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COMMISSION OF THE EUROPEAN COMMUNITIES

TEMPERATURE COEFFICIENT MEASUREMENTS IN ECO WITH PU-CONTAINING ONE AND THREE ROD FUEL ELEMENTS

by

W. HAGE, H. HETTINGER, H. HOHMANN, F. TOSELLI and J. SCHNEIDER

1974

Joint Nuclear Research Centre
Ispra Establishment

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ABSTRACT

Channel temperature coefficient measurements were performed in the D_2O moderated natural uranium critical facility ECO. The purpose of these experiments was to determine the critical height variations as function of the coolant channel temperature by the progressive substitution technique with natural uranium and uranium plutonium fuel elements. The D_2O or H_2O coolant of 1, 5 and 9 central elements was heated step by step from 20 °C to 200 °C. The reactivity effects were measured by two different methods at square lattice pitches between 17.5 cm and 28.05 cm.

KEYWORDS

ECO REACTOR
TEMPERATURE COEFFICIENT
DATA
TEMPERATURE DEPENDENCE
COOLING
CRITICAL SIZE
PILE REPLACEMENT TECHNIQUES
FUEL ELEMENTS
NATURAL URANIUM
PLUTONIUM
HEAVY WATER
WATER
HEATING

1. INTRODUCTION

In D_2O reactors with natural uranium fuel at equilibrium burn-up conditions, the coolant temperature coefficient can become positive due to the rethermalization by the coolant and the positive temperature coefficient of the Pu^{239} η-value.

For safe reactor operation it is therefore necessary to calculate this temperature coefficient with good precision.

The data presented in this report serve to check the assessment methods used for the determination of coolant channel temperature coefficients with fuel rods of natural uranium and uranium plutonium alloy.

A progressive substitution method was applied in the critical facility ECO in order to determine the channel temperature coefficient of the material buckling $\Delta B_M^2/\Delta T_{ch}$ from measured critical height variations as function of coolant channel temperature. In this technique 1, 5 and 9 central fuel channels were heated in steps of about 50°C from 20°C to 200°C. As test elements natural uranium and U-Pu fuel rods in single and 3-rod cluster geometry were investigated. The measurements were performed at different square lattice pitches ranging from 17.5 to 28.05 cm with H_2O and D_2O coolants. The moderator temperature was kept at about 20°C and 60°C. Experiments with U-Pu single rods were performed with two different coolant cross sections.

2. EXPERIMENTAL INSTALLATIONS

2.1. ECO reactor

The experiments were executed in the D_2O moderated critical assembly ECO (Ref.1 and Fig.2.1). The reactor tank had a diameter of 3000 mm and the active fuel zone a height of 2900 mm. The core was surrounded by a 900 mm thick bottom and side reflector of graphite. The loop for the external heating of the 9 special fuel element channels was located outside the biological shielding.

2.2. Coolant loop

The main functions of the coolant loop were : circulation of the coolant through the test channels, heating of the coolant and pressurization of the circuit in order to avoid boiling. Fig.2.2 gives the principal scheme of the loop with its main components. The coolant was circulated by a pump P1 via heat exchangers E1 and E2, a 114 kw electric heater H1, a regulation valve 103 and a degassing tank V2 back to the pump. The fuel element channels were connected in bypass to the main coolant circuit before and after the regulation valve. According to chosen valve positions the coolant was circulated through 1, 5 or 9 test channels. The pressure difference on the regulation valve was adjusted so that for any combination of coolant channels the flow per channel remained approximately constant independent of the number of heated channels.

At the coolant inlet of each channel a 1.5 kw heater was installed, permitting an individual temperature regulation. The coolant inlet and outlet temperature of each channel was measured with thermocouples Chromel-Alumel. All parts in contact with the coolant were made of stainless steel.

2.3. Fuel elements

For the assembling of test elements natural uranium and uranium plutonium rods were available. The fuel rod data are given in Table 2.1.

The rods were assembled either to single rod (U/1/29.2 and U-Pu/1/29.2) or three rod (U/3/29.2 and U-Pu/3/29.2) test elements. In all experiments 9 test channels were investigated, except in the case of the 3-rod cluster element with natural uranium, where only 1 element was available. The cross sections of the test elements are given in Fig.2.3 and 2.4.

Each element has a calandria and a pressure tube. In single rod elements the coolant flowed downwards between pressure tube and separation tube and upwards between separation tube and fuel rod. In the 3-rod cluster elements 4 separation tubes were used for the separation of coolant up and down flow. The interspace calandria pressure tube was purged with N_2 gas for leak detection purposes and thermal insulation. U-Pu single rod experiments were performed with two coolant channels of different coolant to fuel cross section ratios. Fig.2.5 gives the geometrical dimensions of the buffer and reference elements. The fuel rods used were identical to the natural uranium test rods of Table 2.1 but with Al instead of Zircaloy-2 cladding.

2.4. Core configurations and experimental program

During all experiments 89 fuel elements were loaded into the ECO core. In the case of single rod test elements the 9 central channels were surrounded by 80 single rods of natural uranium U/1/29.2. These driver fuel elements (Fig.2.5) were in direct contact with the moderator.

Calculations of the neutron spectrum for the 3-rod cluster experiments suggested a different core configuration. The 9 test elements were surrounded by a buffer zone with twenty-eight 3-rod clusters U/3/29.2 (Fig.2.5) and a driver zone with 52 ECO reference elements U/19/12-Diphyl.

The experiments in the case of the two single rod types U/1/29.2 and U-Pu/1/29.2 were performed with D_2O coolant at the lattice pitches 17.5 cm, 20.5 cm and 23.5 cm at about 20°C and 60°C moderator temperature. U-Pu/1/29.2 measurements with smaller channel were made at lattice pitches 17.5 cm, 19.5 cm and 23.5 cm using D_2O coolant, and at lattice pitches 17.5 cm, 19.5 cm and 20.5 cm with H_2O coolant. The moderator temperature was 20°C.

The 3-rod cluster elements U/3/29.2 and U-Pu/3/29.2 were investigated at the lattice pitches 18.8 cm, 23.5 cm and 28.05 cm with D_2O and H_2O coolants. In most cases the effects were measured at moderator temperatures 22°C and 60°C.

Table 2.2 gives the executed "experimental program" and indicates the table and in brackets the figure number with the corresponding experimental results.

3. EXPERIMENTAL METHOD AND RESULTS

3.1. Experimental method

For the determination of the fuel channel temperature coefficient of the material buckling a progressive substitution technique was applied. First 1 then 5 and finally 9 fuel channels were heated in several steps from 20°C to 200°C at constant moderator temperatures. For each heating step the critical height difference was measured with a D_2O level meter and an inverse neutron kinetics technique (Ref.2).

The experiment was started with fuel, coolant and moderator at the same temperature T_o. After an adjustement of a supercritical moderator level H the reactor diverged with a positive period to a power of about 100 W and was stabilized there on the critical moderator level H_c. From a continuous registration of the reactor power the differential reactivity coefficient $(\frac{\Delta \rho}{\Delta H})_{H_c}$ was obtained.

$$\frac{\Delta \rho}{\Delta H} = \frac{\rho - \rho_c}{H - H_c}$$

ρ = reactivity at moderator level H

ρ_c = " " " H_c

Heating of the coolant was started with the moderator in circulation. After reaching the desired temperature T_1 in the test channel, this temperature was maintained constant for about 15 minutes in order to obtain equilibrium conditions across the channel. From the reactivities at T_o and T_1 (moderator circulation on) the critical height difference was obtained

$$\Delta H_\rho (T_1, T_o) = - \left[\rho(T_1) - \rho(T_o) \right] \left(\frac{\Delta H}{\Delta \rho} \right)_{H_c}$$

A second critical height measurement with the D_2O level meter was performed without moderator circulation at the channel temperature T_1 after a readjustment of the moderator level.

This procedure was repeated for all heating steps until 200°C were reached in the central element. Afterwards the coolant in the loop was cooled down to about 60°C. The same procedure was repeated for the heating of 5 and 9 channels respectively.

During the heating of 5 or 9 fuel elements the power diverged so strongly that the horizontal control plates had to be inserted to lower the reactor power during the heating steps. The plates were extracted for the reactivity measurement after the fuel channel temperature was equilibrated.

During the experiments small drifts of the moderator temperature occurred. In order to correct the experimental results to standard moderator temperature values, the core temperature coefficient $\Delta H/\Delta T$ was determined for all investigated core configurations, measuring critical height changes as function of average core temperature in the ranges around 20°C and 60°C.

For the determination of the average moderator temperature 15 thermoresistors were distributed at 3 axial levels and 5 radial positions in the core. All temperatures were registered in time intervals of 5 minutes. During the measurements the moderator was circulated through an heat exchanger and an electric heater permitting a stabilization of the moderator temperature in the limits of ± 0.1°C.

3.2. Experimental results

The experimental results of the progressive heating of 1, 5 and 9 test elements up to 200°C are summarized in Tables 3.1 to 3.36 and in Fig.3.1 to 3.6.

Each table gives a specification of the general core conditions during the experiments (pitch, moderator temperature, core temperature coefficient $\Delta H/\Delta T$, D_2O-concentration and core position).

Column 1 shows the number of heated fuel channels. The moderator temperature $\bar{T}_m$ (column 2) is derived from at least 10 temperatures measured at different positions in the moderator. $\bar{T}_{ch}$ (column 3) is the mean value between inlet and outlet temperatures of 1, 5 or 9 heated channels. In column 4 the critical waterlevels H_c measured with the levelmeter are reported. These values are corrected to a standard moderator temperature close to 20°C and 60°C and listed in column 5 (H_c^*). The difference in critical heights ΔH_c^* for all heating steps are given in column 6. Column 7 contains the ΔH_ρ^* values obtained from reactivity measurements corrected for moderator temperature drifts. The errors in ΔH_c^* and ΔH_ρ^* are ± 0.2 and ± 0.1 mm respectively.

3.2.1. Single rod fuel elements

The results obtained with single rod test elements are reported in Table 3.1 to 3.18 and illustrated in Fig.3.1 to 3.3.

The critical height variations with natural uranium fuel and D_2O coolant (Table 3.1 to 3.3 and Fig.3.1 for 20°C and Table 3.7 to 3.9 and Fig.3.2 for 60°C moderator temperature) are positive and increase with the lattice pitch. At moderator temperatures of 60°C the effects are larger as compared to the values measured at 20°C. For U-Pu single rod fuel elements (Table 3.4 to 3.6 and Fig.3.1, 3.2) the ΔH_c values become negative and the effects are more pronounced at larger lattice pitches and at higher moderator temperatures. Experiments with fuel elements of smaller coolant cross section lead to positive critical height variations ΔH_c with a maximum at about 150°C for the lattice pitches 19.5 cm and 23.5 cm (Table 3.13 to 3.15 and Fig.3.3).

With this coolant channel the mean energy of the neutrons in the fuel rod is lower, such that the positive contribution of the Pu to the coolant channel reactivity coefficient is considerably reduced.

With single rod fuel elements and H_2O coolant, experiments with U-Pu rods and the small coolant channel cross section were performed only (Table 3.16 to 3.18 and Fig.3.3). The critical height variation is strongly negative due to the reduced neutron absorption in the heated coolant. The effect increases with the lattice pitch.

3.2.2. Three rod fuel elements

Progressive substitution measurements were performed with 3-rod U-Pu fuel clusters with D_2O and H_2O coolant. Table 3.19 to 3.24 and Fig.3.4 give the results for D_2O coolant at moderator temperatures of 20°C and 60°C. At the smallest pitch of 18.8 cm ΔH_c is positive and increases with the moderator temperature. At larger lattice pitches the ΔH_c values become negative for 5 and 9 heated channels at higher channel temperatures. At higher moderator temperatures this behaviour is more pronounced.

