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〈技術レポート〉

Computer Simulation of Nuclear Material Flow and MUF in the Plutonium Fuel Pelletizing Process

核物質移動シミュレーション

1972年7月

動力炉・核燃料開発事業団
東 海 事 業 所

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ABSTRACT

A computer simulation code SASATSU (1), for nuclear material flow and MUF has been programed for analyzing the data of the ATR and Rapsodie compains in the present facility. With this simulation experience, the material flow characteristics in the FBR-line of the new facility is estimated.

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核物質移動シミュレーション

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研究目的 プルトニウム第1開発室の核物質移動データをもとに核物質移動およびMUFの蓄積に関するシミュレーションを行なう。

プルトニウム第1開発室で得られた酸化プルトニウム800Kgの取扱経験をもとにMUF，核物質移動についてのデータを解析し，最もよい核燃料査察システムについて実際的な基準を求めるためのシミュレーションコードSASATSU(1)を開発し，第2開発室のFBRラインについてMUF，核物質移動についてボックス単位，MBA単位で予測した。

Computer Simulation of Nuclear Material Flow and MUF in the Plutonium Fuel Pelletizing Process*

1. Introduction

The purpose of the computer simulation is to integrate MUF (Material unifendified for) experienced in the Laboratories and to establish the reliable, practical, and quantitive criteria for a safeguards system such an analysis enables one to set the most effective material balance area (MBA) with the instrumented check.

In the Plutonium Fuel Fabrication Facility, more than 800 kg of plutonium oxide has been processed to provide for the study of the fuel element for thermal and fast reactors on fuel fabrication development and irradiation test since January, 1966.

The accumulated data from the above activities were evaluated by means of the computer simulation on the material flow and the accountability procedure, and the conclusions obtained are as follows;

(1) The glove box is the best minimum unit as the process step to analyze the material flow because the criticality in a glove box is very carefully controlled of the mass of nuclear materials.

(2) The process line must be flexible because the unknown learning factors make many different fabrication process lines.

(3) The material flow must be followed on as the function of time because the MUF is found extremely sensitive both to the time interval and to the analyzing time delay of nuclear material at the required process step.

2. Computer program description

2.1 General description

The purpose of the computer program is to find out the problem of each process and to estimate the amount of MUF.

Functions of the program are as follows;

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* This work was performed under the auspices of IAEA.

(1) To make a process at one's option.

(2) To make revision and addition of a process easily.

(3) To discover the fault of process.

(4) To make the following tables

i. A mount of nuclear materials in each process at an arbitrary moment

ii. Data sheets for various managements.

The computer program consists of the following subprograms;

(1) A subprogram to generate the process file from the described process card.

(2) A subprogram to revise the process file by the revision card.

(3) A subprogram to output the simulated result and the various data into a magnetic tape.

(4) A subprogram to make a report from the magnetic tape.

Input data of the program are as follows;

(1) Process description data.

(2) Process revison data.

(3) Material data.

(4) Control data.

(5) Box down function data.

Job flow chart is shown in Fig. 1.
Items of output file are as follows;

(1) Box data table.

(2) Flow data table.

(3) Mixed oxide amount in each box at each time.

(4) Flow amount at each time.

(5) Various data after a simulation run are completed such as an effective run time, waiting time, processed amount.

(6) Lot table.

A glove bos is defined by the following method in the program.

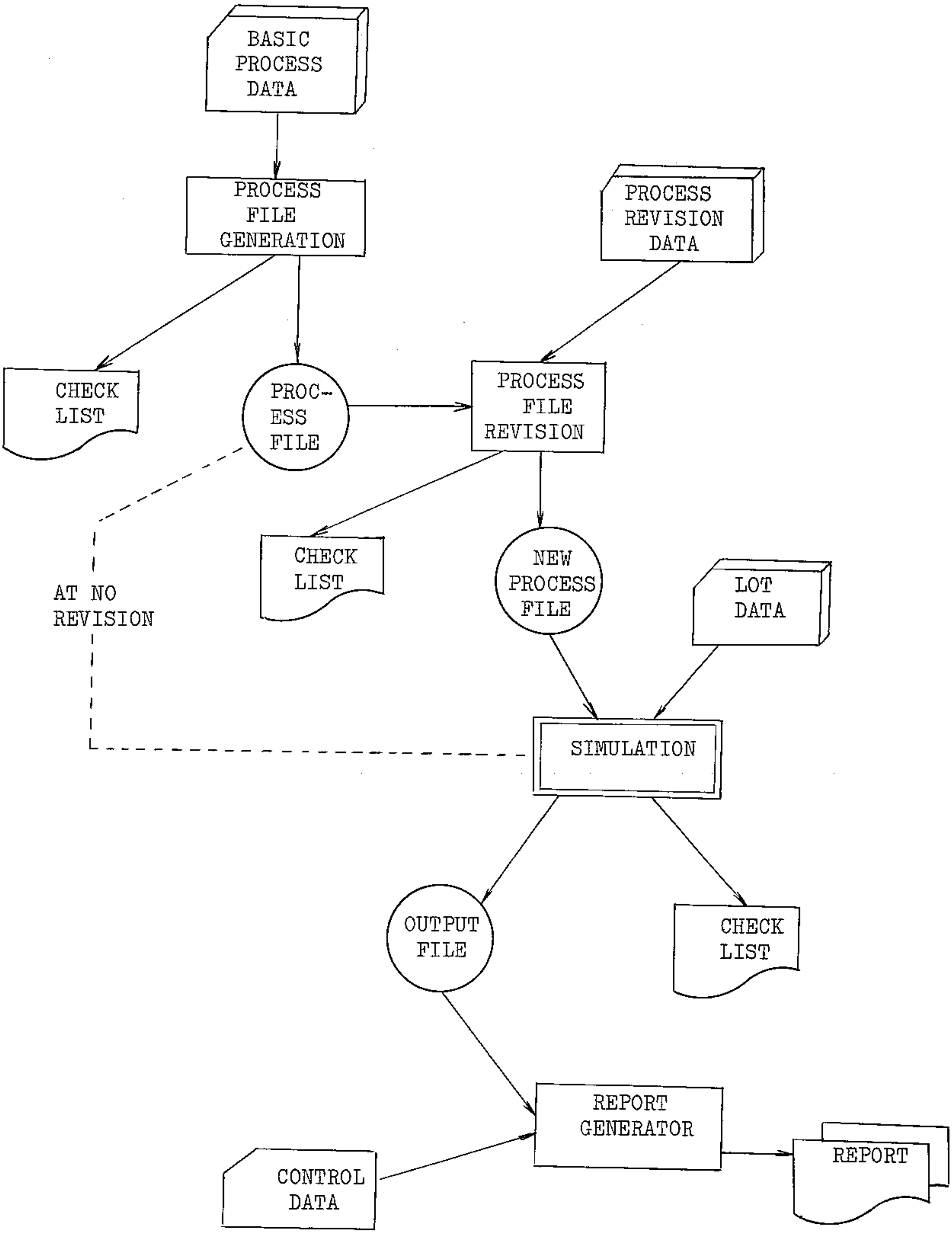
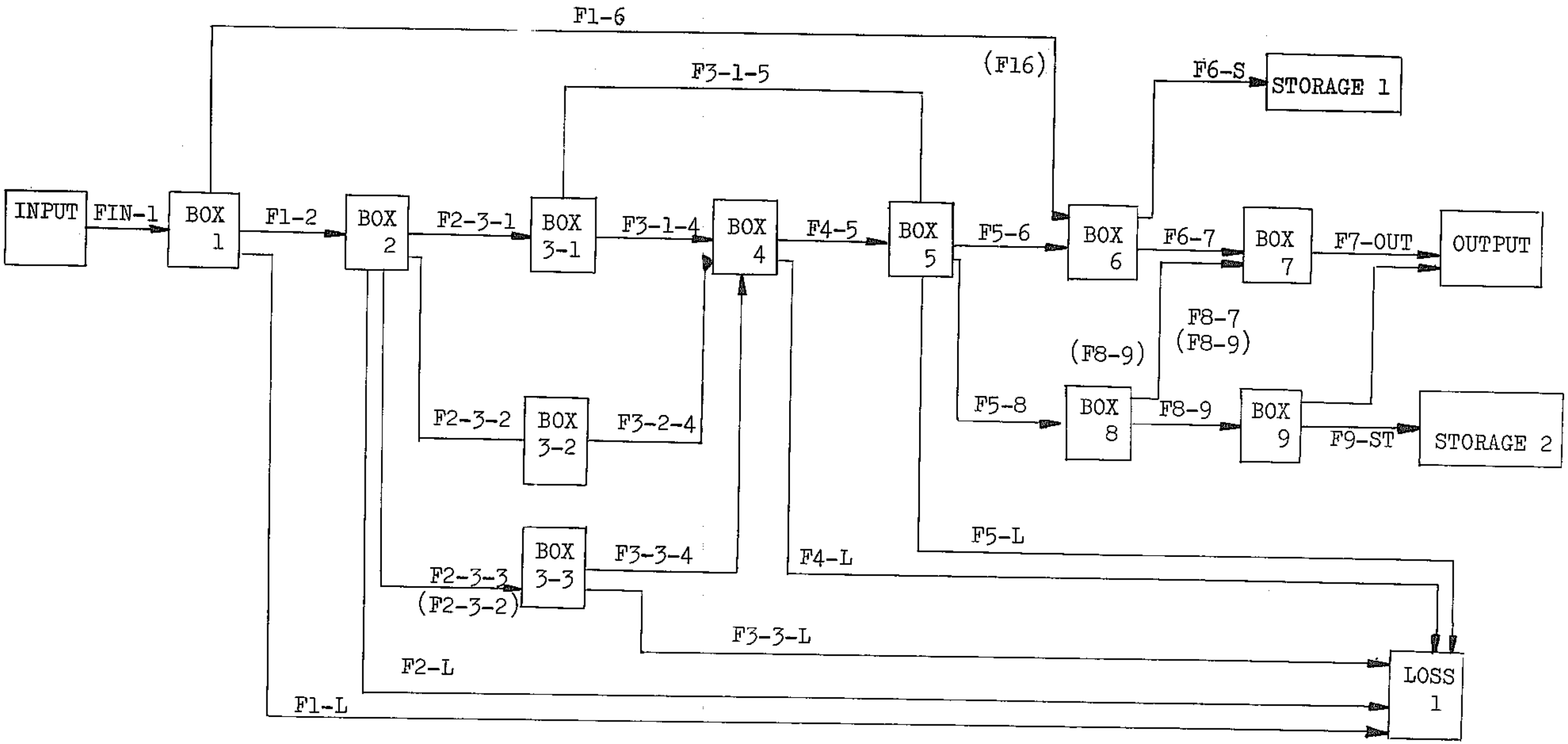


Fig. 1. Job flow chart.

Box name	Description
INPUT	Out-flow only
OUTPUT	In-flow only
LOSS	Loss
STORAGE n (n=1 ~ 9)	Storage only
USER-DEFINED BOX NAME	Normal in and out flow

A sample input of the box definition and process flow is shown in Fig. 2. A sample of the output is also shown in Table 1.



( ) means the intentionally mistaken data.

Fig. 2. Process flow chart.

Table 1. Box list.

CASE NAME (NEW) TESTCASE
(OLD)

NAME C.WAKITA
DATE 6/16/70
TOTAL BOX NO. 16

IN-FLOW 5	4	3	2	1	BOX NAME	OUT-FLOW 1	2	3	4	5
					INPUT	FIN-1				
				FIN-1	BOX1	F1-6	F1-2	F1-L		
				F1-2	BOX2	F2-3-1	F2-3-2	F2-3-3	F2-L	
				F23-1	BOX3-1	F3-1-4	F3-1-5			
				F2-3-2	BOX3-2	F3-2-4				
				F2-3-2	BOX3-3	F3-3-4	F3-3-L			
		F3-3-4	F3-2-4	F3-1-4	BOX4	F4-5	F4-L			
			F4-5	F3-1-5	BOX5	F5-L	F5-8	F5-6		
			F5-6	F16	BOX6	F6-7	F6-5			
				F6-5	STORAGE1					
			F8-9	F6-7	BOX7	F7-OUT				
				F5-8	BOX8	F8-9	F8-9			
				F8-9	BOX9	F9-OUT	F9-ST			
			F9-OUT	F7-OUT	OUTPUT					
				F9-ST	STORAGE2					
F1-L	F2-L	F3-3-L	F4-L	F5-L	LOSS					

PNCT 841-72-26

2.2 Simulation program

The detail explanation is limited to "simulation" in Fig. 1 - Job flow chart.

2.2.1 Material flow system

At first in this code, the material flow system is fixed with arranging the glove boxes and the flows. A glove box is the element used to simulate the flow of material through a process as described in the provious report. The glove box is able to have five in-flows and five out-flows at maximum. These glove boxes and flows have their own names which permit the code to simulate the very complex material flow system up to 50 glove boxes. That is, the relative positions of the box do not matter and even some of the receiver box can be upstream in the process line. The input data for this process are called the system data.

2.2.2 Calculation flow chart

Figures 3 and 4 indicate the calculation flow chart for "simulation". After reading the input, the code initializes the lot table according to the material flow system. The lot table consists of Limit capacity, Process time, Transfer time (bagin-bagout time) and Down time caused by a system failure. Output time is the time ready to transfer material from one box to another after the process is completed in the box. The code searches the box of the scheduled minimum output time in the lot table by the output-time-stepwise. If the receiving boxes are not ready to accept the material flow for some reasons, then the next boxes are searched.

The amount to be transferred is split with the input ratio in the lot table to the receiver boxes except MUF box. The ratio to MUF box is determined either by the gaussian random number or the homogeneous random number.

Providing a steal box, the code can simulate to steal the nuclear material from the specified box as shown in Fig. 4. If a number generated by the homogeneous random number generator (RANDU) for a single run exceeds the stealing frequency index which is input, then the stealing ratio is determined by the gaussian distribution random number as to the same method of MUF ratio.

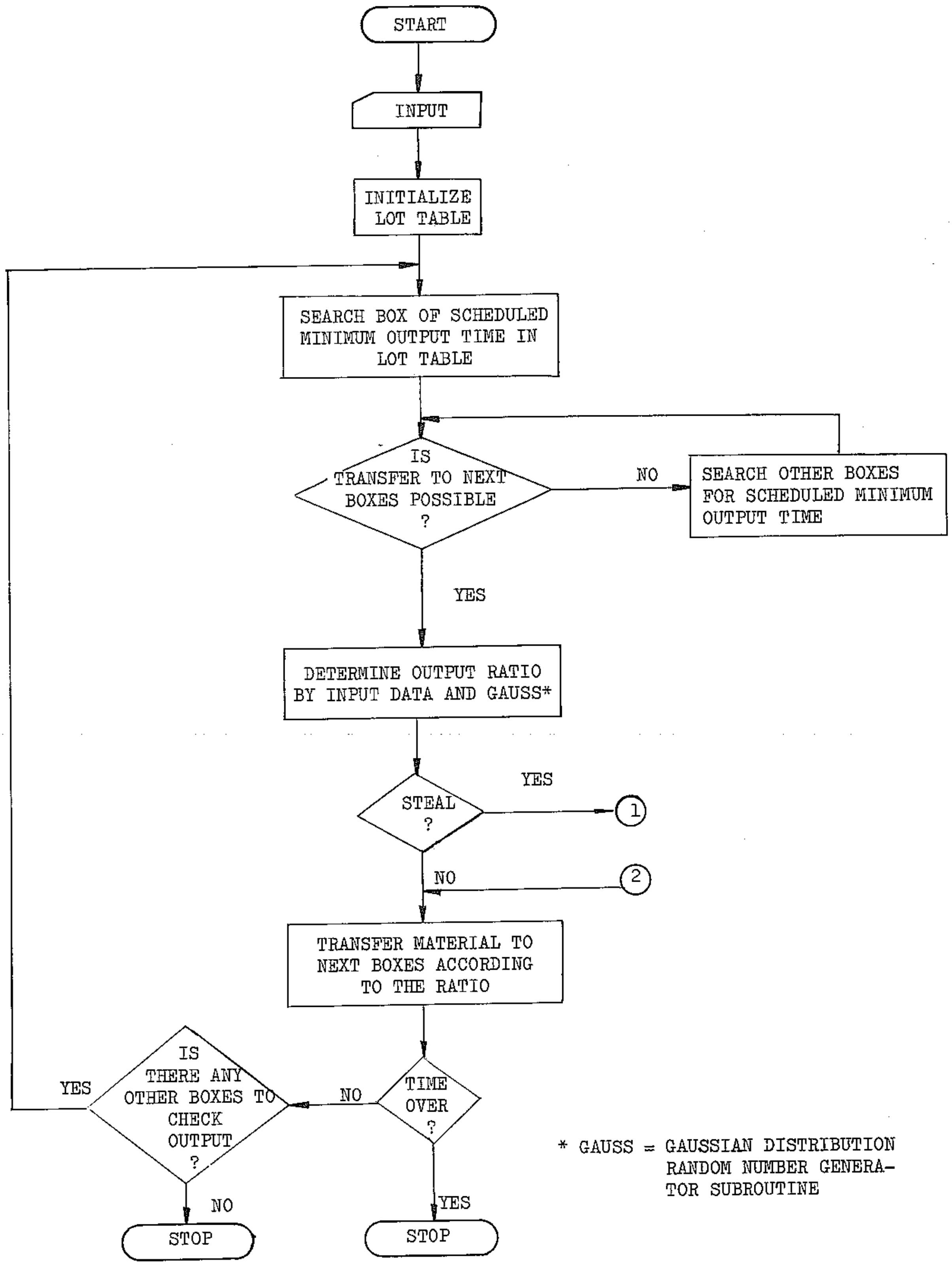
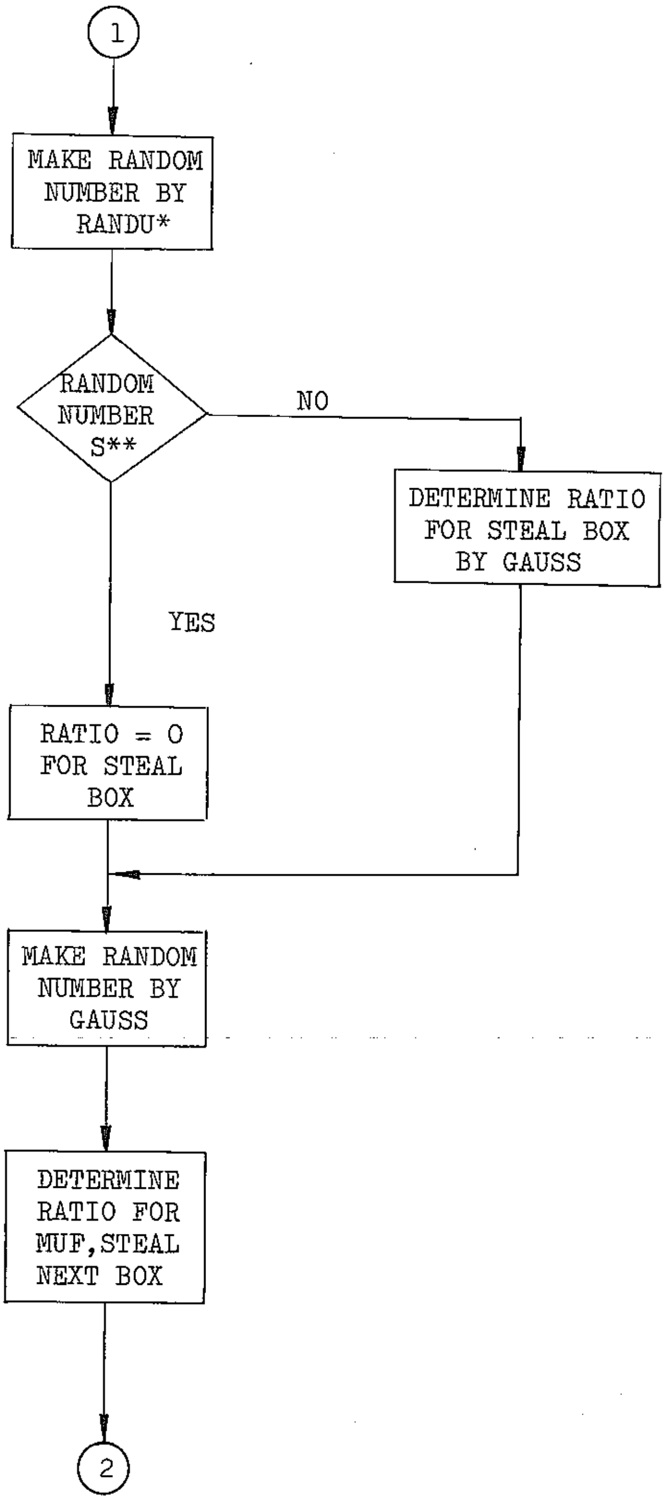


Fig. 3. Simulation MAIN



* RANDU = HOMOGENEOUS RANDOM NUMBER GENERATOR SUBROUTINE

** S = STEAL FREQUENCY INDEX

Fig. 4. Simulation STEAL

2.2.3 Test runs

Test runs for the code have been carried out on the pelletizing processes for the Rapsodie irradiation testing. There are two reasons why this campaign is selected. One is that this campaign has the detail mass balance data and second reason is that this campaign has the complex mass flow history for each lot, i.e. learning factors for mixing lot, sintering lot, grinding lot, and re-sintering lot. The code is verified by the mass flow and time studies in comparison with the actual data. Tested lots are RR-01, RR-02, RR-03, RM-01, RM-02, RM-03, and RM-06.

