electronic supplementary information

**Mathematical Modeling to Minimize Tritium Inventory of the Fuel Cycle of ITER**

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**A. Mathematical Model (Phase II)**

The mathematical formulation of Phase II is presented as MINLP. The model uses a continuous time representation [7]. In Phase II, the objective function is to minimize tritium working inventory in ISS. Tritium working inventory is defined as the difference between the maximum and the minimum inventory of tritium in the ISS in a single cycle..



Eq. 1 and 2 represent working inventory in ISS.

 (1)

 (2)

where *Tmax* is the maximum inventory level in ISS during one cycle and *Tmin* is the minimum inventory level in ISS during one cycle. Eq. 3 represents the allocation constraint that only one of fueling tasks of unit *j* can be performed at event point *n*.

 (3)

Eq. 4 and 5 are mass balance equations based on [5]:

 (4)

 (5)

where  represent the mass flow information between state *s* and task *i*.

Eq. 6 imposes min/max bounds on the batch size of task *i* at event point *n*. Eq. 7 imposes min/max bounds on the inventory of unit *j*.

**** (6)

**** (7)

Eq. 8 is a restriction that at event point *n*, a certain level of inventory should be maintained in a buffer vessel to supply sufficient flowrate after performance of task *i* at event point *n-1*.

**** (8)

Eq. 9 and Eq. 10 represent the constraint that start time of task *i* at event point *n* and finish time of task *i* at event point *n* should be less than the time horizon, *H*.

**** (9)

**** (10)

Eq. 11 represents the duration of task *i* at time point *n*.

**** (11)

Eq. 12 - Eq. 16 represent time constraint. To unify time information on each task *i*, time *Tn* is adopted.

**** (12)

**** (13)

**** (14)

**** (15)

**** (16)

Eq. 17 and Eq. 18 represent the relationship between start time and finish time considering the duration of task *i* at time point *n*.

**** (17)

**** (18)

Eq. 19 - Eq. 21 represent the relationship between start time and finish time considering the duration of task *i* at time point *n*.

**** (19)

**** (20)

**** (21)

Eq. 22 and 23 represent the constraint that separation task at TEP should be performed within a fixed start time and an end time of a VRS return pulse; and then delivery tasks from a buffer vessel of SDS to FS should occur within a fixed start time and an end time of each sub-phase of tokamak demands.

**** (22)

**** (23)

Eq. 24 and 25 represent pulse-pattern constraints that fuel is delivered from ISS to BV only once with a constant flow rate during single B&D cycle.

**** (24)

**** (25)

**Notation**

|  |
| --- |
| *sets* |
| *i* | tasks |
| *j* | units |
| *n* | event points |
| *s* | states |
|  |
| *Parameters* |
| *Fmax, Fmin* | maximum/minimum inventory of unit *j*  | Pa∙m3 |
| *Bmax, Bmin* | maximum/minimum size of task *i*  | Pa∙m3 |
| *H* | time horizon |  |
| *M* | big value |  |
| *Stobi* | minimum inventory level to perform task *i* | Pa∙m3 |
| *Starttimei* | fixed start time of task *i*  | sec |
| *Finishtimei* | fixed finish time of task *i* | sec |
|  |  |  |
|  |  |  |
| *Binary Variables* |  |
|  | binary variables that assign the task *i* at event point *n* |  |
|  | 　 |  |
| *Continuous Variables* |  |
|  | size of task *i* at event point *n* | Pa∙m3 |
|  | inventory of unit *j* at event point *n* | Pa∙m3 |
|  | amount of state *s* at event point *n* | Pa∙m3 |
|  | time at event point *n* | sec |
|  | start time of task *i* at event point *n* | sec |
|  | finish time of task *i* at event point *n* | sec |
|  | duration of task *i* at event point *n* | sec |
| *flowtimei* | start time of transferring task *i*  | sec |