With H_2O coolant all critical height variations are negative, increasing with the channel temperature and with the moderator temperature. ΔH_c as function of lattice pitch shows a minimum between the extreme lattice pitches investigated for a given fuel channel temperature (Table 3.25 - 3.30, and Fig.3.5).

For natural uranium 3-rod cluster experiments only one central fuel element was available.
The measurements with D_2O coolant shows positive critical height variations with temperature and indicate also a minimum between the two extreme pitches (Table 3.31 to 3.33 and Fig.3.6) at the two moderator temperatures investigated. With H_2O coolant the same observations were made but with a negative ΔH_c.

For a comparison of the results all measured data obtained with uranium and uranium-plutonium fuel, heating the central channel only, are presented in Fig.3.6.

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Table 2.1 Fuel Rods Used in Test Elements

Fuel rod data	Type of fuel rod	
	U_{nat}	U-Pu
Fuel material	U -metal	U-Pu -metal
U-235/U-238	0.72%	0.22%
Pu-239/U-238	-	0.27%
Pu-240/Pu-239	-	8.53%
Pu-241/Pu-239	-	0.66%
density (g/cm^3)	18.94	18.69
diameter (mm)	29.2	29.2
length (mm)	2340	2340

TABLE: 2.2 EXPERIMENTAL PROGRAM

		TEST FUEL ELEMENT TYPE								
		U_{nat}/1/29.2		U-Pu/1/29.2			U_{nat}/3/29.2*		U-Pu/3/29.2	
moderator temperat. (°C)		20	60	20	60	20	20	60	20	60
coo-lant	pitch (cm)									
D_2O	17.5	3.1(3.1)	3.7(3.2)	3.4(3.1)	3.10(3.2)	3.13(3.3)	–	–	–	–
	18.8	–	–	–	–	–	3.31(3.6)	3.31(3.6)	3.19(3.4)	3.22(3.4)
	19.5	–	–	–	–	3.14(3.3)	–	–	–	–
	20.5	3.2(3.1)	3.8(3.2)	3.5(3.1)	3.11(3.2)	–	–	–	–	–
	23.5	3.3(3.1)	3.9(3.2)	3.6(3.1)	3.12(3.2)	3.15(3.3)	3.32(3.6)	3.32(3.6)	3.20(3.4)	3.23(3.4)
	28.05	–	–	–	–	–	3.33(3.6)	3.33(3.6)	3.21(3.4)	3.24(3.4)
H_2O	17.5	–	–	–	–	3.16(3.3)	–	–	–	–
	18.8	–	–	–	–	–	3.34(3.6)	–	3.25(3.5)	3.28(3.5)
	19.5	–	–	–	–	3.17(3.3)	–	–	–	–
	20.5	–	–	–	–	3.18(3.3)	–	–	–	–
	23.5	–	–	–	–	–	3.35(3.6)	–	3.26(3.5)	3.29(3.5)
	28.05	–	–	–	–	–	3.36(3.6)	–	3.27(3.5)	3.30(3.5)
channel seize		large				small				

*only one channel heated

Table 3.1

ECO-Pu: Fuel Channel Temperature Coefficient

Core: d = 17.5 cm T_m = 22.3 °C

$\Delta H/\Delta T$ = 1.65 mm/°C C_{D_2O} = 99.664 w.%

9 U_{nat}/1/29.2 – TR – D_2O

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.46	22.46	150.93	150.90		
					0.3	0.38
	22.46	57.25	150.96	150.93		
					0.4	0.36
	22.46	96.15	151.00	150.97		
					0.5	0.49
	22.50	150.15	151.05	151.02		
					0.3	0.38
	22.46	197.60	151.08	151.05		
5	22.37	22.37	150.92	150.91		
					1.9	2.04
	22.46	58.05	151.13	151.10		
					2.1	1.84
	22.45	97.65	151.33	151.31		
					2.2	2.14
	22.40	150.25	151.55	151.53		
					1.8	1.69
	22.46	199.25	151.74	151.71		
9						
	22.44	60.95	151.33	151.31		
					3.3	2.97
	22.44	96.65	151.66	151.64		
					4.4	4.12
	22.48	149.15	152.11	152.08		
					3.0	3.01
	22.61	199.90	152.43	152.38		

*) values corrected to T_m = 22.3 °C

Table 3.2

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 20.5 cm T_m = 22.3 °C

$\Delta H/\Delta T$ = 2.05 mm/°C C_{D_2O} = 99.664 w.%

9 U_{nat}/1/29.2 – TR – D_2O

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.16	22.16	171.13	171.16		
					0.5	0.68
	22.26	60.50	171.20	171.21		
					0.5	0.44
	22.27	98.20	171.25	171.26		
					0.7	0.70
	22.28	149.70	171.33	171.33		
					0.9	0.66
	22.19	198.20	171.40	171.42		
5						
	22.18	61.70	171.48	171.51		
					2.2	2.41
	22.18	99.40	171.70	171.73		
					2.6	2.67
	22.21	149.05	171.97	171.99		
					1.7	1.82
	22.32	201.20	172.16	172.16		
9						
	22.26	60.30	171.66	171.67		
					4.5	4.22
	22.26	98.40	172.11	172.12		
					4.8	4.95
	22.33	149.25	172.61	172.60		
					3.6	3.53
	22.36	201.65	172.97	172.96		

*) values corrected to T_m = 22.3 °C

Table 3.3

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm $\qquad T_m$ = 22.3 °C

$\Delta H/\Delta T$ = 2.95 mm/°C $\qquad C_{D_2O}$ = 99.663 w.%

9 U_{nat}/1/29.2 – TR – D_2O

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.21	22.21	207.93	207.96		
					0.7	0.93
	22.22	60.25	208.01	208.03		
					0.8	0.74
	22.23	99.90	208.09	208.11		
					1.6	1.44
	22.24	150.85	208.25	208.27		
					2.3	1.93
	22.26	200.00	208.49	208.50		
5						
	22.24	62.00	208.52	208.54		
					3.3	3.59
	22.29	98.50	208.87	208.87		
					4.2	4.21
	22.29	149.35	209.29	209.29		
					3.1	3.46
	22.31	201.25	209.60	209.60		
9						
	22.29	61.70	208.75	208.75		
					7.1	7.22
	22.27	101.25	209.45	209.46		
					7.5	7.87
	22.31	152.00	210.21	210.21		
					4.2	4.76
	22.37	201.50	210.65	210.63		

*) values corrected to T_m = 22.3 °C

Table 3.4

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 17.5 cm $\quad$ T_m = 22.3 °C

$\Delta H/\Delta T$ = 1.45 mm/°C $\quad$ C_{D_2O} = 99.685 w.%

9 U-Pu/1/29.2 - TR - D_2O

80 U/1/29.2 - D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.32	22.32	154.56	154.56		
					0.0	0.01
	22.40	60.00	154.57	154.56		
					-0.1	0.03
	22.39	97.75	154.56	154.55		
					-0.2	-0.11
	22.45	153.00	154.55	154.53		
					-0.3	-0.17
	22.48	202.00	154.53	154.50		
5						
	22.45	63.35	154.60	154.58		
					-0.5	-0.24
	22.48	98.10	154.56	154.53		
					-0.8	-0.74
	22.55	150.60	154.49	154.45		
					-1.0	-1.11
	22.60	198.60	154.39	154.35		
9						
	22.54	58.35	154.60	154.57		
					-0.6	-0.56
	22.53	97.25	154.54	154.51		
					-1.6	-1.36
	22.59	148.05	154.39	154.35		
					-2.2	-2.05
	22.67	198.70	154.18	154.13		

*) values corrected to T_m = 22.3 °C

Table 3.5

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 20.5 cm $\qquad T_m$ = 22.3 °C

$\Delta H/\Delta T$ = 1.70 mm/°C $\qquad C_{D_2O}$ = 99.686 w.%

9 U-Pu/1/29.2 – TR – D_2O

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.03	22.03	176.04	176.09		
					-0.3	0.07
	22.05	56.75	176.02	176.06		
					0.0	-0.04
	22.03	100.75	176.01	176.06		
					-0.3	-0.13
	22.19	150.50	176.01	176.03		
					-0.9	-0.43
	22.38	200.60	175.95	175.94		
5						
9	22.45	22.45	176.18	176.16		
					0.2	0.08
	22.54	60.15	176.22	176.18		
					-0.9	-0.76
	22.62	101.00	176.14	176.09		
					-2.4	-2.32
	22.65	146.70	175.91	175.85		
					-3.6	-3.42
	22.54	199.45	175.53	175.49		

*) values corrected to T_m = 22.3 °C

Table 3.6

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm T_m = 22.3 °C

$\Delta H/\Delta T$ = 2.40 mm/°C C_{D_2O} = 99.684 w.%

9 U-Pu/1/29.2 - TR - D_2O

80 U/1/29.2 - D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.35	22.35	215.52	215.51		
					0.1	0.11
	22.38	63.10	215.54	215.52		
					- 0.1	- 0.17
	22.31	98.75	215.51	215.51		
					- 0.4	- 0.63
	22.42	153.00	215.50	215.47		
					- 0.6	- 0.71
	22.42	204.00	215.44	215.41		
5	22.49	63.80	215.58	215.53		
					- 0.5	- 0.67
	22.34	101.10	215.49	215.48		
					- 2.1	- 2.12
	22.29	152.45	215.27	215.27		
					- 3.1	- 3.18
	22.45	197.50	215.00	214.96		
9	22.43	58.85	215.55	215.52		
					- 0.7	- 0.99
	22.39	97.95	215.47	215.45		
					- 3.7	- 3.82
	22.37	147.30	215.10	215.08		
					- 6.1	- 5.36
	22.51	197.20	214.52	214.47		

*) values corrected to T_m = 22.3 °C

Table 3.7

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 17.5 cm $\qquad T_m$ = 60.3 °C

$\Delta H/\Delta T$ = 3.05 mm/°C $\qquad C_{D_2O}$ = 99.668 w.%

9 U_{nat}/1/29.2 – TR – D_2O

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	60.04	60.04	159.11	159.19		
					0.1	0.67
	60.08	98.50	159.13	159.20		
					0.4	0.54
	60.12	151.15	159.18	159.24		
					0.7	0.58
	60.12	202.50	159.25	159.31		
5	59.93	64.85	159.14	159.25		
					2.2	1.91
	60.12	100.40	159.41	159.47		
					2.4	2.55
	60.06	150.30	159.64	159.71		
					1.7	1.57
	60.16	198.70	159.84	159.88		
9	60.08	61.70	159.18	159.25		
					3.9	3.74
	60.13	99.05	159.59	159.64		
					4.7	4.48
	60.22	151.40	160.09	160.11		
					3.3	2.95
	60.33	200.90	160.45	160.44		

*) values corrected to T_m = 60.3 °C

Table 3.8

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 20.5 cm $\quad T_m$ = 60.3 °C

$\Delta H/\Delta T$ = 3.00 mm/°C $\quad C_{D_2O}$ = 99.669 w.%

9 U_{nat}/1/29.2 – TR – D_2O

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1						
	60.13	60.13	180.36	180.41		
					0.4	0.74
	60.20	99.35	180.42	180.45		
					0.8	0.64
	60.18	148.00	180.49	180.53		
					0.3	0.53
	60.12	203.65	180.51	180.56		
5						
	60.06	62.00	180.40	180.47		
					2.6	2.46
	60.11	98.45	180.67	180.73		
					3.3	3.44
	60.14	152.70	181.01	181.06		
					1.8	2.07
	60.19	202.00	181.21	181.24		
9						
	60.01	63.00	180.46	180.55		
					4.6	4.70
	60.11	101.20	180.95	181.01		
					5.6	5.39
	59.89	149.30	181.45	181.57		
					3.5	4.19
	60.23	199.45	181.90	181.92		

