J
1			GR	BE	BE	BE	GR			
2		CF	GR	ECN-010	ECC-001	ECN-012	GR	CF		
3			CI	ECC-003	ECN-001	ECC-004	CI			
4			CI	ECN-003	CI	ECN-005	CI			
5			CI	ECC-006	ECN-007	ECC-007	CI			
6			GR	ECN-017	ECN-015	ECN-019	GR			
7			GR	GR	BE	GR				
8				CF						
9										
10										

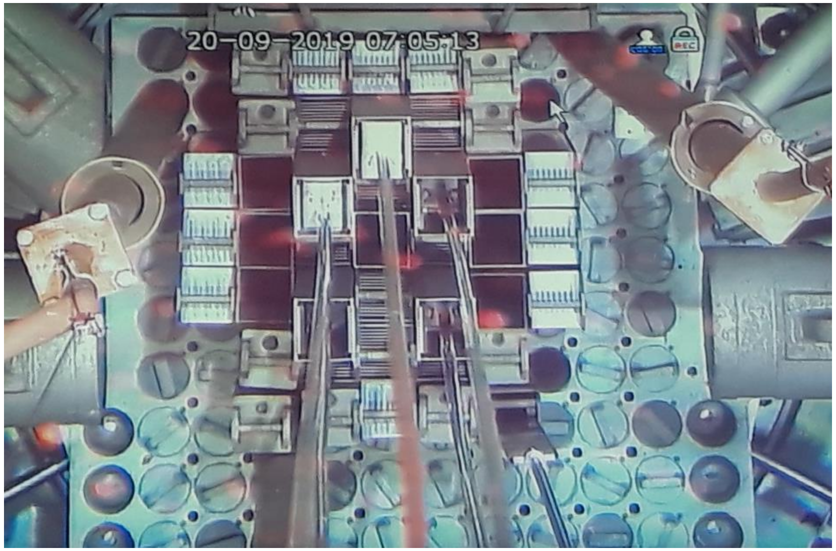
Core 08

	A	B	C	D	E	F	G	H	I	J
1			GR	BE	BE	BE	GR		CF	
2		CF	GR	ECN-010	ECC-001	ECN-012	GR			
3		BE	CI	ECC-003	ECN-001	ECC-004	CI	BE		
4		BE	CI	ECN-003	CI	ECN-005	CI	BE		
5		BE	CI	ECC-006	ECN-007	ECC-007	CI	BE		
6			GR	ECN-017	ECN-015	ECN-019	GR			
7			GR	GR	BE	GR	BCF			
8			CF							
9										
10										

Stage C: Heading to the Starter Up Core

Control rod position to reach criticality in core configurations

Core	Date	BS1	BS2	BS3	BC1	BC2
Core 07	Set 16	100%	100%	100%	100%	40.9%
Core 07A	Set 18	100%	100%	100%	100%	32.2%
Core 07B	Set 18	100%	100%	100%	100%	23.4%
Core 07C	Set 19	100%	100%	100%	67.4%	0.0%
Core 07D	Set 19	100%	100%	100%	43.6%	0.0%
Core 08	Set 20	100%	100%	100%	36.5%	0.0%



Reactor in critical state

Date: **September 20, 2019**

Time: **8:00 am**

Control rod position:

BS1 = 100%

BS2 = 100%

BS3 = 100%

BC1 = 36.5%

BC2 = 0%

5 CFA
9 SFA
10 BE
9 GR
7 CI

Stage C: Starter Up Core

Reactivity measurements
- Control rod reactivity
- Excess reactivity
- Insertion coefficient of reactivity by vacuum in core 08

Neutron flux measurement
- Flow distribution
- Peak power factor

Power calibration by neutron noise

Core 08

	A	B	C	D	E	F	G	H	I	J
1			GR	BE	BE	BE	GR		CF	
2		CF	GR	ECN-010	ECC-001	ECN-012	GR			
3		BE	CI	ECC-003	ECN-001	ECC-004	CI	BE		
4		BE	CI	ECN-003	CI	ECN-005	CI	BE		
5		BE	CI	ECC-006	ECN-007	ECC-007	CI	BE		
6			GR	ECN-017	ECN-015	ECN-019	GR			
7			GR	GR	BE	GR	BCF			
8			CF							
9										
10										

