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FORMULATION OF DETAILED CONSUMABLES MANAGEMENT MODELS FOR THE DEVELOPMENT (PREOPERATIONAL) PERIOD OF ADVANCED SPACE TRANSPORTATION SYSTEM

NOVEMBER 1976 CONTRACT NO. NAS9-14264

VOLUME II

CONSUMABLES DATA BASE WORKBOOK

Prepared by

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Systems Analysis Section

TRW

DEFENSE AND SPACE SYSTEMS GROUP

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Technical Report
for
Contract NAS 9-14264

Formulation of Detailed Consumables Management Models for the Development (Preoperational) Period of Advanced Space Transportation System

VOLUME II

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PREFACE

Future manned space programs that will have increased launch frequencies and reusable systems require an implementation of new consumables and systems management techniques that will relieve both the operations support personnel and flight crew activities. These techniques must be developed for the optimum combination of an onboard and ground support consumables management system consistent with the goals of the program. Effective operational performance of the consumables management techniques of a total system requires that a very explicit definition of the time, place, and method of performance of each function be determined by trade studies to ascertain that the operational methods do, indeed, meet these goals. This requires that the complete consumables management cycle be considered by including the mission planning and scheduling functions, prelaunch activities, onboard mission functions, ground mission support functions, and postmission activities.

Formulation of models required for the mission planning and scheduling function and establishment of the relation of those models to prelaunch, onboard, ground support and postmission functions for the development phase of Space Transportation Systems (STS) was conducted under Contract NAS 9-14264 during the period 1 November 1975 to 31 October 1976. The preoperational Space Shuttle is used as the design baseline for the subject model formulations.

Analytical models were developed which consist of a Mission Planning Processor with appropriate consumables data base, a method of recognizing potential constraint violations in both the planning and flight operationsa functions, and a Flight Data File for storage/retrieval of information over an extended period which interfaces with a Flight Operations Processo for monitoring of the actual flights.

The Final Report for the Formulation of Detailed Consumables Management Models for the Development Period of Advanced Space Transportation Systems consists of an Executive Summary and five Technical Volumes. The Technical Volumes include information required for the implementation of a Consumables Management System. The individual volumes consist of:

Volume I. Detailed Requirements for the Mission Planning Processor

Volume II. Consumables Data Base Workbook

Volume III. Study of Constraints/Limitations for STS Consumables Management

Volume IV. Flight Data File Contents

Volume V. Flight Operations Processor Requirements

Two additional documents were issued in the course of the contract execution. These reports support the development of the Consumables Management System. The reports are:

Study of Existing Analytical Models for STS Consumables Management, dated February 1976.

Documentation of Computer Routines Developed to Determine Cyclic Probability (CYCPRO) Trends of Shuttle Heater Usage, dated September 1976.

This volume of the technical reports, Volume II, defines the data required by the Mission Planning Processor to calculate the consumables. The data is structured as a set of "Consumables Data Worksheets" for each mission activity. This affords uniform specification of consumables data, identifies the consumables associated with each activity, and facilitates the updating and maintenance process.

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1. INTRODUCTION

The purpose of this document is to define the consumables characteristic data associated with the performance of the mission activities required by the Mission Planning Processor (Volume I) to calculate the consumables requirements. The activity data is defined in terms of discrete time periods having a distinct rate for each consumable required to support the performance of a given operation.

The data is structured in a series of "Consumable Data Worksheets" for each activity that includes a profile of its operations and the rate of each consumable required to support the given activity. The data worksheets provide for the uniform specification of consumables data, allows for the ready identification of the consumables affected by a given activity, and facilitates the updating process.

Section 2 defines an activity and the data that must be included in the data worksheets and presents as an example of its use and application the consumables data requirements for the performance of the EVA.

Section 3 of this report presents the consumables data for the activities currently identified for the Shuttle Spacecraft, and Section 4 identifies the sources of these data.

2. ACTIVITIES

2.1 ACTIVITY DEFINITION

In general, an activity is defined as a series of operations* performed in a prescribed sequence in order to effect a distinct crew and/or spacecraft related function. The activities are used as the basic building blocks to formulate a mission and should include every event to be performed, from those routinely scheduled in support of the crew life support and spacecraft maintenance functions, to those required to attain specific mission objectives.

The performance of an activity is usually preceded by a series of preparatory steps during which specific subsystems required to support the given activity are activated. Likewise, at the completion of the activity these subsystems must be deactivated and the spacecraft returned to its normal operating configuration. Thus, the activity is divided into three time periods; a preparation period, the activity itself, and a post-activity period. These time periods consist of "K", "J", and "L" operations respectively, where:

K = number of operations prior to the reference start time of the activity

J = number of operations performed between the reference start and reference stop times of the activity

L = number of operations performed after the reference stop time of the activity, and

N = total number of operations, i.e., N = K+J+L.

Each operation within each of the three time periods is characterized by a time duration (ΔT) and a consumable rate (Ri). The operations

*The term "operation" is here used to mean a time interval for which a consumable rate remains constant.

within each of the three activity periods are further characterized by a fixed time duration except for the last operation of the "J" period which is open-ended. The time duration of the fixed time operations is specified in the activity definition. The time duration of the open-ended operation in the "J" activity period is calculated in the Mission Planning Processor from the defined fixed time ΔTs and either the activity reference start and stop times, or the ΔV requirements specified by the user (via keyboard entry) during the construction of the timeline.

In summary and in order to perform the consumables analysis, the definition of the activity must contain:

a) The number of operations performed within each of the three activity periods.

b) The time (ΔT) required to perform each of its operations with the exception of the last one (in the "J") activity period which is open-ended.

c) A corresponding rate (Ri) for each consumable used during each operation.

d) The pre-act and post-act ΔTs.

Figure 2-1 depicts a typical activity for which there are 3 "K", 4 "J", 2 "L", and 9 "N" operations and the pre-activity and post-activity ΔTs are X and Y hours, respectively. It should be noted that level changes in this figure are intended to show consumables step rate changes at specified times within the activity and that these levels do not correspond to the magnitude of the rates. The actual magnitude of the various consumables rates are specified in a tabular form that will be introduced subsequently.

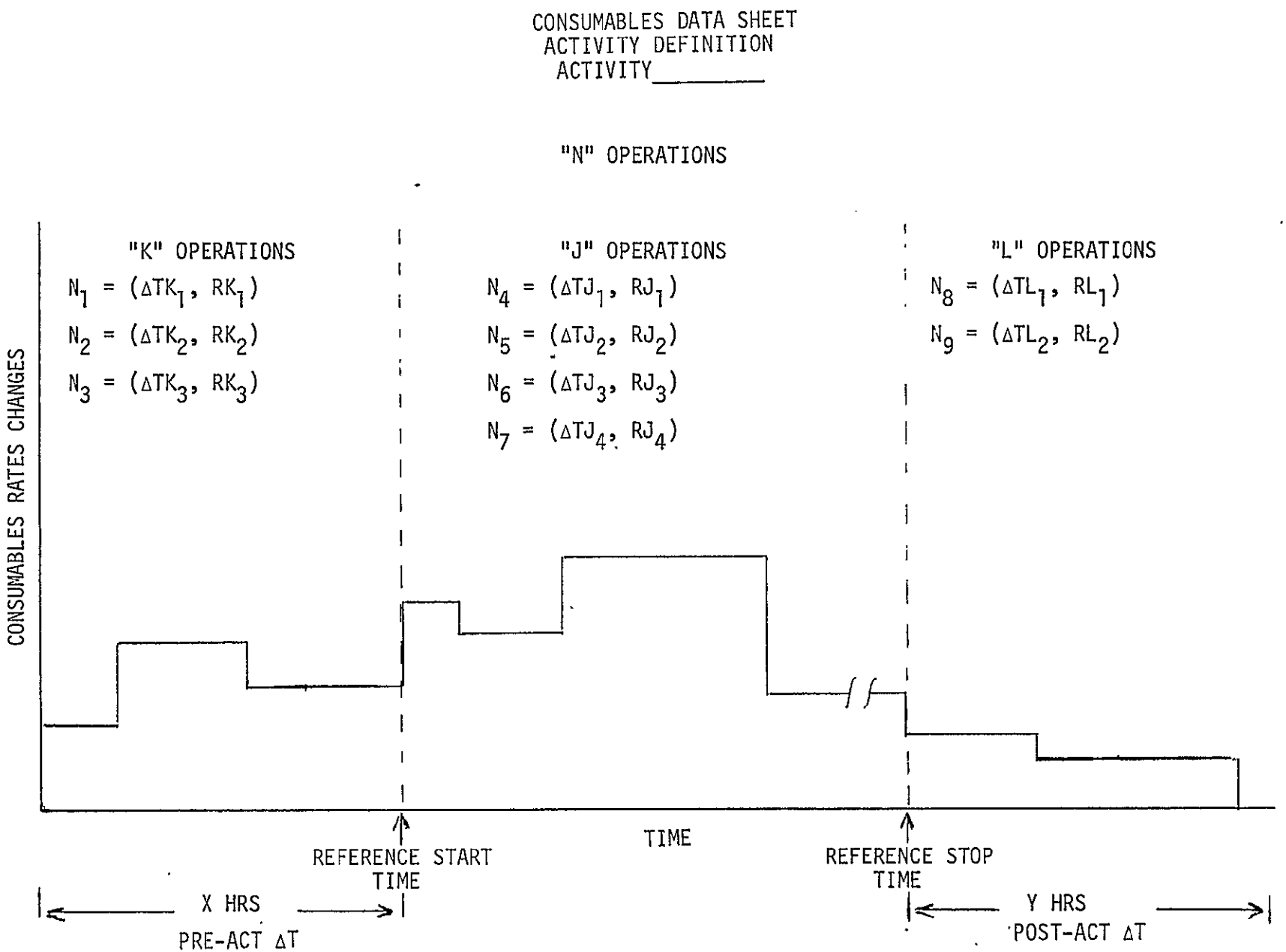


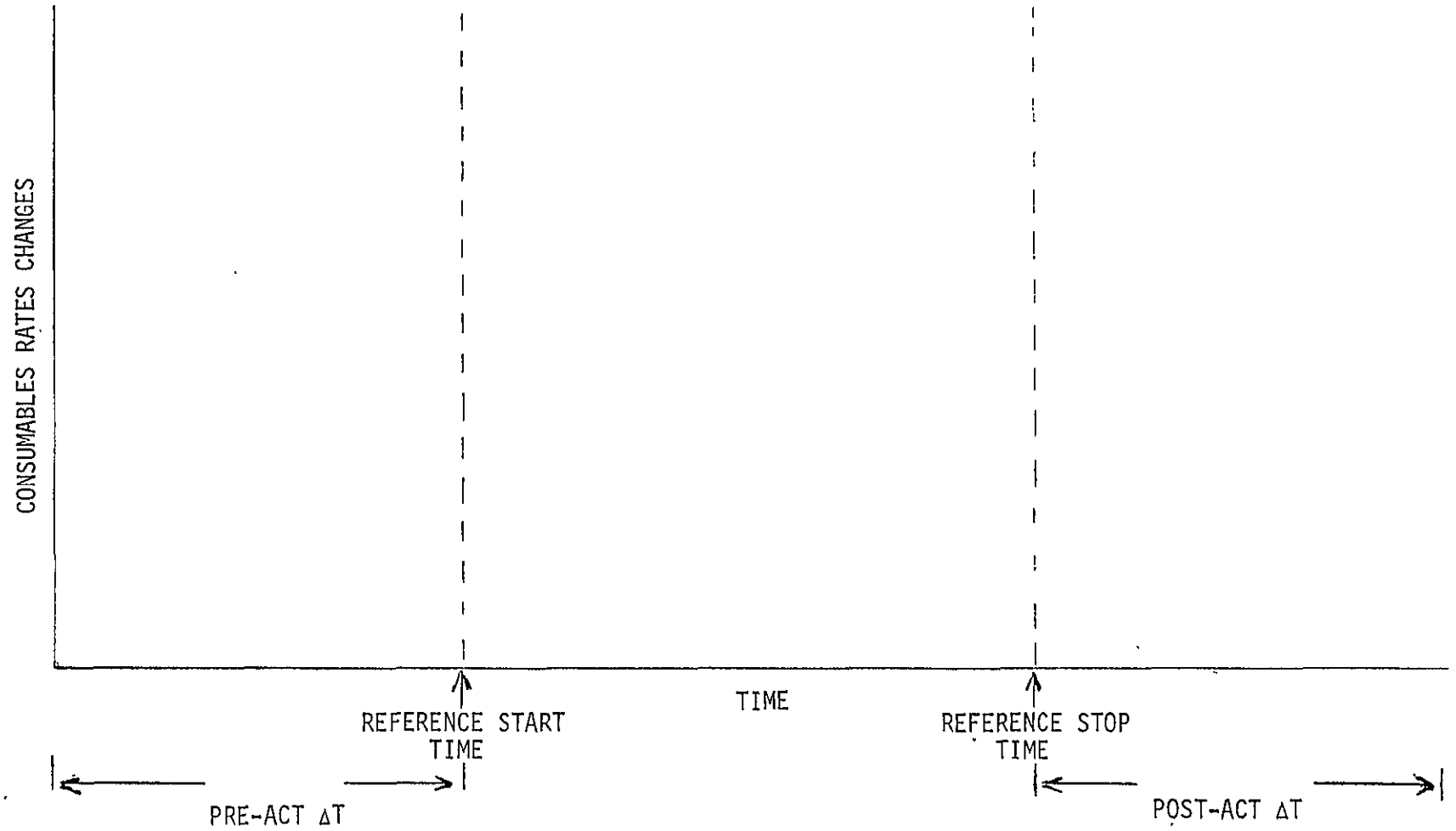
Figure 2-1. Activity Definition Profile

2.2 ACTIVITY CONSUMABLES DATA SPECIFICATION

The consumables data to be specified for each activity consists of a qualitative and a quantitative part. The former should include a general description of the objectives of the activity, crew size, types of consumables required, operational sequence, limitations, assumptions, as well as the parameters (independent variables) to be specified by the user via keyboard entry when using the Mission Planning Processor during the construction of the timeline. The quantitative part includes the consumables data as defined in the preceding section and is to be specified by means of uniformly formatted data sheets. The first of these is to present a graphical description of the activity illustrating the operations performed during the three activity periods as shown in Figure 2-1, and should also include the pre-act and post-act ΔTs. The second data sheet is to specify for each consumable as required, the ΔT and the corresponding consumables rates for each operation performed in the activity. Sample data sheet forms are included as Figure 2-2 and Table 2-I.