*) values corrected to T_m = 60.3 °C

Table 3.9

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm $\quad T_m$ = 60.3 °C

$\Delta H/\Delta T$ = 3.70 mm/°C $\quad C_{D_2O}$ = 99.670 w.%

9 U_{nat}/1/29.2 – TR – D_2O

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	60.03	60.03	219.04	219.14		
					2.1	2.07
	59.96	100.40	219.22	219.35		
					1.1	1.30
	60.00	152.35	219.35	219.46		
					0.8	0.85
	60.05	200.25	219.45	219.54		
5	60.03	61.95	219.37	219.47		
					3.8	4.26
	60.11	98.60	219.78	219.85		
					4.6	4.80
	60.18	151.35	220.27	220.31		
					3.4	3.55
	60.07	202.80	220.56	220.65		
9	59.98	62.05	219.48	219.60		
					7.7	7.79
	59.89	101.95	220.22	220.37		
					7.6	7.98
	60.05	150.40	221.04	221.13		
					5.6	5.07
	60.13	200.60	221.63	221.69		

*) values corrected to T_m = 60.3 °C

Table 3.10

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 17.5 cm $\quad$ T_m = 60.0 °C

$\Delta H/\Delta T$ = 2.40 mm/°C $\quad$ C_{D_2O} = 99.679 w.%

9 U-Pu/1/29.2 – TR – D_2O

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	60.45	60.45	162.39	162.35		
					0.1	–0.06
	60.42	98.50	162.39	162.36		
					–0.2	–0.13
	60.41	148.75	162.37	162.34		
					–0.2	–0.15
	60.46	200.00	162.36	162.32		
5	60.26	62.40	162.39	162.40		
					–0.4	–0.44
	60.40	100.65	162.38	162.36		
					–0.9	–0.80
	60.42	146.30	162.30	162.27		
					–1.6	–1.48
	60.46	198.70	162.15	162.11		
9	60.32	61.95	162.39	162.39		
					–0.9	–0.66
	60.46	98.10	162.34	162.30		
					–1.3	–1.22
	60.45	146.55	162.21	162.17		
					–2.4	–2.54
	60.45	199.40	161.97	161.93		

*) values corrected to T_m = 60.3 °C

Table 3.11

ECO-Pu: Fuel Channel Temperature Coefficient

Core: d = 20.5 cm $\qquad T_m$ = 60.0 °C

$\Delta H/\Delta T$ = 2.60 mm/°C $\qquad C_{D_2O}$ = 99.680 w.%

9 U-Pu/1/29.2 - TR - D_2O

80 U/1/29.2 - D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	60.32	60.32	184.80	184.80		
					-0.2	-0.09
	60.34	97.65	184.79	184.78		
					-0.3	-0.16
	60.33	150.50	184.76	184.75		
					-0.3	-0.40
	60.35	200.65	184.74	184.72		
5	60.25	63.40	184.81	184.82		
					-0.7	-0.61
	60.36	99.00	184.77	184.75		
					-1.4	-1.50
	60.41	151.10	184.64	184.61		
					-2.0	-2.10
	60.47	197.60	184.45	184.41		
9	60.40	61.55	184.82	184.79		
					-1.4	-1.21
	60.54	98.70	184.71	184.65		
					-2.0	-2.50
	60.39	149.20	184.47	184.45		
					-4.2	-4.21
	60.47	199.50	184.07	184.03		

*) values corrected to T_m = 60.3 °C

Table 3.12

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm T_m = 60.0 °C

$\Delta H/\Delta T$ = 3.10 mm/°C C_{D_2O} = 99.680 w.%

9 U-Pu/1/29.2 - TR - D_2O

80 U/1/29.2 - D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1						
	60.37	60.37	226.41	226.39		
					- 0.2	0.01
	60.46	94.25	226.42	226.37		
					- 0.4	- 0.13
	60.35	153.35	226.34	226.33		
					- 0.9	- 0.56
	60.33	202.00	226.25	226.24		
5						
	60.27	63.35	226.39	226.40		
					- 1.3	- 1.48
	60.46	99.85	226.32	226.27		
					- 2.3	- 2.34
	60.35	150.05	226.05	226.04		
					- 4.3	- 4.06
	60.39	201.55	225.64	225.61		
9						
	60.34	64.00	226.39	226.38		
					- 1.6	- 1.72
	60.40	99.90	226.25	226.22		
					- 4.6	- 4.47
	60.49	149.30	225.82	225.76		
					- 7.5	- 7.90
	60.24	200.15	224.99	225.01		

*) values corrected to T_m = 60.3 °C

Table 3.13

ECO-Pu: Fuel Channel Temperature Coefficient

Core: d = 17.5 cm T_m = 20.3 °C

$\Delta H/\Delta T$ = 1.70 mm/°C C_{D_2O} = 99.605 w.%

9 U-Pu/1/29.2 – TR – D_2O small channel
80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	20.21	20.21	151.35	151.37		
					+ 0.2	+ 0.12
	20.14	59.00	151.36	151.39		
					– 0.0	+ 0.10
	20.15	99.45	151.36	151.39		
					+ 0.1	+ 0.02
	20.17	152.40	151.38	151.40		
					– 0.1	+ 0.03
	20.18	196.45	151.37	151.39		
5	20.24	20.24	151.39	151.40		
					+ 0.4	+ 0.44
	20.22	59.26	151.43	151.44		
					+ 0.4	+ 0.41
	20.03	104.60	151.43	151.48		
					+ 0.4	+ 0.30
	20.25	150.05	151.51	151.52		
					+ 0.1	+ 0.05
	20.21	196.90	151.51	151.53		
9	–	–	–	–		
					–	–
	20.23	57.00	151.44	151.45		
					+ 0.6	+ 0.62
	20.21	106.05	151.49	151.51		
					+ 0.4	+ 0.45
	20.22	148.80	151.54	151.55		
					+ 0.2	+ 0.14
	20.30	201.05	151.57	151.57		

*) values corrected to T_m = 20.3 °C

Table 3.14

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 19.5 cm $\quad T_m$ = 20.3 °C

$\Delta H/\Delta T$ = 1.90 mm/°C $\quad C_{D_2O}$ = 99.606 w.%

9 U-Pu/1/29.2 – TR – D_2O small channel
80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	20.17	20.17	164.76	164.79		
					– 0.5	– 0.35
	20.11	55.00	164.70	164.74		
					+ 0.1	+ 0.14
	20.13	99.66	164.72	164.75		
					– 0.2	+ 0.06
	20.09	146.20	164.69	164.73		
					+ 0.3	– 0.05
	20.04	198.60	164.71	164.76		
5	–	–	–	–		
					–	–
	20.21	56.50	164.78	164.80		
					+ 0.5	+ 0.58
	20.07	100.30	164.81	164.85		
					+ 0.4	+ 0.52
	20.15	150.10	164.86	164.89		
9	20.06	20.06	164.71	164.76		
					+ 0.7	+ 0.68
	20.12	60.30	164.80	164.83		
					+ 0.4	+ 0.24
	20.13	102.15	164.84	164.87		
					+ 0.6	+ 0.37
	20.15	150.85	164.90	164.93		
					– 0.4	– 0.13
	20.18	201.95	164.87	164.89		

*) values corrected to T_m = 20.3 °C

Table 3.15

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm T_m = 20.3 °C

$\Delta H/\Delta T$ = 2.35 mm/°C C_{D_2O} = 99.604 w.%

9 U-Pu/1/29.2 - TR - D_2O small channel
80 U/1/29.2 - D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	20.05	20.05	214.86	214.92		
					- 0.1	- 0.12
	20.10	58.15	214.86	214.91		
					+ 0.0	+ 0.07
	20.03	104.20	214.85	214.91		
					+ 0.0	+ 0.21
	20.07	154.40	214.86	214.91		
					- 0.2	+ 0.05
	20.05	199.40	214.83	214.89		
5	-	-	-	-		
					-	-
	20.08	60.10	214.92	214.97		
					+ 0.2	+ 0.40
	20.08	106.40	214.94	214.99		
					- 0.2	+ 0.19
	20.12	152.80	214.93	214.97		
					- 0.2	+ 0.24
	20.15	197.95	214.91	214.95		
9	20.15	20.15	214.90	214.94		
					+ 0.8	+ 1.15
	20.17	59.20	214.99	215.02		
					+ 0.5	+ 0.78
	20.16	101.50	215.04	215.07		
					+ 0.2	+ 0.18
	20.21	148.25	215.07	215.09		
					- 0.7	- 0.54
	20.28	198.15	215.01	215.02		

*) values corrected to T_m = 20.3 °C

Table 3.16

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 17.5 cm T_m = 20.3 °C

$\Delta H/\Delta T$ = 1.95 mm/°C C_{D_2O} = 99.611 w.%

9 U-Pu/1/29.2 – TR – H_2O small channel

80 U/1/29.2 – D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	20.45	20.45	167.96	167.93		
					– 0.7	– 0.59
	20.36	59.27	167.87	167.86		
					– 0.9	– 0.78
	20.30	101.01	167.77	167.77		
					– 1.3	– 1.28
	20.21	150.65	167.62	167.64		
					– 1.6	– 1.56
	20.28	203.67	167.48	167.48		
5	–	–	–	–		
					–	–
	20.48	56.23	167.64	167.61		
					– 4.6	– 4.45
	20.47	97.68	167.18	167.15		
					– 7.7	– 7.63
	20.39	152.28	166.40	166.38		
					– 7.4	– 7.58
	20.26	199.50	165.63	165.64		
9	–	–	–	–		
					–	–
	20.32	60.38	167.24	167.24		
					– 9.3	– 9.01
	20.31	103.99	166.31	166.31		
					–11.6	–11.91
	20.24	151.16	165.14	165.15		
					–15.0	–15.17
	20.36	203.52	163.66	163.65		

*) values corrected to T_m = 20.3 °C

Table 3.17

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 19.5 cm T_m = 20.3 °C

$\Delta H/\Delta T$ = 2.17 mm/°C C_{D_2O} = 99.613 w.%

9 U-Pu/1/29.2 - TR - H_2O small channel

80 U/1/29.2 - D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	20.25	20.25	184.93	184.94		
					- 0.9	- 0.65
	20.22	56.49	184.83	184.85		
					- 1.2	- 1.15
	20.20	105.18	184.71	184.73		
					- 1.7	- 1.59
	20.20	154.77	184.54	184.56		
					- 1.5	- 1.60
	20.23	201.54	184.39	184.41		
5	-	-	-	-		
					-	-
	20.23	54.10	184.56	184.58		
					- 5.6	- 5.72
	20.23	97.62	184.00	184.02		
					- 8.7	- 8.67
	20.24	151.56	183.13	183.15		
					- 9.7	- 9.81
	20.27	203.21	182.17	182.18		
9	20.31	20.31	184.94	184.94		
					- 6.8	- 6.73
	20.32	56.17	184.26	184.26		
					-10.6	-11.32
	20.35	101.41	183.21	183.20		
					-15.3	-15.49
	20.39	151.92	181.69	181.67		
					-16.2	-16.98
	20.27	200.47	180.04	180.05		

*) values corrected to T_m = 20.3 °C

Table 3.18

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 20.5 cm $\qquad T_m$ = 20.3 °C

$\Delta H/\Delta T$ = 2.28 mm/°C $\qquad C_{D_2O}$ = 99.610 w.%

9 U-Pu/1/29.2 - TR - H_2O small channel

80 U/1/29.2 - D_2O

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	20.01	20.00	197.36	197.43		
	20.07	58.15	197.28	197.33	- 1.0	- 0.94
	20.10	100.08	197.17	197.22	- 1.1	- 1.20
	20.10	155.97	196.98	197.03	- 1.9	- 1.88
	20.13	203.94	196.78	196.82	- 2.1	- 1.93
5	-	-	-	-		
	20.17	57.84	196.95	196.98	-	-
	20.16	99.70	196.31	196.34	- 6.4	- 6.24
	20.19	151.28	195.39	195.42	- 9.2	- 9.68
	20.16	202.13	194.29	194.32	-11.0	-11.07
9	-	-	-	-		
	20.17	59.67	196.52	196.55	-	-
	20.20	104.61	195.31	195.33	-12.2	-12.20
	20.06	153.07	193.70	193.76	-15.7	-16.56
	20.17	205.78	191.66	191.69	-20.7	-21.00

