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PARAMETRIC EXPRESSIONS OF TRITIUM FLOW RATES
AND INVENTORIES IN A TARGET FACTORY

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PARAMETRIC EXPRESSIONS OF TRITIUM FLOW RATES
AND INVENTORIES IN A TARGET FACTORY

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ABSTRACT

Parametric expressions have been derived for tritium flow rates and inventories in a target factory. The expressions are based on a tritium system that interfaces with a generalized target production process. The relationship of flow rates and inventories to target production form a basis for a parametric study to determine the amount of tritium involved in the target factory of an ICF power plant.

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INTRODUCTION

In an ICF power plant there are two systems that involve the handling of tritiated fuel for laser fusion. These systems are the target factory and the laser fusion reactor. Both contain an inventory of tritium along with recovery processes. The amount of tritium involved in the ICF power plant will depend on the tritium flow rates and inventories of these systems. Meier¹ has derived parametric expressions for the quantity of tritium related to the reactor. In this paper, expressions are derived that may be used for a parametric study of the flow rates and inventories of tritium in a target factory.

TRITIUM SYSTEM IN A TARGET FACTORY

The tritium inventories and flow rates of a proposed target factory have been examined with respect to production of targets to meet the reactor injection rate for laser fusion. A basic block diagram of a tritium system interfacing the target factory is presented in Figure 1. The tritium system consists of three sections: fill process and storage, recovery, and tritium source.

Fill Process and Storage

In the analysis the target fill is assumed to take place within the cryogenic processing steps just before injection into the reactor^{2,3}. The fill process section is shown in Figure 2 interfacing a multiple processing system having an output connected to a storage section. The purpose of the storage section is to maintain a supply of targets in case of a production interruption.

A. Pipe-line Mode

In the beginning stages of the DT fill, a "pipe-line" effect results due to the requirement of loading the fill process section. The number of targets that initially get filled at the $s=m$ step is pI' where

p = the number of production lines

I' = the number of targets in the $s=m$ process step

The number of targets that proceed to the next processing step $s=m+1$ is $pI' q_m$, where q represents a yield factor for each step in the system. Thus after $s-m+1$ steps the amount of targets contributing to an output of the fill process section is the product of the q yield factors for each step,

$$pI' \left[\prod_{i=m}^s q_i \right] \quad (1)$$

The quantity of targets rejected from the fill process section after the $s=m$ step is $pI' (1-q_m)$. The quantity rejected after the $s=m+1$ step is $pI' q_m (1-q_{m+1})$ plus the amount that is again rejected from the $s=m$ step. Repeating this process for subsequent steps leads to Table 1 where the number of rejected targets is given for each step during the loading of the fill process section. Expression (2) of Table 1 represents the rejected target output of the fill process section after the pipe-line is completely filled.

Step	Quantity
m	$pI'(1-q_m)$
m+1	$pI'(1-q_m) + pI'q_m(1-q_{m+1}) = pI'(1-q_mq_{m+1})$
m+2	$pI'(1-q_m) + pI'q_m(1-q_{m+1}) + pI'q_mq_{m+1}(1-q_{m+2}) = pI'(1-q_mq_{m+1}q_{m+2})$
s	$pI'(1-q_m) + pI'q_m(1-q_{m+1}) + \dots + pI' \left[\prod_{i=m}^{s-1} q_i \right] (1-q_s)$ $= pI' \left\{ 1 - \left[\prod_{i=m}^s q_i \right] \right\} \quad (2)$

Table 1. The quantity of rejected targets during loading of subsequent steps in the fill process section. Expression (2) is the rejected target output after completing the final processing step.

To determine the total amount of rejected targets that are available for the recovery section during the pipe-line mode, the quantity after each step is summed. Hence the total number acquired during loading is given by the following expression,

$$\begin{aligned}
 & pI'(1-q_m) + pI'(1-q_m q_{m+1}) + pI'(1-q_m q_{m+1} q_{m+2}) + \dots + pI' \left\{ 1 - \left[\prod_{i=m}^s q_i \right] \right\} \\
 & = pI' \left\{ (s-m+1) - \sum_{i=m}^s \left[\prod_{j=m}^i q_j \right] \right\} \quad (3)
 \end{aligned}$$

After loading the fill process section, the number of targets in each step is indicated in Table 2. The inventory of targets within

Step	Quantity
m	pI'
m+1	$pI' q_m$
m+2	$pI' q_m q_{m+1}$
s	$pI' \left[\prod_{i=m}^{s-1} q_i \right]$

Table 2. The number of targets in each processing step after loading the fill process section.