3. Input data description

To learn MUF characteristics with mass flow, process time, process steps, thruput, and waiting time from the PFDL* experiences, the two-region critical experiment and Rapsodie irradiation campaign are simulated with the code using the measured MUF at each process step.

3.1 Two-region critical experiment fuel campaign (expressed as ATR campaign in the proceeding section)

An analysis has been performed using the code on the box-wise material flow compared with the MBA-wise material flow. The material balance area (MBA) used here is defined as the area from master mixing to storage (total pelletizing process). This analysis consists of calculating the variance of MUF of each box and MBA with and without stealing.

Figure 5 schematically illustrates the material flow system of the ATR campaign. Diagram (a) in the figure simulates the pelletizing process of the campaign as a material balance area (MBA).

Diagram (b) presents the box-wise simulation of the same campaign. Figure 6 shows the material flow system of the ATR campaign with stealing material from the inspection and grinding box. Although there are countless stealing methods to be considered, one stealing method is assumed as follows. The stochastic amount of the nuclear material is stolen from the specified glove box (which, mostly, has the max. MUF) with the ratio of the same gaussian distribution of MUF in the box in the specified frequency.

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* Plutonium Fuel Development Laboratory.

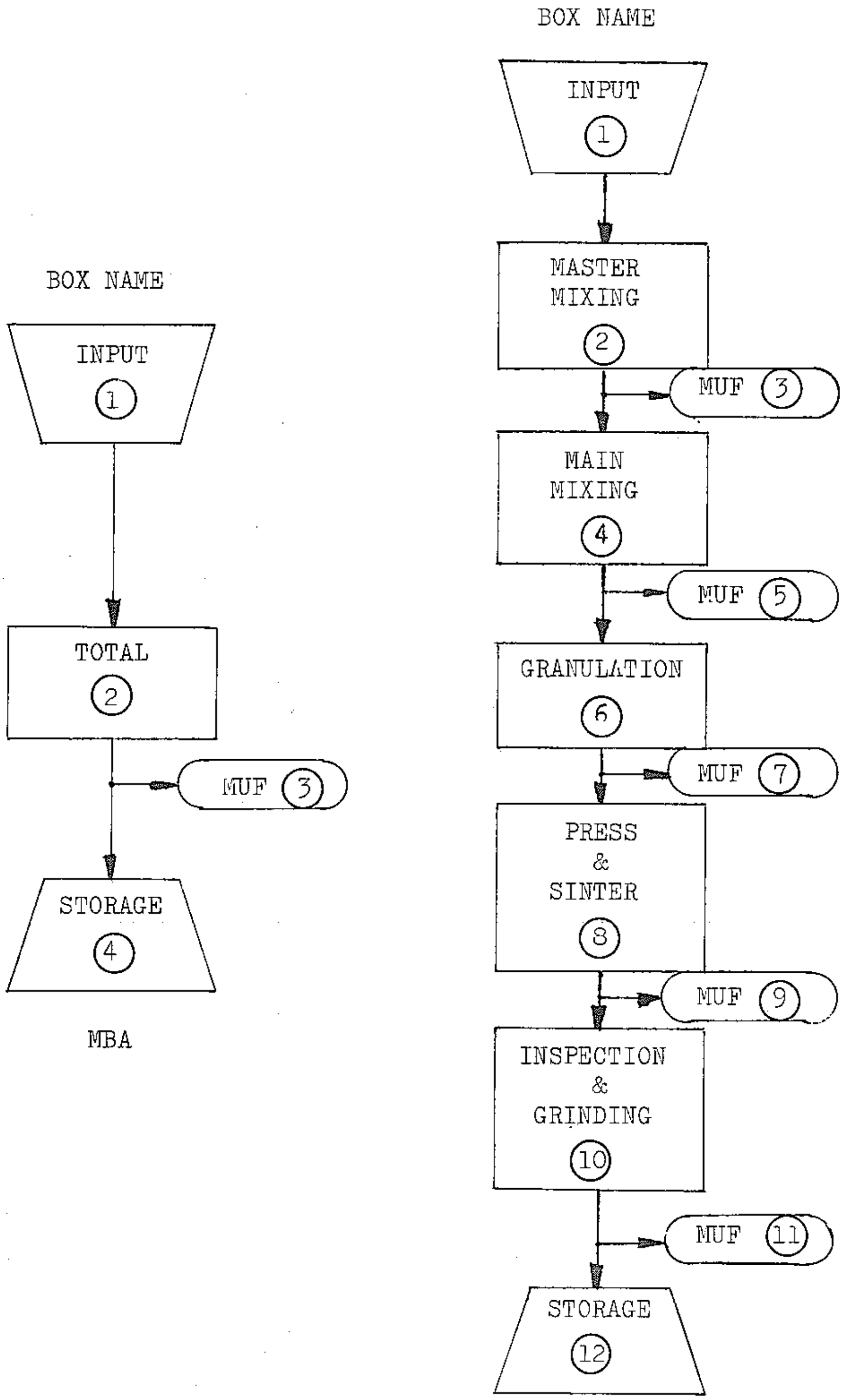

Fig. 5. Material flow diagram of ATR campaign - normal runs.

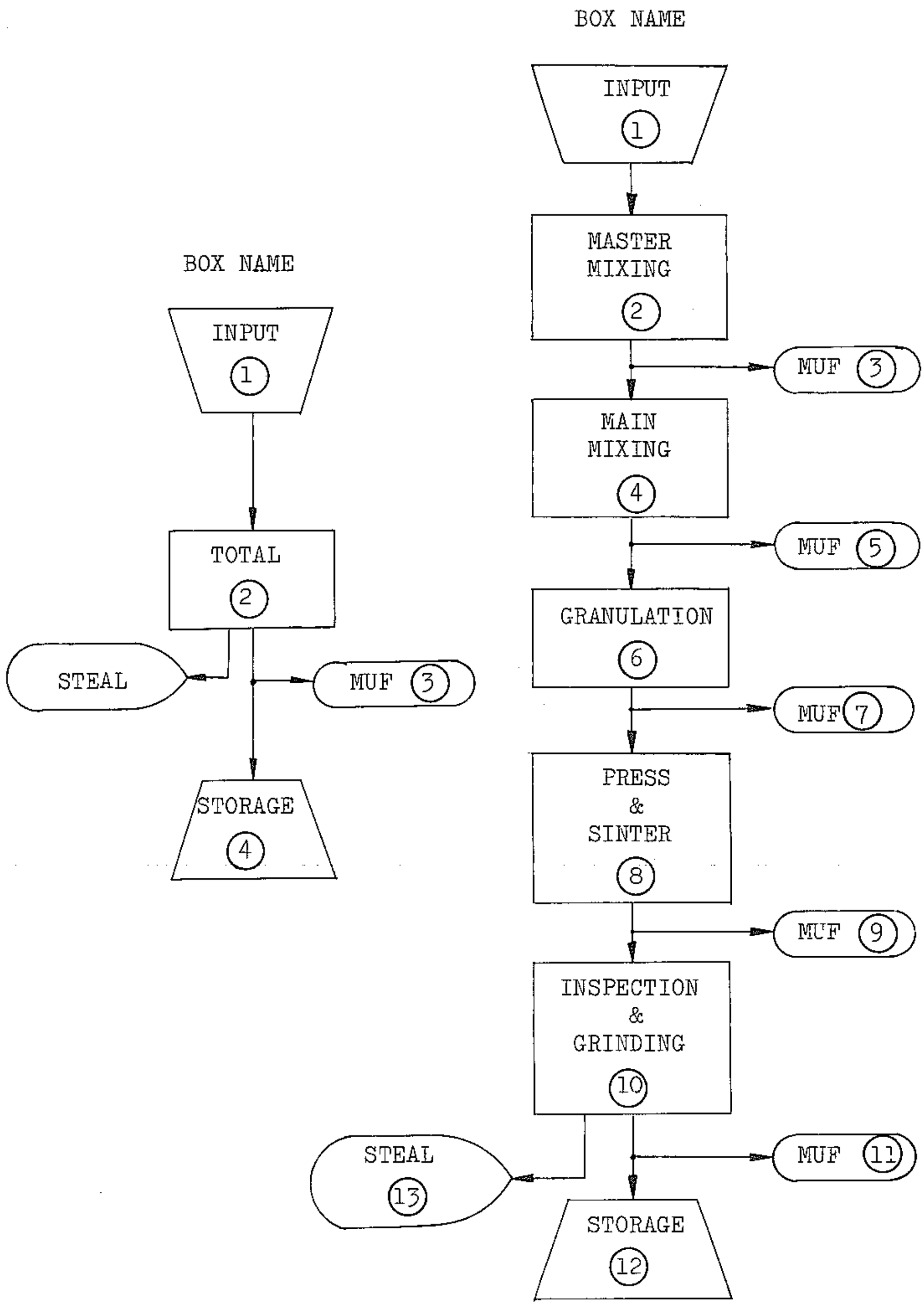

Fig. 6. Material flow diagram of ATR campaign - steal.

The configuration of the material flow diagram described above is initialized by the system input data as follows;

(1) Box name is as shown in Figs. 5 and 6.

(2) Box capacity is fixed 1.67 kg/hour throughout the storage box based on the facility experience.

(3) Transfer time (or bagin-bagout time) is also fixed 1.25 hours throughout the storage box based on the facility experience.

Process data applied to ATR campaign are;

(1) Composition of fuel is 0.5 w/o PuO_2-99.5 w/o UO_2.

(2) Isotope ratios (%) are

Pu 238	0.038
Pu 239	90.142
Pu 240	8.533
Pu 241	1.189
Pu 242	0.098
U 234	0.0056
U 235	0.7110
U 238	99.2834

(3) Total run is 76 lots.

(4) Input time interval is 10 hours.

(5) Input mass weight per run is 7.5 kg.

(6) MUF ratio is generated by the gaussian random number. The gaussian distribution of MUF ratio is verified with the gaussian distribution check sheet presented in Figs. 7 ~ 12 for each box except press and sinter box. The input data for the gaussian distribution for each box are listed in Table 2.

(7) The stealing frequency is set once per ten run at random during ATR campaign.

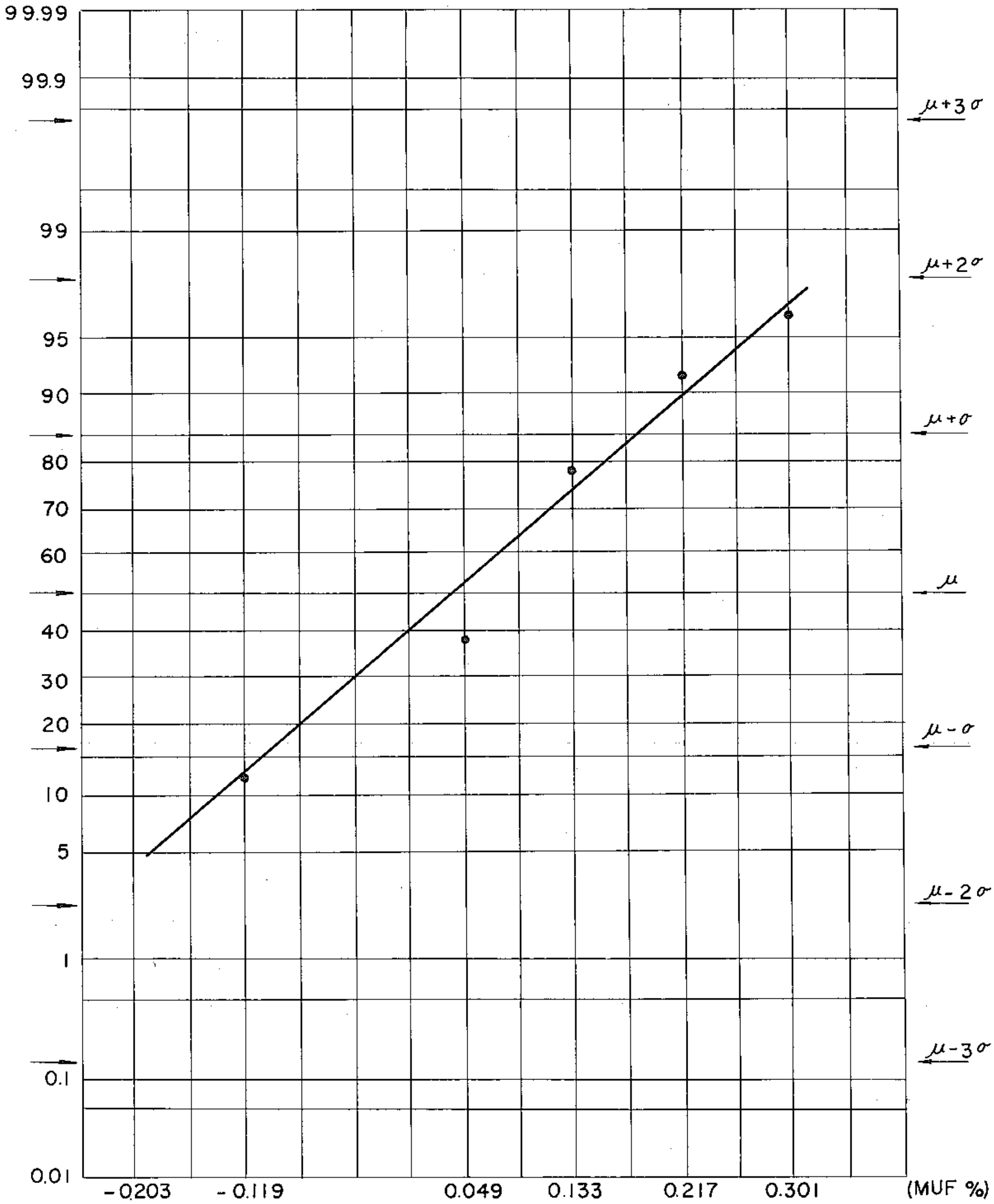

Fig. 7. Gaussian distribution check of MUF of master mixing.

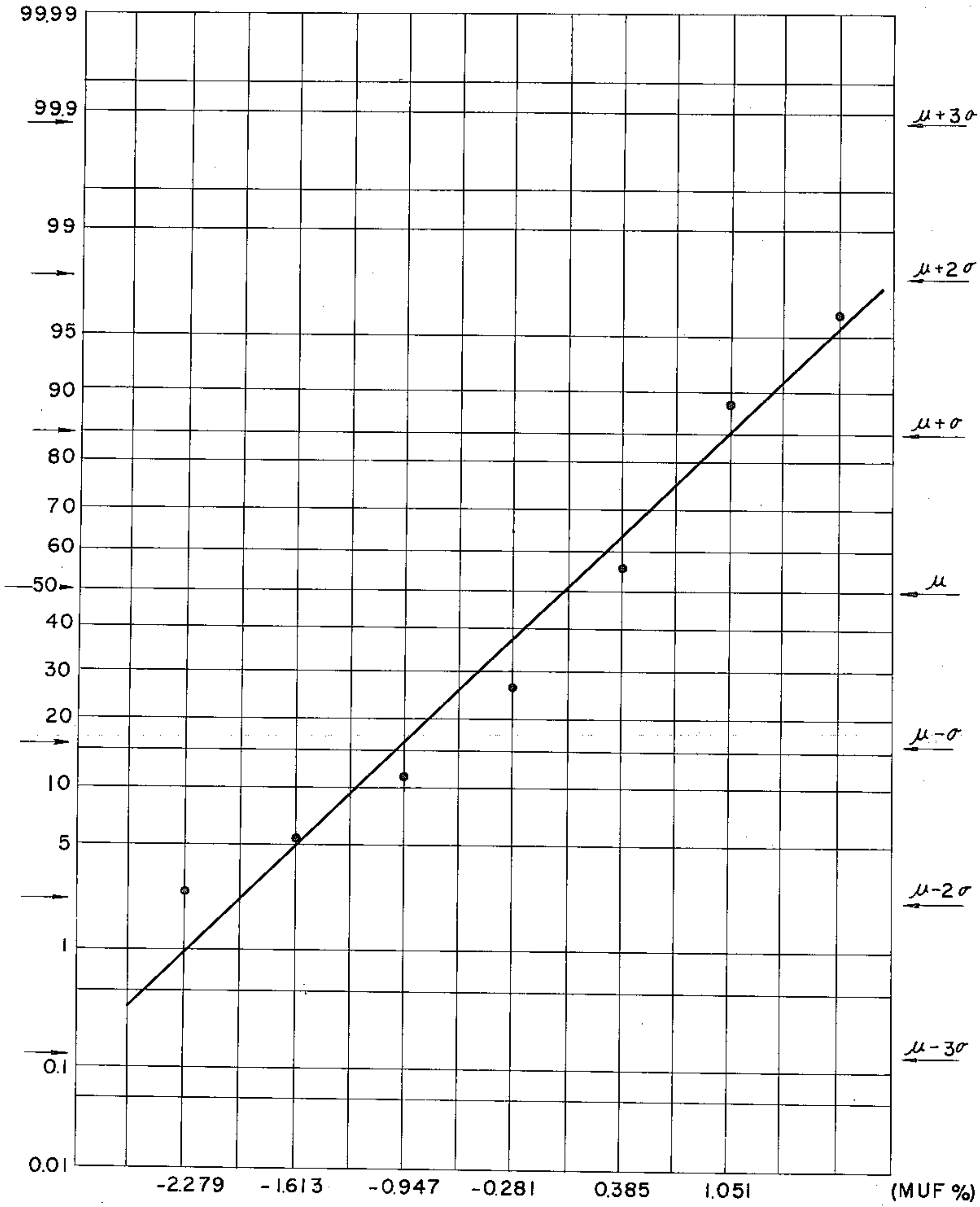

Fig. 8. Gaussian distribution check of MUF of main mixing.