*) values corrected to T_m = 20.3 °C

Table 3.19

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 18.8 cm $\qquad T_m$ = 22.3 °C

$\Delta H/\Delta T$ = 1.16 mm/°C $\qquad C_{D_2O}$ = 99.735 w.%

9 U-Pu/3/29.2 – TR – D_2O

28 U/3/29.2 – D_2O

52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.21	22.30	149.70	149.71		
					0.2	0.04
	22.21	53.00	149.72	149.73		
					0.1	0.15
	22.21	103.00	149.73	149.74		
					0.3	0.11
	22.21	154.75	149.76	149.77		
					–	0.15
	22.21	198.75	–	–		
5						
	22.17	65.40	149.82	149.84		
					0.6	0.60
	22.22	102.00	149.89	149.90		
					0.5	0.48
	22.39	149.75	149.96	149.95		
					0.5	0.38
	22.39	198.00	150.01	150.00		
9						
	22.25	61.80	149.87	149.88		
					1.3	1.11
	22.32	98.65	150.01	150.01		
					1.2	0.84
	22.42	146.80	150.14	150.13		
					0.5	0.62
	22.57	203.50	150.21	150.18		

*) values corrected to T_m = 22.3 °C

Table 3.20

ECO-Pu: Fuel Channel Temperature Coefficient

Core: d = 23.5 cm $\quad T_m$ = 22.3 °C

$\Delta H/\Delta T$ = 0.92 mm/°C $\quad C_{D_2O}$ = 99.735 w. %

9 U-Pu/3/29.2 – TR – D_2O
28 U/3/29.2 – D_2O
52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.21	22.21	136.90	136.91		
					0.0	0.04
	22.21	57.40	136.90	136.91		
					0.0	0.04
	22.19	101.60	136.90	136.91		
					0.0	0.00
	22.15	152.00	136.90	136.91		
					0.1	– 0.02
	22.21	200.60	136.91	136.92		
5						
	22.26	61.90	136.95	136.95		
					0.2	0.12
	22.20	100.80	136.96	136.97		
					0.0	– 0.04
	22.23	150.85	136.96	136.97		
					– 0.5	– 0.32
	22.24	198.85	136.91	136.92		
9						
	22.19	61.40	136.97	136.98		
					0.2	0.23
	22.17	102.20	136.99	137.00		
					– 0.1	– 0.15
	22.18	147.65	136.98	136.99		
					– 0.8	– 0.64
	22.15	196.75	136.90	136.91		

*) values corrected to T_m = 22.3 °C

Table 3.21

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 28.05 cm T_m = 22.3 °C

ΔH/ΔT = 0.85 mm/°C C_{D_2O} = 99.735 w.%

9 U-Pu/3/29.2 -TR - D_2O

28 U/3/29.2 - D_2O

52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.11	22.11	156.26	156.28		
					0.1	0.15
	22.14	53.40	156.28	156.29		
					0.1	0.00
	22.13	90.45	156.28	156.30		
					0.1	0.02
	22.11	135.45	156.29	156.31		
					0.0	-0.07
	22.13	196.40	156.29	156.31		
5						
	22.11	60.25	156.33	156.35		
					0.0	0.01
	22.13	91.90	156.33	156.35		
					-0.3	- 0.14
	22.15	137.20	156.31	156.32		
					-0.4	-0.56
	22.18	177.60	156.27	156.28		
9						
	22.15	55.85	156.36	156.37		
					0.0	0.09
	22.16	79.10	156.36	156.37		
					-0.2	-0.22
	22.18	131.90	156.34	156.35		
					-1.5	-1.10
	22.34	183.00	156.20	156.20		

*) values corrected to T_m = 22.3 °C

Table 3.22

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 18.8 cm T_m = 60.0 °C

$\Delta H/\Delta T$ = 2.85 mm/°C C_{D_2O} = 99.734 w.%

9 U-Pu/3/29.2 - TR - D_2O

28 U/3/29.2 - D_2O

52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1						
	59.90	59.90	157.22	157.33		
					0.2	0.50
	59.73	101.00	157.19	157.35		
					0.2	0.09
	59.99	150.90	157.28	157.37		
					0.2	0.25
	59.96	199.75	157.29	157.39		
5						
	59.76	59.75	157.24	157.39		
					0.8	0.44
	59.78	99.75	157.32	157.47		
					0.6	0.71
	59.95	150.70	157.43	157.53		
					0.5	1.00
	59.97	201.30	157.49	157.58		
9						
	59.78	59.50	157.19	157.34		
					1.4	1.25
	60.11	101.35	157.43	157.48		
					1.3	1.29
	60.04	149.05	157.54	157.61		
					0.7	0.47
	60.13	196.20	157.63	157.68		

*) values corrected to T_m = 60.3 °C

Table 3.23

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm T_m = 60.0 °C

$\Delta H/\Delta T$ = 1.36 mm/°C C_{D_2O} = 99.734 w.%

9 U-Pu/3/29.2 - TR - D_2O

28 U/3/29.2 - D_2O

52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	60.38	60.38	141.15	141.14		
					0.0	0.12
	60.36	98.90	141.15	141.14		
					- 0.1	- 0.18
	60.36	148.35	141.14	141.13		
					- 0.2	- 0.29
	60.41	200.90	141.13	141.11		
5	60.08	60	141.13	141.16		
					0.2	0.19
	60.09	97	141.15	141.18		
					- 0.3	- 0.20
	60.10	151.25	141.12	141.15		
					- 0.3	- 0.41
	60.10	195.95	141.09	141.12		
9	59.97	60.10	141.15	141.19		
					0.0	0.23
	60.07	98.80	141.16	141.19		
					- 0.3	- 0.43
	60.10	148.20	141.13	141.16		
					- 1.0	- 1.07
	60.07	196.45	141.03	141.06		

*) values corrected to T_m = 60.3 °C

Table 3.24

ECO-Pu: Fuel Channel Temperature Coefficient

Core: d = 28.05 cm $\quad T_m$ = 60.0 °C

$\Delta H/\Delta T$ = 1.10 mm/°C $\quad C_{D_2O}$ = 99.734 w.%

9 U-Pu/3/29.2 - TR - D_2O

28 U/3/29.2 - D_2O

52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	59.94	62.90	160.04	160.08		
	59.99	99.90	160.05	160.08	0.0	0.20
	59.78	151.00	160.02	160.08	0.0	0.09
	59.90	202.90	160.00	160.04	- 0.4	- 0.13
5	59.79	64.20	160.04	160.10		
	59.91	96.30	160.02	160.06	- 0.4	- 0.08
	59.73	149.20	159.96	160.02	- 0.4	- 0.34
	59.74	197.00	159.86	159.92	- 1.0	- 0.99
9	59.88	58.15	160.05	160.10		
	59.73	101.25	160.00	160.06	- 0.4	- 0.28
	59.98	148.05	159.93	159.97	- 0.9	- 0.84
	59.94	199.35	159.73	159.77	- 2.0	- 2.14

*) values corrected to T_m = 60.3 °C

Table 3.25

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 18.8 cm T_m = 22.3 °C

$\Delta H/\Delta T$ = 1.70 mm/°C C_{D_2O} = 99.720 w.%

9 U-Pu/3/29.2 - TR - H_2O

28 U/3/29.2 - D_2O

52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.22	22.22	170.63	170.64		
					- 1.5	- 2.17
	22.22	58.25	170.48	170.49		
					- 2.1	- 2.19
	22.19	101.00	170.26	170.28		
					- 3.1	- 2.88
	22.23	151.00	169.96	169.97		
					- 3.2	- 3.14
	22.23	199.25	169.64	169.65		
5						
	22.18	56.60	169.75	169.77		
					- 11.6	- 11.38
	22.12	99.00	168.58	168.61		
					- 14.6	- 14.45
	22.14	149.05	167.12	167.15		
					- 15.8	- 15.82
	22.12	199.45	165.54	165.57		
9	22.04	22.04	170.67	170.71		
					- 18.3	- 18.16
	22.07	61.00	168.83	168.88		
					- 19.6	- 19.20
	22.07	100.75	166.88	166.92		
					- 26.0	- 25.77
	22.15	150.85	164.29	164.32		
					- 26.8	- 26.10
	22.19	200.15	161.62	161.64		

*) values corrected to T_m = 22.3 °C

Table 3.26

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm $\qquad$ T_m = 22.3 °C

$\Delta H/\Delta T$ = 0.92 mm/°C $\qquad$ C_{D_2O} = 99.722 w.%

9 U – Pu/3/29.2 – TR – H_2O

28 U/3/29.2 – D_2O

52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.09	22.09	158.62	158.64		
					– 1.0	– 1.52
	22.03	58.50	158.51	158.54		
					– 1.7	– 1.56
	22.07	101.25	158.35	158.37		
					– 1.9	– 1.97
	22.06	149.65	158.16	158.18		
					– 2.4	– 1.36
	22.11	198.90	157.92	157.94		
5	22.07	22.07	158.68	158.70		
					– 6.8	– 6.78
	22.08	58.90	158.00	158.02		
					– 8.1	– 8.07
	22.10	100.00	157.19	157.21		
					–11.1	–11.07
	22.12	152.45	156.08	156.10		
					– 10.7	–10.57
	22.21	196.80	155.02	155.03		
9						
	22.09	57.00	157.55	157.57		
					–15.4	–15.02
	22.14	99.65	156.01	156.03		
					–19.3	–18.81
	22.26	148.15	154.10	154.10		
					–21.3	–21.36
	22.41	198.80	151.98	151.97		

*) values corrected to T_m = 22.3 °C

Table 3.27

ECO-Pu : Fuel Channel Temperature Coefficient

Core : d = 28.05 cm T_m = 22.3 °C

$\Delta H/\Delta T$ = 0.88 mm/°C C_{D_2O} = 99.723 w %

9 U - Pu/3/29.2 - TR - H_2O

28 U/3/29.2 - D_2O

52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.09	22.09	187.50	187.52		
					0.1	- 0.40
	22.12	57.00	187.51	187.53		
					- 1.9	- 1.72
	22.13	99.00	187.32	187.34		
					- 2.9	- 2.74
	22.13	152.35	187.03	187.05		
					- 3.0	- 2.73
	22.11	201.50	186.73	186.75		
5						
	22.15	59.40	186.88	186.89		
					- 9.5	- 9.53
	22.13	99.20	185.92	185.94		
					- 14.0	- 13.51
	22.22	149.35	184.53	184.54		
					- 15.2	- 14.54
	22.23	197.15	183.01	183.02		
9						
	22.10	57.60	186.30	186.32		
					- 20.0	- 18.88
	22.38	100.00	184.33	184.32		
					- 25.0	- 23.51
	22.23	148.65	181.81	181.82		
					- 27.1	- 25.67
	22.26	197.50	179.11	179.11		