Excess reactivity of the cores configurations

Core	Excess reactivity		βeff
	($)	(pcm)	
Core 07	2.234	1722.41	771
Core 08	6.1	4562.0	753

Reactivity of the control rods

Rods	ρ ($)	ρ (pcm)
BC1	4.72	3552
BC2	3.43	2580
BS1	2.25	1694
BS2	2.92	2199
BS3	3.07	2313
BCF	0.092	69

Insertion coefficient of reactivity in core 08

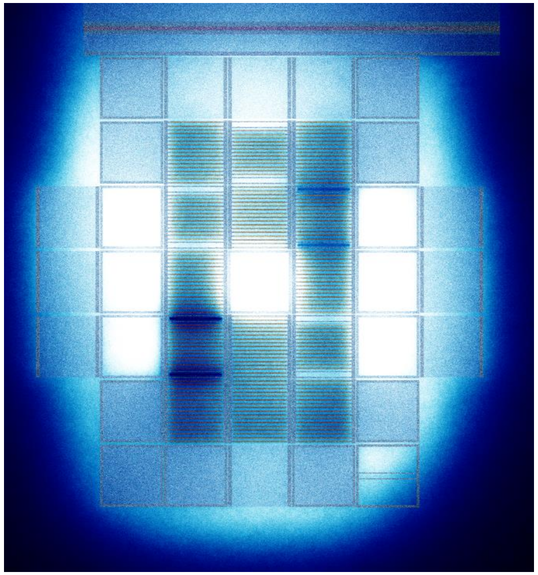
by vacuum

Core	αv
Core 08	- 209 pcm/%V

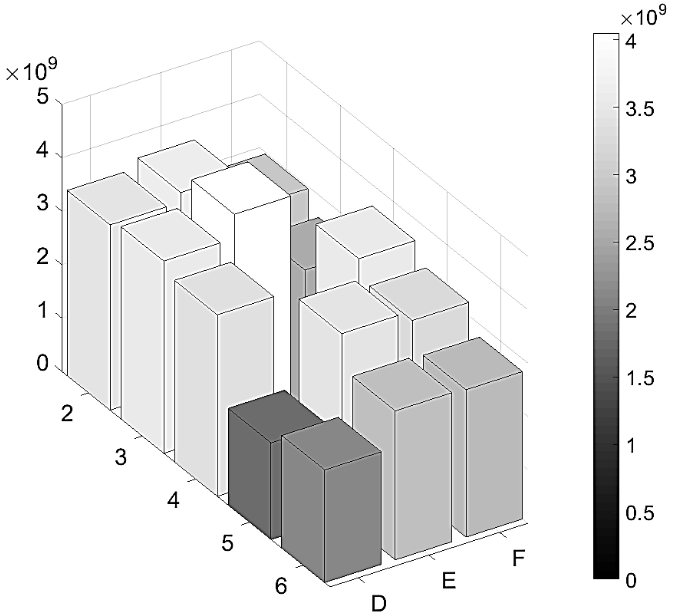
by temperature

Core	α_T
Core 08	- 5.2 ± 0.3 pcm/°C

Stage C: Starter Up Core

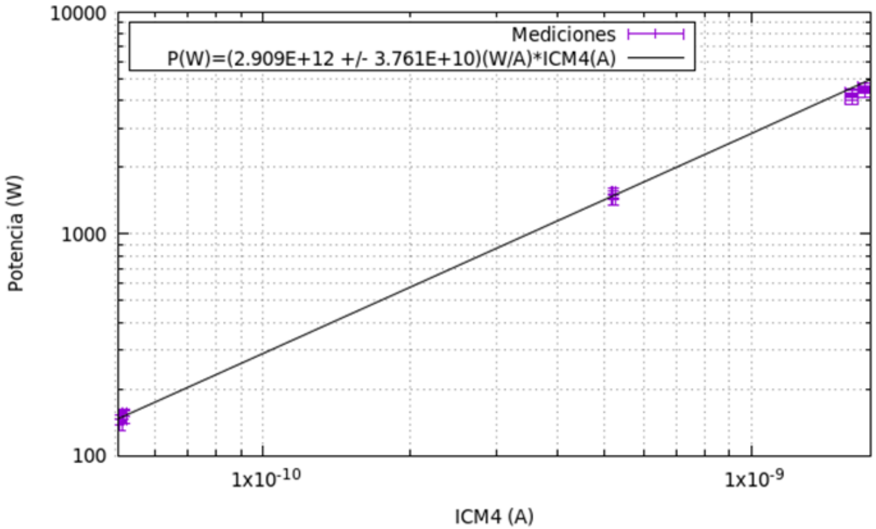


Neutron flux measurement



Power calibration by neutron noise

Pn = (2.943 ± 0.060)E+12 W/A

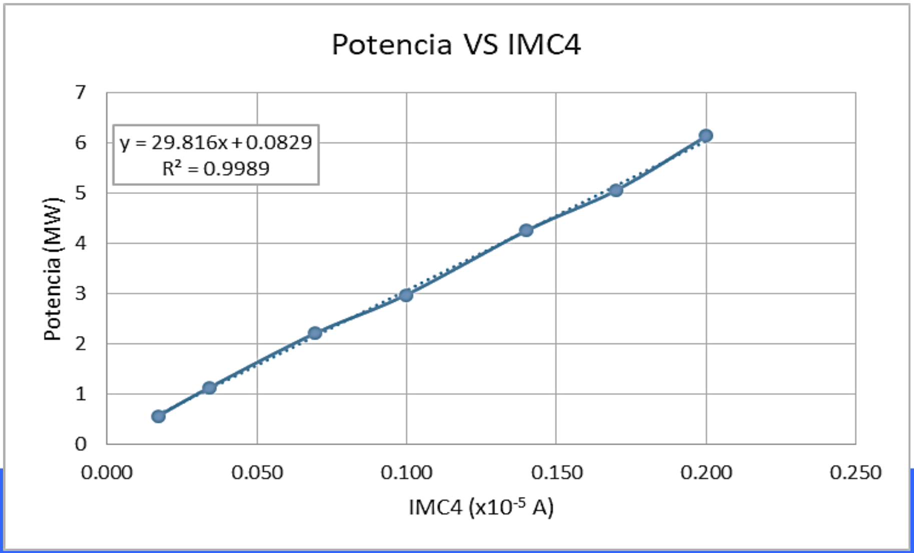


Stage D: Heading to Operating Power

The operating power was progressively increased to verify the performance of the instrumentation and systems, but above all to assess safety.

Date		Time	ICM4	%BC1	%BC2	Pn (MW)
Sep 25	22:03	2 hrs	$0.17\ 10^{-6}$	40.7 %	0 %	**0.57**
Sep 26	00:35	2 hrs	$0.34\ 10^{-6}$	40.9 %	0 %	**1.13**
Sep 26	02:54	6 hrs	$0.70\ 10^{-6}$	41.9 %	0 %	**2.22**
Sep 26	12:07	6 hrs	$0.10\ 10^{-5}$	52.8 %	0 %	**2.98**
Sep 26	21:52	8 hrs	$0.14\ 10^{-5}$	61.8 %	0 %	**4.26**
Sep 27	05:42	8 hrs	$0.17\ 10^{-5}$	66.1 %	0 %	**5.06**