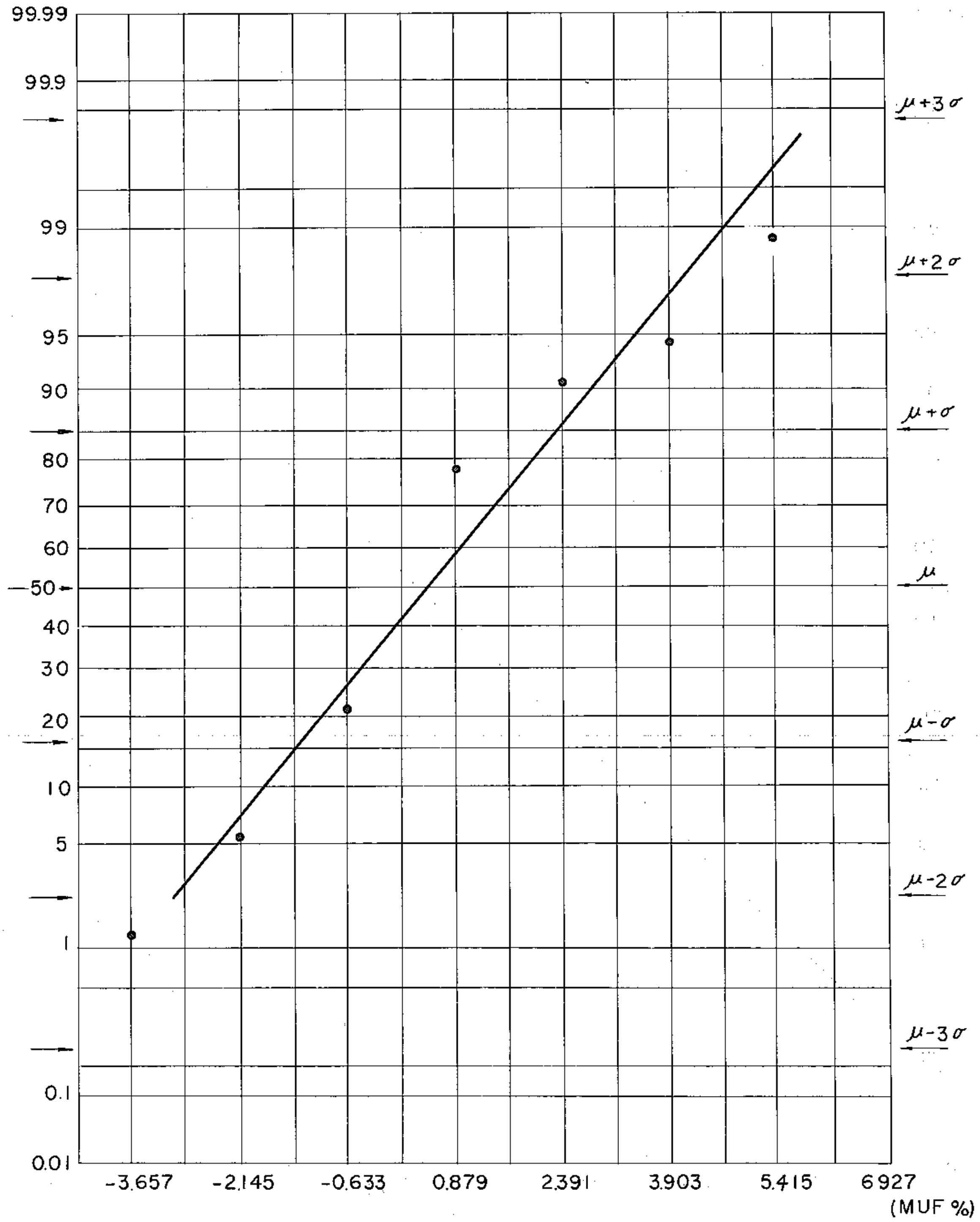

Fig. 9. Gaussian distribution check of MUF of granulation.

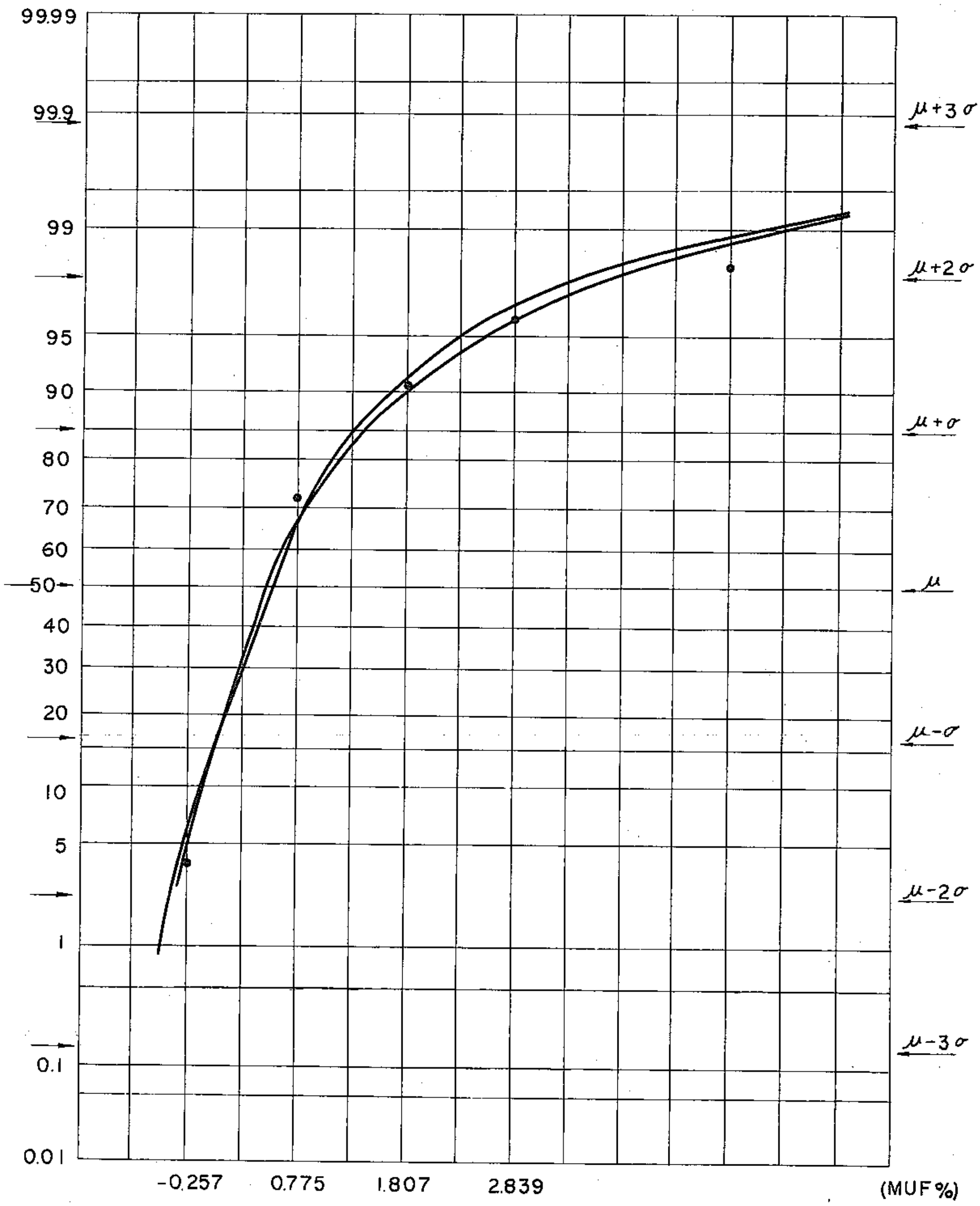

Fig. 10. Gaussian distribution check of MUF of press and Sintering.

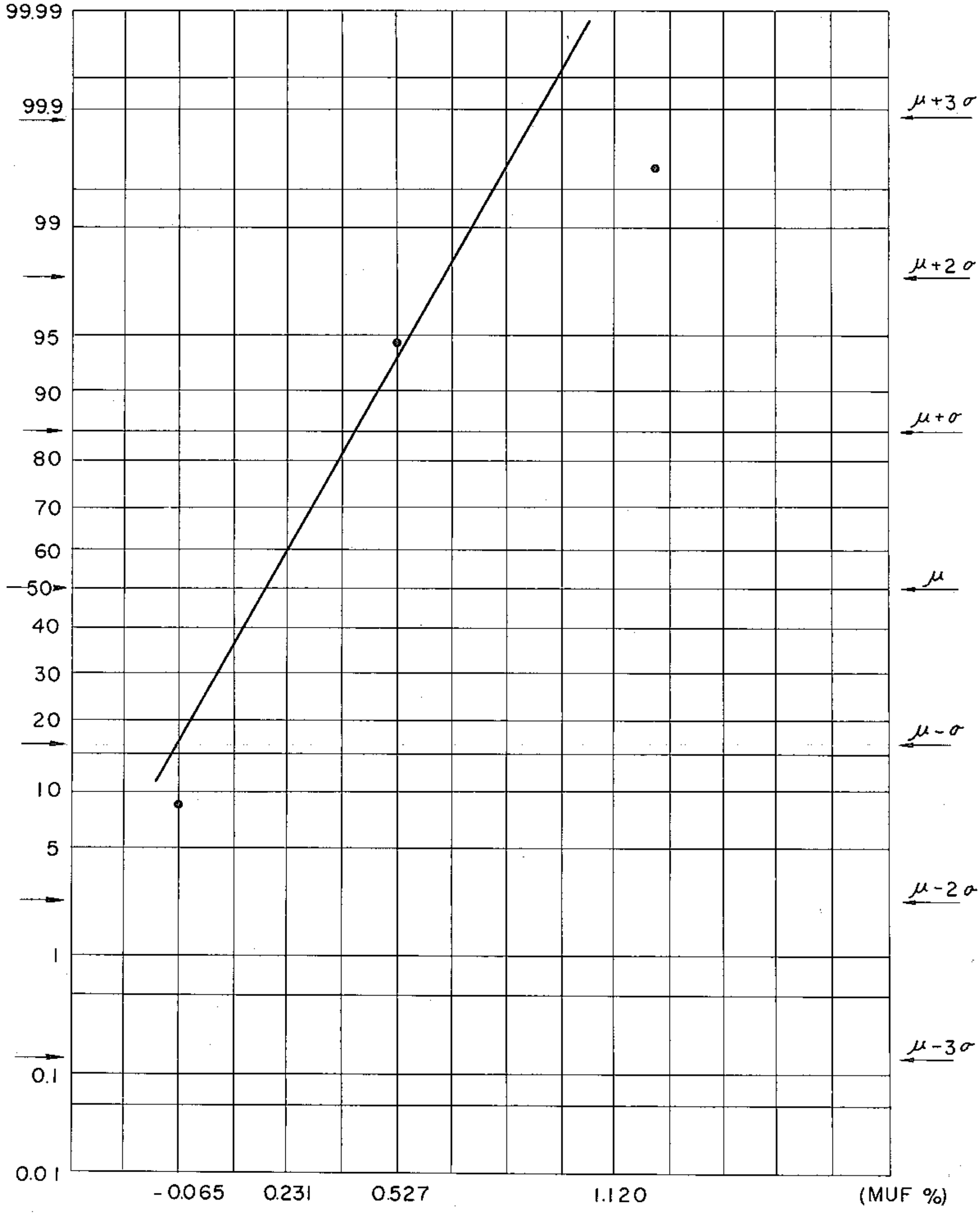

Fig. 11. Gaussian distribution check of MUF of inspection and grinding.

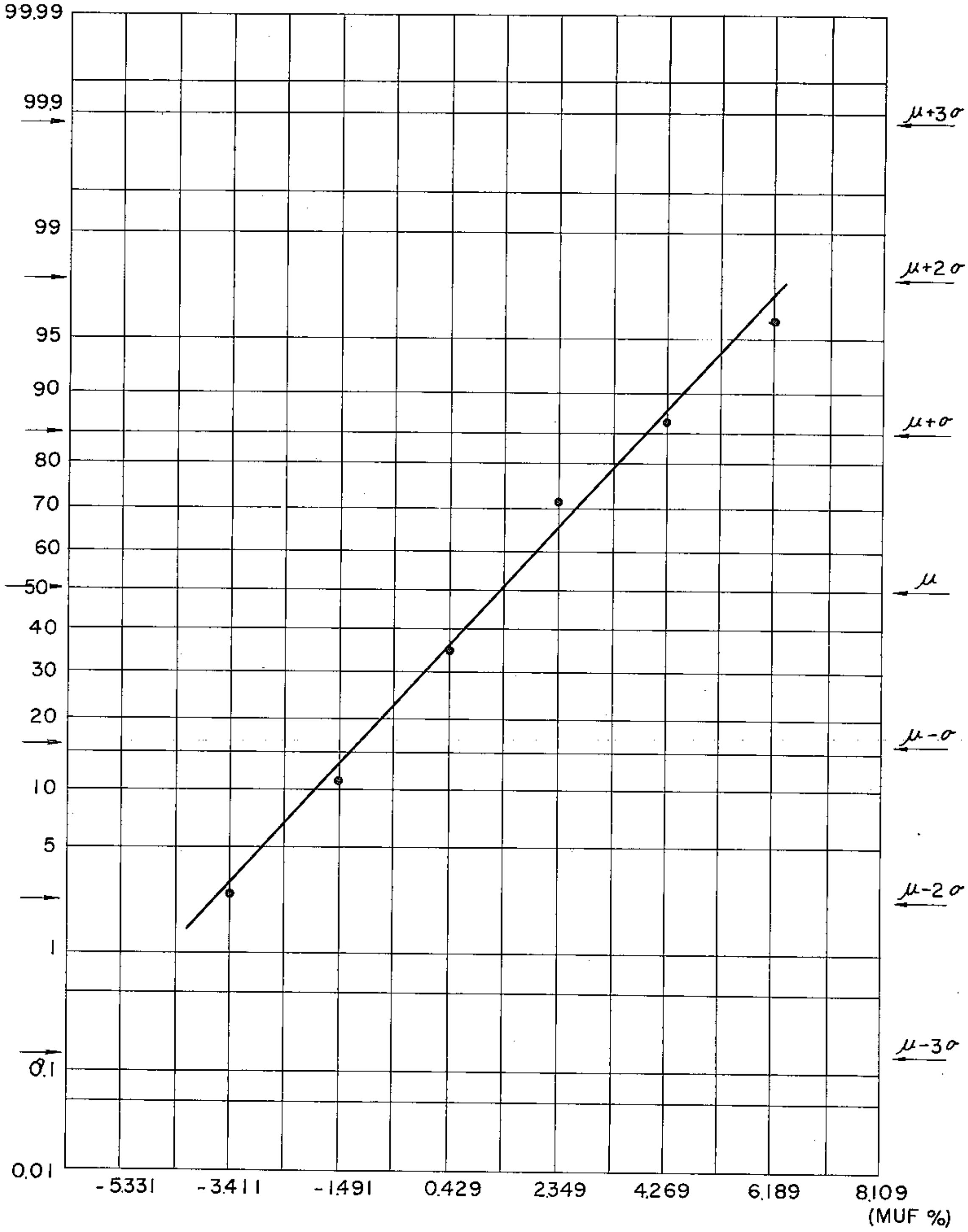

Fig. 12. Gaussian distribution check of Total MUF.

Table 2. Mean and standard deviation of the gaussian distribution of MUF in ATR campaign.

Process	Mean	σ
Master mixing	0.051	0.22
Main mixing	0.090	1.22
Granulation	0.040	2.81
Press and sintering	1.112	2.88
Inspection and grinding	0.159	0.55
Total	1.426	3.99

3.2 Rapsodie irradiation campaign

An analysis for Rapsodie irradiation campaign has been performed in the same manner as for ATR campaign. Figure 13 illustrates the material flow system of the Rapsodie irradiation campaign.
System input data are as follows;

(1) Box name is as shown in Fig. 13.

(2) Capacity is fixed at 100 g/hour throughout the storage box based on the facility experience.

(3) Transfer time is also set at 1.25 hours throughout the storage box based on the facility experience.

Process input data are as follows;

(1) Composition of fuel is 18 w/o PuO_2-82 w/o UO_2.

(2) Isotope ratios (%) are

Pu 238	0.038
Pu 239	90.142
Pu 240	8.533
Pu 241	1.189
Pu 242	0.098
U 235	60.0
U 238	40.0

(3) Total run is 50 lots.

(4) Input time interval is 10 hours.

(5) Input mass weight per run is 1000 g.

(6) MUF ratio is generated by the homogeneous random number based on the measurements of Rapsodie irradiation campaign described in the previous report. Those data are presented in Table 3.

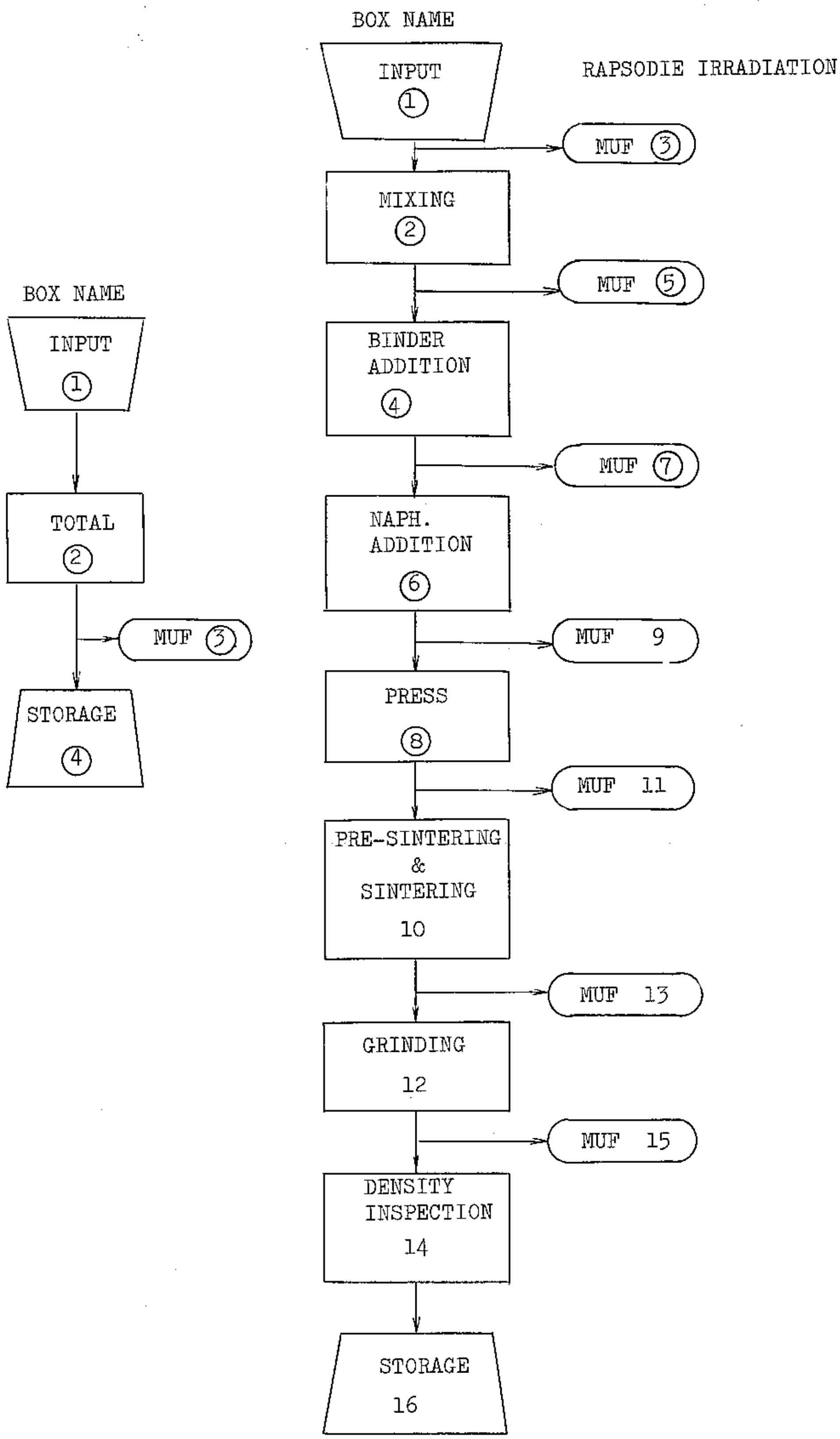

Fig. 13. Material flow diagram of Rapsodie campaign - normal runs.