*) values corrected to T_m = 22.3 °C

Table 3.28

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 18.8 cm T_m = 60.3 °C

$\Delta H/\Delta T$ = 3.03 mm/°C C_{D_2O} = 99.718 w.%

9 U-Pu/3/29.2 - TR - H_2O

28 U/3/29.2 - D_2O

52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	60.03	60.03	178.30	178.38		
					- 3.1	- 2.93
	60.04	99.90	177.99	178.07		
					- 3.7	- 3.62
	60.04	149.75	177.62	177.70		
					- 4.2	- 4.43
	60.05	203.00	177.20	177.28		
5	59.94	61.10	177.99	178.10		
					- 12.4	- 13.04
	60.10	99.85	176.80	176.86		
					- 16.3	- 17.13
	60.06	148.95	175.16	175.23		
					- 17.8	- 18.08
	60.13	198.60	173.40	173.45		
9	60.09	58.60	177.97	178.03		
					- 23.8	- 24.82
	60.08	101.45	175.58	175.65		
					- 28.4	- 28.65
	60.10	149.20	172.75	172.81		
					- 29.6	- 29.55
	60.13	198.35	169.80	169.85		

*) values corrected to T_m = 60.3 °C

Table 3.29

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm $\quad T_m$ = 60.3 °C

$\Delta H/\Delta T$ = 1.57 mm/°C $\quad C_{D_2O}$ = 99.717 w.%

9 U-Pu/3/29.2 – TR – H_2O

28 U/3/29.2 – D_2O

52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	60.18	60.18	162.87	162.89		
	60.08	101.15	162.65	162.69	– 2.0	– 1.98
	60.09	151.00	162.42	162.45	– 2.4	– 2.38
	60.23	204.15	162.15	162.16	– 2.9	– 2.97
5	60.07	55.70	162.74	162.78		
	60.16	101.65	161.77	161.79	– 9.9	– 10.37
	59.91	151.95	160.57	160.63	–11.6	– 12.08
	60.03	199.75	159.35	159.39	–12.4	– 12.61
9	60.05	59.55	162.67	162.71		
	60.06	101.15	161.02	161.06	–16.5	– 16.37
	59.98	149.45	158.95	159.00	–20.6	– 20.66
	59.93	202.40	156.52	156.58	–24.2	– 23.64

*) values corrected to T_m = 60.3 °C

Table 3.30

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 28.05 cm $\qquad T_m$ = 60.3 °C

$\Delta H/\Delta T$ = 1.45 mm/°C $\qquad C_{D_2O}$ = 99.716 w.%

9 U – Pu/3/29.2 – TR – H_2O

28 U/3/29.2 – D_2O

52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	60.01	60.01	191.55	191.59		
					– 2.7	– 2.64
	59.94	101.15	191.27	191.32		
					– 3.0	– 3.03
	59.99	150.90	190.97	191.02		
					– 3.2	– 3.11
	60.09	199.50	190.67	190.70		
5	59.97	60.90	191.38	191.43		
					– 11.9	– 11.56
	60.02	100.90	190.20	190.24		
					– 15.0	– 15.30
	59.95	151.00	188.69	188.74		
					– 14.9	– 15.48
	59.96	197.20	187.20	187.25		
9	60.16	58.75	191.41	191.43		
					– 22.6	– 22.46
	60.06	102.55	189.13	189.17		
					– 26.4	– 25.40
	60.03	149.25	186.49	186.53		
					– 29.5	– 29.27
	60.01	198.80	183.54	183.58		

*) values corrected to T_m = 60.3 °C

Table 3.31

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 18.8 cm T_m = 22 °C, 60 °C

$\Delta H/\Delta T$ = 1.16 mm/°C, 2.85 mm / °C C_{D_2O} = 99.709 w.%, 99.707 w %

1 U/3/29.2 - TR - D_2O
8 U - Pu/3/29.2 - TR - D_2O
28 U/3/29.2 - D_2O
52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1, T_m = 22°C	22.07	22.07	149.12	149.15		
					0.3	0.36
	22.05	57.65	149.15	149.18		
					0.5	0.31
	22.10	98.75	149.21	149.23		
					0.5	0.50
	22.14	152.15	149.26	149.28		
					0.5	0.39
	22.12	202.15	149.31	149.33		
1, T_m = 60°C						
	59.93	60.35	156.93	157.04		
					0.6	0.72
	59.75	99.35	156.94	157.10		
					0.5	0.46
	59.75	152.90	156.99	157.15		
					0.2	0.52
	59.91	202.35	157.06	157.17		

*) values corrected to T_m = 22.3 °C and 60.3 °C

Table 3.32

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm

$\Delta H/\Delta T$ = 0.92 mm/°C, 1.36 mm / °C

T_m = 22 °C, 60 °C

C_{D_2O} = 99.709 w.%, 99.707 w %

1 U/3/29.2 - TR - D_2O

8 U - Pu/3/29.2 - TR - D_2O

28 U/3/29.2 - D_2O

52 U/19/12 - Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1 T_m = 22°C	22.01	37.25	136.64	136.67		
					0.2	0.21
	22.00	58.65	136.66	136.69		
					0.2	0.33
	22.04	99.50	136.69	136.71		
					0.5	0.36
	22.05	153.65	136.74	136.76		
					0.2	0.18
	22.06	203.35	136.76	136.78		
1 T_m = 60°C						
	60.05	57.10	141.02	141.05		
					0.3	0.24
	60.17	100.50	141.06	141.08		
					0.5	0.36
	60.15	151.65	141.11	141.13		
					0.3	0.24
	60.09	200.75	141.13	141.16		

*) values corrected to T_m = 22.3 °C and 60.3 °C

Table 3.33

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 28.05 cm

$\Delta H/\Delta T$ = 0.85 mm/°C; 1.1 mm/°C

T_m = 22 °C; 60 °C

C_{D_2O} = 99.707 w.%; 99.707 w %

1 U/3/29.2 – TR – D_2O

8 U – Pu/3/29.2 – TR – D_2O

28 U/3/29.2 – D_2O

52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.11	22.10	156.04	156.06		
					0.3	0.36
T_m = 22°C	22.10	61.90	156.07	156.09		
					0.4	0.31
	22.08	98.25	156.11	156.13		
					0.4	0.32
	22.06	152.50	156.15	156.17		
					0.3	0.22
	22.08	199.65	156.18	156.20		
1						
T_m = 60°C	59.99	60.00	160.02	160.05		
					0.5	0.35
	59.99	99.25	160.07	160.10		
					0.5	0.36
	59.97	152.75	160.11	160.15		
					0.4	0.21
	59.93	204.50	160.15	160.19		

*) values corrected to T_m = 22.3 °C and 60.3 °C

Table 3.34

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 18.8 cm $\quad T_m$ = 22.3 °C

$\Delta H/\Delta T$ = 1.70 mm/°C $\quad C_{D_2O}$ = 99.712 w.%

1 U/3/29.2 – TR – H_2O

8 U – Pu/3/29.2 – TR – H_2O

28 U/3/29.2 – D_2O

52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.06	32.50	169.82	169.86		
					– 0.6	– 0.55
	22.08	59.90	169.76	169.80		
					– 0.6	– 0.68
	22.09	97.75	169.70	169.74		
					– 1.4	– 1.03
	22.13	153.50	169.57	169.60		
					– 1.1	– 1.10
	22.17	203.25	169.47	169.49		
5						
9						

*) values corrected to T_m = 22.3 °C

Table 3.35

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 23.5 cm $\qquad T_m$ = 22.3 °C

$\Delta H/\Delta T$ = 0.92 mm/°C $\qquad C_{D_2O}$ = 99.712 w.%

1 U/3/29.2 – TR – H_2O

8 U-Pu/3/29.2 – TR – H_2O

28 U/3/29.2 – D_2O

52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.08	22.08	158.17	158.19		
					– 0.6	– 0.42
	22.10	61.65	158.11	158.13		
					– 0.3	– 0.40
	22.12	98.65	158.08	158.10		
					– 1.1	– 0.72
	22.05	153.15	157.97	157.99		
					– 0.9	– 0.81
	22.09	201.25	157.88	157.90		
5						
9						