The structure of the activity consumables data specification as described in the preceding paragraph was designed to satisfy a twofold purpose; that of establishing an identifying relation with the Mission Planning community, and that of providing the data required for the consumables analysis. In regard to the latter, the format chosen allows for the uniform specification of the consumables data throughout the planning cycle. During the early planning stages when data is ill-defined, an activity might consist of one single operation representing an average consumable rate. As the cycle moves closer to the operational phase and the data becomes better defined, the activity can include as many operations as there are consumable rate changes. In addition, the format allows for the ready identification of the consumables associated with any given activity, and should facilitate the updating and maintenance process.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY_____



NUMBER OF OPERATIONS: K____; J____; L____; N____ (TOTAL)

Figure 2-2. Activity Definition Data Sheet (Sample Form)

Table 2-I. Consumables Data Sheet (Sample)

CONSUMABLES DATA SHEET
ACTIVITY_____

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR

REMARKS:

2.3 CONSUMABLES DATA APPLICATION

As an illustration of the concepts defined in the preceding sections, the consumables data associated with the Shuttle EVA performance is presented in the following paragraphs.

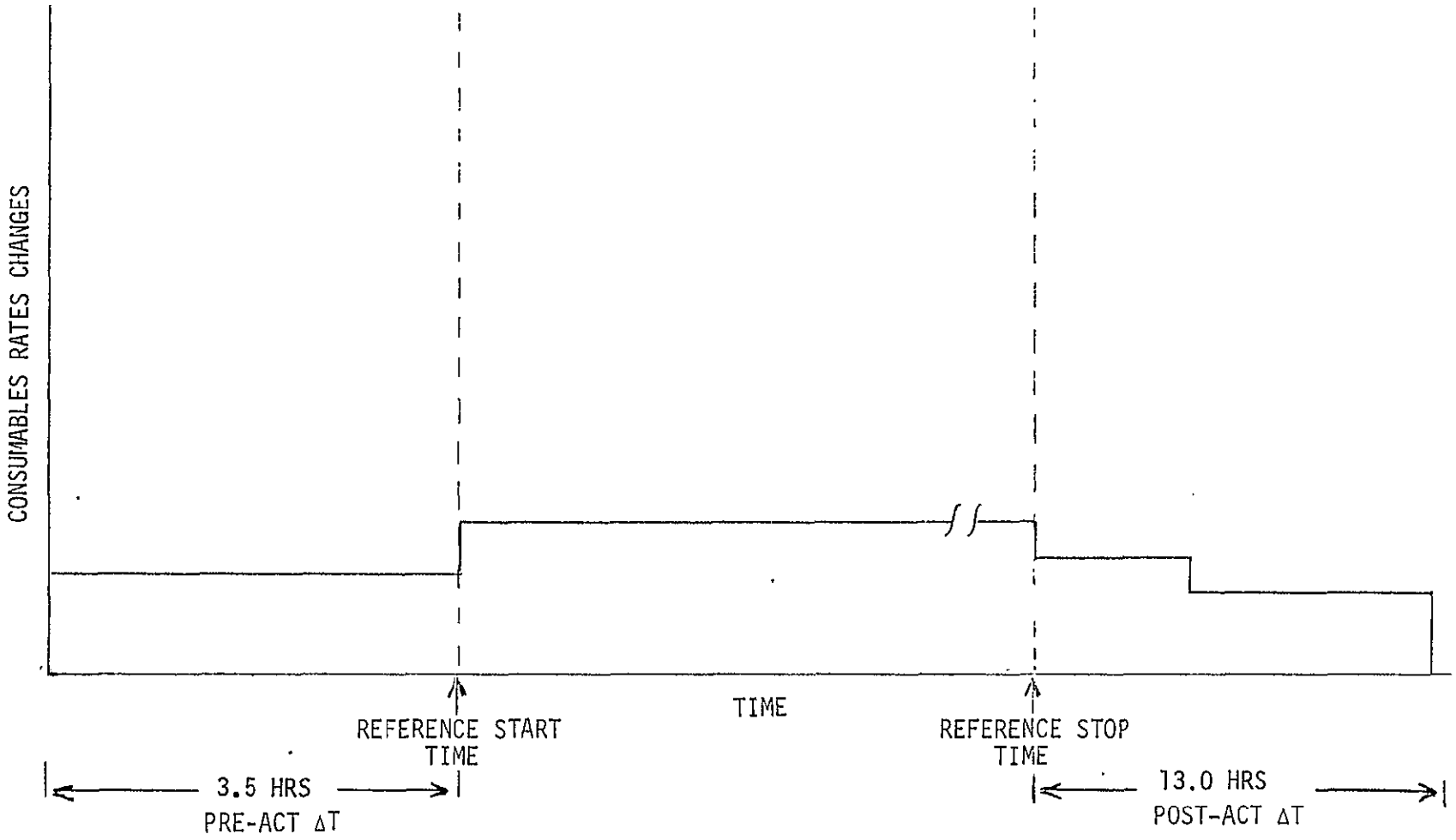
2.3.1 DESCRIPTION

The objective of the Extra Vehicular Activity (EVA) is to allow one or more crewmen to egress the pressurized cabin into free space for the performance of a given mission objective. The activity is initiated by the crew donning the Astronaut Life Support Assembly (ALSA) that provides a safe and conditioned environment. A pure oxygen prebreathing cycle from a portable oxygen supply follows to effect denitrogenization of the crew after which the egress into free space is accomplished via the airlock. At the completion of the assigned task in free space the crew returns to the airlock, the pressure of which is increased and equalized with that of the cabin to allow the crew entry and the re-establishing of normal systems configuration. The activity is completed with the crew doffing and recharging the ALSA package. The influence variables for this activity are start time, stop time, and number of crew members involved.

2.3.2 CONSUMABLES DATA

The consumables data associated with the EVA is herein included in Figure 2-3 and Table 2-II. Figure 2-3 depicts a plot profile of the activity from where it can be seen that the pre-activity period has one ("K") operation, the activity period is characterized by one ("J") operation and two ("L") operations are performed during the post-activity period, for a total of 4 ("N") operations for the overall activity. In addition, Figure 2-3 also specifies the ΔTs for the pre-activity and post-activity periods as 3.5 and 13.0 hours respectively. Table 2-II gives the consumables rates and the ΔTs associated with the performance of each operation. The consumables required are:

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY EVA



NUMBER OF OPERATIONS: K 1 ; J 1 ; L 2 ; N 4 (TOTAL)

Figure 2-3. EVA Activity Definition

Table 2-II. EVA Consumables Data Sheet

CONSUMABLES DATA SHEET
ACTIVITY EVA

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES									
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			3.5	175.89			0.2857*M	-				
2		✓		≈	426.32			-0.073*M	-		-0.0964*M		
3			✓	0.04	133.05			61.75	204.75				
4			✓	12.96	133.05			0.179*M	-				

REMARKS:

*Where M is equal to the number of crewmen on EVA

EPS - The EPS consumables (WATTS) required for EVA correspond to the power required for the activation and operation of flood lights, TV camers and monitors, and other communications equipment used by the crew while outside the pressurized environment.

ECS - ECS consumables include:

O_2: The oxygen requirements during EVA have two components; one relating to direct crew functions such as the prebreath cycle, suit pressurization and ALSA recharge; and the other to non-crew related requirements such as the quantity required to repressurize the airlock at the completion of the EVA. The corresponding rates are shown in Table 2-II as #/HR with a note to multiply by the number of crewmen those reflecting crew related functions. The negative rate included for the "J" operation (N=2) corresponds to the metabolic oxygen not supplied by the main oxygen supply to the crew while on the ALSA, since a rate for the duration of the mission is included in the Flight Common Activity.

N_2: The nitrogen requirements correspond to that quantity used to repressurize the airlock prior to the crew ingressing to the Shuttle cabin.

LiOH: The CO_2 generated by the crewmen while on the ALSA package is removed by this unit, consequently, the negative rate shown corresponds to that quantity of LiOH not used by the cabin CO_2 removal system during the EVA performance and already included in the Flight Common Activity.

3. SHUTTLE SPACECRAFT ACTIVITIES

The consumables data for the activities currently identified for the Shuttle Spacecraft are included in this section. As reported in Reference 3, the activities were selected with a view toward compatibility with those activities defined in Reference 5 while maintaining the structure required to perform the consumables analysis.

The activity data is presented using the worksheets defined in Section 2. The parameters included in the worksheet specify the consumables rates directly for the ECS and APU and indirectly for the EPS, RCS, and OMS systems. The EPS data input reflects watts (rate of energy consumption) which is separated into the direct consumables of H_2 and O_2 required in the output processing. The RCS and OMS data input reflect acceleration (rate of change of ΔV) which is weighted to spacecraft mass properties and separated into the direct consumables of fuel and oxidizer in the output processing.

Table 3 gives a summary of the presently defined activities and includes the consumables associated with the performance of each activity.

The 24 activities presented include the consumables requirements for distinct mission events to be selected by the user to construct the timeline for a given mission. In addition, a common activity which includes the consumables required to support the launch; orbital crew life support and spacecraft routine maintenance functions; deorbit and landing operations is included in Section 3.25.

Table 3. Shuttle Activities Summary

ACTIVITY		CONSUMABLE									
					ECS				APU		
NO.	NAME	1. EPS	2. RCS	3. OMS	4. O_2	5. N_2	6. LiOH	7. H_2O	8. FUEL	9. H_2O	TOTAL CONS.
1	OMS MANEUVER	✓	✓	✓							3
2	RCS TRANSLATION	✓	✓								2
3	ATTITUDE HOLD	✓	✓								2
4	RENDEZVOUS	✓	✓								2
5	STATION KEEPING	✓									1
6	DOCK	✓	✓								2
7	UNDOCK	✓	✓								2
8	PTC	✓	✓								2
9	EVA	✓			✓	✓	✓				4
10	IVA	✓					✓				2
11	MANIPULATOR OPS	✓									1
12	IMU ALIGNMENT	✓	✓								2
13	PAYLOAD BAY DOORS	✓									1
14	PAYLOAD CONSUMABLES	✓									1
15	COMPUTER	✓									1
16	TV	✓									1
17	DOWNLINK	✓									1
18	UPLINK	✓									1
19	FUEL CELL PURGE	✓									1
20	EAT	✓						✓			2
21	SLEEP	✓			✓						2
22	WASTE MANAGEMENT	✓			✓	✓		✓			4
23	APU CHECKOUT	✓							✓	✓	3
24	RESERVED										

3.1 OMS MANEUVER

3.1.1 DESCRIPTION

The objective of this activity is to realize a change in the orbit of the Shuttle using the thrust generated by the OMS engines. The activity is initiated by the performance of an IMU alignment, after which the GN&C, RCS, and OMS subsystems are configured by the crew to the desired thrusting program, a rotational maneuver using the RCS thrusters is then performed to place the Shuttle in the attitude required for the burn. Ignition of the OMS engines is then effected to the thrust level and for the time duration necessary to attain the desired orbital change, with RCS thrusting used during OMS firing to maintain the proper attitude. An RCS trim burn, if required, follows OMS engines shutdown, after which a second RCS rotational maneuver is performed to fix the spacecraft attitude in the new acquired orbit. Reconfiguration of the spacecraft subsystems by the crew completes the OMS maneuver. The influence variables for an OMS maneuver are start time and ΔV required by the maneuver. The stop time, as dictated by the required burn time, is calculated internally.

3.1.2 CONSUMABLES DATA

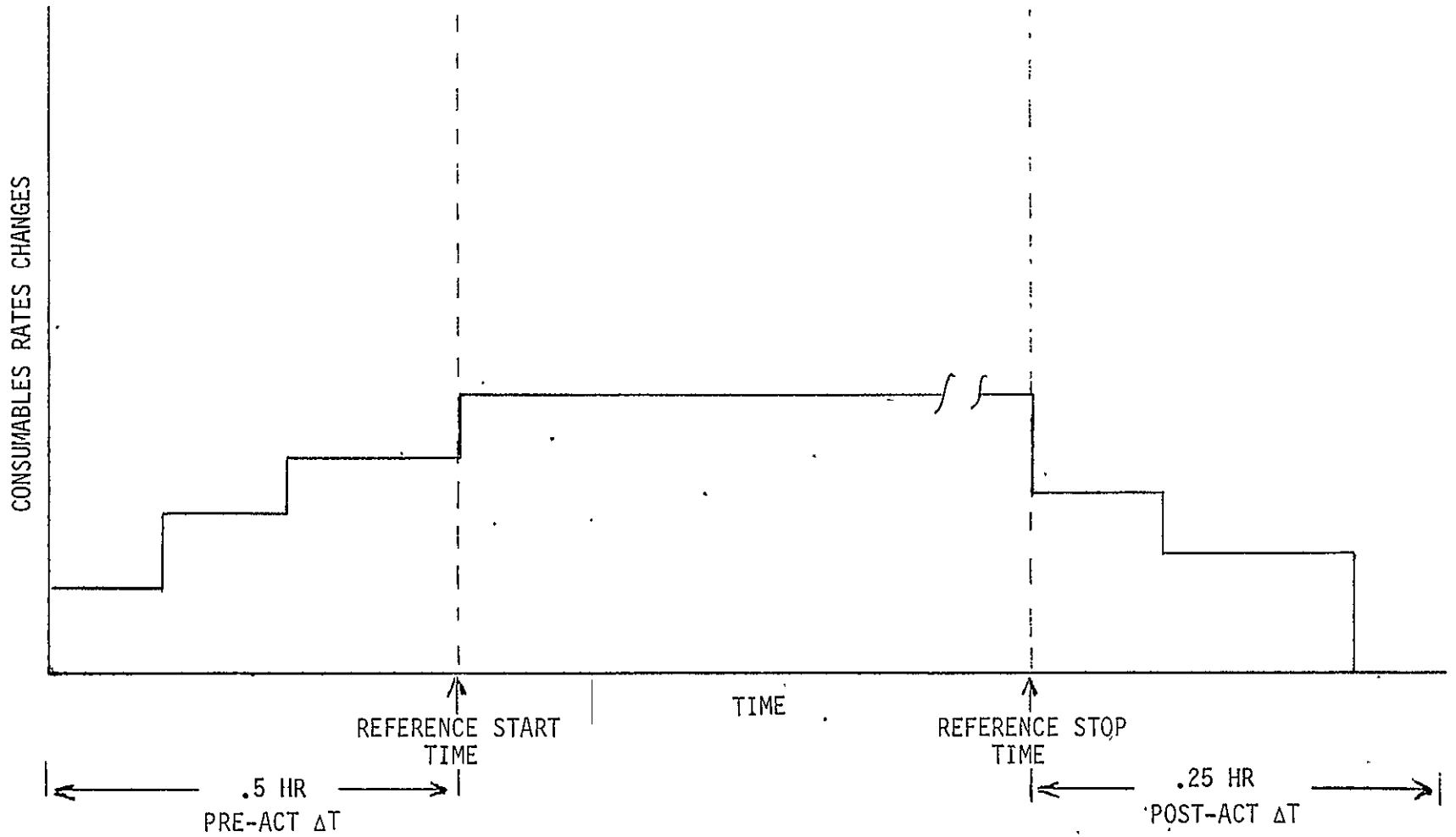
The consumables data associated with the performance of the OMS maneuver are presented in Figure 3-1 and Table 3-I. Figure 3-1 depicting the operations profile for the activity shows that the pre-activity period is 0.5 hours and consists of 3 "K" operations. The activity period consists of one open-ended "J" operation whose time duration is to be calculated in the Mission Planning Processor. The post-activity period is 0.25 hours and is characterized by 2 "L" operations. Table 3-I gives the ΔTs for each operation and the associated rates for the consumables, which are:

EPS - The EPS consumables correspond to the power required to operate the equipment associated with the IMU alignment performance; the OMS engines; such as isolation and propellant feed valves, heaters, etc., and the additional GN&C equipment required for programming and control of the thrusting operation.