the fill process section is thus the sum of the targets in each step,

$$\begin{aligned}
 & pI' + pI' q_m + pI' q_m q_{m+1} + \dots + pI' \left[\prod_{i=m}^{s-1} q_i \right] \\
 &= pI' \left\{ 1 + \sum_{i=m}^{s-1} \left[\prod_{j=m}^i q_j \right] \right\} \quad (4)
 \end{aligned}$$

To supply the storage section with an inventory of targets to meet a possible production interruption, the loaded fill process section must be activated N additional number of times. The output of the fill process section is given by expression (1). The storage inventory would therefore contain

$$NpI' \left[\prod_{i=m}^s q_i \right] \quad (5)$$

targets. However, by activating the fill process section N additional number of times an increase in the number of rejected targets results. From (2) the additional number of rejected targets is expressed as

$$NpI' \left\{ 1 - \left[\prod_{i=m}^s q_i \right] \right\} \quad (6)$$

Consequently, to enter the production mode the quantity of rejected targets acquired is the sum of (3) and (6) and is represented as T_{fr} :

$$T_{fr} = pI' \left\{ (s-m+1) - \sum_{i=m}^s \left[\prod_{j=m}^i q_j \right] \right\} + NpI' \left\{ 1 - \left[\prod_{i=m}^s q_i \right] \right\} \quad (7)$$

B. Production Mode

The reactor target injection rate R is dependent on the rate of output of the fill process section

$$R = pr_I \quad (8)$$

The fill process output rate r_I for a single production line is given by the following relation

$$r_I = I' \left[\begin{array}{c} s \\ \Pi \\ i=m \end{array} q_i \right] / t_C \quad (9)$$

where t_C is the time interval for the slowest processing step in the cryogenic system². Substituting (9) in (8) gives

$$pI' = Rt_C \quad (10)$$

$$\left[\begin{array}{c} s \\ \Pi \\ i=m \end{array} q_i \right]$$

In the production mode the number of filled targets leaving the fill process section in the time interval t_C is given by (1). Also the number of rejected targets is the amount rejected by all the process steps as indicated by (2) for the s step in Table 1.

C. Inventory

The inventory of targets for the fill process and storage section is given by expressions (4) and (5) respectively. Substituting (10) in these expressions and multiplying each by m_f , the amount of tritium per target, the inventory of tritium in terms of R becomes:

fill process;

$$\left[\begin{array}{c} m_f R t_C \\ s \\ \parallel \\ q_i \\ i=m \end{array} \right] \left\{ 1 + \sum_{i=m}^{s-1} \left[\begin{array}{c} i \\ \parallel \\ q_j \\ j=m \end{array} \right] \right\} \quad (11)$$

storage;

$$m_f N R t_C \quad (12)$$

Recovery

Figure 3 shows the recovery as a multiple processing section with x number of processing steps having yield factors represented by r. The recovery section includes a redundant recovery system (RRS) to account for yield factors of $r < 1.0$. The RRS may be thought of as an environmental gas purification or gettering system that can contribute to the recovery output at an efficiency represented by z.

A. Pipe-line Mode

The tritium input is from the loading of the fill process section and from the creation of an inventory in the storage section. The amount of tritium involved is given by expression (7) for T_{fr} . For simplicity the quantity of tritium that enters the first recovery step $x=1$ is considered to be a batch amount $m_f T_{fr}$. Thus the amount of tritium recoverable from x number of processing steps is based on the product of the yield factors

$$m_f T_{fr} \left[\prod_{i=1}^x r_i \right] \quad (13)$$

However, the RRS allows additional recovery. The approach used to express the amount of additional recovery is similar to the approach leading to (2) for the fill process section. The quantity of tritium entering the RRS is therefore the sum of uncollected tritium from each of the x processing steps and is expressed as

$$m_f T_{fr} \left\{ 1 - \left[\prod_{i=1}^x r_i \right] \right\} \quad (14)$$

If the RRS operates at a processing efficiency z , the additional amount that is recoverable is

$$m_f T_{fr} z \left\{ 1 - \left[\prod_{i=1}^x r_i \right] \right\} \quad (15)$$

and the amount that must be considered as unrecoverable or waste becomes

$$m_f T_{fr} (1-z) \left\{ 1 - \left[\prod_{i=1}^x r_i \right] \right\} \quad (16)$$

By summing (13) and (15), the total output of the recovery section while in the pipe-line mode that can be sent back to the source is

$$m_f T_{fr} \left\{ z + (1-z) \left[\prod_{i=1}^x r_i \right] \right\} \quad (17)$$