*) values corrected to T_m = 22.3 °C

Table 3.36

ECO-Pu : Fuel Channel Temperature Coefficient

Core: d = 28.05 cm T_m = 22.3 °C

$\Delta H/\Delta T$ = 0.88 mm/°C C_{D_2O} = 99.712 w.%

1 U/3/29.2 – TR – H_2O

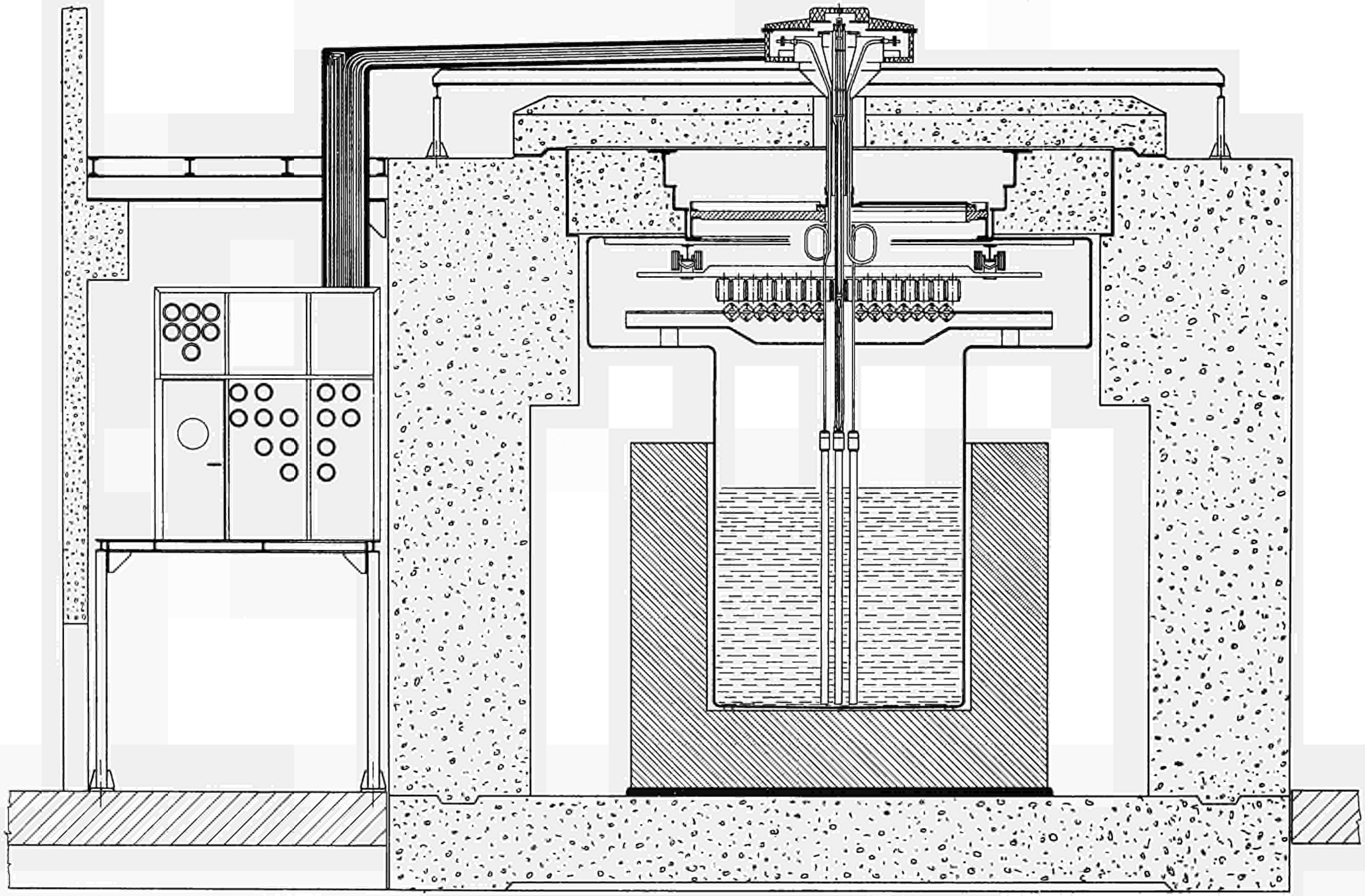
8 U-Pu/3/29.2 – TR – H_2O

28 U/3/29.2 – D_2O

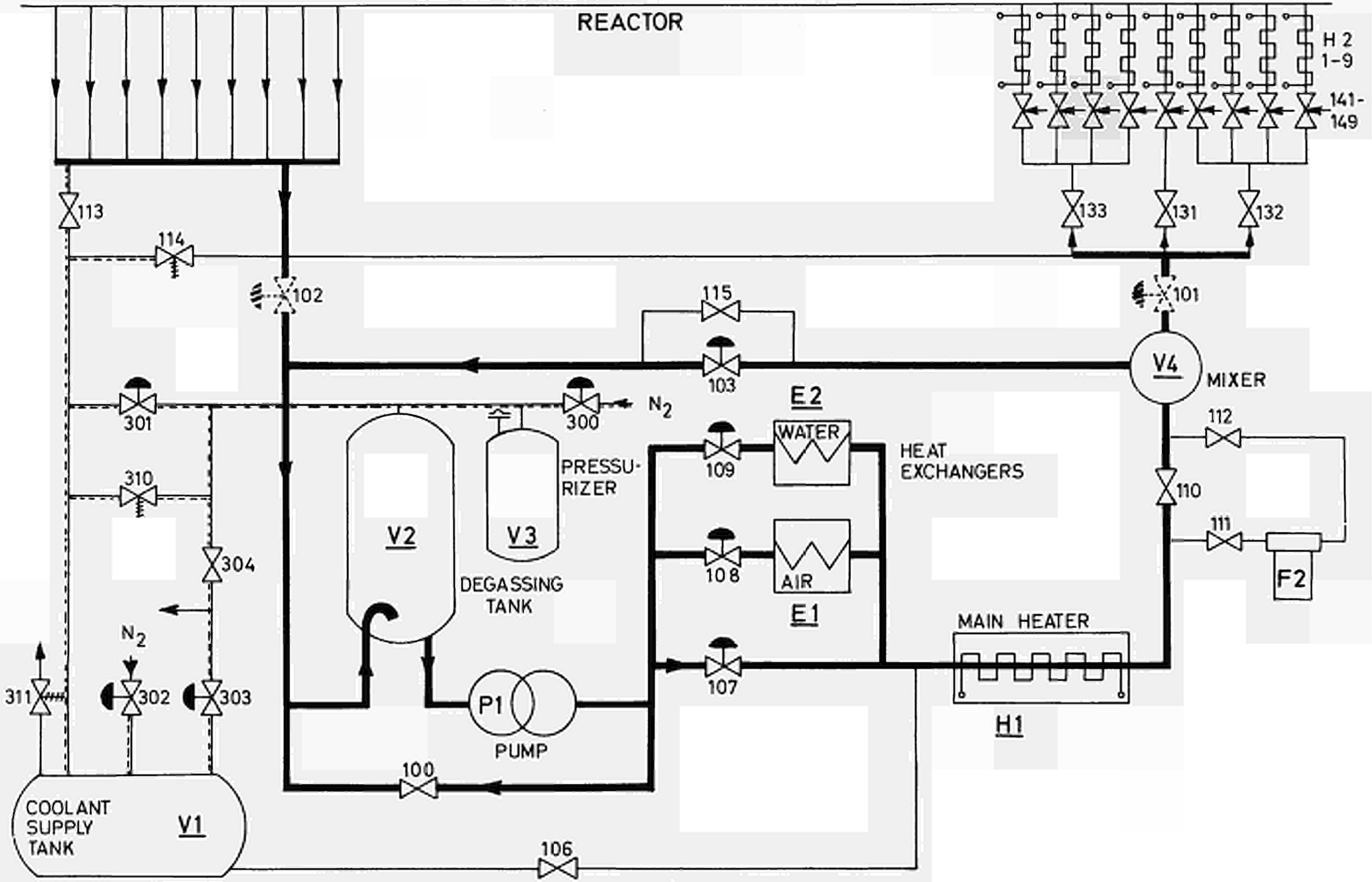
52 U/19/12 – Diphyl

Heated elements	$\bar{T}_m$ (°C)	$\bar{T}_{ch}$ (°C)	H_c (cm)	H_c^* (cm)	ΔH_c^* (mm)	ΔH_s^* (mm)
1	22.27	22.27	187.62	187.62		
					– 0.6	– 0.49
	22.27	60.90	187.56	187.56		
					– 0.3	– 0.67
	22.29	98.75	187.53	187.53		
					– 1.0	– 1.09
	22.29	152.90	187.43	187.43		
					– 1.5	– 1.23
	22.31	200.65	187.28	187.28		
5						
9						