RCS - The RCS consumables consist of the propellants required for the IMU alignment and to perform the rotation maneuvers to fix the spacecraft attitude prior to and at the completion of OMS engines firing. An equivalent acceleration of 5.03 ft/(sec-hr) for a period of 0.167 hours is used to obtain the propellant requirement to perform each rotation maneuver. The RCS propellant required for attitude control during OMS firing as well as for the trim burn are TBD.

OMS - The OMS Propellant is the consumable required to effect the desired orbital change. The acceleration $\bar{F}(\Delta V)$ and the burn duration $\theta(\Delta V)$ ("J" operation ΔT) are calculated in the Mission Planning Processor from the ΔV requirements.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY OMS MANEUVER



NUMBER OF OPERATIONS: K 3 ; J 1 ; L 2 ; N 6 (TOTAL)

Figure 3-1. OMS Maneuver Profile

Table 3-I. OMS Maneuver Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY OMS MANEUVER

N	K	J	L	ΔT (HRS).	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			0.25	1296.77	5.03	-						
2	✓			0.083	1472.68	-	-						
3	✓			0.167	2358.76	5.03	-						
4		✓		θ(ΔV)	3140.11	TBD	F(ΔV)						
5			✓	0.083	175.91	TBD							
6			✓	0.167	1061.99	5.03							

REMARKS:

3.2 RCS TRANSLATION MANEUVERS

3.2.1 DESCRIPTION

The objective of this activity is to effect an orbital change of the Shuttle by the use of the RCS thrusters. A preparation period during which GN&C equipment is activated and a rotation maneuver performed to fix the spacecraft attitude precede the translation burn. The activity is terminated after the targeted thrust has been achieved. RCS translation maneuvers are typically used during rendezvous, docking, and undocking operations. The influence variables for an RCS translation maneuver are start time and ΔV required by the maneuver. The stop time, as dictated by the required burn time, is calculated internally.

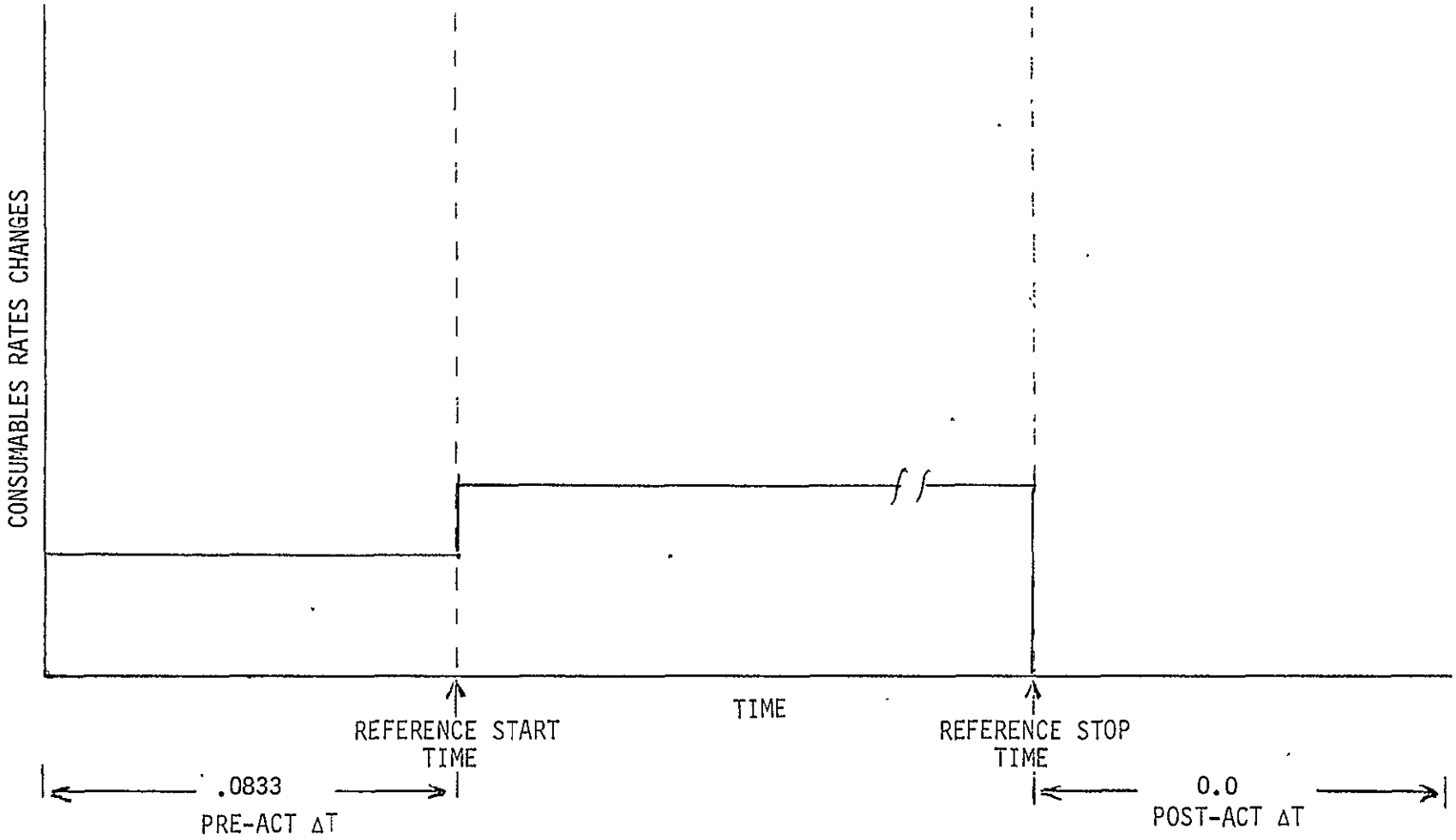
3.2.2 CONSUMABLES DATA

The 5 minute preparation period in which a rotation maneuver to fix the spacecraft attitude is performed has one K operation as shown in Figure 3-2, and the J operation corresponds to the translation burn. Table 3-II presents the ΔTs and the corresponding consumables rates. The time and propellant required for the translation maneuver are calculated in the MPP from the ΔV specified. The consumables include:

EPS - The electrical power required to activate the RCS and associated control equipment. Note that the rates included correspond to the automatic mode of operation.

RCS - The RCS propellant requirements include an equivalent acceleration of 10.06 ft/(sec-hr) for a period of 0.083 hours for the rotation maneuver.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY RCS TRANSLATION MANEUVERS



NUMBER OF OPERATIONS: K 1 ; J 1 ; L - ; N 2 (TOTAL)

Figure 3-2. RCS Translation Maneuver Profile

Table 3-II. RCS Translation Maneuver Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY RCS MANEUVER

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			.083	175.91	10.6							
2		✓		$\theta(\Delta V)$	1061.99	$F(\Delta V)$							

REMARKS:

3.3 ATTITUDE HOLD

3.3.1 DESCRIPTION

The objective of this activity is to attain and hold within a specified deadband the Shuttle Spacecraft in a given attitude for a specified time period. The activity starts with the crew performing a rotation maneuver to place the spacecraft in the desired attitude. This attitude is then maintained at the desired deadband by the RCS thrusters. The influence variables for an attitude hold are start time, stop time, spacecraft altitude, and type of hold (local vertical or inertial).

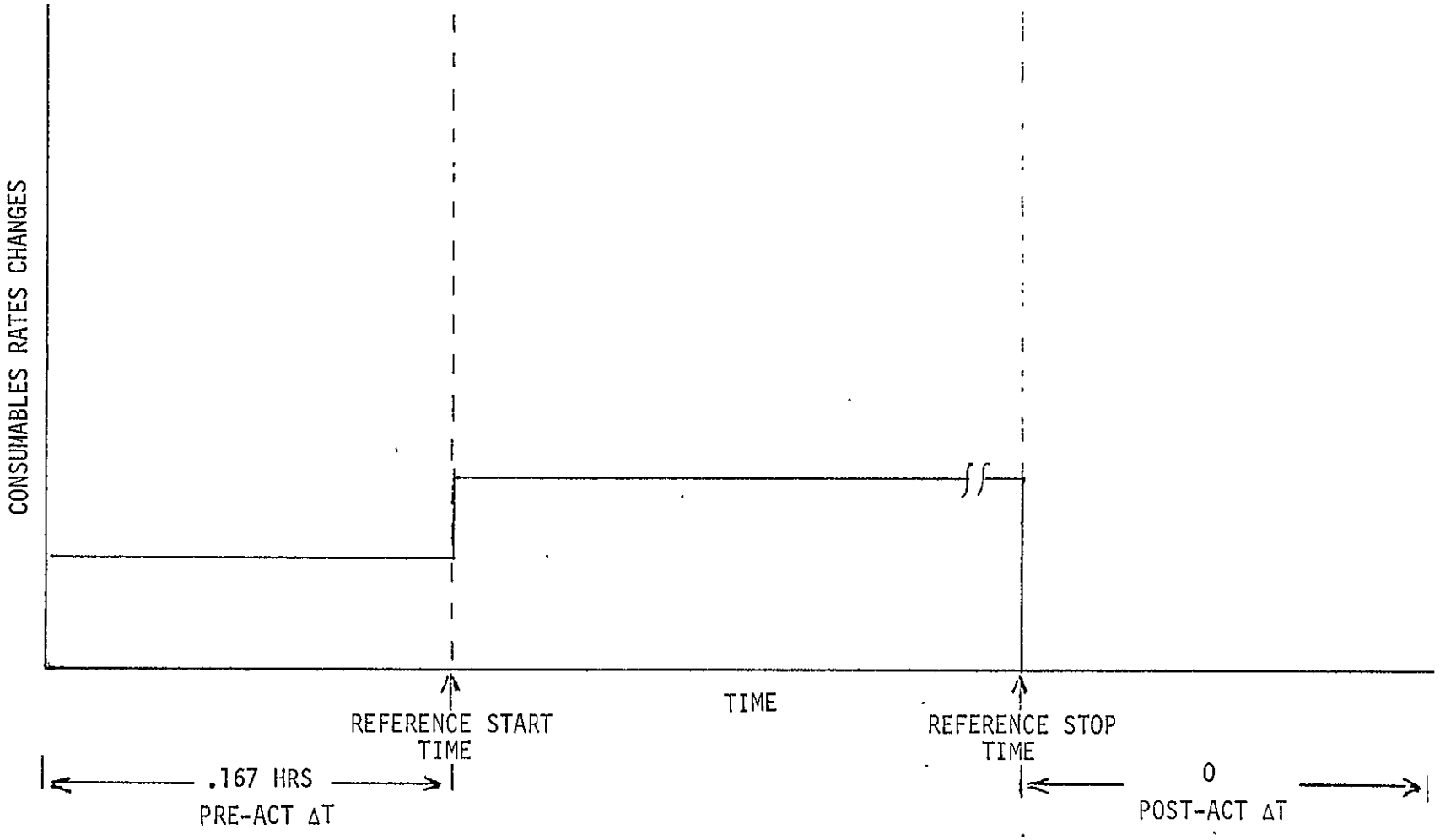
3.3.2 CONSUMABLES DATA

This activity consists of a 0.167 hours preparation period in which the rotation maneuver is performed after the proper GN&C configuration is achieved. The attitude is then maintained for as long as it is required by the automatic firing of the RCS thrusters. Figure 3-3 shows the one "K" and "J" operation required while Table 3-III gives the ΔTs and rates for the consumables used, which are:

EPS - The EPS consumables correspond to the activation of the GN&C and RCS equipment as well as the heater requirements.

RCS - The RCS propellant requirements include the rotation maneuver, entered as an equivalent acceleration of 5.03 ft/(sec-hr) for a period of 0.165 hours in Table 3-III, and the equivalent acceleration required to hold the spacecraft attitude. This latter quantity F(a,I) is calculated in the MPP from the altitude a and the hold type indicator I.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY ATTITUDE HOLD



NUMBER OF OPERATIONS: K 1 ; J 1 ; L 0 ; N 2 (TOTAL)

Figure 3-3. Attitude Hold Profile

Table 3-III. Attitude Hold Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY ATTITUDE HOLD

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			.167	TBS	5.03							
2		✓		~	TBS	F(a,I)							

REMARKS:

3.4 RENDEZVOUS

3.4.1 DESCRIPTION

The objective of this activity is to place the Shuttle in the proximity of another spacecraft by means of a series of propulsive maneuvers. The operations caused by this particular activity correspond to the TPF maneuvers which are initiated when the crew activates the GN&C and RCS subsystems to the desired configuration in preparation of the performance of a rotation burn to fix the spacecraft attitude, after which a braking burn is performed. A second rotation maneuver performed at the completion of the braking burn completes this activity. Note that the operations to achieve orbital transfer through TPI, or docking, are not included. The OMS maneuver activity is used for the phasing, height, co-elliptic, and TPI burns. The influence variables for the rendezvous activity are start time and ΔV required for the braking burn.