Table 3. MUF used for uniform distribution random number generation in Rapsodie campaign.

Mixing	—	—	—	0.22	0.22		1.30	-0.2	0.68	0.44
Binder	-0.09	0.00	0.20	0.00	-0.04	0.26	0.21	-0.04	0.00	0.06
Naphthalene addition	—	—	—	1.10	1.29	0.15	0.62	1.31	0.53	0.83
Press	0.13	0.56	0.18	1.73	1.14	0.07	0.37	0.24	0.00	0.49
Pre-sintering and sintering	-0.32	0.00	0.00	—	0.00	0.00	0.00	—	0.53	0.03
Grinding	2.02	1.74	0.55	—	10.24	8.03	6.20	—	4.08	4.69
Density inspection	0.00	0.00	0.12	—	0.00	0.03	—	—	0.00	0.02
Total	5.57	5.61	1.65	1.73	17.41	12.05	10.55	1.79	7.62	7.11

3.3 Estimation of MUF of the material flow by simulating the new facility.

The MUF characteristics learned in PFDL is extraporated to the new facility with the code for illustrating the role of the computer model and the quantitative target of the measurement techniques, before the integrated experiment in the new facility, is carried out for the purpose of evaluating the measurement system in order to understand MUF characteristics on criticality, accountability and quality control systems for safeguards across the material balance in near future.

The new facility of FBR line is illustrated in Fig. 14. There are four cases, box-wise measurements and total in-out measurements with and without steal seen in Fig. 13.

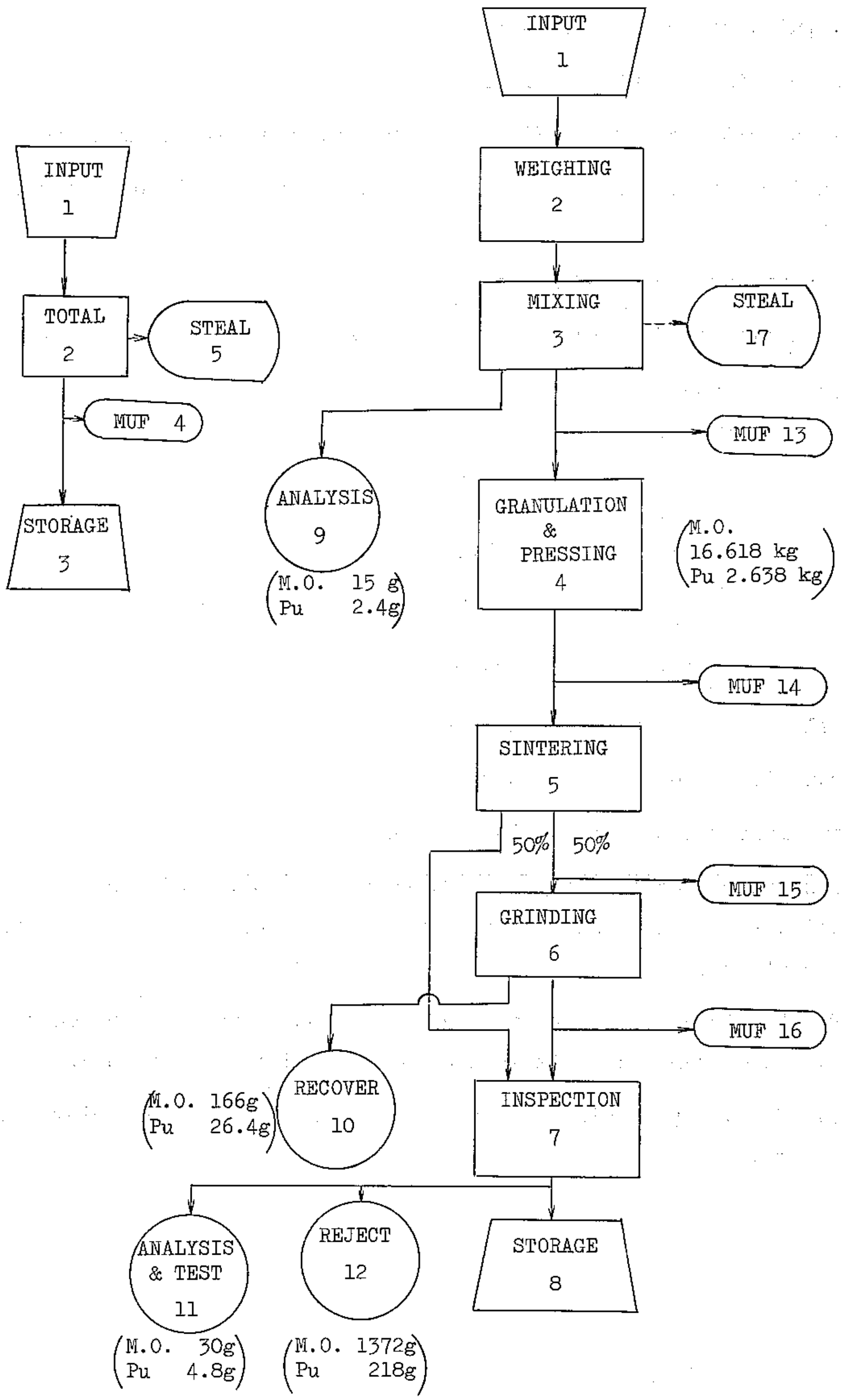

Fig. 14. Material flow diagram of FBR line for one campaign - normal and steal.

System input data are as follows;

(1) Box name is presented in Fig. 13.

(2) Box capacity is fixed 2.7778 Kg/hour throughout the storage box.

(3) Transfer time is used the present facility data 1.25 hours for every flow.

Process input data are as follows;

(1) Composition of fuel is 18 w/o PuO_2-82 w/o UO_2.

(2) Isotope ratios (%) are

Pu 238	0.1
Pu 239	70.0
Pu 240	24.4
Pu 241	5.0
Pu 242	0.5
U 235	23.0
U 238	77.0

(3) Total run is 50 in this campaign.

(4) Input time interval is 6 hours.

(5) Input mass weight per run is 16.67 kg.

(6) The split ratios to Analysis (9), Recovery (10), Analysis and Metallography (11), and Reject Box (12) are shown in Fig. 12 with a parenthesis.

(7) MUF ratio is generated by the gaussian random number. The mean values and standard deviations σ used are listed in Table 4.

(8) Steal frequency is also set once per ten run at random during this campaign.

Table 4. Mean and standard deviation of the gaussian distribution of MUF in a compaign of FBR line.

	Mean	σ
Mixing	0.2	1.22
Granulation and press	0.2	2.81
Sintering	0.1	2.88
Grinding	0.4	3.00
Total	0.9	4.00

4. Output data description

4.1 Study of PFDL experience

4.1.1 ATR campaign

Table 5 shows the calculated and measured mass balance at the end of 76 runs for ATR campaign. The agreement is not so favorable with the experimental data. It is about double in the total MUF. This large difference appears to mainly come from the input data both of mean and standard deviation of the gaussian distribution of MUF which has been taken from the experiment.

The effect of material control area size on the variance of MUF with and without steal is illustrated in Table 6. It is observed that the MUF for box-wise control is always larger than that for MBA-wise control.

The detail comparison of this trend over the working hour is illustrated in Figs. 16 and 17 when the material is loaded in the manner as shown in Fig. 15. It is worth pointing out that even in steal case, MUF for box-wise control becomes larger than that for IBA wise control at the and of runs.

Table 6 also indicates the effect of stealing material on the process output. The process output of the steal case happened to be sometimes more than that of the normal case. Comparison between Fig. 18 and 19, however, indicates the possibility of preventing steal with the correlation of the standard deviation of MUF and steal. So that, if the mean and standard deviation of steals is large enough, the process output of the steal case is always smaller than that of the normal case.

Table 5. Mass balance calculated and measured for ATR campaign (76 runs).

Process		Calculated MUF (g)	Measured MUF (g)	Claculated MUF (%)	Measured MUF (%)
Input material		570000	570467	100%	100%
Output material		560812	565606	98.387	99.148
Difference		9188	4861	1.613	0.852
MUF	Master mixing	318	-19	0.056	-0.003
	Main mixing	221	418	0.039	0.073
	Granulation	1810	225	0.318	0.039
	Press & sintering	5233	4195	0.918	0.735
	Inspection & grinding	1605	42	0.282	0.007
	Total	9187	4861	1.613	0.851

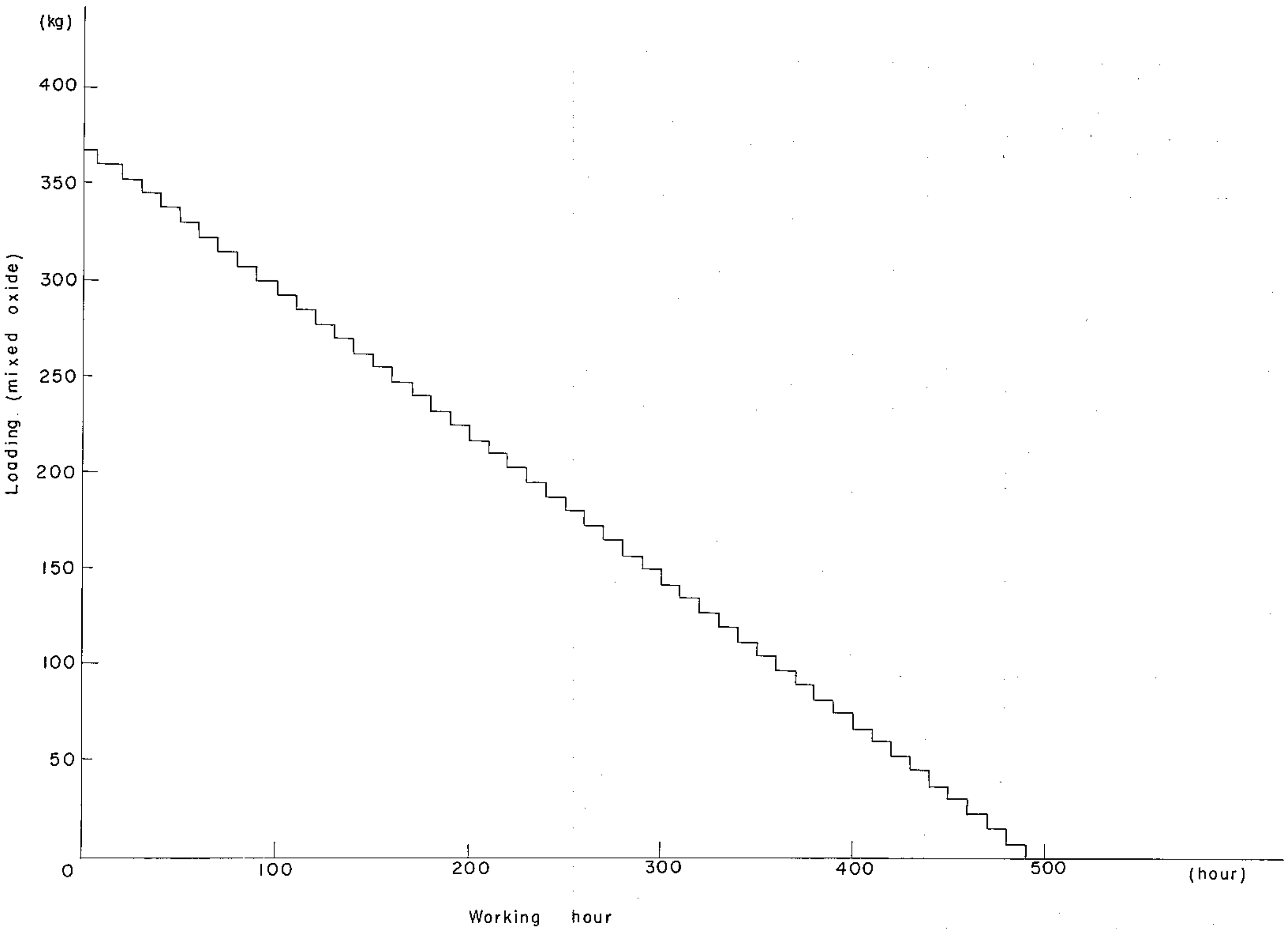

Fig. 15. Loading amount of mixed oxide to the present facility for ATR campaign.

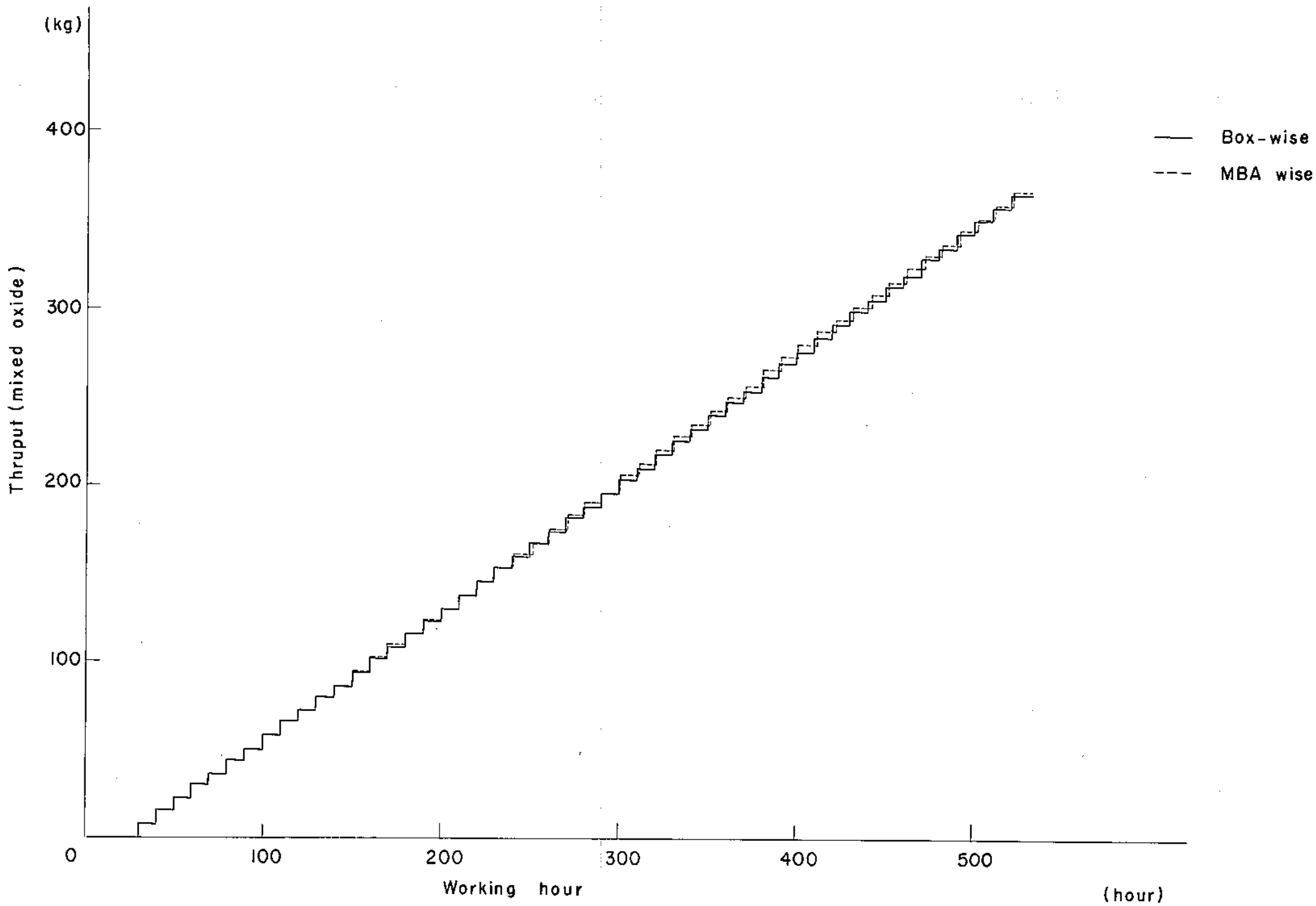

Fig. 16. Thruput of mixed oxide for ATR campaign - normal.