Sep 27	14:09	26 hrs	$0.20\ 10^{-5}$	80.1 %	0%	**6.14**
Sep 28	16:00	Fin	$0.20\ 10^{-5}$	100 %	16%	**6.14**

Pn = 29.816 • ICM4 + 0.0829



Reactor in operating power
Date: **September 27, 2019**
Time: **14:09**
Control rod position:

- BS1 = 100%
- BS2 = 100%
- BS3 = 100%
- BC1 = 80.1%
- BC2 = 0%

Pn = 6.14 MW
ICM4 = 0.20 10^{-5} A

CONCLUSIONES

The design and construction of the silicide fuels assemblies were carried out applying an approved quality system.

The commissioning and operation of the reactor with the silicide fuels assemblies were carried out in compliance with national and international safety standards.

The knowledge acquired is very important and very valuable, this allows us to face new challenges with the confidence that the technical staff has the capacity and knowledge to carry them out.

Currently the reactor is operating under the conditions that had been determined by calculation. Obviously there are some improvements that must be implemented.

Thank you very much!!

RP-10

IPEN

RP-10 U_3Si_2

DIRECCION DE PRODUCCION

SUBDIRECCION DE OPERACION DE REACTORES NUCLEARES

DEPARTAMENTO DE CALCULO, ANALISIS Y SEGURIDAD

TERMOHIDRAULICA RP-10

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