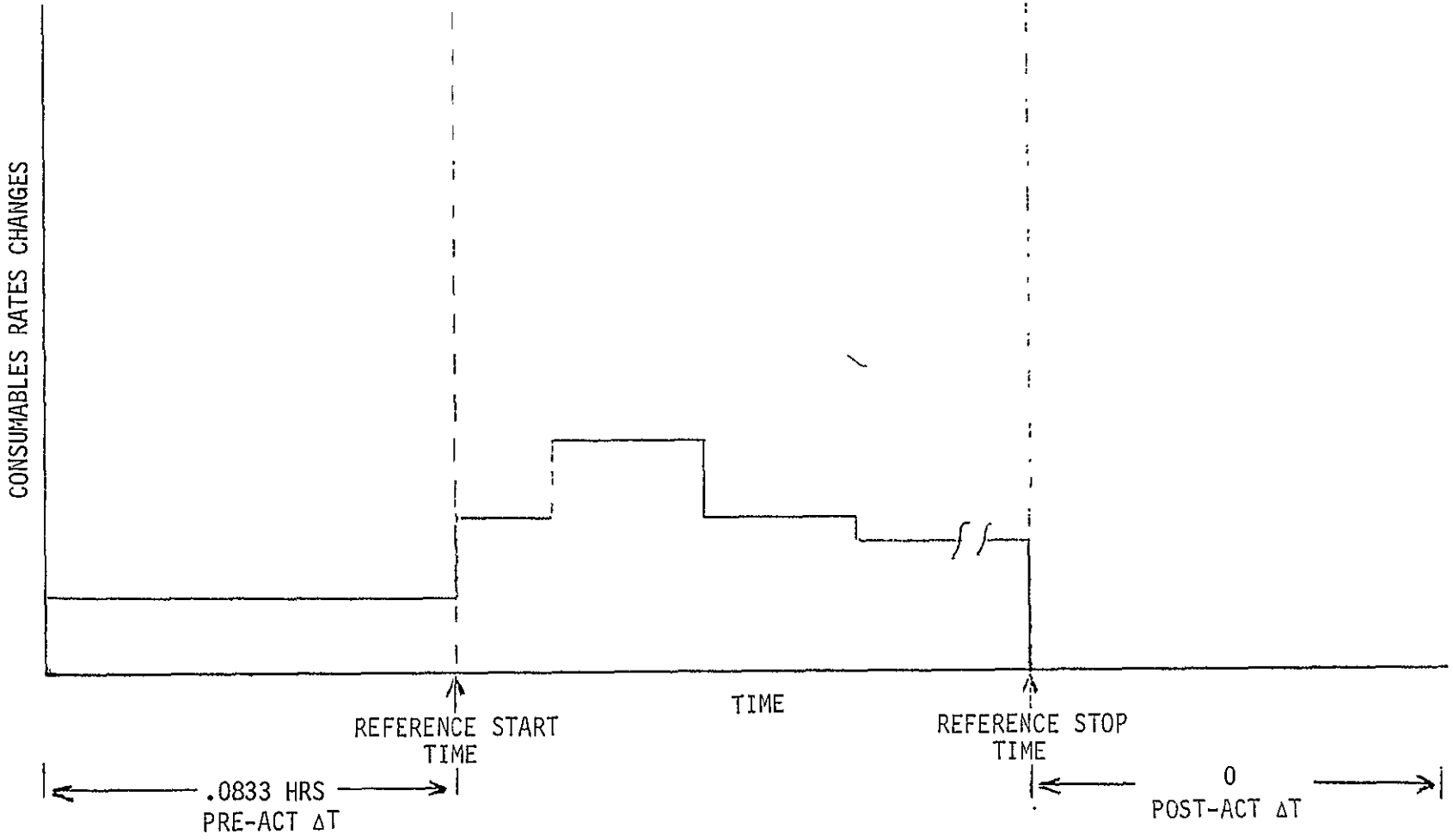
3.4.2 CONSUMABLES DATA

As shown in Figure 3-4, this activity has a 0.083 hours "K" operation during the pre-operation period in which the guidance and control equipment is activated. Four "J" operations are performed during the next time period corresponding to the two rotation maneuvers, the braking burn, and an open-ended period used to reconfigure the Shuttle subsystems. Each of the two rotation burns are entered as an equivalent acceleration of 5.03 ft/(sec/hr) for 0.167 hours. The ΔV required for the braking burn and entered by the user is used to calculate the acceleration $F(\Delta V)$ and the burn time $\theta(\Delta V)$. The operations ΔTs, together with the consumables rates, are presented in Table 3-IV, and include:

EPS - The electrical power required for the operation of the GN&C and RCS subsystems.

RCS - The propellant quantities used to perform the rotation and braking maneuvers.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY RENDEZVOUS



NUMBER OF OPERATIONS: K 1 ; J 4 ; L 0 ; N 5 (TOTAL)

Figure 3-4. Rendezvous Profile

Table 3-IV. Rendezvous Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY RENDEZVOUS

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			.0833	175.91	-							
2		✓		.167	1924.68	5.03							
3		✓		θ(ΔV)	1924.68	F(ΔV)							
4		✓		.167	1924.68	5.03							
5		✓		〃	862.69	-							

REMARKS:

3.5 STATION KEEPING

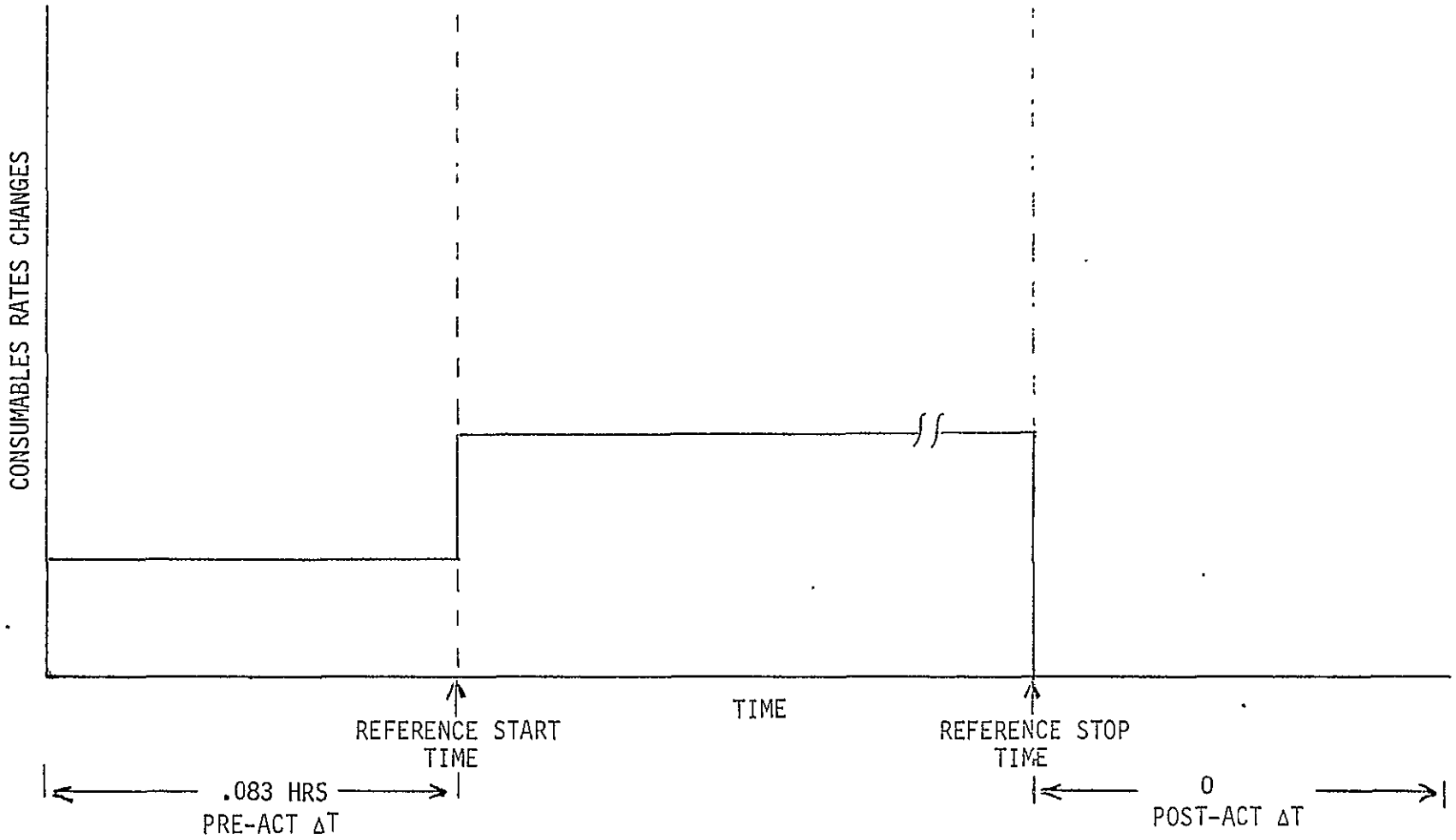
3.5.1 DESCRIPTION

The objective of this activity is to maintain a given spatial relationship between the Shuttle and another free flying spacecraft. Although not limited to, this activity usually forms part of the rendezvous or separation sequences where a waiting period is required to satisfy specific mission and/or spacecraft requirements prior to docking or after undocking. The activity is preceded by a short preparation period in which navigation and communication equipment is activated. Spacecraft pointing or attitude hold requirements to be effected with the RCS subsystem, if required, are not included herein. The influence variables for station keeping are start time and stop time.

3.5.2 CONSUMABLES DATA

The consumables for this activity consist of the electrical power required to operate the navigation and communications equipment. As shown in Figure 3-5, a 0.083 hours "K" preparation operation precedes the open-ended "J" operation. The consumables rates are given in Table 3-V.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY STATION KEEPING



NUMBER OF OPERATIONS: K 1 ; J 1 ; L 0 ; N 2 (TOTAL)

Figure 3-5. Station Keeping Profile

Table 3-V. Station Keeping Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY STATION KEEPING

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			0.083	51.40								
2		✓		∿	711.40								

REMARKS:

3.6 DOCKING

3.6.1 DESCRIPTION

The objective of the docking activity is to establish a physical connection between the Shuttle and another spacecraft. Docking is normally performed after a rendezvous sequence and preceded by station keeping and includes the propulsive maneuvers using the RCS subsystem to achieve contact. The activity includes a rotation and a docking burn. The influence variables for Docking are stop time (contact) and the docking burn ΔV.

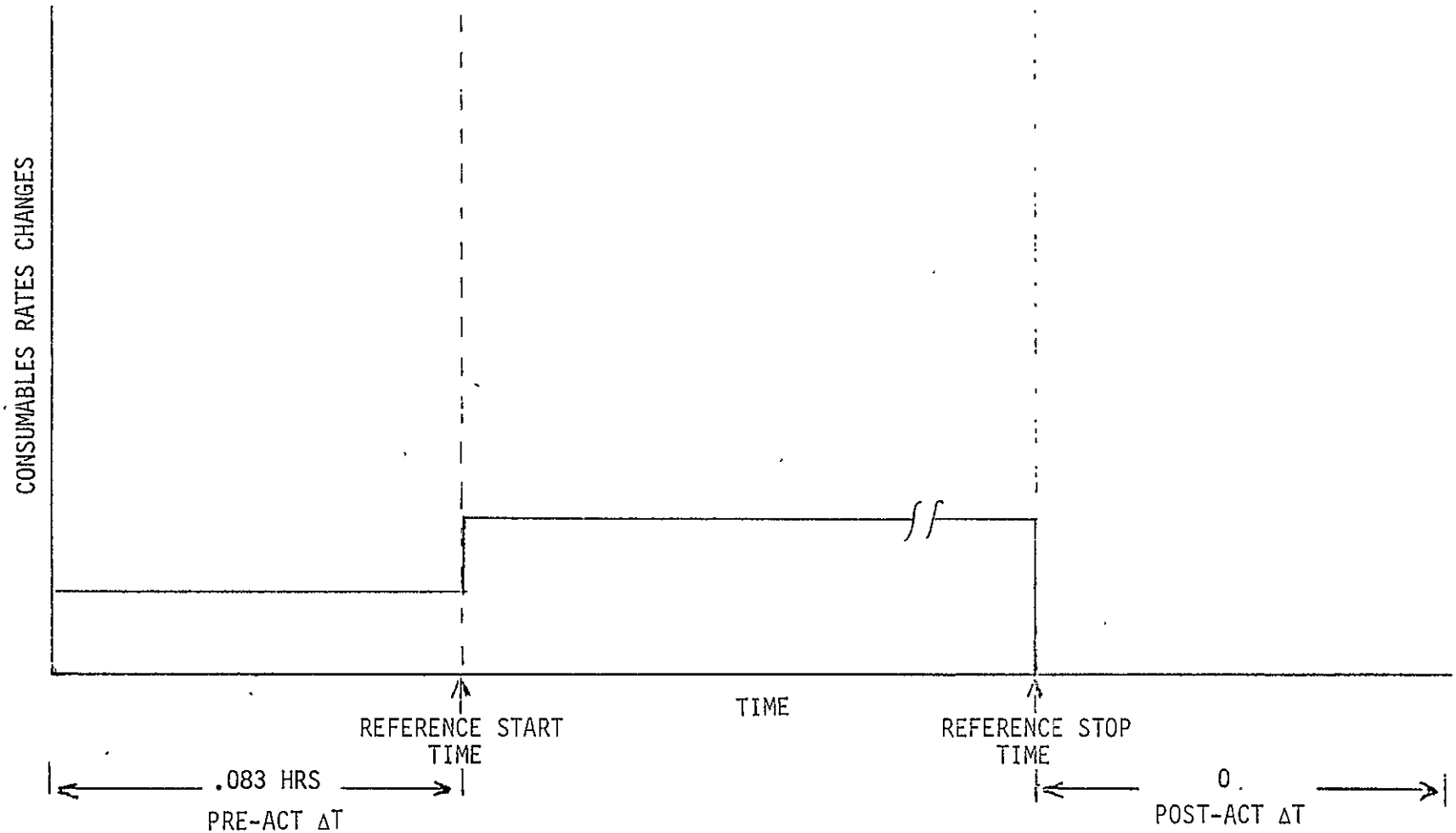
3.6.2 CONSUMABLES DATA

Figure 3-6 shows the profile for this activity which includes a 0.083 hour preparation ("K") operation in which the systems (GN&C and RCS) are activated and the rotation maneuver is performed; and a single "J" operation corresponding to the docking burn. Table 3-VI includes the consumables and their associated rates which are:

EPS - The electrical power required for the GN&C and RCS subsystems in addition to docking lights, radar, and other communications equipment.