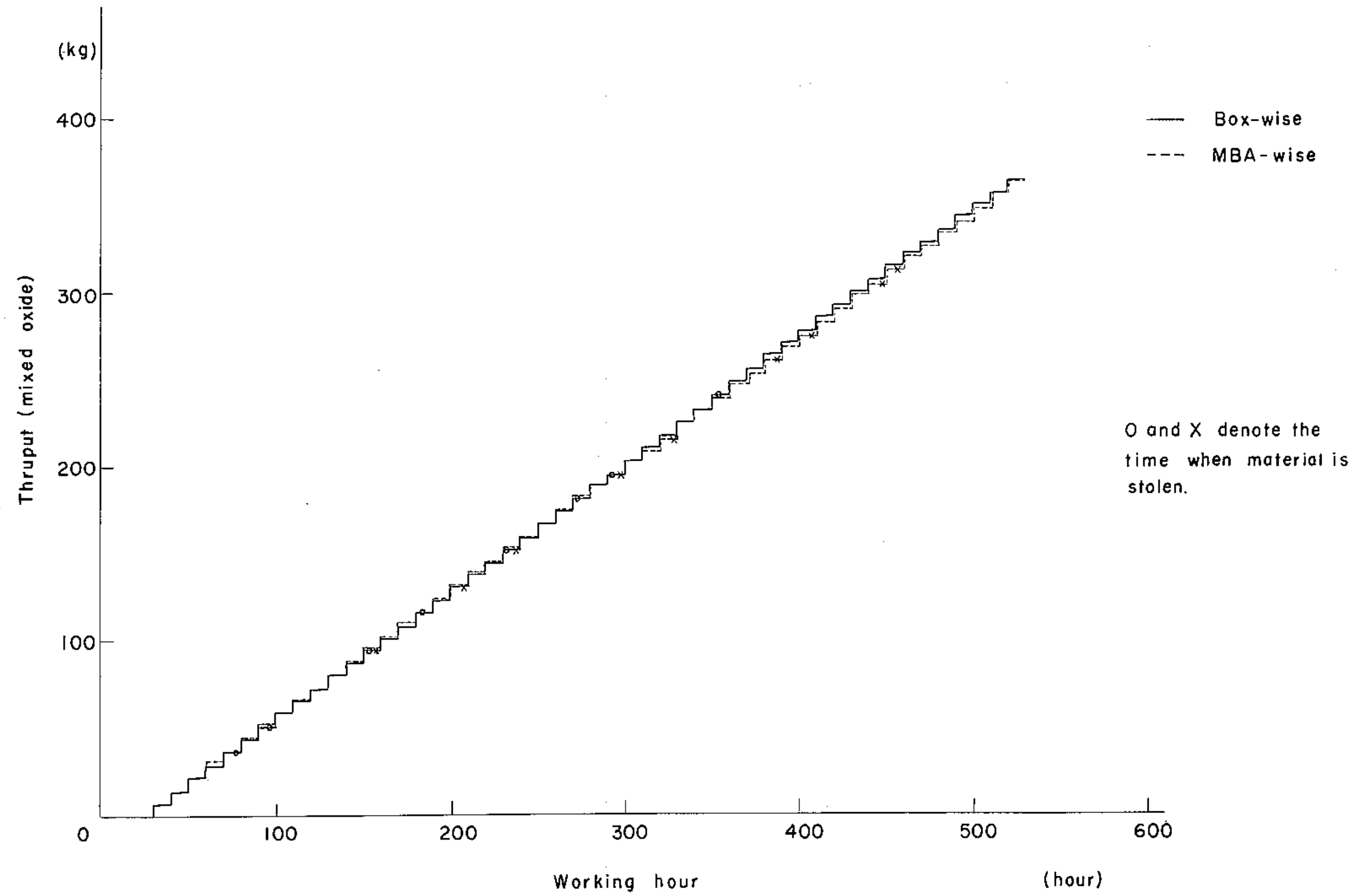

Fig. 17. Thruput of mixed oxide for ATR campaign - steal.

Table 6. Calculated mass balance for four ATR campaigns (50 runs).

Process			MBA-wise Material balance		Box-wise Material balance	
			Normal	Steal	Normal	Steal
Input		(g) (%)	375000 100	375000 100	375000 100	375000 100
Output		(g) (%)	367782 98.075	365562 97.483	366839 97.824	366340 97.691
Difference		(g) (%)	9218 1.925	9438 2.517	8161 2.176	8660 2.309
MUF	Master mixing	(g) (%)			165 0.044	151 0.040
	Main mixing	(g) (%)			302 0.081	1378 0.367
	Granulation	(g) (%)			2186 0.583	1791 0.478
	Press & sinter	(g) (%)			4778 1.274	4518 1.205
	Inspection & grinding	(g) (%)			729 0.194	445 0.119
	Total	(g) (%)			8160 2.176	8283 2.209
Steal		(g) (%)		3207 0.8552		374 0.0997
Working hour (hour)			497	471	520	509

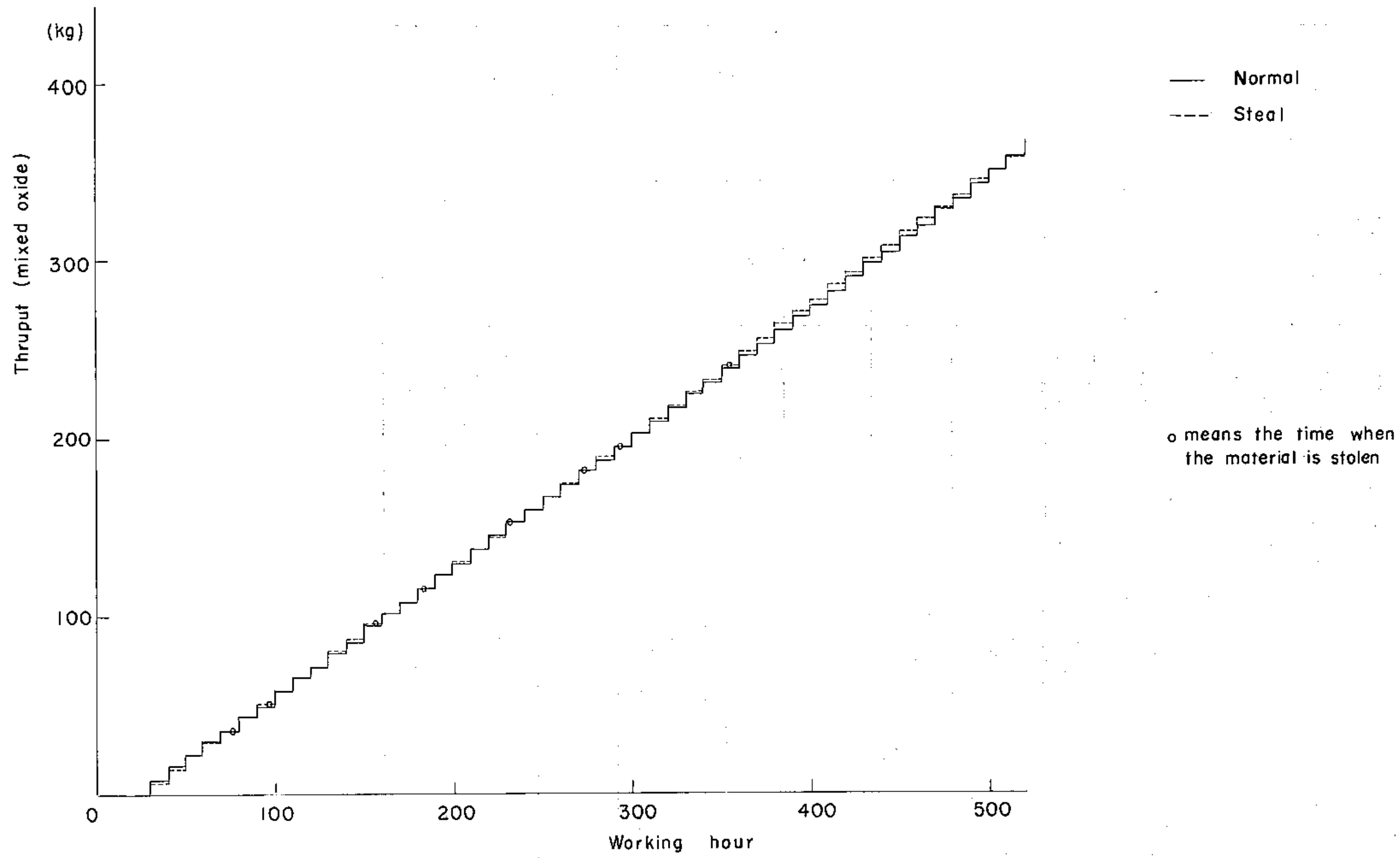

Fig. 18. Thruput of mixed oxide for ATR campaign - box-wise.

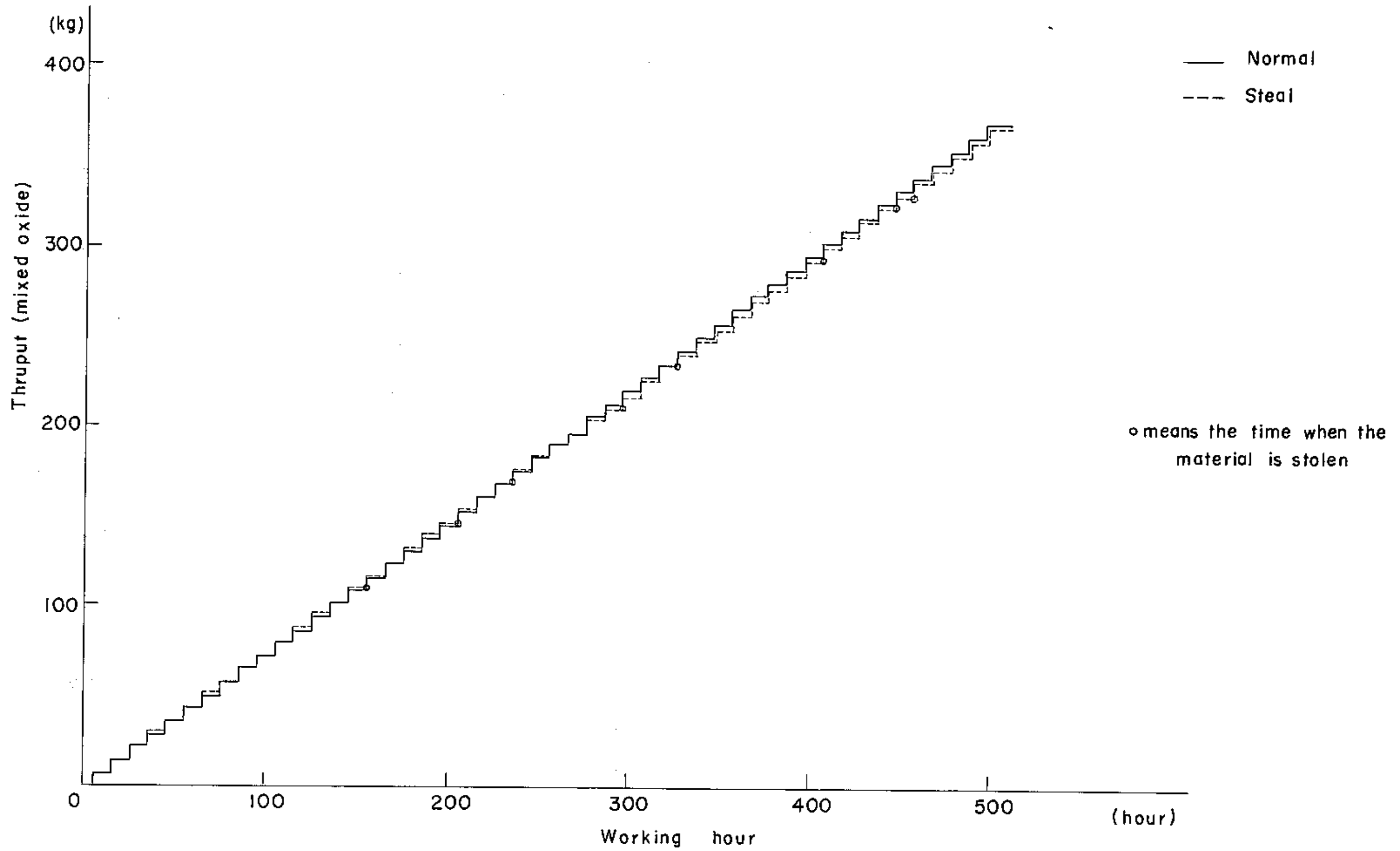

Fig. 19. Thruput of mixed oxide for ATR campaign -MBA-wise.

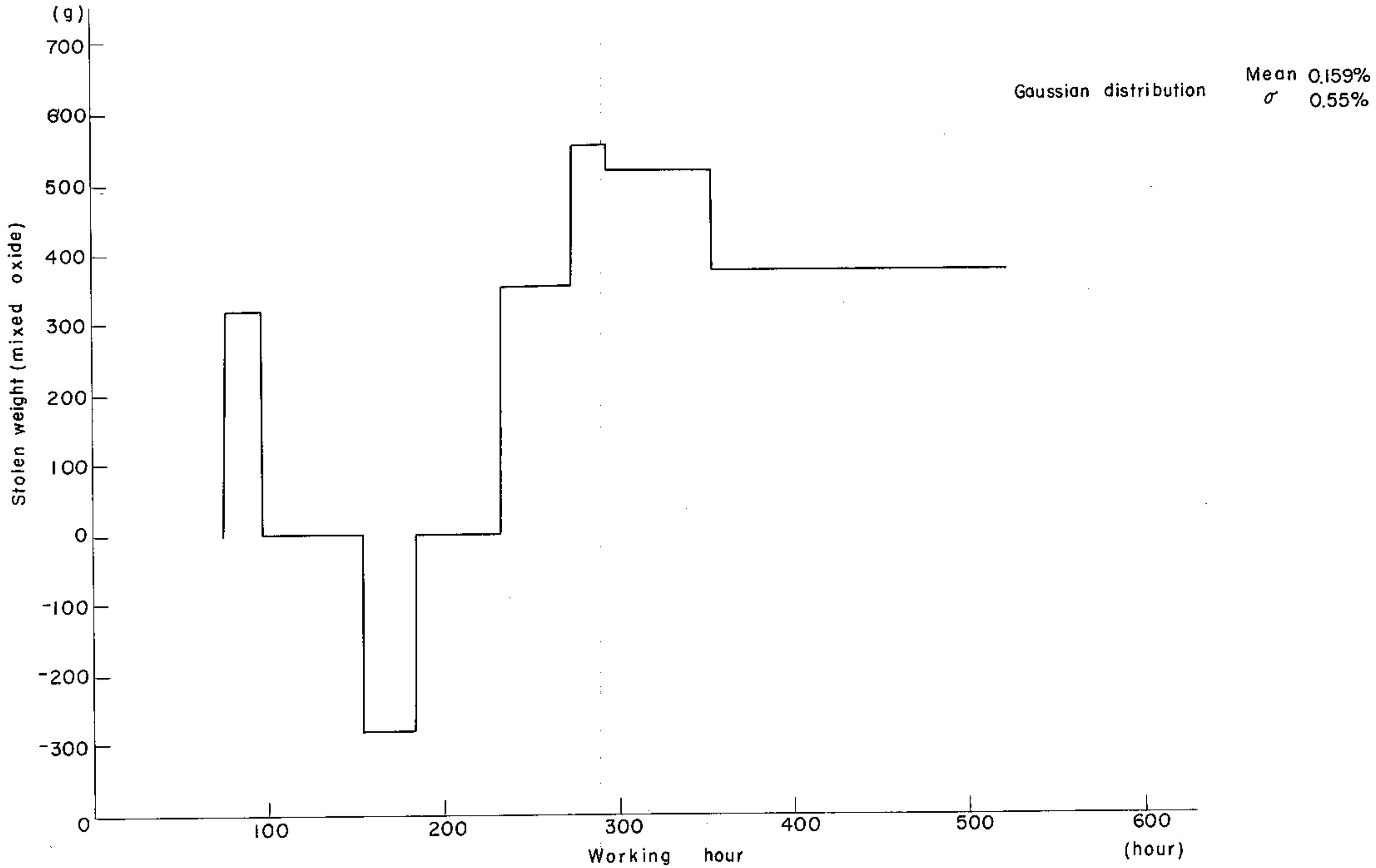

Fig. 20. Stolen weight from inspection and grinding box for ATR campaign.

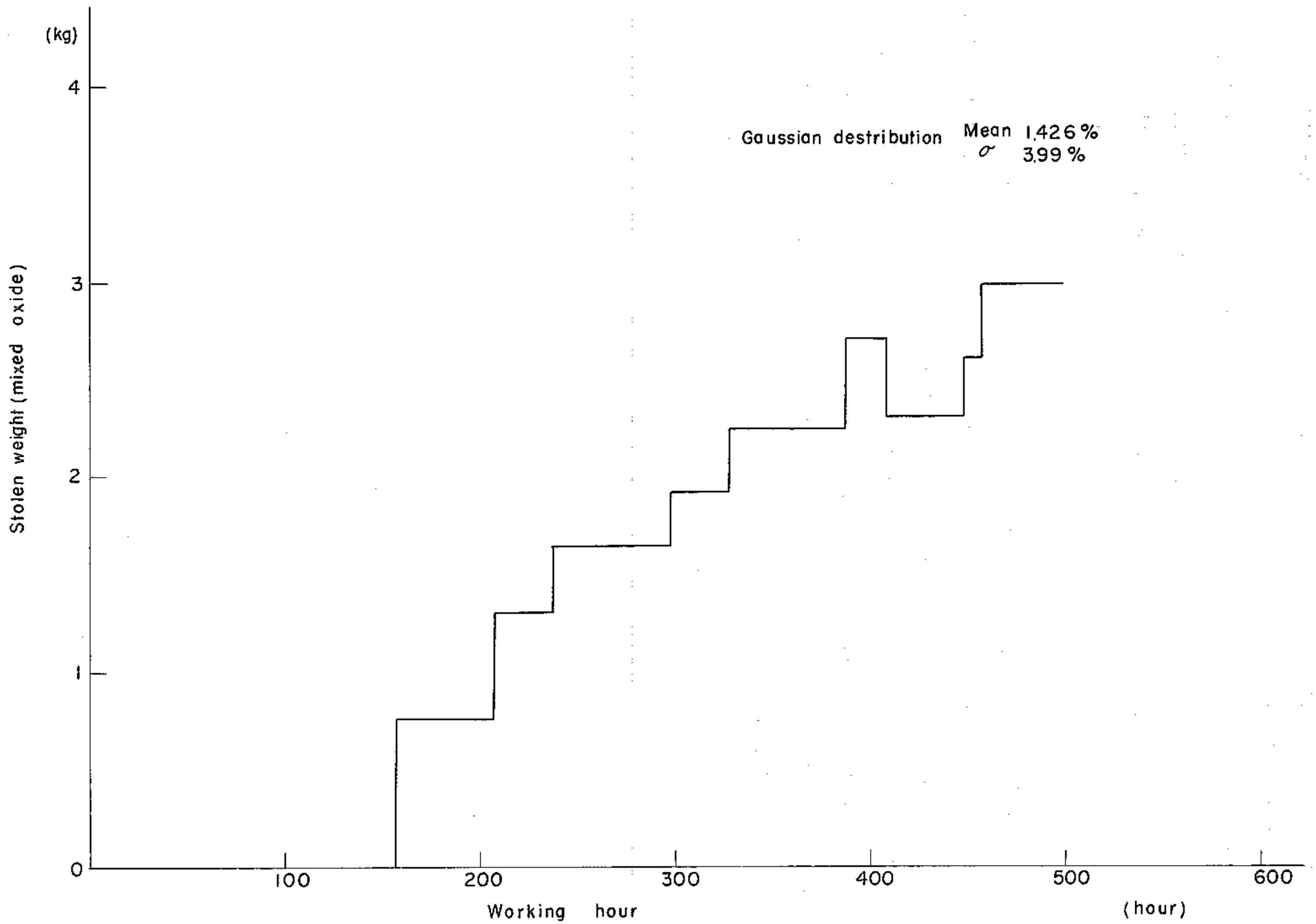

Fig. 21. Stolen weight from MBA-wise box for ATR campaign.

Working hour listed in Table 6 is fairly well agreed with the real working hour.