B. Production Mode

During the production mode the input rate R_{fr} for the recovery section is determined by dividing (2) by t_c of the fill process section,

$$R_{fr} = \frac{pI'}{t_c} \left\{ 1 - \left[\prod_{i=m}^s q_i \right] \right\} \quad (18)$$

The amount of tritium, therefore, entering the recovery step $x=1$ in the time interval t_c is

$$m_f pI' \left\{ 1 - \left[\prod_{i=m}^s q_i \right] \right\}$$

$$= m_f R t_C \left\{ 1 - \left[\frac{s}{\pi} q_i \right]_{i=m} \right\} \quad (19)$$

by the substitution of (10). Of this amount (19) entering the recovery section, the quantity of recoverable tritium T_r becomes

$$T_r = \frac{m_f R t_C}{\left[\frac{s}{\pi} q_i \right]_{i=m}} \left\{ 1 - \left[\frac{s}{\pi} q_i \right]_{i=m} \right\} \left[\frac{x}{\pi} r_i \right]_{i=1} \quad (20)$$

Furthermore, the quantity that will enter the RRS is represented as

$$T_{rr} = \frac{m_f R t_C}{\left[\frac{s}{\pi} q_i \right]_{i=m}} \left\{ 1 - \left[\frac{s}{\pi} q_i \right]_{i=m} \right\} \left\{ 1 - \left[\frac{x}{\pi} r_i \right]_{i=1} \right\} \quad (21)$$

Similarly to (15) and (16), the amount of additional recovery due to the RRS and is available to the source is

$$z T_{rr} \quad (22)$$

and the amount of tritium that must be considered as unrecoverable or waste is

$$(1-z) T_{rr} \quad (23)$$

The total amount of recoverable tritium is thus the sum of (20) and (22),

$$T_r + z T_{rr} \quad (24)$$

In terms of a recovery section output rate $\dot{m}_R$ providing an input to the source, (24) is divided by a time interval t_R

$$\dot{m}_R = \frac{T_r + z T_{rr}}{t_R} \quad (25)$$

where t_R is the time interval for the slowest recovery step in the section. Likewise, the output rate $\dot{m}_Z$ associated with unrecoverable tritium or waste is determined by dividing (23) by t_R

$$\dot{m}_Z = \frac{(1 - z) T_{rr}}{t_R} \quad (26)$$

In steady state, the input rate is equal to the output rates of the recovery section,

$$\dot{m}_f R_r = \dot{m}_R + \dot{m}_Z \quad (27)$$

By substituting and rearranging, it can be shown that

$$t_C = t_R$$

Consequently, in the production mode, the time interval for the slowest recovery step must be less than or equal to the slowest fill process step. If

$$t_R > t_C$$

an additional number W of recovery sections must be added to obtain the relation

$$t_R < W t_C$$

C. Inventory

The inventory of tritium in the fill recovery section is the amount within the recovery processing and in the RRS. The amount of tritium in the x number of processing steps is obtained by an expression similar to (4) for the inventory of targets in the fill process section. The amount of tritium in the RRS is taken from (21) as the amount that enters the system for redundant recovery.

In the production mode the input of tritium to the recovery processing and the RRS is continuous allowing for a constant inventory. Hence using an expression similar to (4),

$$\begin{aligned}
 & \frac{m_f R t_C}{\left[\begin{smallmatrix} s \\ \prod \\ i=m \end{smallmatrix} q_i \right]} \left\{ 1 - \left[\begin{smallmatrix} s \\ \prod \\ i=m \end{smallmatrix} q_i \right] \right\} \left\{ 1 + r_1 + r_1 r_2 + \dots + \left[\begin{smallmatrix} x-1 \\ \prod \\ i=1 \end{smallmatrix} r_i \right] \right\} \\
 &= \frac{m_f R t_C}{\left[\begin{smallmatrix} s \\ \prod \\ i=m \end{smallmatrix} q_i \right]} \left\{ 1 - \left[\begin{smallmatrix} s \\ \prod \\ i=m \end{smallmatrix} q_i \right] \right\} \left\{ 1 + \sum_{i=1}^{x-1} \left[\begin{smallmatrix} i \\ \prod_{j=1} \end{smallmatrix} r_j \right] \right\} \quad (28)
 \end{aligned}$$

the total inventory of the fill recovery section is the sum of (21) and (28):

recovery;

$$\frac{m_f R t_C}{\left[\begin{smallmatrix} s \\ \prod \\ i=m \end{smallmatrix} q_i \right]} \left\{ 1 - \left[\begin{smallmatrix} s \\ \prod \\ i=m \end{smallmatrix} q_i \right] \right\} \left\{ 2 - \left[\begin{smallmatrix} x \\ \prod \\ i=1 \end{smallmatrix} r_i \right] + \sum_{i=1}^{x-1} \left[\begin{smallmatrix} i \\ \prod_{j=1} \end{smallmatrix} r_j \right] \right\} \quad (29)$$

Source

The tritium source supplies the fuel to fill targets. Its output is connected to the $s=m$ step of the fill process section. The source input is from both the recovery section and the reactor system¹.