RCS - The RCS propellant required for the rotation maneuver is entered as an equivalent acceleration of 5.03 ft/(sec-hr) for 0.167 hour. The dock burn acceleration $F(\Delta V)$ and burn time $\theta(\Delta V)$ are calculated internally.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY DOCKING



NUMBER OF OPERATIONS: K 1 ; J 1 ; L 0 ; N 2 (TOTAL)

Figure 3-6. Docking Profile

Table 3-VI. Docking Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY DOCKING

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES									
					EPS	RCS	OMS	ECS					APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR		FUEL #/HR	H_2O #/HR
1	✓			.0833	51.4	5.03								
2		✓		θ(ΔV)	1185.76	F(ΔV)								

REMARKS:

3.7 UNDOCKING

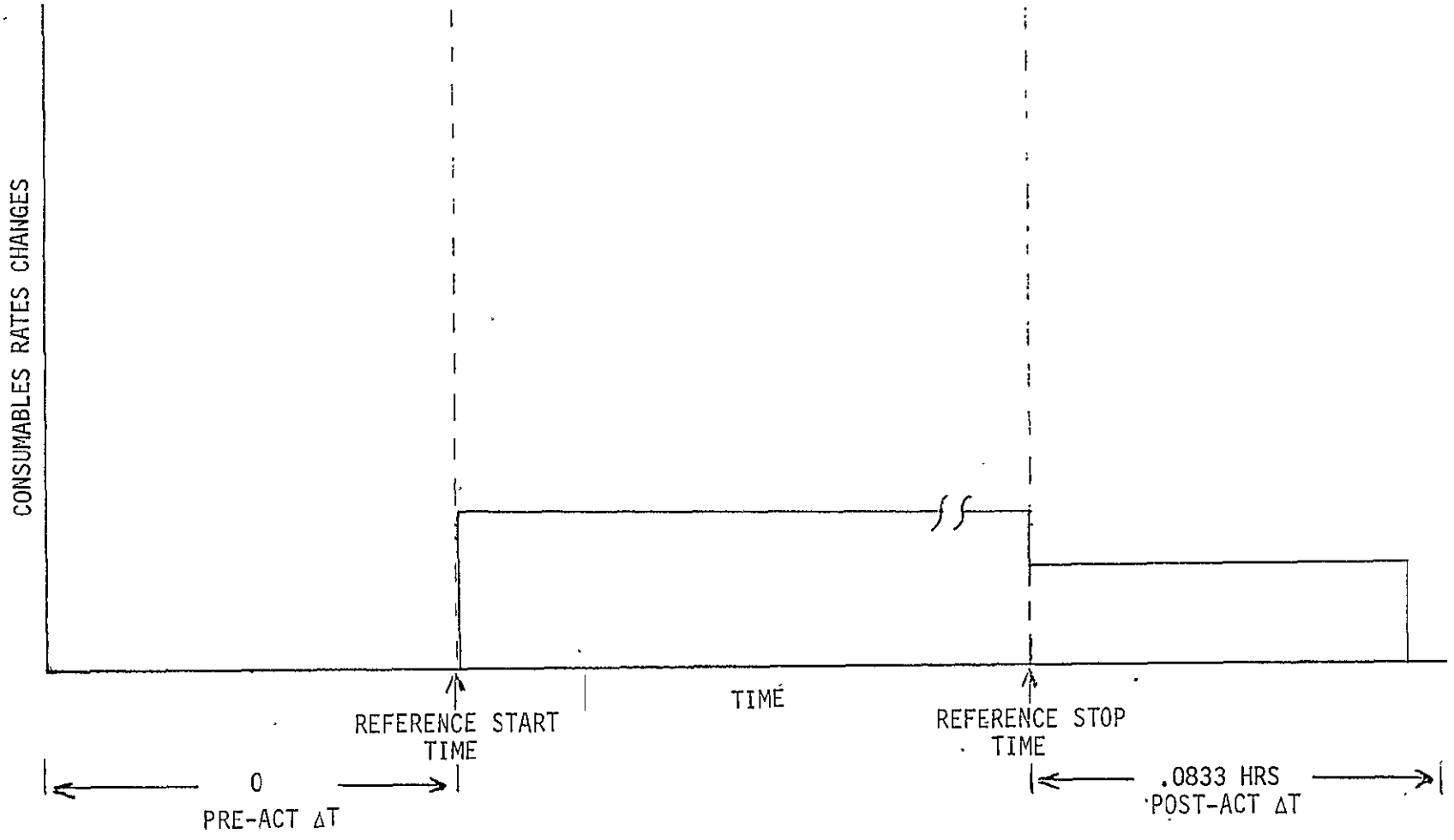
3.7.1 DESCRIPTION

The objective of this activity is to effect the separation of the Shuttle from another spacecraft. The activity is initiated by the configuration and activation of the GN&C and RCS subsystems to perform a translation burn to achieve the physical separation. The activity is completed after a rotation burn is performed to fix the Shuttle to the desired attitude. The influence variables for undocking are start time (separation) and the separation burn ΔV.

3.7.2 CONSUMABLES DATA

The consumables data is the same as that defined for the docking (see Section 3.6.2) except that the order for the propulsive maneuvers is reversed. These data are presented in Figure 3-7 and Table 3-VII.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY UNDOCKING



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 1 ; N 2 (TOTAL)

Figure 3-7. Undocking Profile

Table 3-VII. Undocking Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY UNDOCKING

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		θ(ΔV)	1185.76	F(ΔV)							
2			✓	.0833	51.40	5.03							

REMARKS:

3.8 PASSIVE THERMAL CONTROL (PTC)

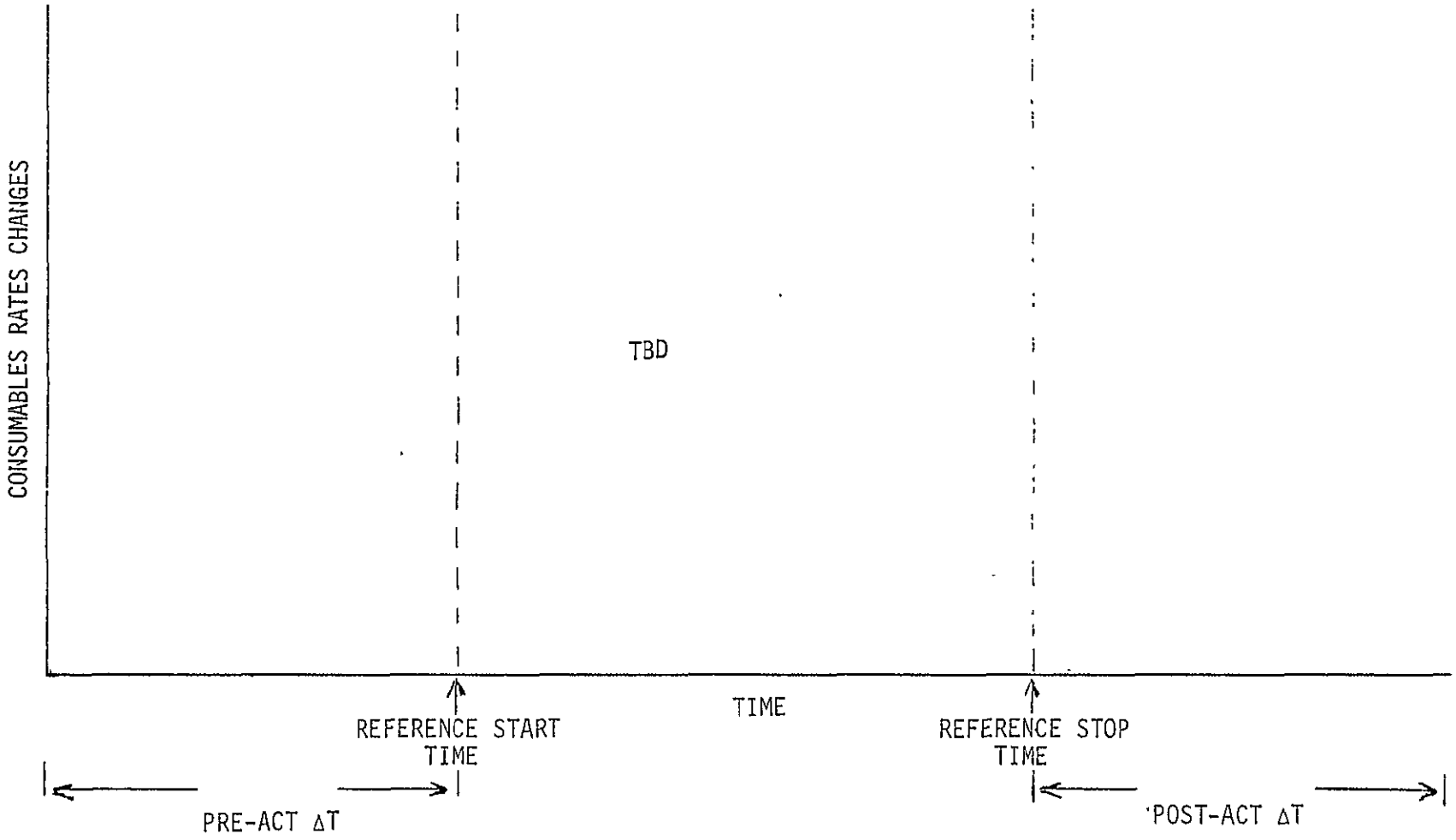
3.8.1 DESCRIPTION

The objective of this activity is directed toward the utilization of the space environment to achieve thermal control of the Shuttle. PTC is effected by rotating at a given rate the spacecraft about one of its axes to expose the entire Shuttle to the desired environment. The activity is used to stabilize the spacecraft temperature during prolonged periods of drift flight, or to thermally condition a given subsystem prior to the performance of the activity, such as the warming of fuel lines prior to the performance of propulsive maneuvers.

3.8.2 CONSUMABLES DATA

The consumables data for PTC is TBD.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY PASSIVE THERMAL CONTROL



NUMBER OF OPERATIONS: K_____; J_____; L_____; N_____ (TOTAL)

Figure 3-8. Passive Thermal Control Profile

Table 3-VIII. Passive Thermal Control Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY PASSIVE THERMAL CONTROL

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES									
					EPS	RCS	OMS	ECS				APU		
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
								TBD					

REMARKS:

3.9 EVA

3.9.1 DESCRIPTION

The objective of the Extra Vehicular Activity (EVA) is to allow one or more crewmen to egress the pressurized cabin into free space for the performance of a given mission objective. The activity is initiated by the crew donning the Astronaut Life Support Assembly (ALSA) that pro vides a safe and conditioned environment. A pure oxygen prebreathing cycle from a portable supply follows to effect denitrogenization of the crew after which the egress into free space is accomplished via the airlock. At the completion of the assigned task in free space, the crew returns to the airlock, the pressure of which is increased and equalized with that of the cabin to allow the crew entry and the re-establishing of normal systems configuration. The activity is completed with the crew doffing and re-charging the ALSA package. The influence variables for this activity are start time, stop time, and number of crew members involved.

3.9.2 CONSUMABLES DATA

The consumables data associated with the EVA is herein included in Figure 3-9 and Table 3-IX. Figure 3-9 depicts a plot profile of the activity from where it can be seen that the pre-activity period has one ("K") operation, the activity period is characterized by one ("J") operation and two ("L") operations are performed during the post-activity period, for a total of 4 ("N") operations for the overall activity. In addition, Figure 3-9 also specifies the ΔTs for the pre-activity and post-activity periods as 3.5 and 13.0 hours respectively. Table 3-IX gives the consumables rates and the ΔTs associated with the performance of each operation. The consumables required are:

EPS - The EPS consumables (WATTS) required for EVA correspond to the power required for the activation and operation of flood lights, TV cameras and monitors, and other communications equipment used by the crew while outside the pressurized environment.

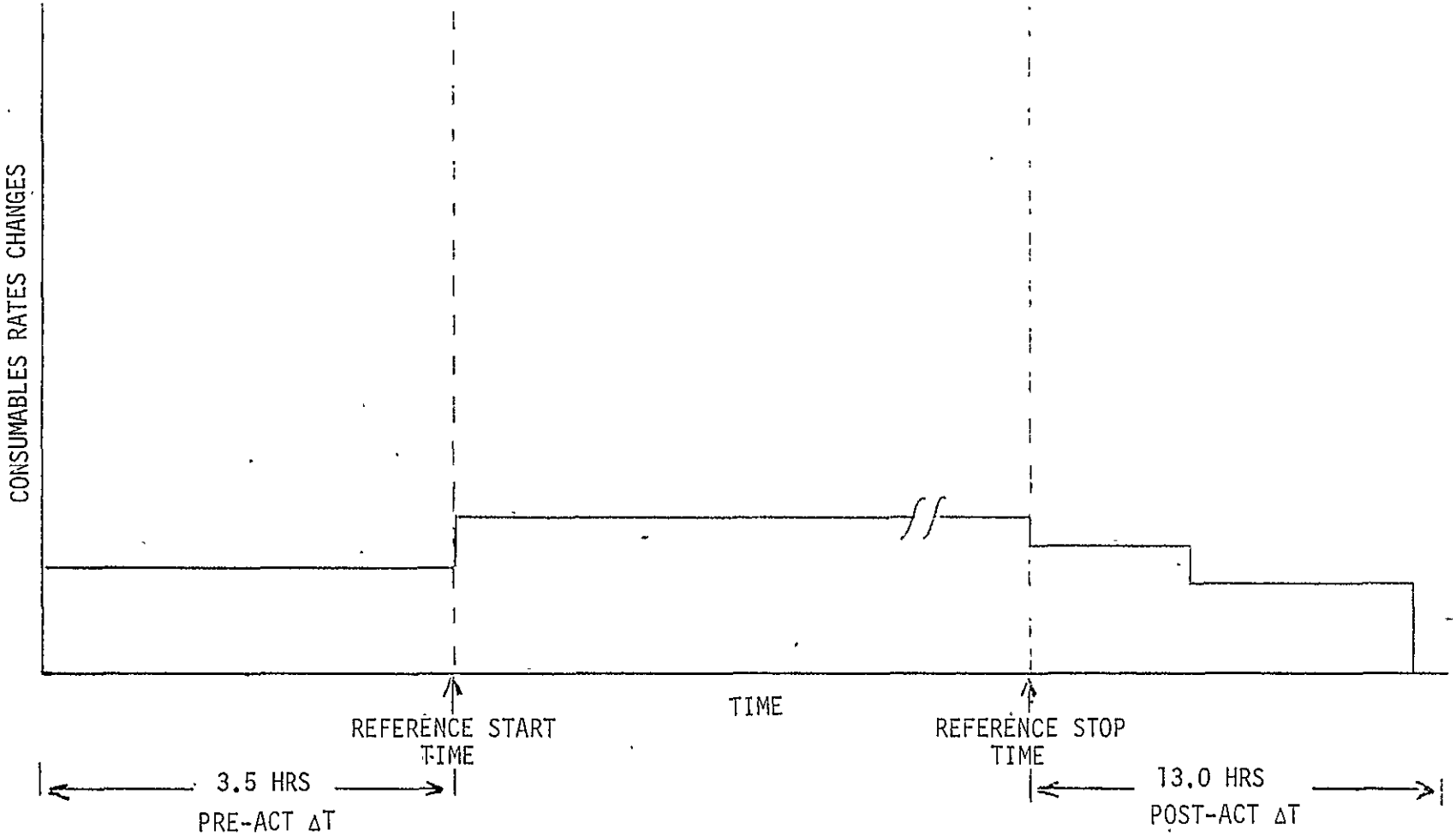
ECS - ECS consumables include:

O_2: The oxygen requirements during EVA have two components; one relating to direct crew functions such as the prebreath cycle, suit pressurization, and ALSA recharge; and the other to non-crew related requirements such as the quantity required to repressurize the airlock at the completion of the EVA. The corresponding rates are shown in Table 3-IX as #/HR with a note to multiply by the number of crewmen those reflecting crew related functions. The negative rate included for the "J" operation (N=2) corresponds to the metabolic oxygen not supplied by the main oxygen supply to the crew while on the ALSA, since a rate for the duration of the mission is included in the Flight Common Activity.