The time behaviour of MUF for each box is shown in Figs. 22 ~ 27. The maximum difference of the total MUF between two ATR 50 runs campaigns (normal and steal), is about 2.8 kg as indicated in Fig. 22. For comparison, the maximum difference 2.3 kg of that in box-wise control, appeared in both of the granulation and, press and sinter box shown in Figs. 25 and 26. This implies that the reproducibility of the MUF time characteristics depends on the standard deviation of MUF. If the standard deviation is large enough compared with the mean value, the possibility to pick up the negative MUF ratio increases. It can, therefore, be expected that the target mean and standard deviation must be smaller than 0.051% and 0.22% respectively in the MUF range of 200 g (mixed oxide) for the 400 kg (mixed oxide) campaign, assuming that the MUF has the gaussian distribution. According to the PFDL experiences, MUF seldom becomes negative in some boxes within the variance of the MUF discussed above. Therefore the homogeneous random number is used for the Rapsodie irradiation campaign as the different MUF distribution.

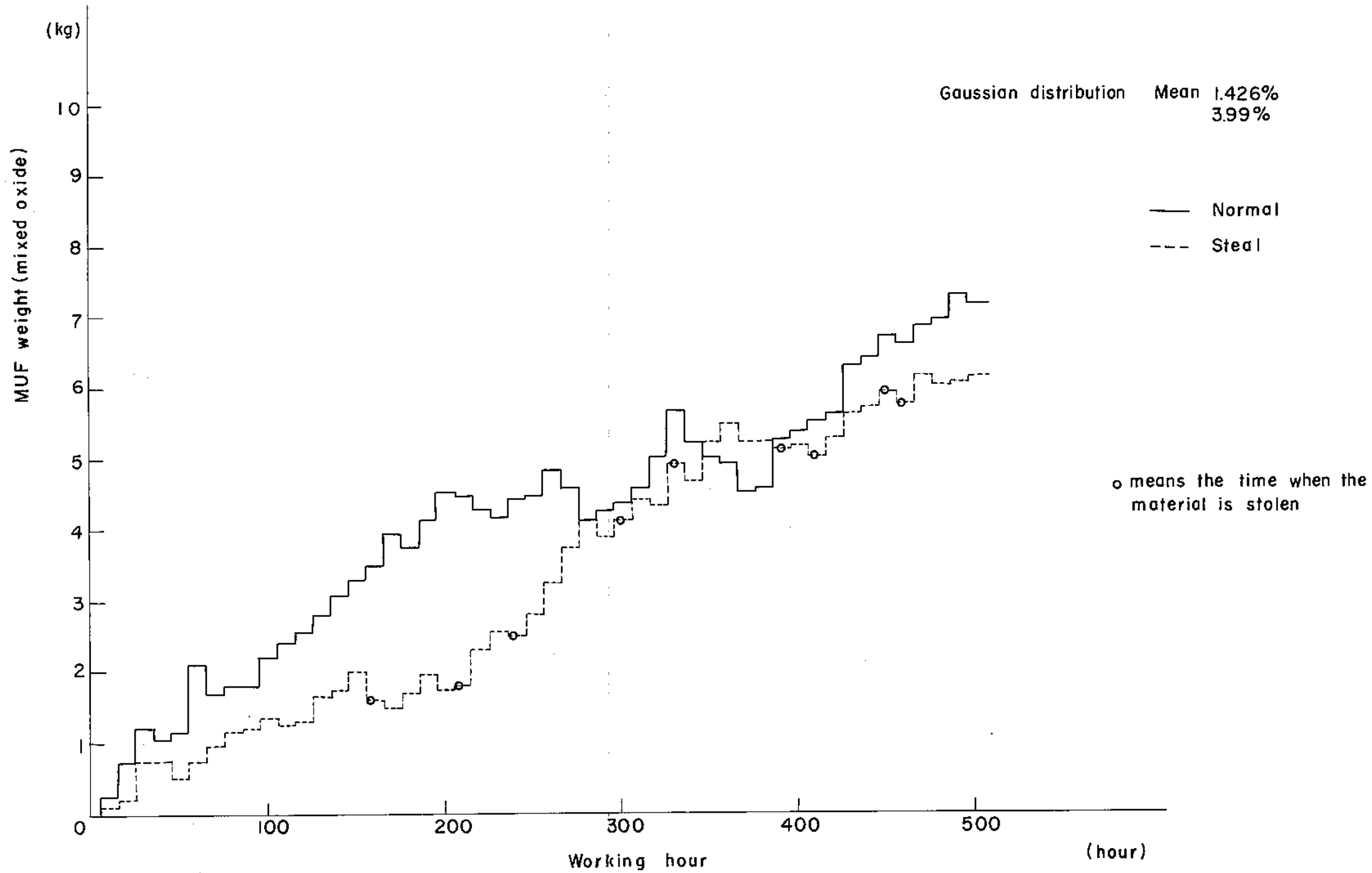

Fig. 22. MUF weight of total for ATR campaign.

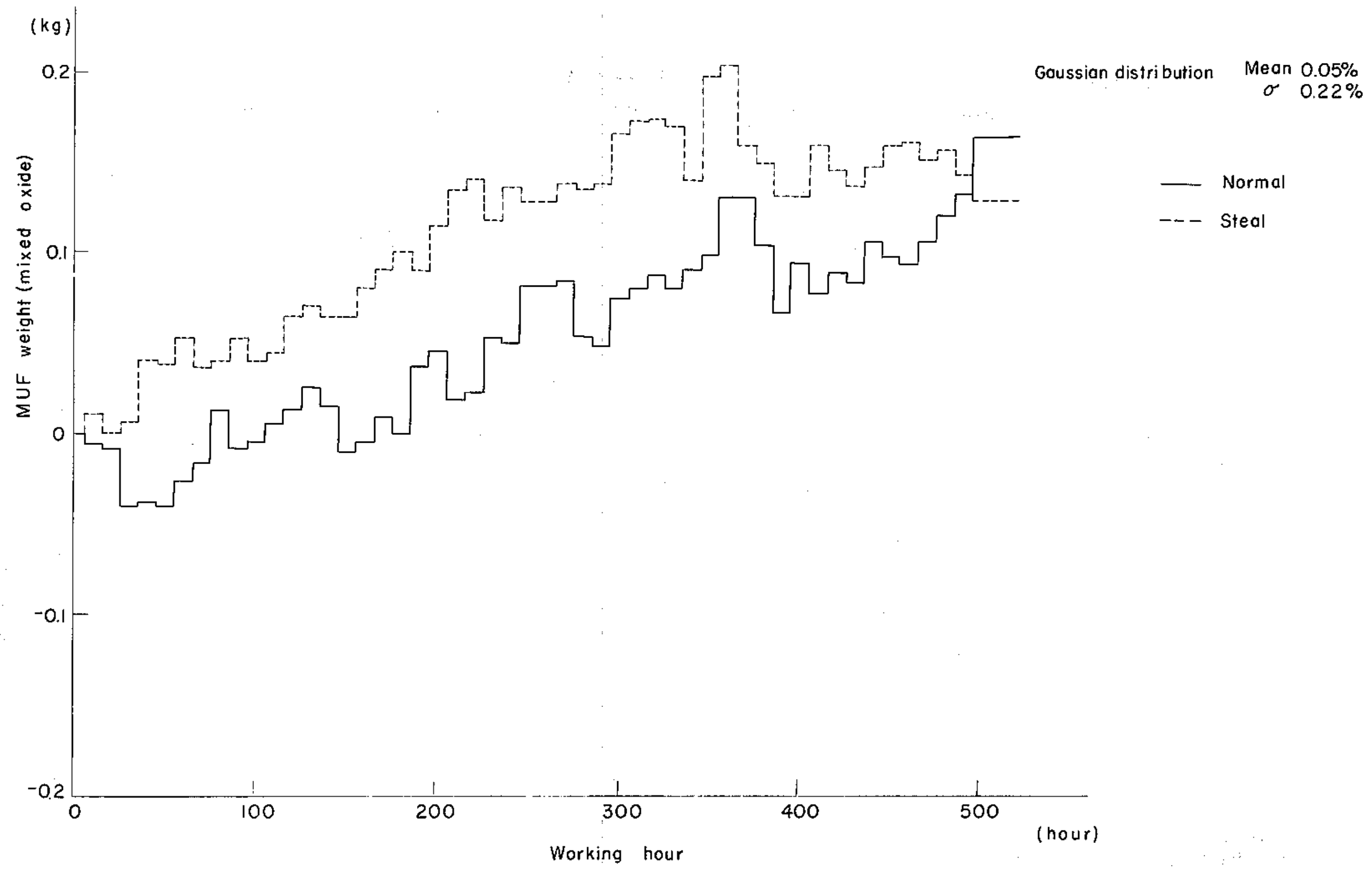

Fig. 23. MUF weight of master mixing box for ATR campaign.

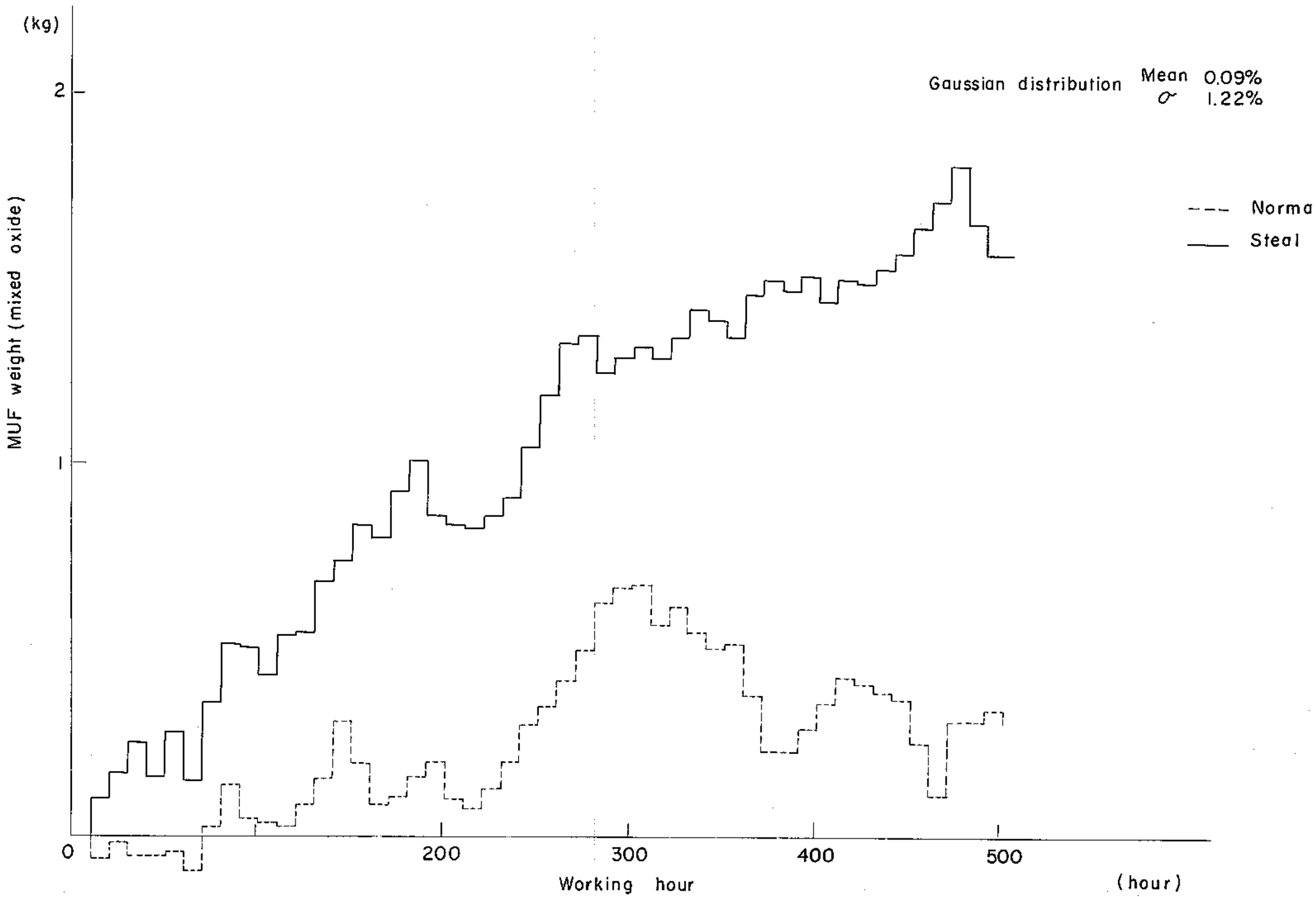

Fig. 24. MUF weight of main mixing box for ATR campaign.

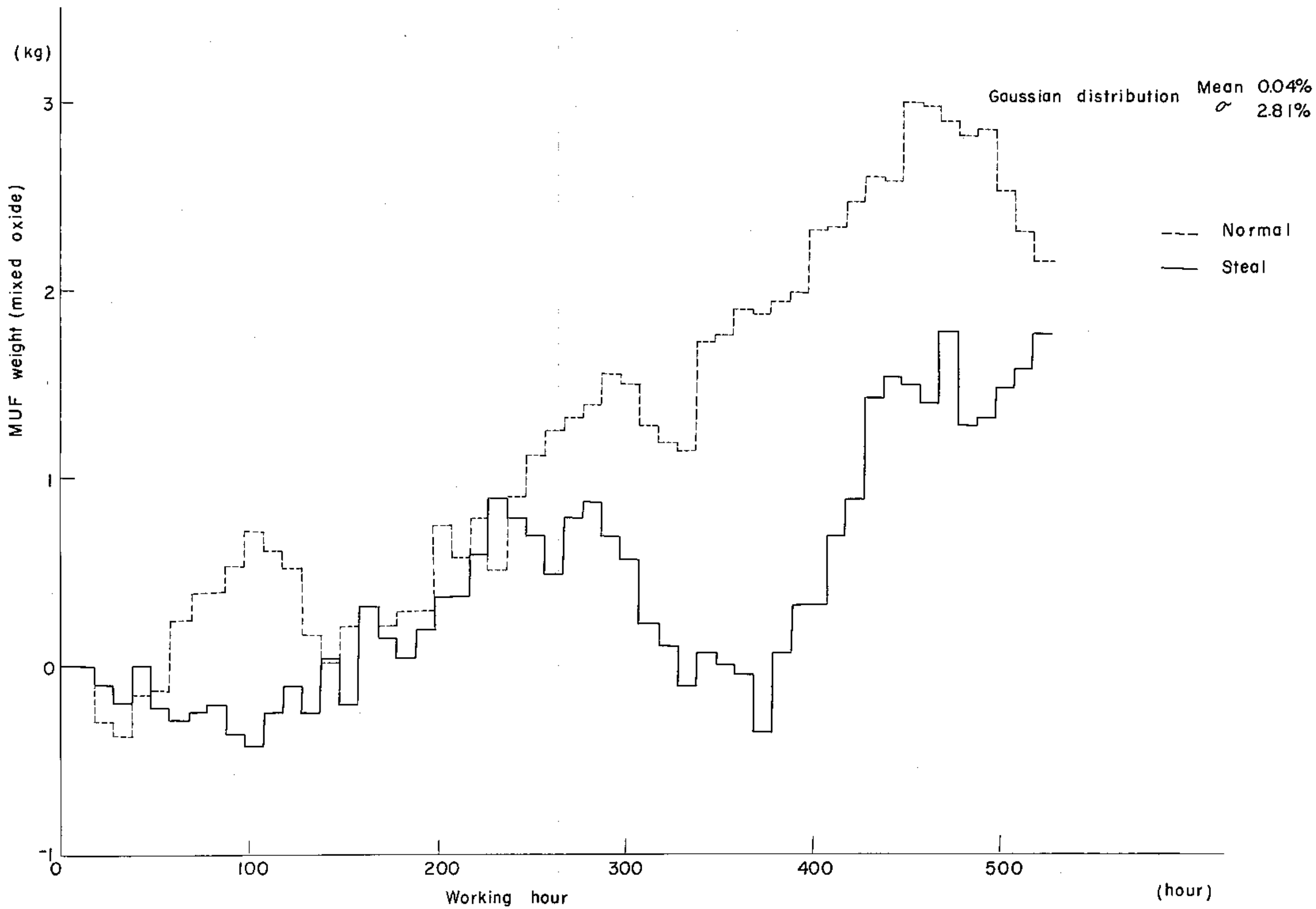

Fig. 25. MUF weight of granulation box for ATR campaign.

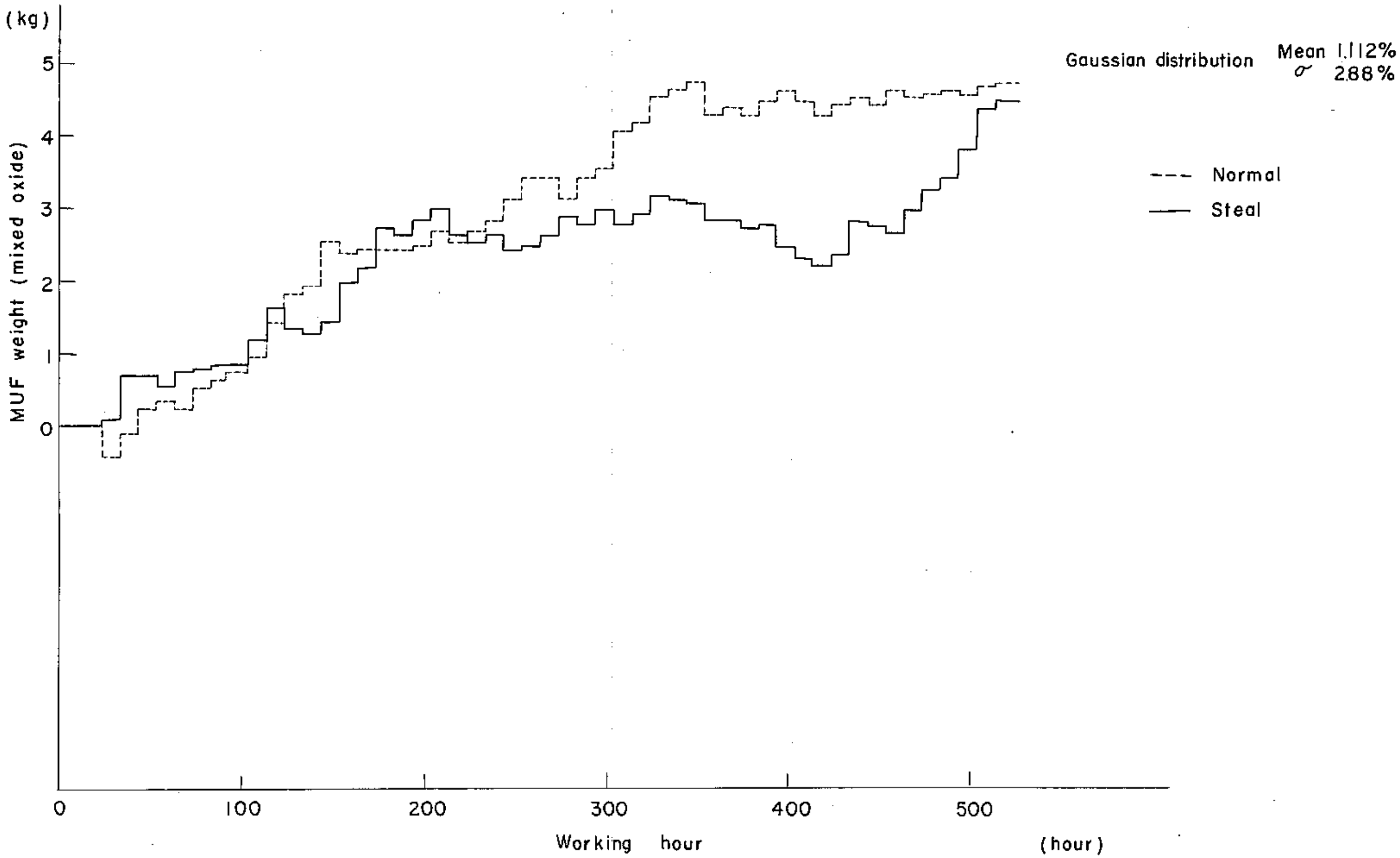

Fig. 26. MUF weight of press and sintering box for ATR campaign.