The output rate of the source $\dot{m}_s$ is constant for both the pipe-line and production modes. The rate $\dot{m}_s$ is governed by the number of pI' targets and the characteristic time interval t_c for the fill process section,

$$\dot{m}_s = \frac{m_f pI'}{t_c} \quad (30)$$

By substitution of (10), the source output rate can be related to the reactor target injection rate R,

$$\dot{m}_s = \frac{m_f R}{\left[\begin{array}{c} s \\ \prod q_i \\ i=m \end{array} \right]} \quad (31)$$

A. Pipe-line Mode

The number of times that pI' targets are filled at the $s=m$ step during this mode is

$$(s-m+1)+N$$

where $(s-m+1)$ is the number of fill process steps and N is the number of additional target fills necessary to create a storage inventory. The amount of tritium used is

$$\dot{m}_s t_C (s-m+1)+N = \frac{m_f R t_C}{\left[\begin{matrix} s \\ i=m \end{matrix} \right] q_i} (s-m+1)+N \quad (32)$$

The source input in this mode is only due to the recovery section and is given by (17):

$$m_f T_{fr} \left\{ z + (1-z) \left[\begin{matrix} x \\ i=1 \end{matrix} \right] r_i \right\}$$

B. Production Mode

The source output rate $\dot{m}_s$ is given by (31). The recoverable input rate is the sum of the output rate $\dot{m}_R$ from recovery and $\dot{m}_E$ from the reactor. In steady state,

$$\dot{m}_s = \dot{m}_R + \dot{m}_E \quad (33)$$

The rate $\dot{m}_E$ is the total output rate from the reactor system¹ and is given as

$$\dot{m}_E = \dot{m}_r + \dot{m}_e \quad (34)$$

where $\dot{m}_r$ = tritium recovery rate from lithium

$\dot{m}_e$ = tritium exhaust rate

C. Inventory

The amount of tritium source needed to start-up an ICF power plant is the sum of the inventories of each tritium section in the target factory plus the tritium inventory associated with the reactor system. For the target factory, the inventories are given by the sum of (11) and (12) for fill process and storage and (29) for recovery. An expression for the tritium inventory for the reactor system has been derived by Meier¹.

SUMMARY

Parametric expressions have been derived for the quantity of tritium that would be involved in the target factory of an ICF power plant. The approach was to interface a tritium system with a generalized target production process. The tritium system consisted of three sections: fill process and storage, recovery, and tritium source. Each section was analyzed as to the tritium flow rates and inventories resulting from both a pipe-line and production mode of operation. The derived expressions involve production parameters along with the rate of target injection into the reactor.

The tritium source section was analyzed having an output dependent on the rate of target production and an input from both the recovery section and the reactor system. The initial source inventory of tritium required to start-up an ICF power plant can be determined from the expressions derived in Reference (1) and the inventory expressions derived for both the fill process and storage section and the recovery section. With these expressions a parametric study can later be performed to examine the tritium inventory of a power plant as a function of production variables.

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REFERENCES

- 1) W. R. Meier, "Build-Up of Tritium in a Liquid Lithium Breeding Blanket for an Inertial-Confinement Fusion Chamber", Lawrence Livermore National Laboratory, UCRL - 85245.
- 2) J. W. Sherohman and C. D. Hendricks, "Preliminary Analysis of a Target Factory for Laser Fusion", Lawrence Livermore National Laboratory, UCID-18719, June 10, 1980.
- 3) J. W. Sherohman and W. R. Meier, "A Parametric Study of a Target Factory for Laser Fusion", Lawrence Livermore National Laboratory, UCRL-84264, October 8, 1980.

FIGURE CAPTIONS

Fig. 1. A basic block diagram of a tritium system interfacing a cryogenic process of a target factory.

Fig. 2. A general tritium fill process section interfacing a multiple cryogenic processing system.

Fig. 3. A multiple recovery processing section that includes a redundant recovery system (RRS).

FIGURE 1

FIGURE 2

FIGURE 3