N_2: The nitrogen requirements correspond to that quantity used to repressurize the airlock prior to the crew ingressing to the Shuttle cabin.

LiOH: The CO_2 generated by the crewmen while on the ALSA package is removed by this unit, consequently, the negative rate shown corresponds to that quantity of LiOH not used by the cabin CO_2 removal system during the EVA performance and already included in the Flight Common Activity.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY EVA



NUMBER OF OPERATIONS: K 1 ; J 1 ; L 2 ; N 4 (TOTAL)

Figure 3-9. EVA Profile

Table 3-IX. EVA Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY EVA

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			3.5	175.89			0.2857*M	-		-		
2		✓		≈	426.32			-0.073*M	-		-0.096*M		
3			✓	0.04	133.05			61.75	204.75		-		
4			✓	12.96	133.05			0.179*M	-		-		

REMARKS:

*Where M is equal to the number of crew members performing EVA

3.10 INTRAVEHICULAR ACTIVITY (IVA)

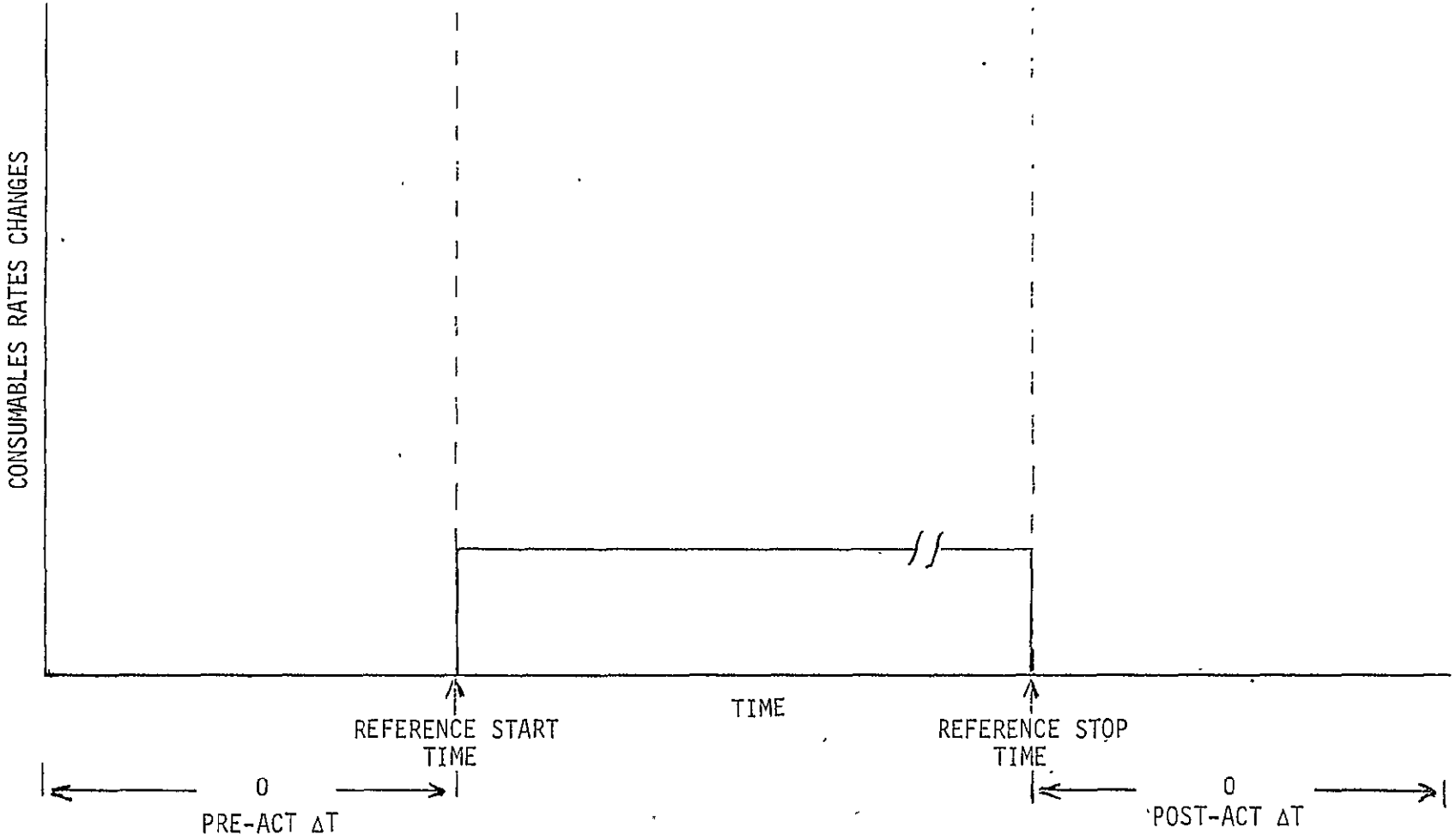
3.10.1 DESCRIPTION

The objective and characteristics of the IVA are similar in nature to those of the EVA inasmuch as it involves the egress of one or more crewmen from the Orbiter cabin. In the IVA the transfer is to a pressurized area which is the same as that of the Orbiter cabin, and therefore is performed in the unsuited mode, i.e., without the use of the pressurized suits, and without the necessity to unpressurize the airlock. If the transfer is to an unpressurized payload or to an atmosphere contaminated vehicle, the activity becomes an EVA.

3.10.2 CONSUMABLES DATA

The IVA consumables data is presented in Figure 3-10 and Table 3-X and consists of the electrical power required for TV monitoring. The negative CO_2 rate corresponds to that quantity produced by the crew while outside the Orbiter cabin and absorbed by the payload cleansing system. This rate needs to be deducted since the flight common activity considers a constant rate removed in the Orbiter cabin for the duration of the mission.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY IVA



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-10. IVA Profile

Table 3-X. IVA Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY IVA

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		~	12.90						-0.096* M		

REMARKS:

*Where M is equal to the number of crewmen on EVA

3-11. MANIPULATOR OPERATIONS

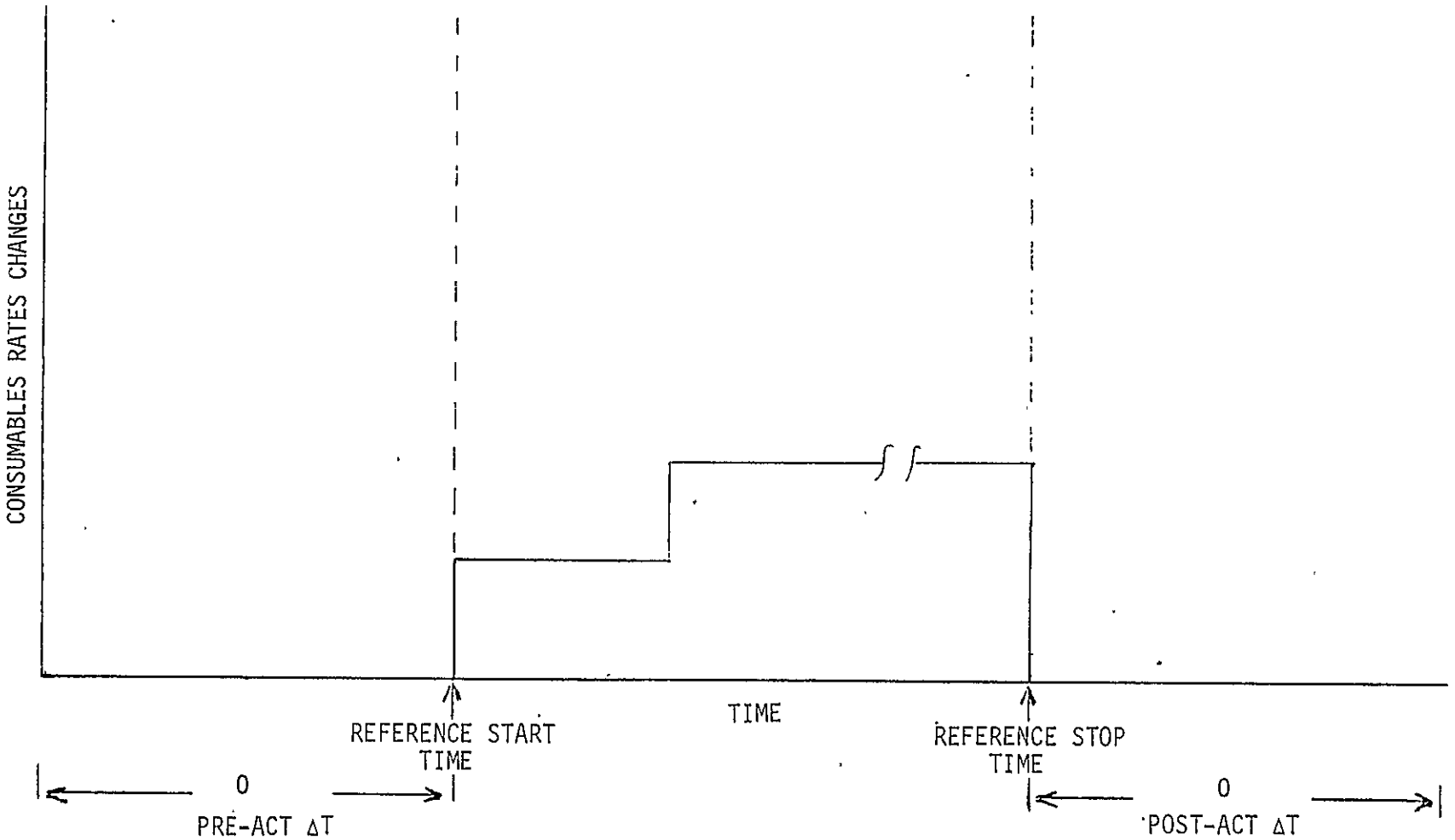
3-11.1 DESCRIPTION

The objective of this activity is to provide the Shuttle with the capability to remotely control the deployment and retrieval/service of payloads. The activity consists in the operation of electromechanical devices that physically remove the deployable spacecraft out of the payload bay to be released into space. These operations are supported by the activation of flood lights and television monitoring equipment. The retrieval/service operation is the same as above except that the order in which the operations are performed is reversed to effect the capture of the free flying spacecraft. The influence variables for this activity are start time and stop time.

3-11.2 CONSUMABLES DATA

The consumables requirements for this activity consist of the electrical power required to operate the special equipment used in the operations, such as motorized driver, flood lights, television equipment, etc. Figure 3-11 and Table 3-XI depict the activity profile and consumables rates respectively.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY MANIPULATOR OPERATIONS



NUMBER OF OPERATIONS: K 0 ; J 2 ; L 0 ; N 2 (TOTAL)

Figure 3-11. Manipulator Operations Profile

Table 3-XI. Manipulator Operations Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY MANIPULATOR OPERATIONS

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		.217	4135.16								
2		✓		≈	3000.98								

REMARKS:

3.12 IMU ALIGNMENT

3.12.1 DESCRIPTION

The objective of this activity is to align by means of star tracker measurements the Inertial Measurement Unit of the Shuttle with respect to some coordinate system. The activity, as a rule, is performed automatically by a computer, is initiated by the crew loading the desired parameters and totally executed by the computer. If the IMU alignment errors exceed the tolerance limits, a course alignment requiring a rotation maneuver using the RCS system must first be performed and then followed by the automatic procedure to complete the alignment. One such maneuver is included in this activity. The influence variables for this activity are start time and stop time. This activity should be used when an alignment is to be performed independently of the OMS maneuver and the deorbit preparation, since it is included as a part of these activities.

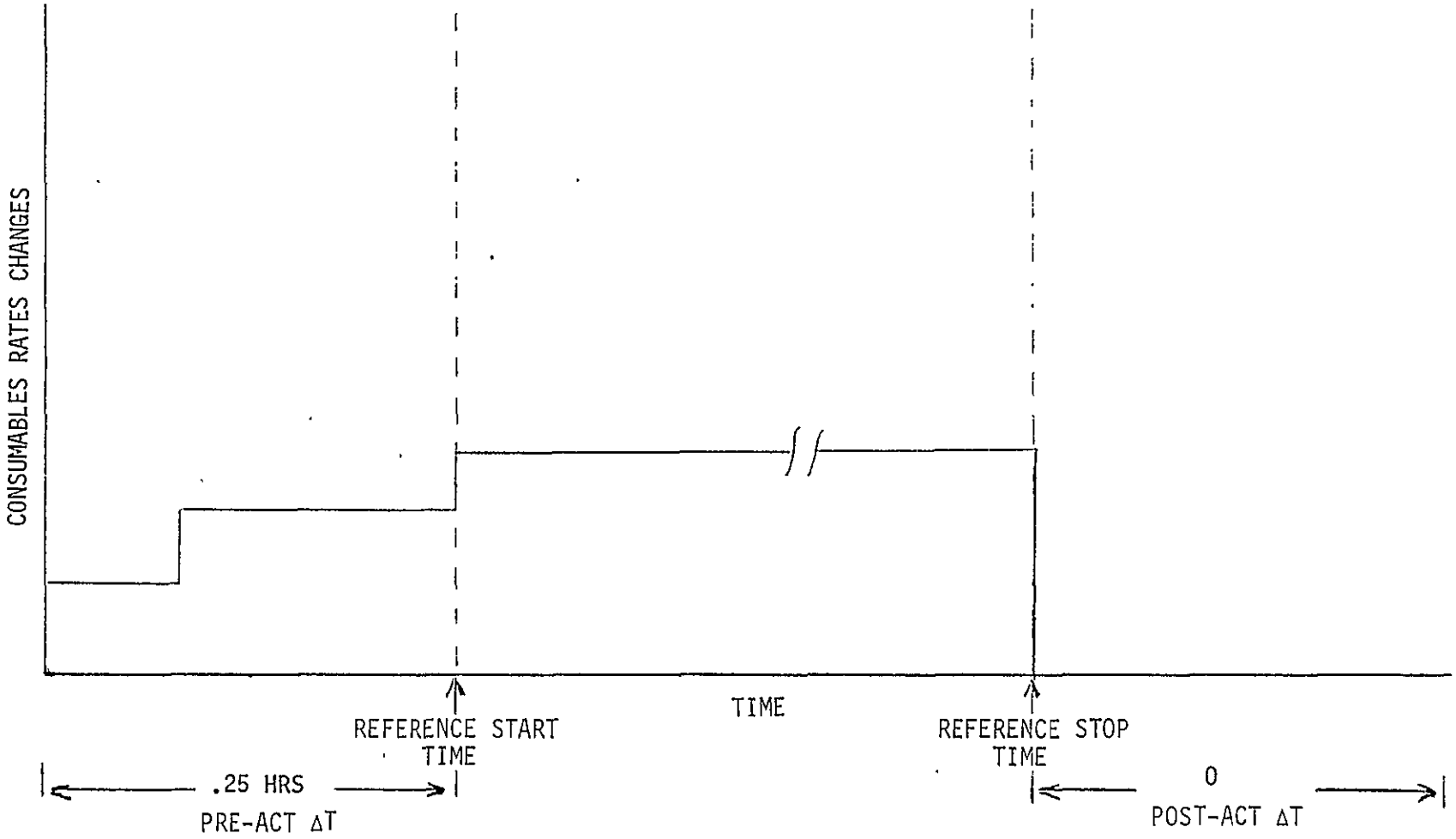
3.12.2 CONSUMABLES DATA

The consumables data is presented in Figure 3-12 and Table 3-XII. Figure 3-12 shows the preparation period to consist of 2 ("K") operations that include a 0.083 hour equipment warm-up period and the rotation maneuver. The "J" operation corresponds to the automatic computer procedure. The consumables rates are presented in Table B-3-XII and include:

EPS - The electrical power to operate the GN&C and RCS subsystems.