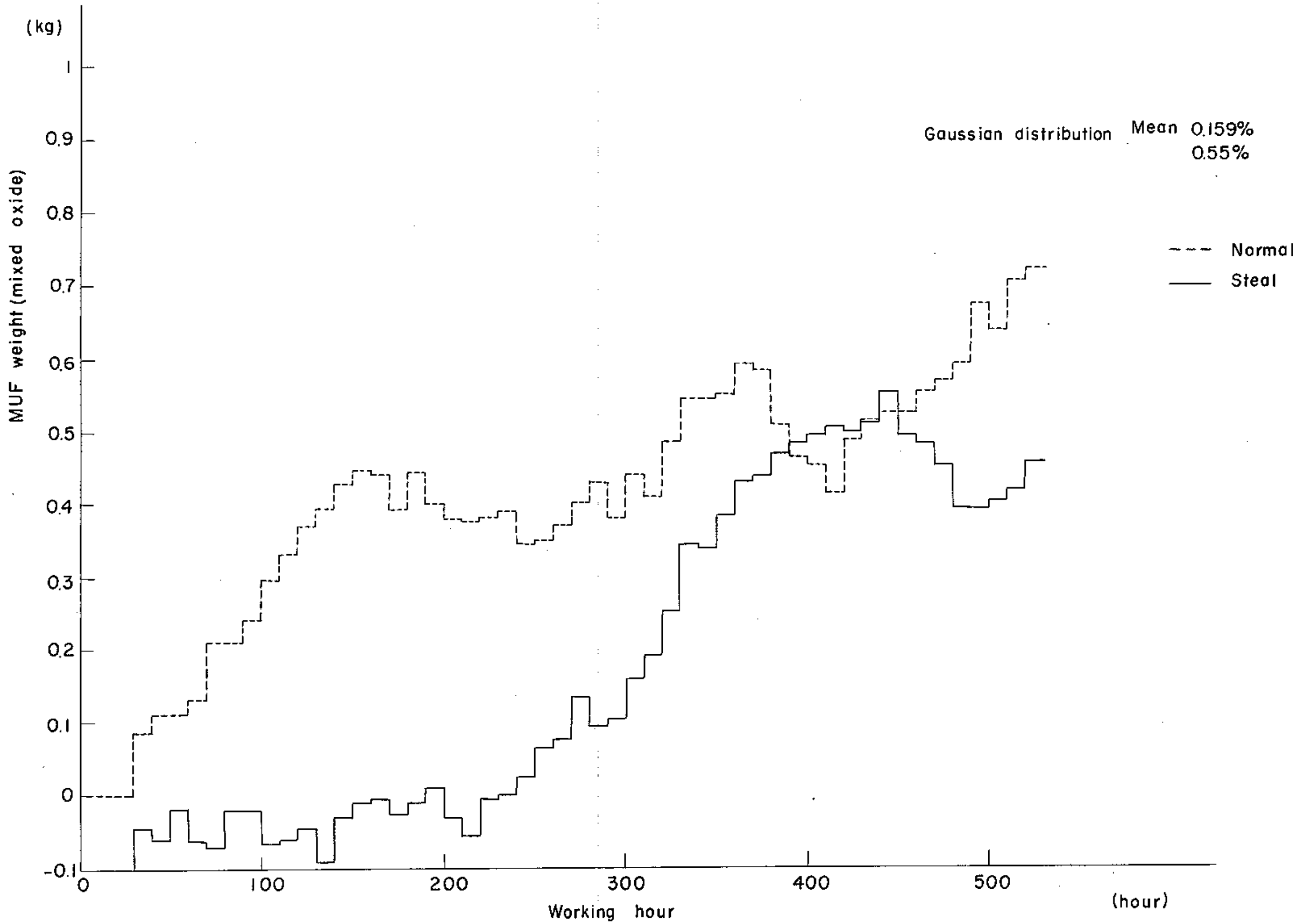

Fig. 27. MUF weight of inspection and grinding box for ATR campaign.

4.1.2 Rapsodie irradiation campaign

Table 7 illustrates the mass balances both of the calculated (50 runs) and the measured (9 runs) values. Although the calculated value of the total MUF is not favorable with that of the measured, the trend of the MUF composition is in quite good agreement in such a small actual campaign data.

The calculated detail time profiles of the mass balance and MUF for the Rapsodie irradiation campaign are plotted in Figs. 28 ~ 33. It is worth pointing out that all the time profiles of the mass balance behave very similar, mostly linear due to the homogeneous random number choice. This indicates that if the actual MUF data is accumulated, then the MUF characteristics for time varying can be predicted more precisely with this homogeneous random distribution.

Table 7. MUF (mixed oxide) calculated and measured for Rapsodie irradiation campaign.

Process		Calculated MUF (50 runs) (g)	(g)	Measured MUF (9 runs) (g)
Input		50000	100.000	100.000
Output		46810	93.620	96.000
Difference		3190	6.380	4.000
MUF	Mixing	278	0.556	0.198
	Binder addition	38	0.076	0.063
	Naphthalene addition	390	0.780	0.488
	Press	269	0.538	0.075
	Pre-sintering & sintering	43	0.086	-0.001
	Grinding	2161	4.322	3.166
	Density inspection	11	0.022	0.0104
Total		3190	6380	3.9994

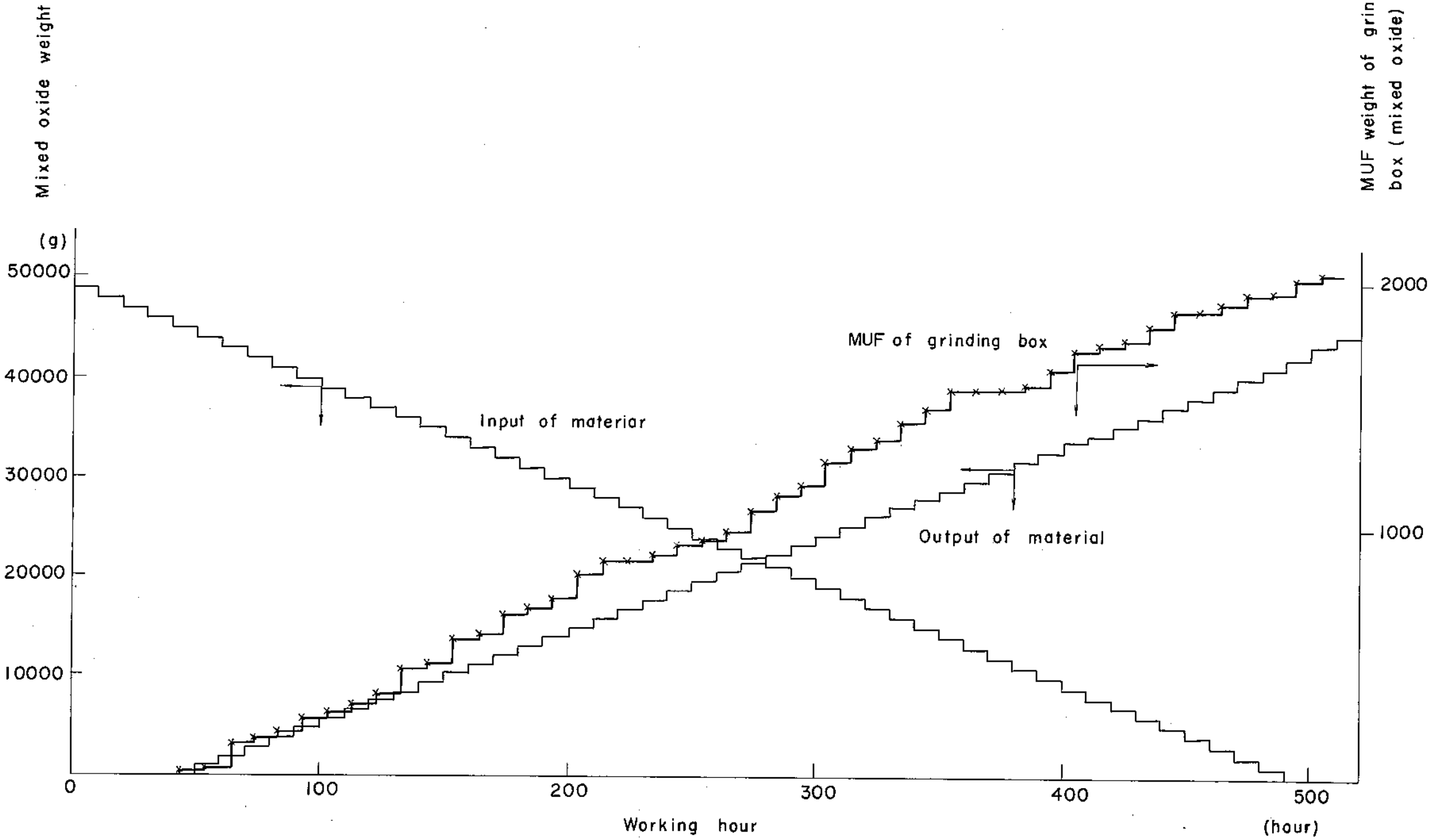

Fig. 28. Material flow of input, output and grinding box for Rapsodie irradiation campaign.

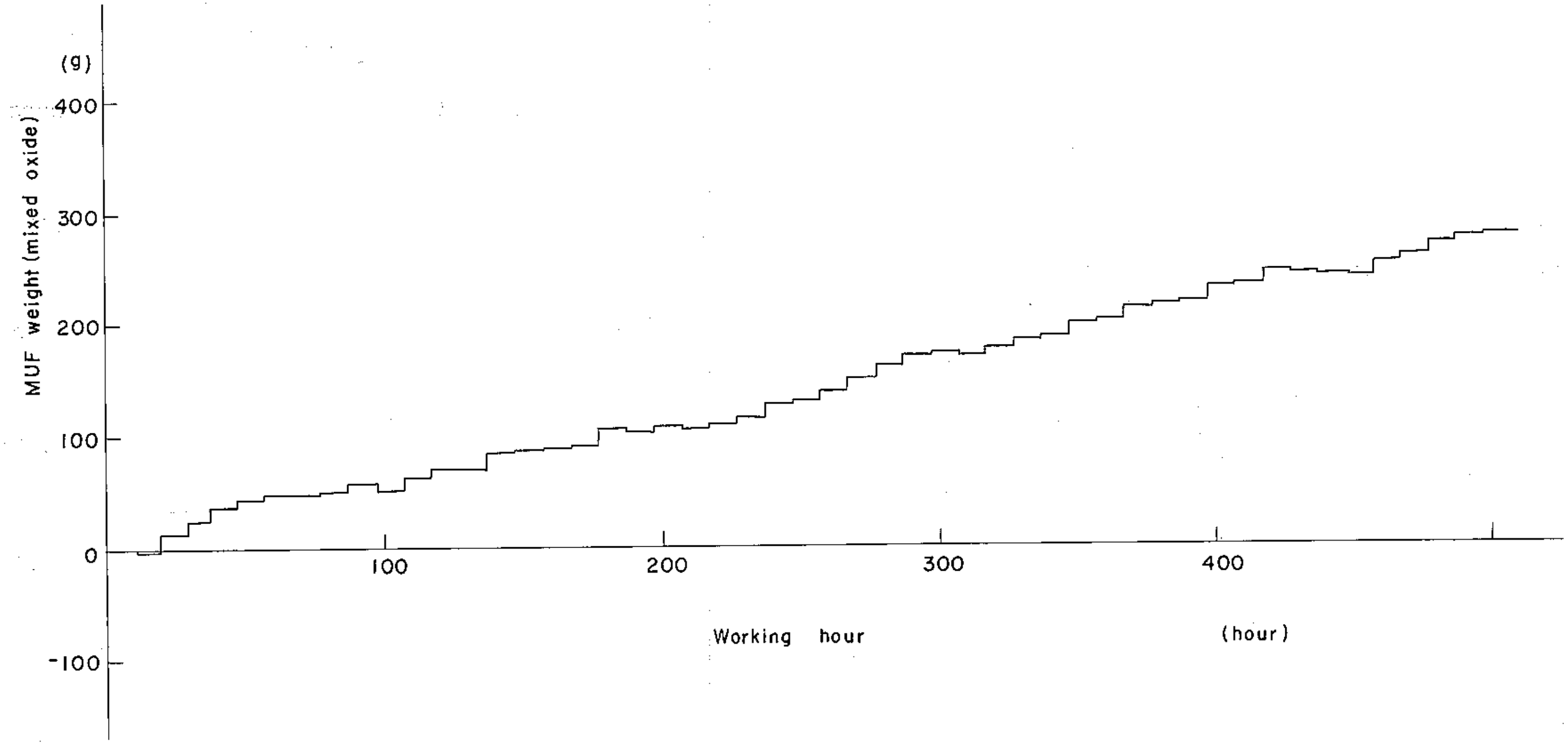

Fig. 29. MUF weight of mixing box for Rapsodie irradiation campaign.

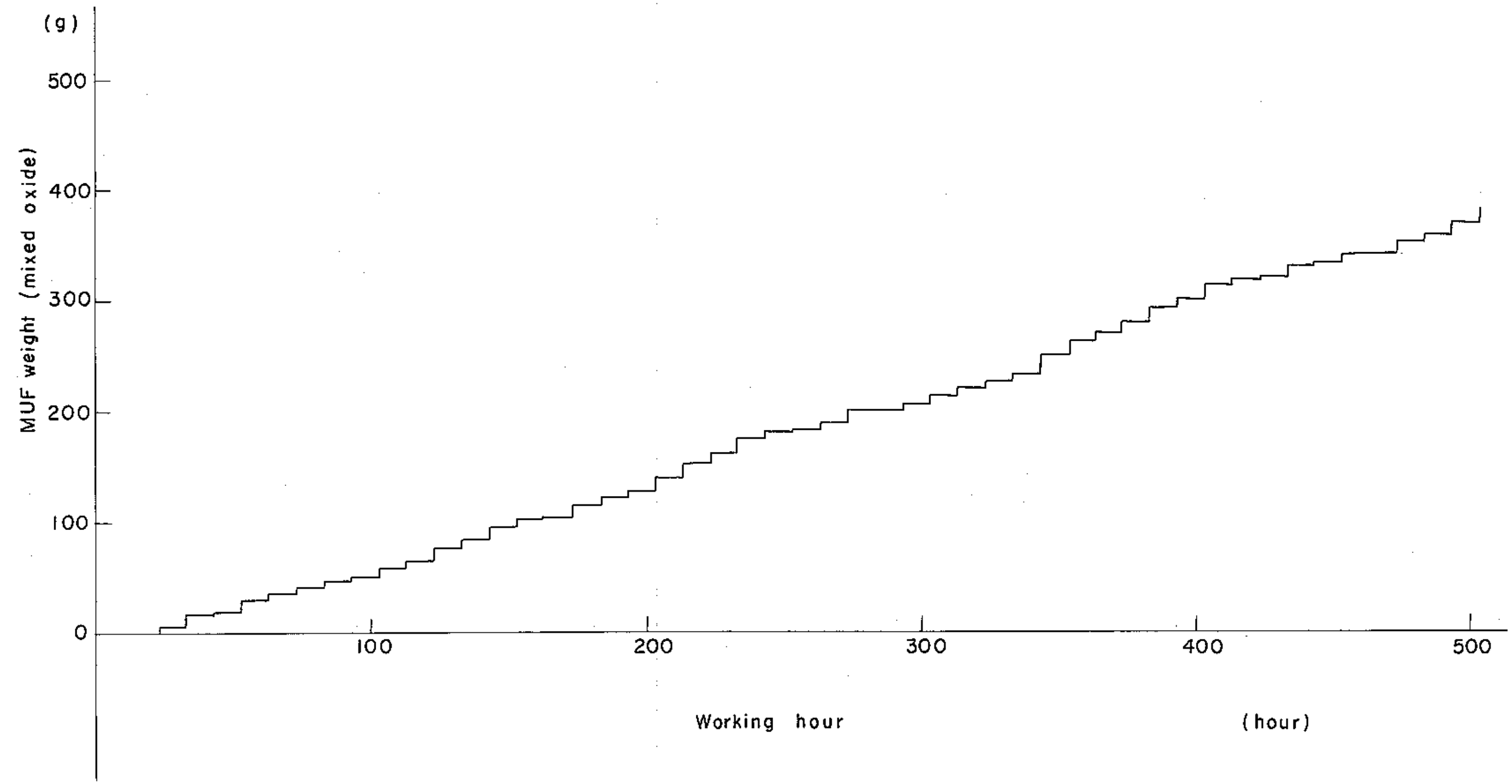

Fig. 30. MUF weight of naphthalene addition box for Rapsodie irradiation campaign.

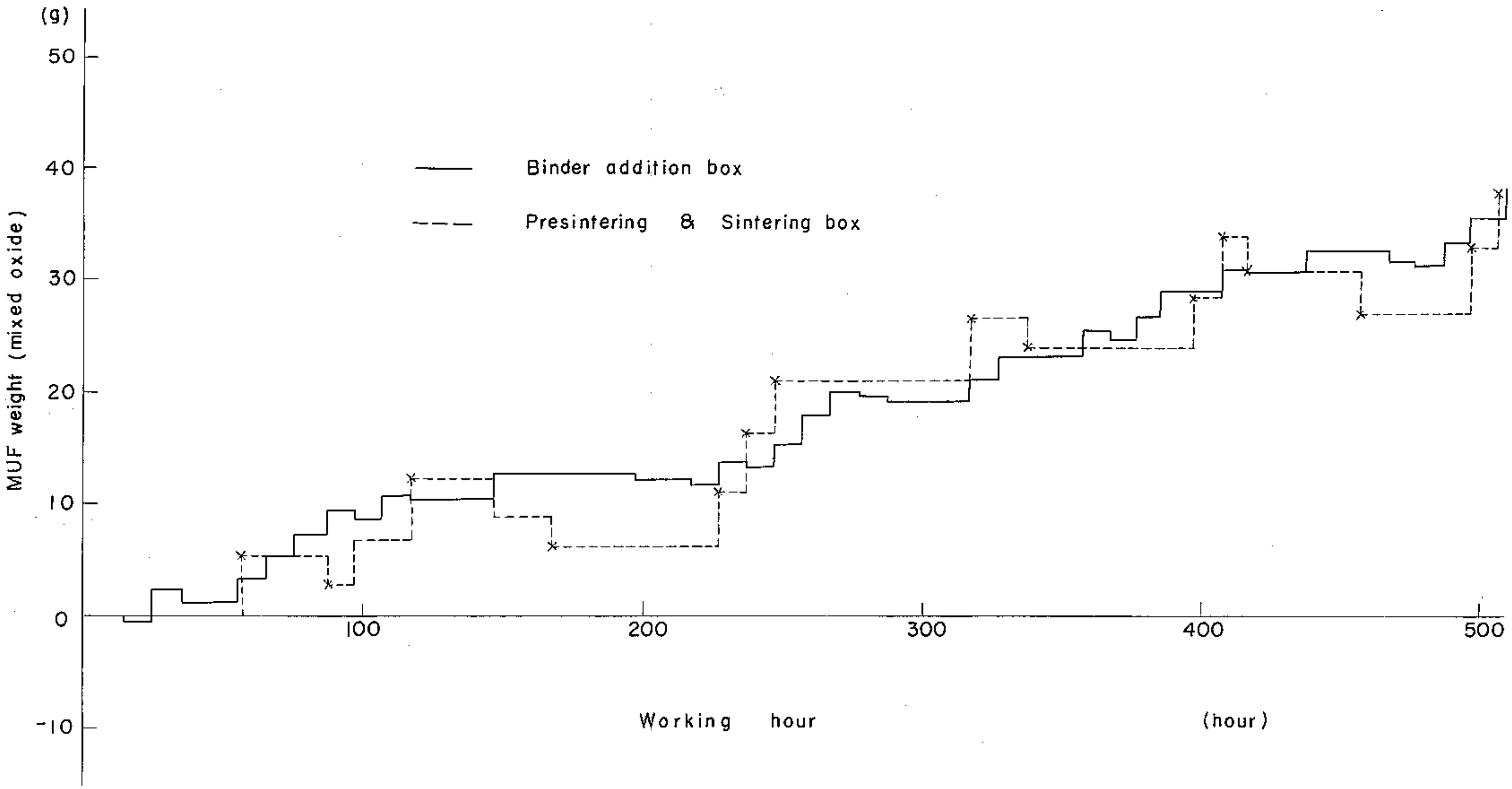

Fig. 31. MUF weight of binder addition box and pre-sintering & sintering box for Rapsodie irradiation campaign.