*) values corrected to T_m = 22.3 °C

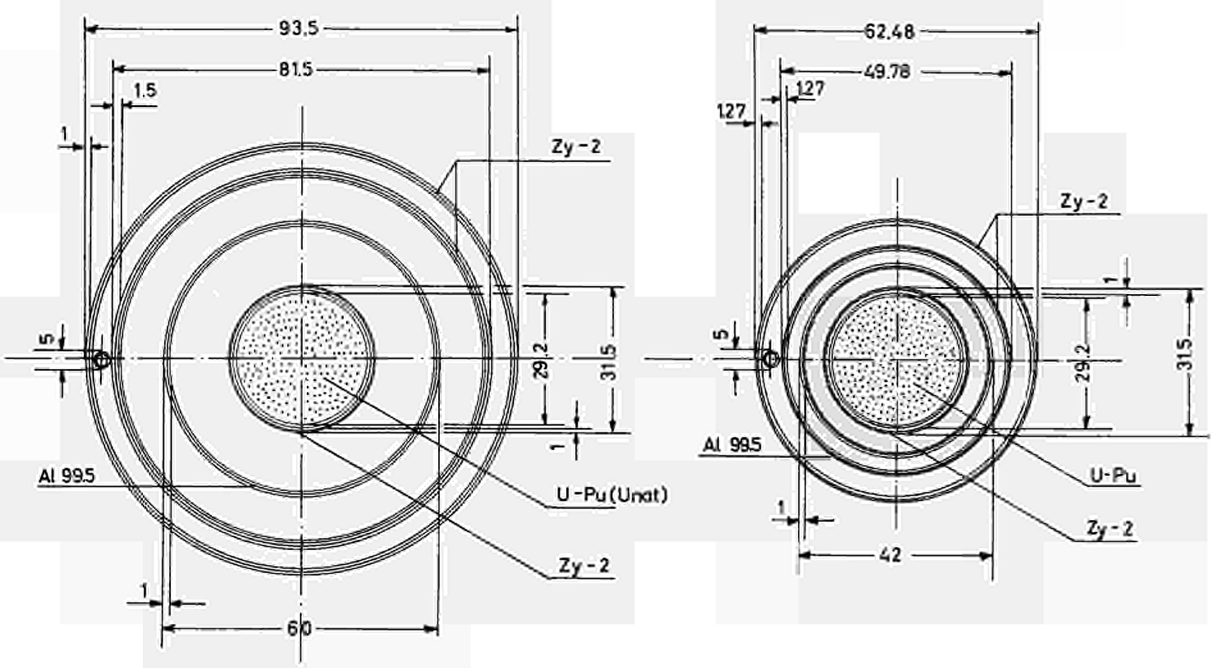


ECO : REACTOR AND LOOP FIG. 2-1



ECO:COOLANT LOOP

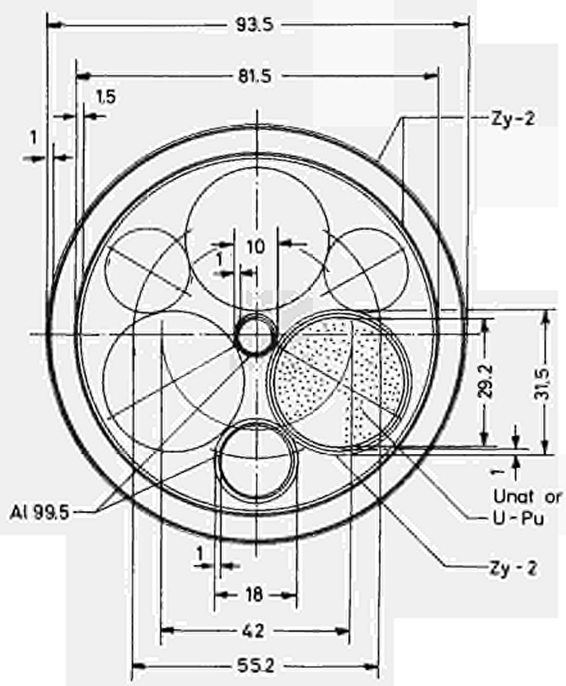
FIG. 2.2



Unat/1/29.2
U-Pu/1/29.2

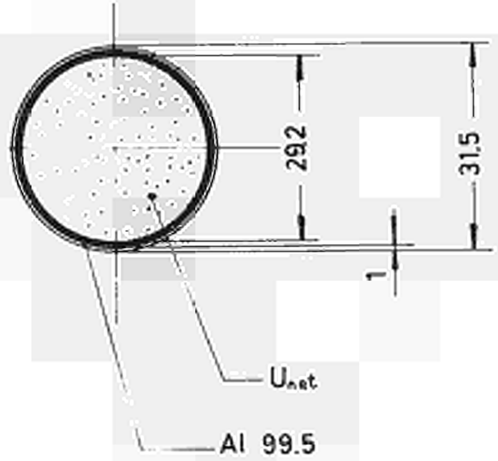
U-Pu/1/29.2 small channel

ECO: SINGLE ROD TEST ELEMENT FIG: 2.3

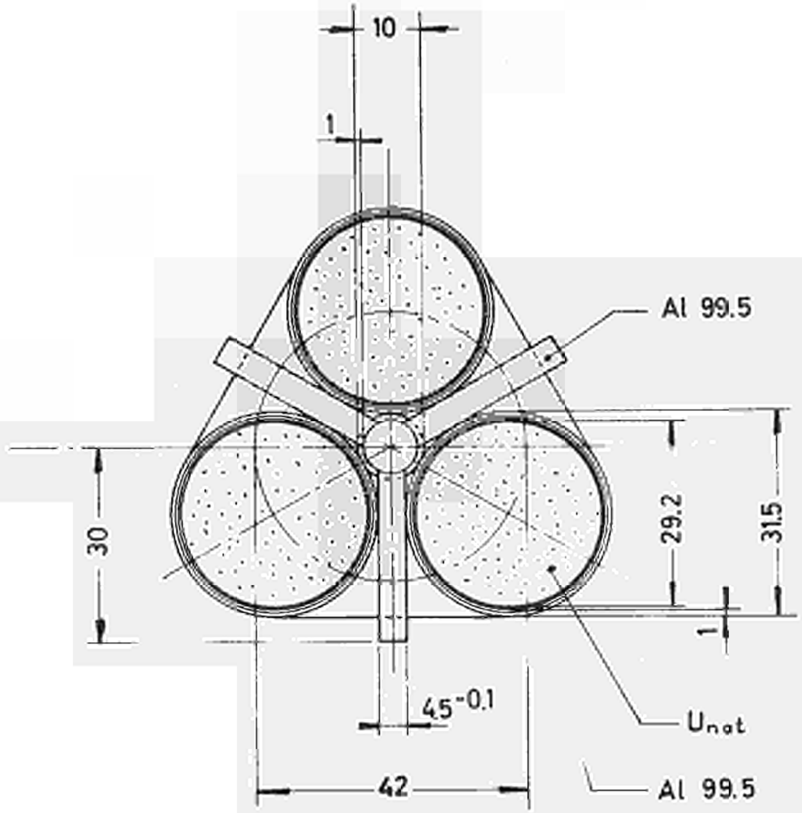


Unat/3/29.2 or U-Pu/3/29.2

ECO: 3 ROD TEST ELEMENT FIG: 2.4



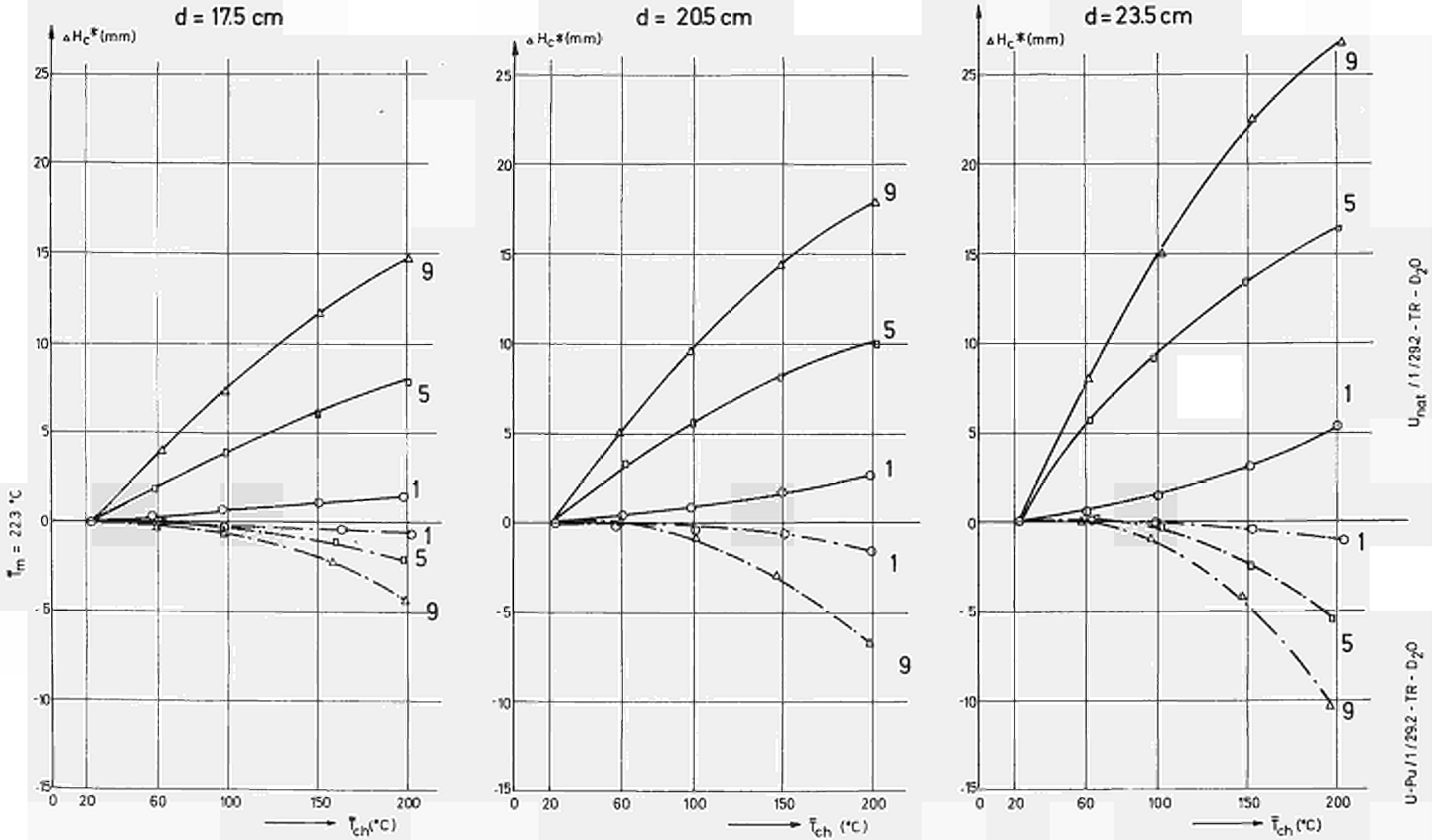
U/1/29.2



U/3/29.2

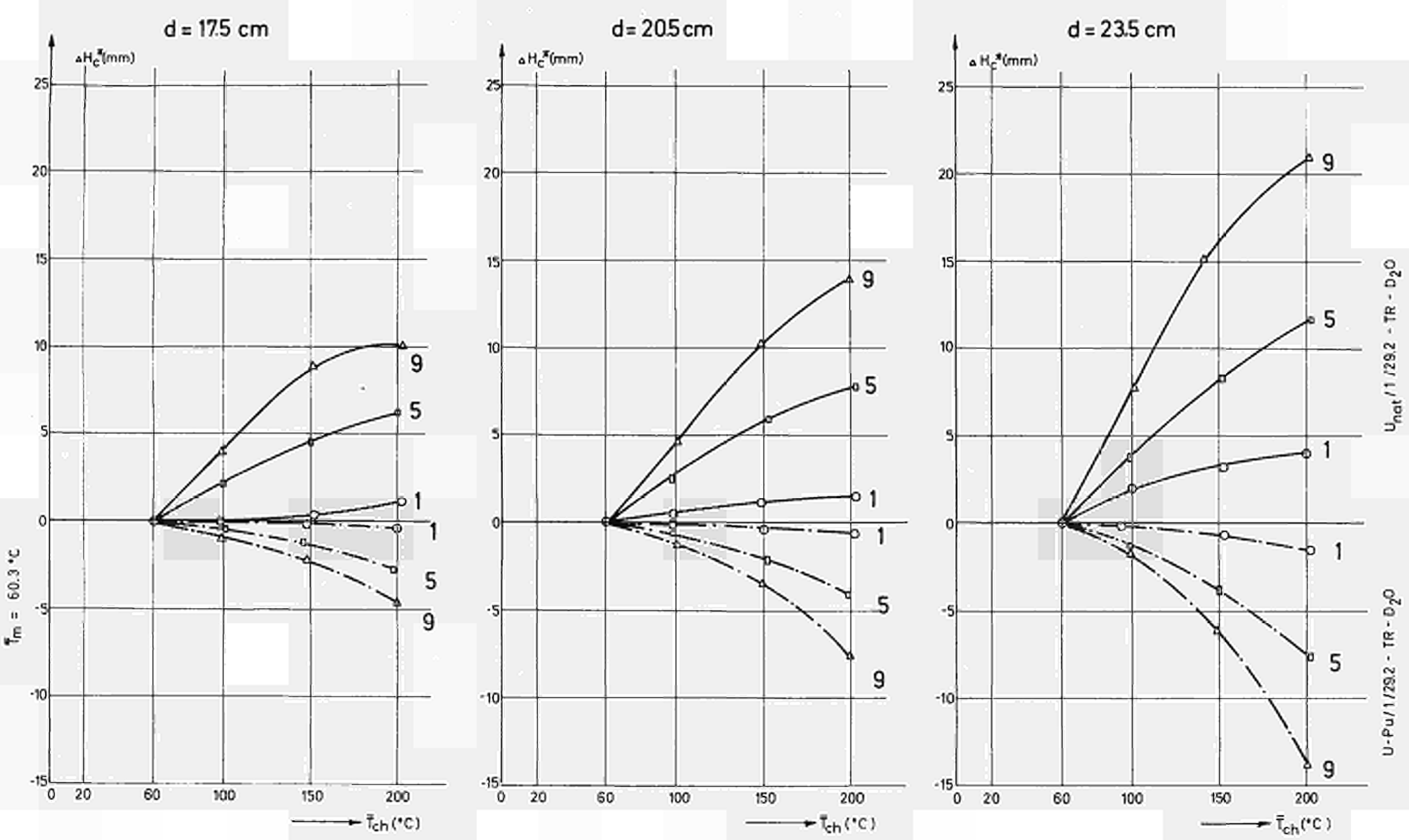
REFERENCE ELEMENTS

FIG: 2.5



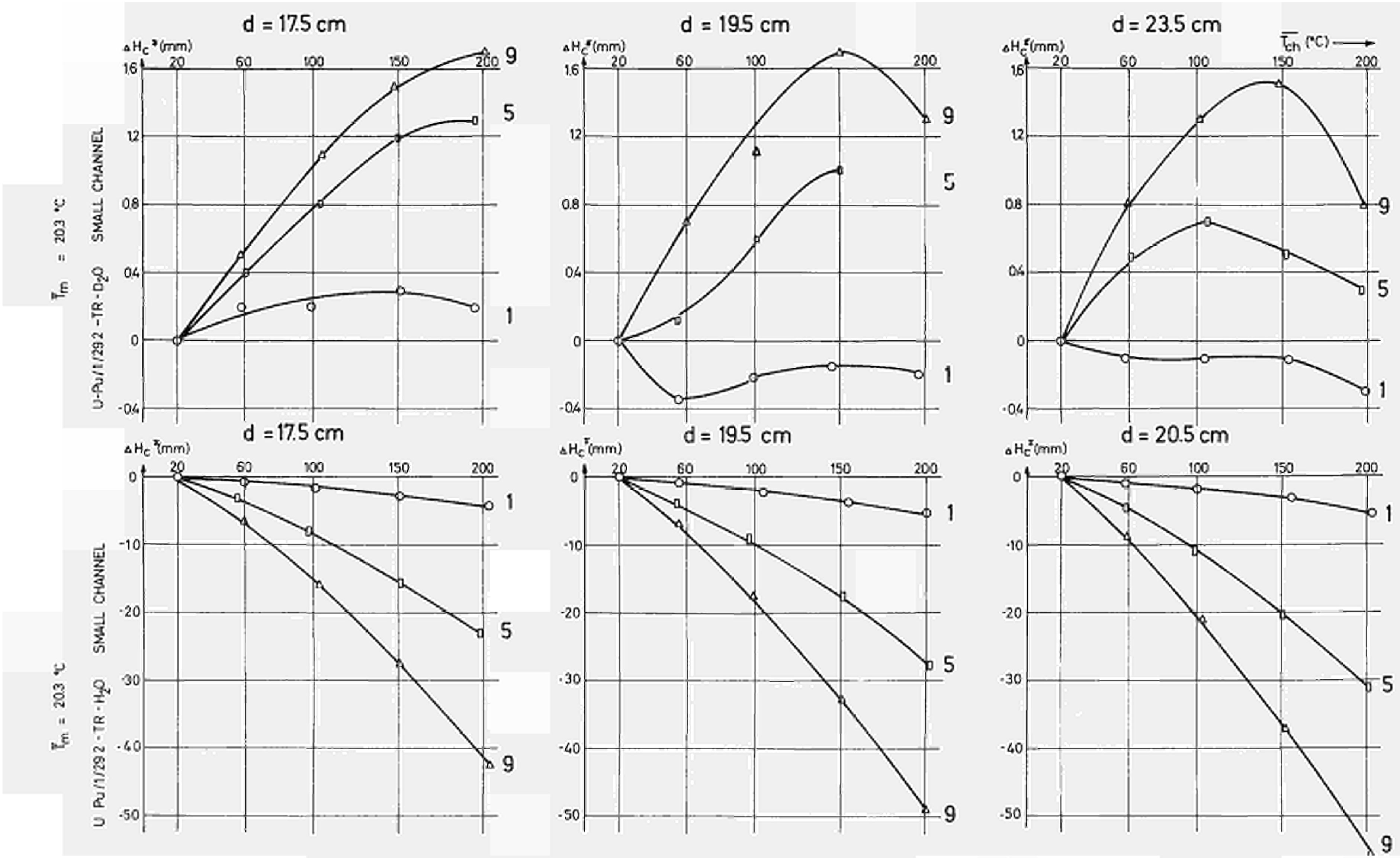