RCS - The propellant required for the rotation maneuver, which consists of an equivalent acceleration of 5.03 ft/(sec-hr) for a period of .167 hours required for the operation.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY IMU ALIGNMENT



NUMBER OF OPERATIONS: K 2 ; J 1 ; L 0 ; N 3 (TOTAL)

Figure 3-12. IMU Alignment Profile

Table 3-XII. IMU Alignment Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY IMU ALIGNMENT

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			.25	221.91								
2	✓			.167	1107.99	5.03							
3		✓		~	593.9								

REMARKS:

3.13 PAYLOAD BAY DOORS

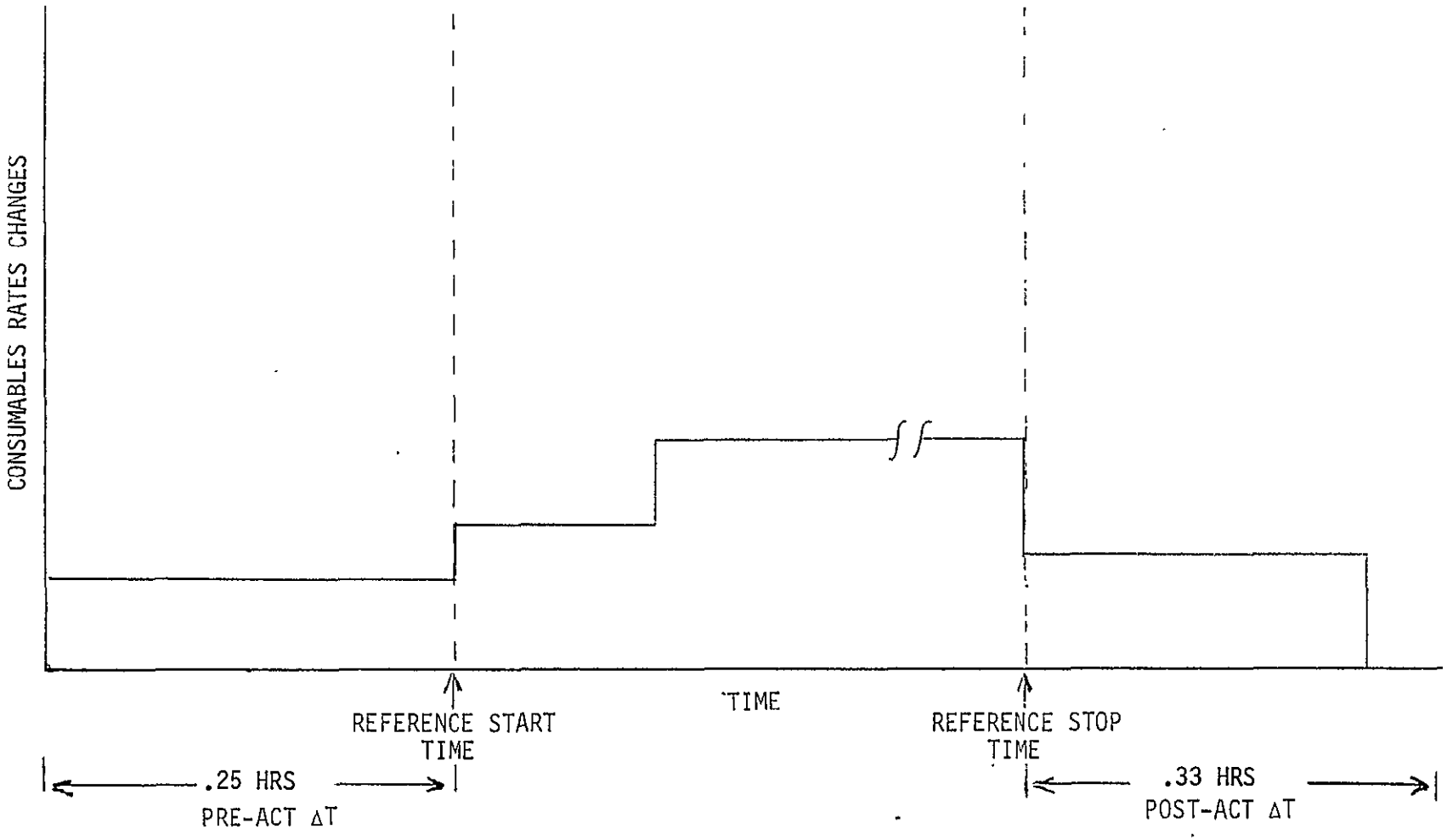
3.13.1 DESCRIPTION

The objective of this activity is to effect the operations required to open and close the Shuttle Payload Bay Doors. Payload bay doors are opened by means of electromechanical actuators to provide access to the payload and to deploy the radiator. This operation is performed as soon as the Shuttle arrives at its desired orbit. The doors are closed immediately prior to reentry. The influence variables are start (open) and stop (close) time for the payload bay doors in the open position.

3.13.2 CONSUMABLES DATA

The consumables required for this activity correspond to the electrical power required to operate the electromechanical driver to open and close the payload bay doors. In addition, since the radiator is deployed as the payload bay doors are opened, the power requirements include that required to activate and maintain operational the freon pumps in support of the active thermal control subsystem. The activity profile and consumables rates are presented in Figure 3-13 and Table 3-XIII, respectively.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY PAYLOAD BAY DOORS



NUMBER OF OPERATIONS: K 1 ; J 2 ; L 1 ; N 4 (TOTAL)

Figure 3-13. Payload Bay Doors Profile

Table 3-XIII. Payload Bay Doors Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY PAYLOAD BAY DOORS

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			.25	1113.14								
2		✓		.50	1113.14								
3		✓		≈	1599.77								
4			✓	.33	1797.83								

REMARKS:

3.14 PAYLOAD CONSUMABLES

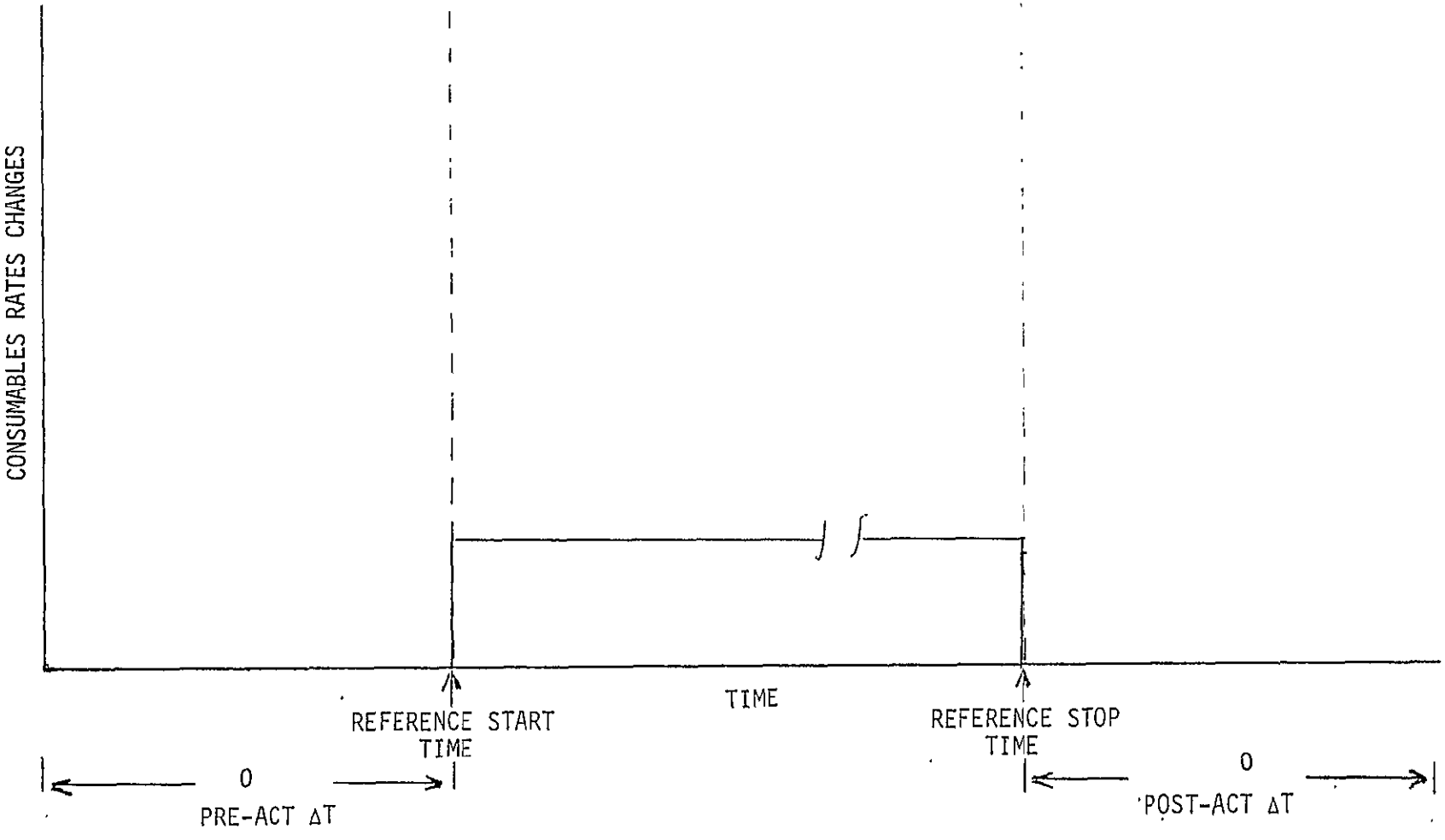
3.14.1 DESCRIPTION

The objective of this activity is that of supporting the payload operations. This support consists of the electrical energy and/or other consumables supplied to the payload from the Shuttle storage and distribution systems.

3.14.2 CONSUMABLES DATA

The consumables data for this activity are to be specified by the user as the activity is scheduled using the Mission Planning Processor. An example of these data is shown in Figure 3-14 and Table 3-XIV.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY PAYLOAD CONSUMABLES



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-14. Payload Consumables Profile

Table 3-XIV. Payload Interface Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY PAYLOAD CONSUMABLES

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		~	TBS								

REMARKS:

3.15 COMPUTER

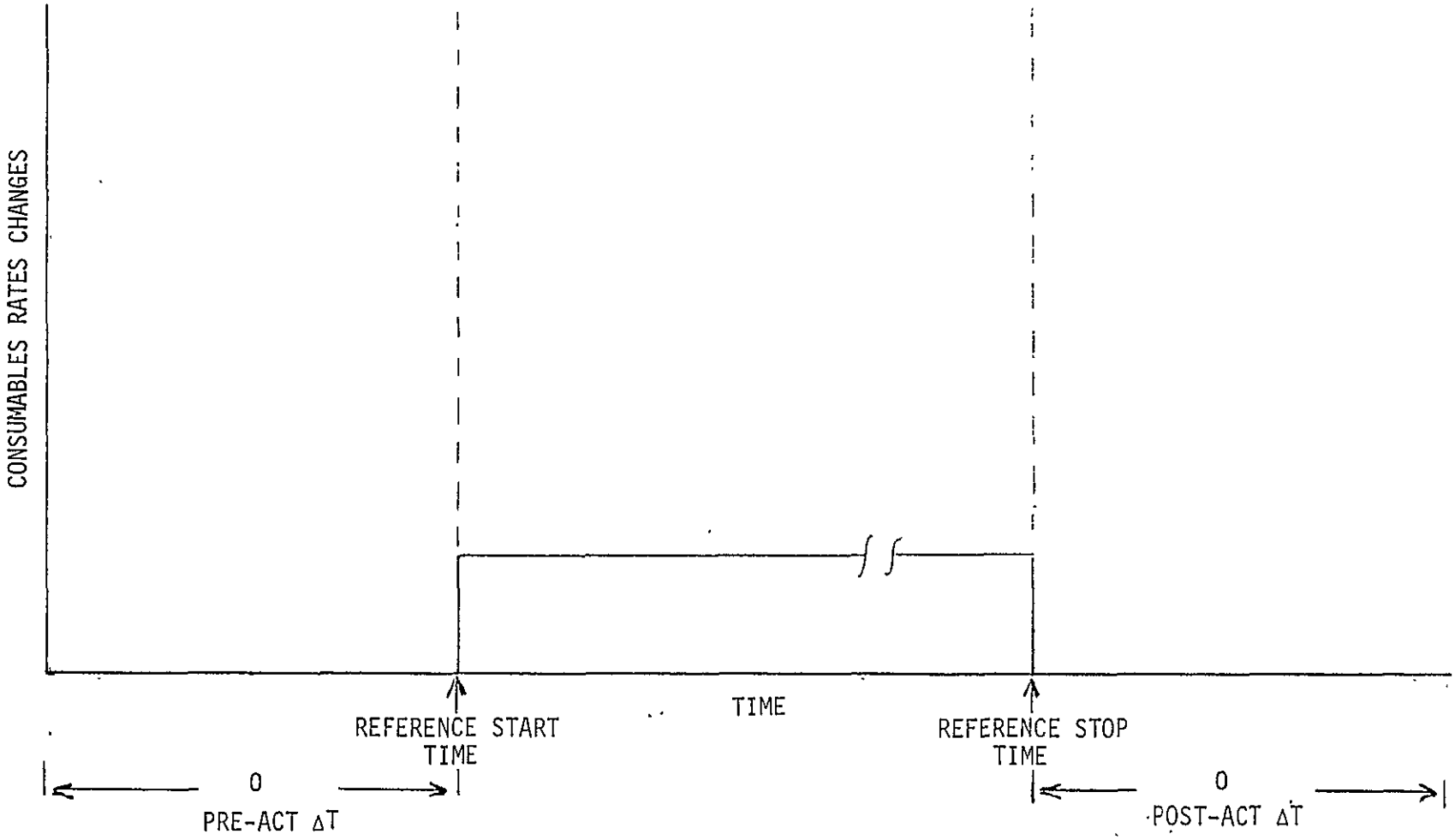
3.15.1 DESCRIPTION

The objective of this activity is to support the computer requirements of the payload imposed on the Orbiter. The influence variables for this activity are start time and stop time.