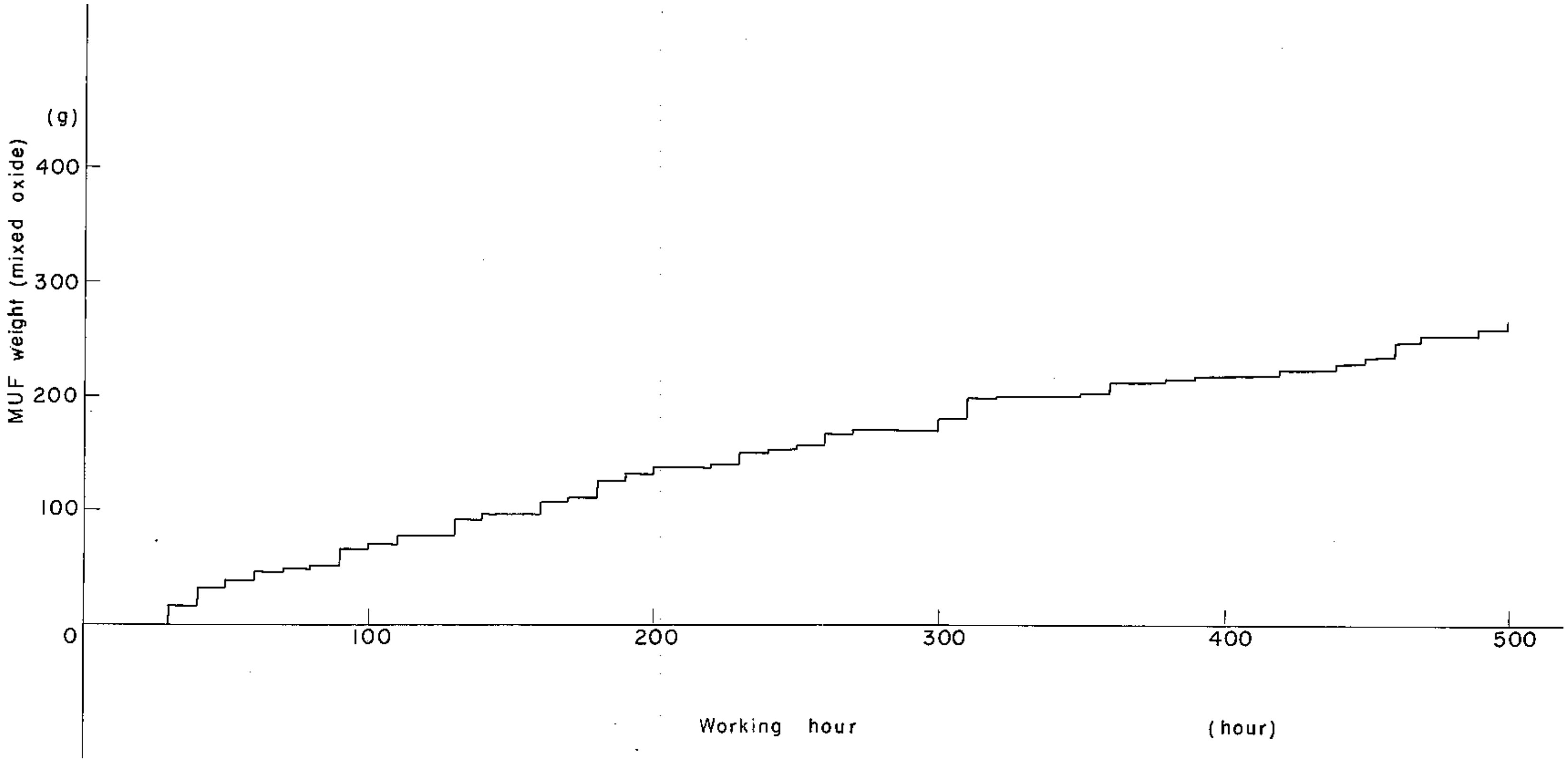

Fig. 32. MUF weight of press box for Rapsodie irradiation campaign.

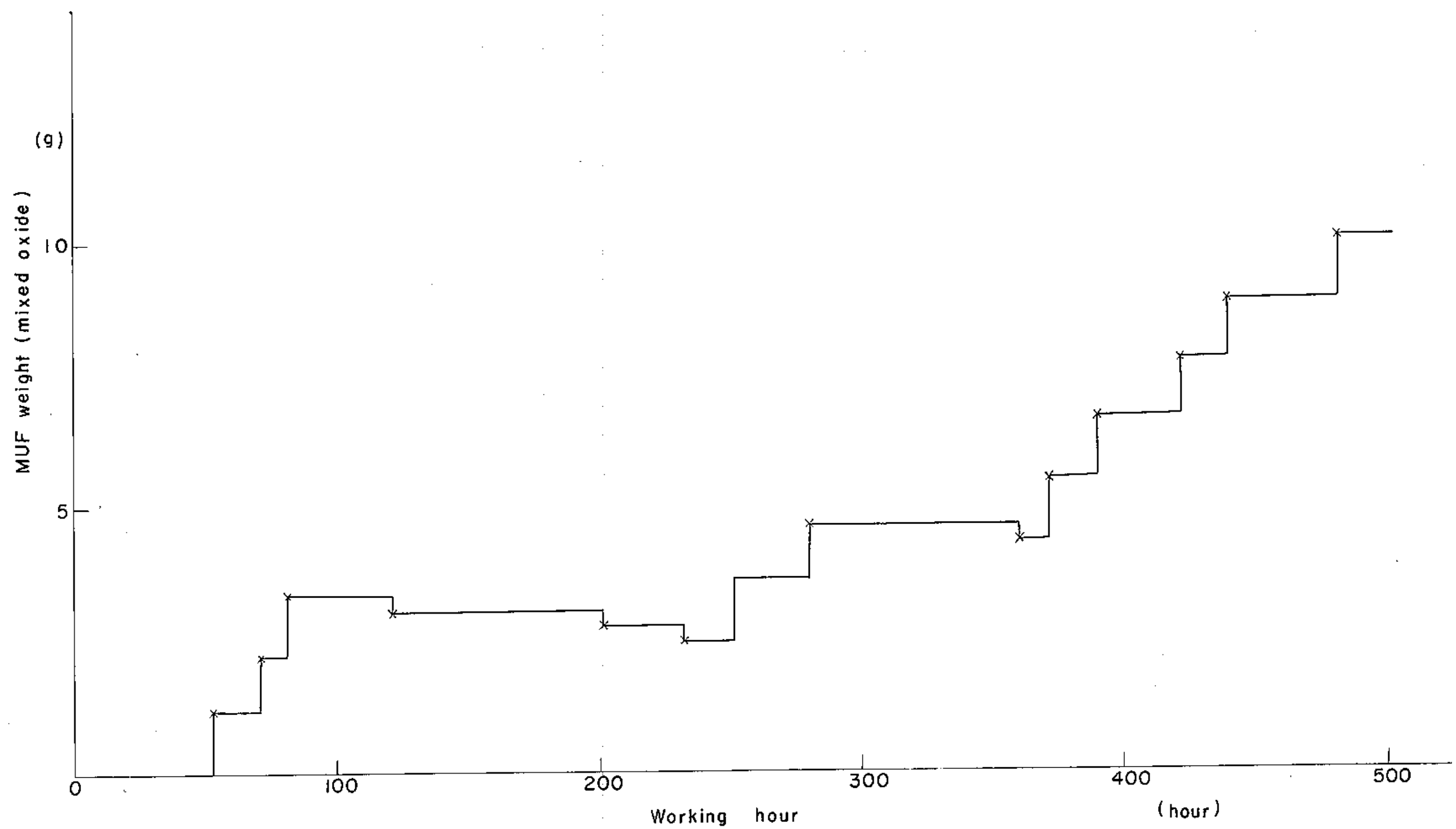

Fig. 33. MUF weight of density inspection box for Rapsodie irradiation campaign.

4.2 Estimation of mass flow in the new facility

Table 8 shows the estimated mass balances for four FBR-line 50 runs cases such as the MBA-wise and box-wise mass balances with and without steal, using the best input data for MUF distributions at present, which is listed in Table 4. This implies the following remarks.

(1) Total MUF of this campaign will fall between 0.13 and 1.6% of total input mixed oxide weight.

(2) Total MUF closed by MBA will be smaller than that closed by box as discussed in ATR campaign simulation.

(3) Finding steal would be very difficult with the knowledge of the present MUF distribution value.

(4) The MUF distribution in the boxes of granulation and pressing, sintering should be re-evaluated and changed to other distribution such as χ^2-distribution.

(5) Working hour of 333 in this campaign will be converted to about 100 calender days.

Table 9 is one of the computer output which shows the total amount of fuel compositions for the FBR-line 50 runs campaign. The box number in the table is shown in Fig. 14.

Total MUF fluctuation with plant thrupt is illustrated in Fig. 34. It implies that this facility is still in the transient stage for 50 runs up to 833 kg of mixed oxide with the present information on MUF characteristics.

For an FBR-line 50 runs campaign case (17 boxes, 50 runs), run time on the IBM 360/I-75 computer system was 11.30 minutes.

Table 8. MUF (mixed oxide) calculated mass balance for four FBR-line 50 runs

Process		Unit	MBA-wise Material balance Normal	MBA-wise Material balance Steal	Box-wise Material balance Normal	Box-wise Material balance Steal
Input		(g) (%)	833350 100	833350 100	833350 100	833350 100
Output		(g) (%)	824204 98.90	823721 98.84	685983 82.32	671068 80.53
Difference		(g) (%)	9146 1.10	9629 1.16	147367 17.68	162282 19.47
MUF	Mixing	(g) (%)			652.36 0.078	1210 0.145
MUF	Granulation & pressing	(g) (%)			-2924.98 -0.350	-575.58 -0.069
MUF	Sintering	(g) (%)			-888.06 -0.010	9025.04 1.419
MUF	Grinding	(g) (%)			1886.18 -0.13	13154.88 1.578
MUF	Total	(g) (%)		1569 0.19		-127.02 -0.015
Steal		(g) (%)			750 0.09	750 0.09
Analysis		(g) (%)			8300 0.99	8300 0.99
Recover		(g) (%)			3000 0.36	3000 0.36
Analysis & metallography		(g) (%)			137200 16.46	137200 16.46
Working hour		(hour)	302.50	302.50	332.77	332.42

Table 9. Material balance and composition, end of box-wise FBR-line
50 runs campaign-steal.
(volume unit is gram and time unit is hour.)

```
* * * * * * * * * SELECTED LOT-50 * * * * * * *
* * * RATIO IN ADDLOT SUB.          50     7     0     100.00     30.000     1372.00     0.0     0.0
* * * DOWN INFORMATION               0     0     0     0     00
* * * * * * * * TIME=   332.42* * * * * * * * * *
                OS-TIME=    11.30 MIN
                LOT NO =       53
```

BOX-NO	VOLUME	PU-238	Pu-239	Pu-240	Pu-241	Pu-242	U-235	U-238	PU	O	U
1	0.0	0.00	-0.11	-0.14	-0.05	-0.00	-0.11	-0.06	-1.41	-1.39	-0.79
2	0.0	0.0	0.0	0.0	-0.00	-0.00	0.0	0.0	-0.00	0.0	0.0
3	0.29	0.00	0.04	-0.01	-0.00	0.00	0.00	0.02	0.00	0.02	0.02
4	0.33	0.00	0.04	0.01	-0.00	-0.00	0.01	0.03	-0.02	0.17	0.04
5	0.25	0.00	0.05	0.00	-0.00	-0.00	-0.01	0.05	-0.06	0.01	0.06
6	0.05	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.01
7	0.29	0.00	-0.00	-0.01	0.00	0.00	-0.01	-0.01	0.04	-0.31	0.02
8	671068.38	109.45	76615.38	26705.99	5472.52	547.25	17610.74	58958.04	109450.00	485047.13	76568.56
9	750.00	0.12	85.63	29.85	6.12	0.61	19.68	65.89	122.32	542.09	85.57
10	8300.00	1.35	947.61	330.31	67.69	6.77	217.82	729.21	1353.72	5999.23	947.02
11	3000.00	0.49	342.51	119.39	24.46	2.45	78.73	263.57	489.29	2168.39	342.30
12	137200.00	22.38	15664.07	5459.99	1118.85	111.89	3600.54	12053.92	22377.01	99166.13	15654.35
13	1210.05	0.20	138.15	48.16	9.87	0.99	31.76	106.31	197.36	874.62	138.07
14	-575.58	-0.09	-65.71	-22.91	-4.69	-0.47	-15.11	-50.57	-93.88	-416.04	-65.67
15	9025.04	1.47	1030.39	359.16	73.60	7.36	236.84	792.91	1471.99	6523.31	1029.76
16	3495.42	0.57	399.07	139.10	28.50	2.85	91.73	307.09	570.10	2526.49	398.82
17	-127.02	-0.02	-14.50	-5.06	-1.04	-0.10	-3.35	-11.16	-20.72	-91.81	-14.49

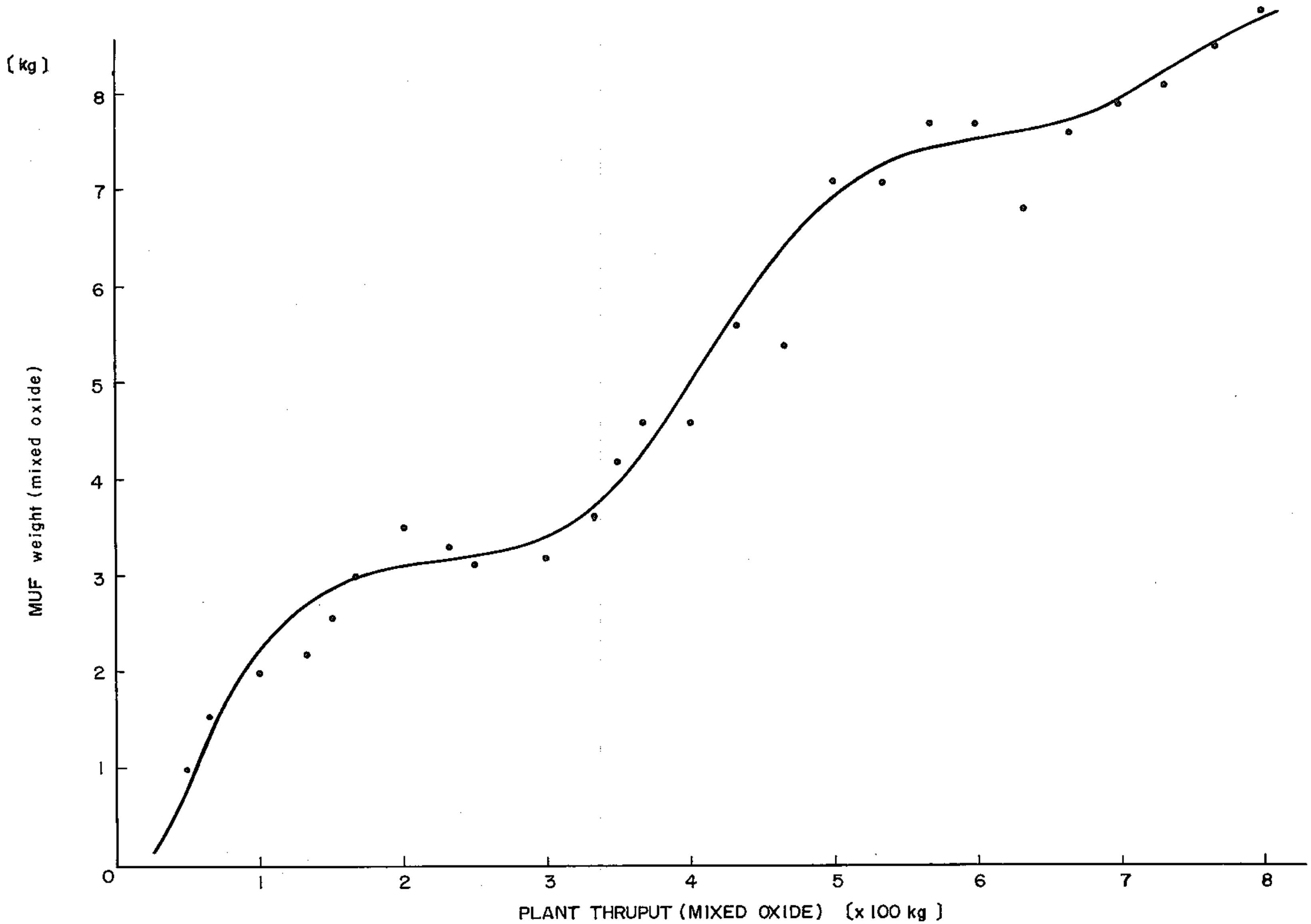

Fig. 34. MUF vs plant thruput relation for FBR-line 50 runs campaign

5. Conclusion

The conclusions drawn from this simulation study are;

(1) It has greatly increased quantitative understandings of the material balance and MUF characteristics as a function of time.

(2) It has disclosed clearly that thermoore reliable MUF distribution data are extremely needed, especially on the standard deviations of MUF.

(3) It has showed that MBA-wise method is good enough to check the mass flow and MUF distribution if the reliable MUF distribution has been achieved for every process.

(4) It has indicated the possibility of a simple rule which indicates a steel if the measurements of the mass balance appears to be outside of normal statistical expectancies.

The estimations of the mass flow in the new facility will be evaluated with the integral experiments in near future. Until that time, the code is going to be improved in the following functions;

(1) To simulate the difference between book and physical inventory.

(2) To use many different distribution for MUF as an option.

(3) To plot the output data.

(4) To put the learning curve subroutine for evaluating the plant thruput characteristics.