ΔH AS FUNCTION OF CHANNEL TEMPERATURE

FIG. 3.1



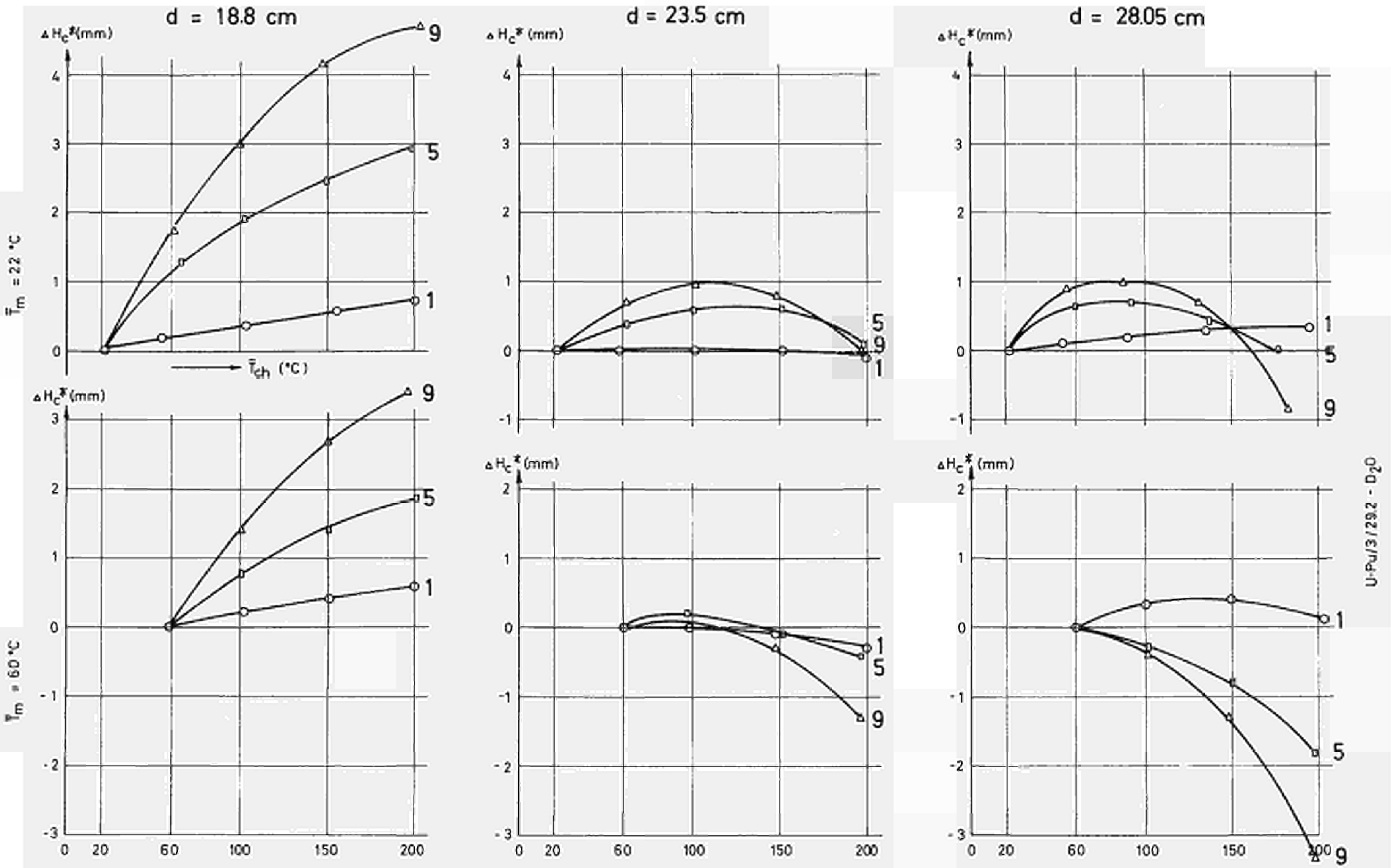
ΔH AS FUNCTION OF CHANNEL TEMPERATURE

FIG. 3.2



ΔH AS FUNCTION OF CHANNEL TEMPERATURE

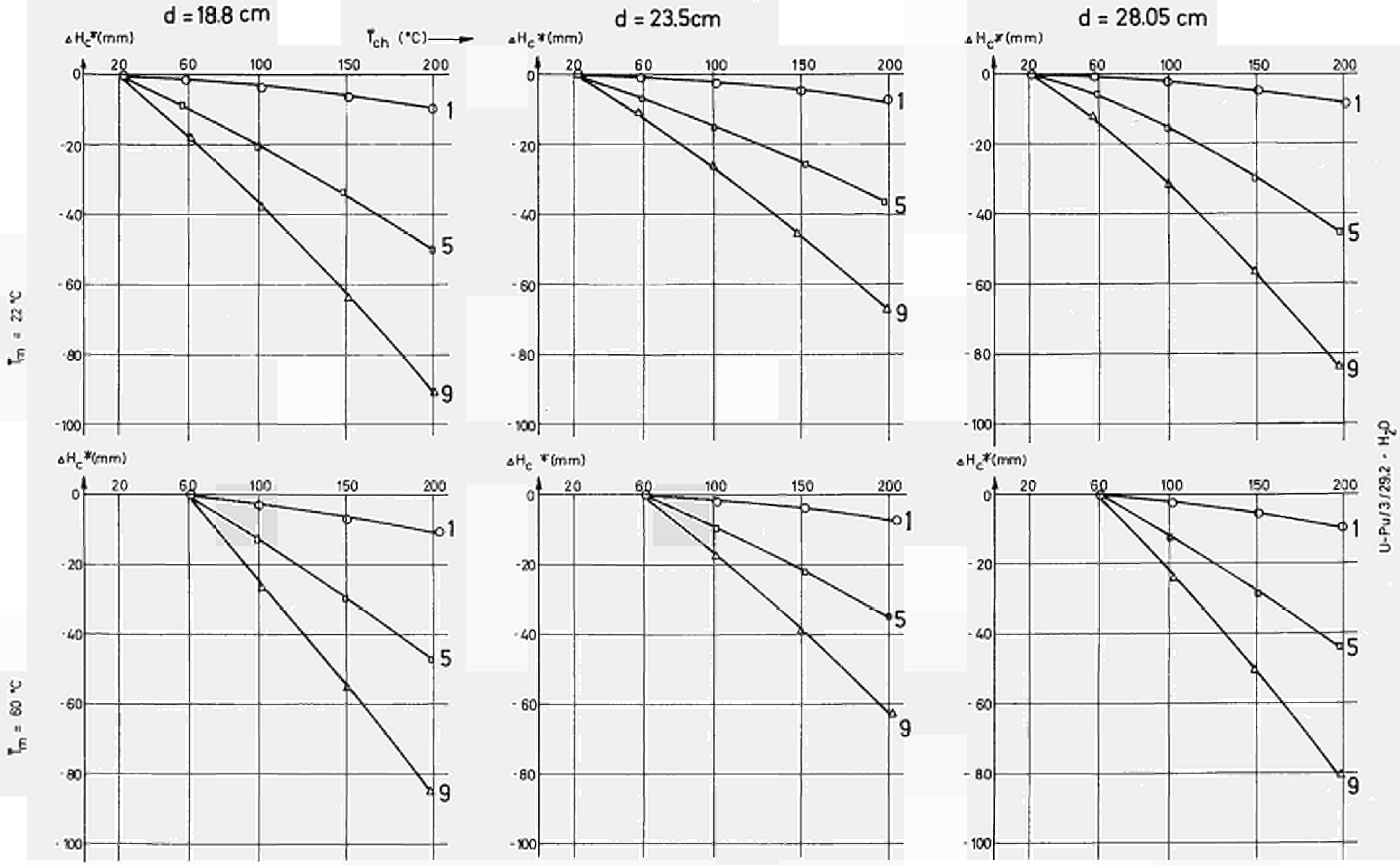
FIG. 3.3



ΔH AS FUNCTION OF CHANNEL TEMPERATURE

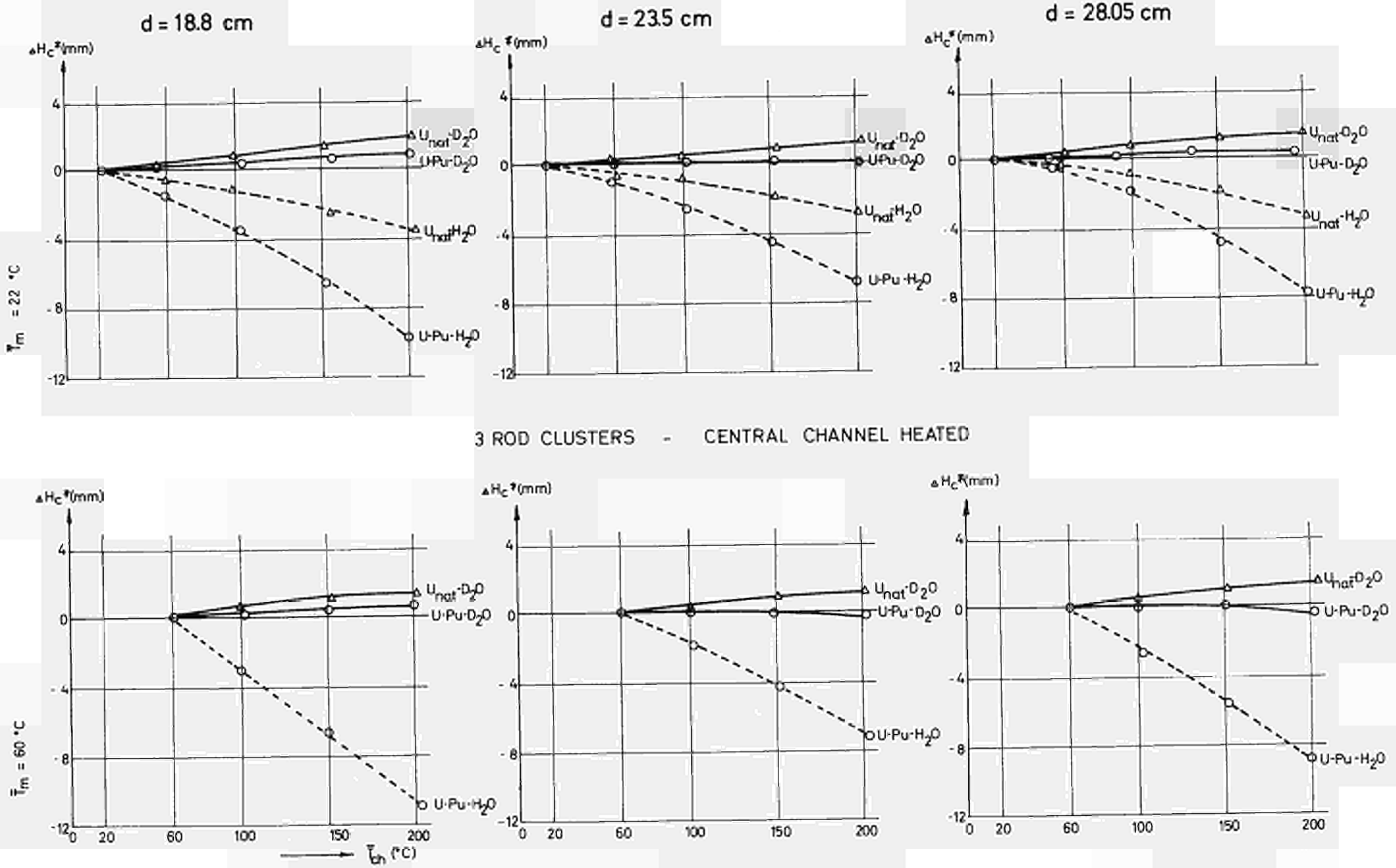
FIG. 3.4

U-Pu/3/29.2 - D_2O



ΔH AS FUNCTION OF CHANNEL TEMPERATURE

FIG. 3.5



ΔH AS FUNCTION OF CHANNEL TEMPERATUR

FIG. 3.6

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Alfred Nobel

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