3.15.2 CONSUMABLES DATA

The consumables data consists of the electrical power required to operate the computer. The activity profile and consumables rates are included in Figure 3-15 and Table 3-XV.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY COMPUTER



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-15. Computer Profile

Table 3-XV. Computer Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY COMPUTER

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		~	TBS								

REMARKS:

3.16 TV

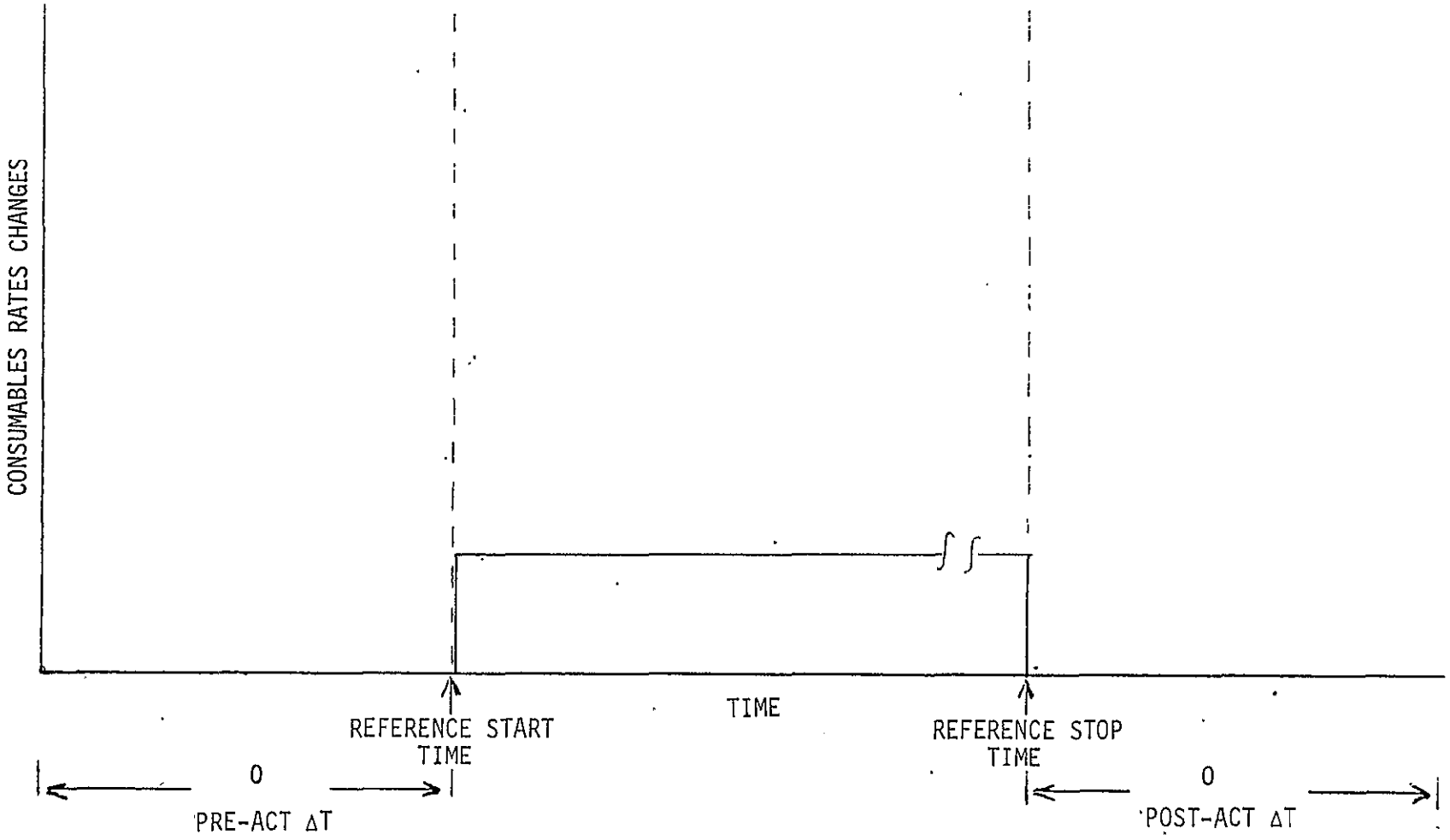
3.16.1 DESCRIPTION

The objective of this activity is to provide additional television coverage. This activity already scheduled is scheduled during the performance of EVA or Manipulator Operations. The influence variables for this activity are start time and stop time.

3.16.2 CONSUMABLES DATA

The consumables for this activity correspond to the electrical power requirements for the operation of the TV system. Figure 3-16 and Table 3-XVI present the profile and rates for this activity.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY TV



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-16. TV Profile

Table 3-XVI. TV Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY TV

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		≈	129.0								

REMARKS:

3-17 DOWNLINK

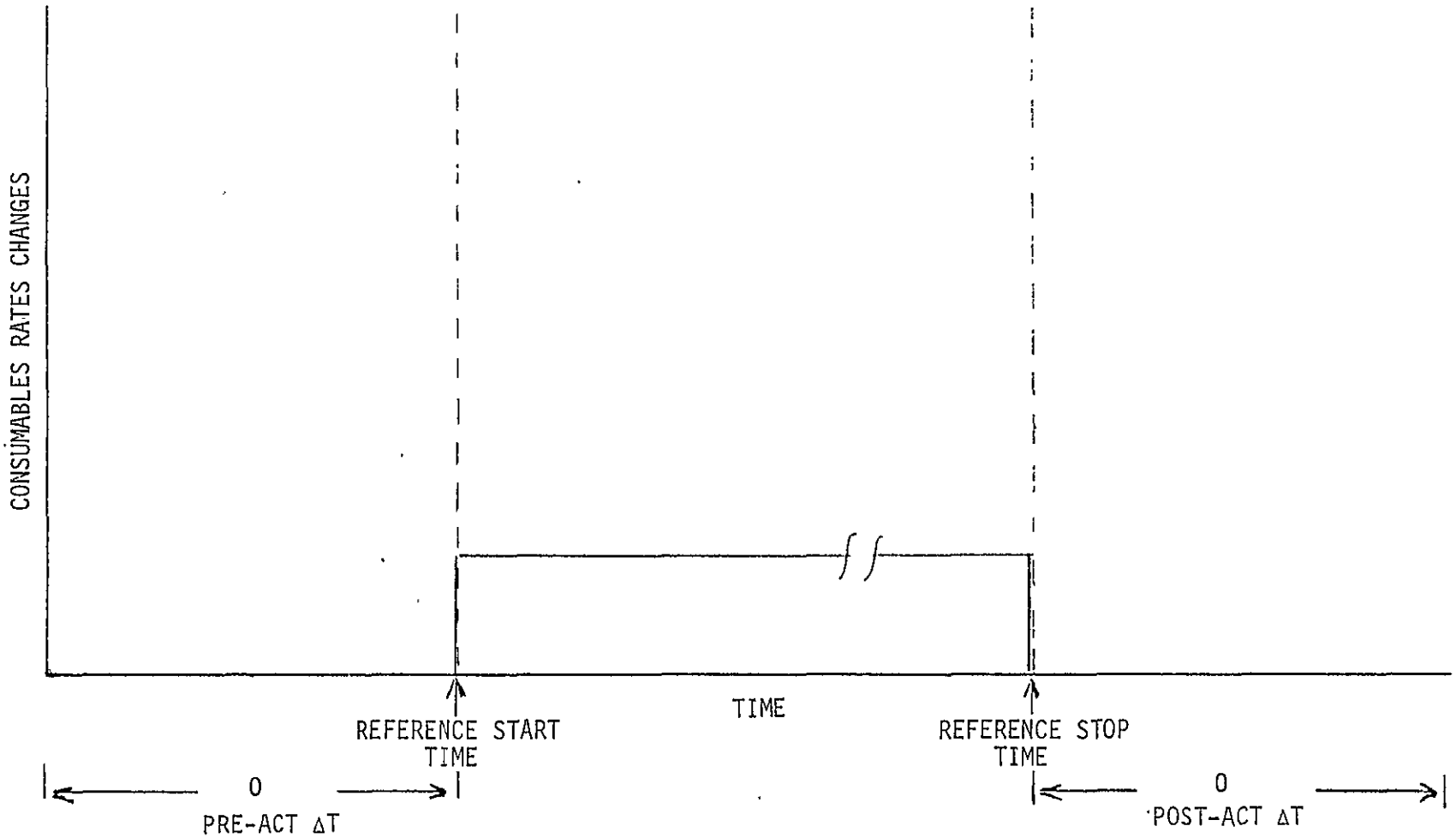
3.17.1 DESCRIPTION

The objective of this activity is to support the downlink requirements of the payload. The influence variables for this activity are start time and stop time.

3.17.2 CONSUMABLES DATA

The consumables requirements for this activity include the electrical power required for the operation of the communications subsystem of the Orbiter. Figure 3-17 and Table 3-XVII show the activity profile and associated consumables rates.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY DOWNLINK



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-17. Downlink Profile

Table 3-XVII. Downlink Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY DOWNLINK

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		~	TBS								

REMARKS:

3.18 UPLINK

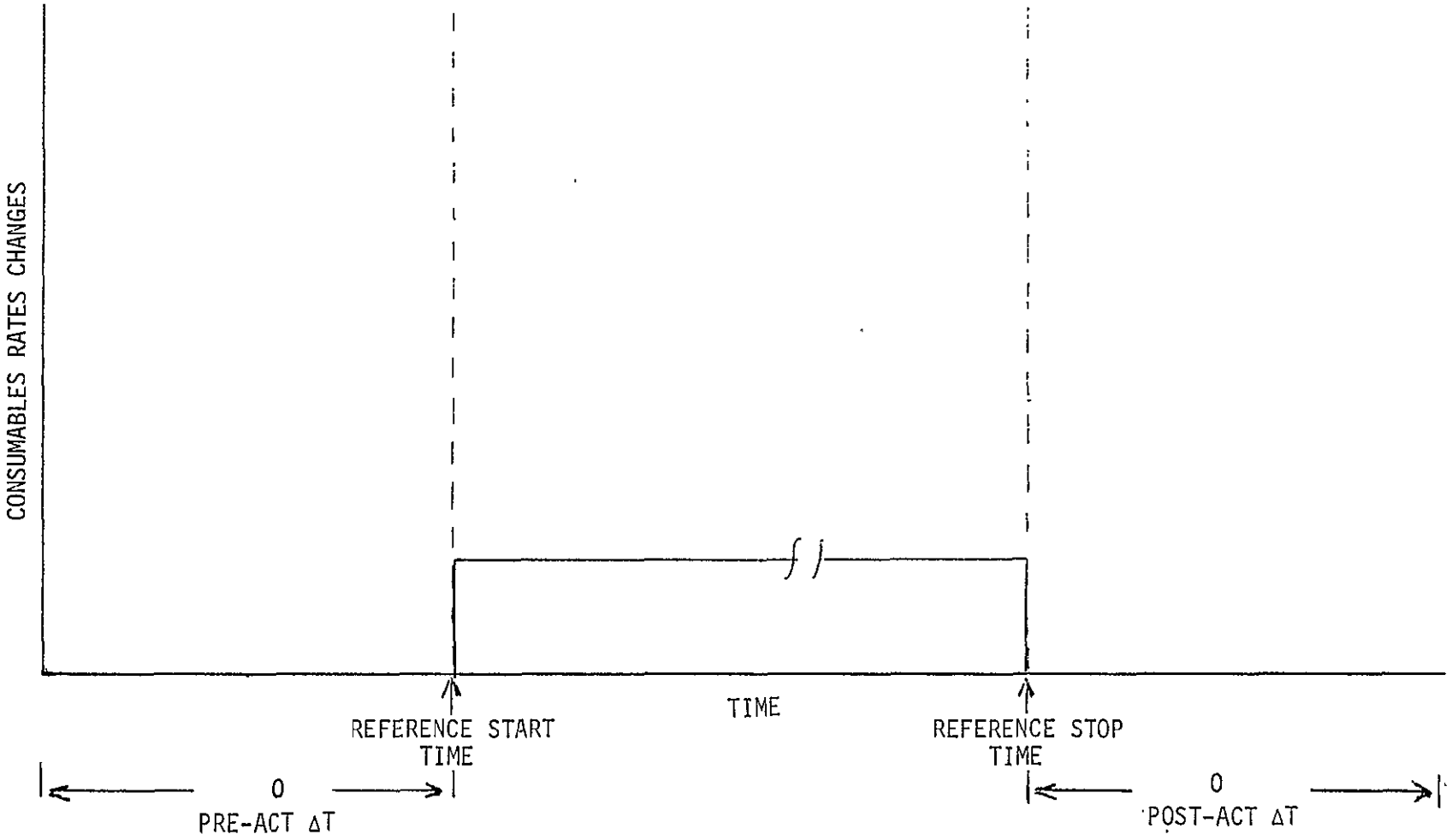
3.18.1 DESCRIPTION

The objective of this activity is to support the uplink communications requirements of the payload. The influence variables for this activity are start time and stop time.

3.18.2 CONSUMABLES DATA

The consumables data required for this activity consist of the electrical power required for the operation of Shuttle communications subsystem.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY UPLINK



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-18. Uplink Profile

Table 3-XVIII. Uplink Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY UPLINK

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		Δ		~	TBS								

REMARKS:

3.19 FUEL CELL PURGE

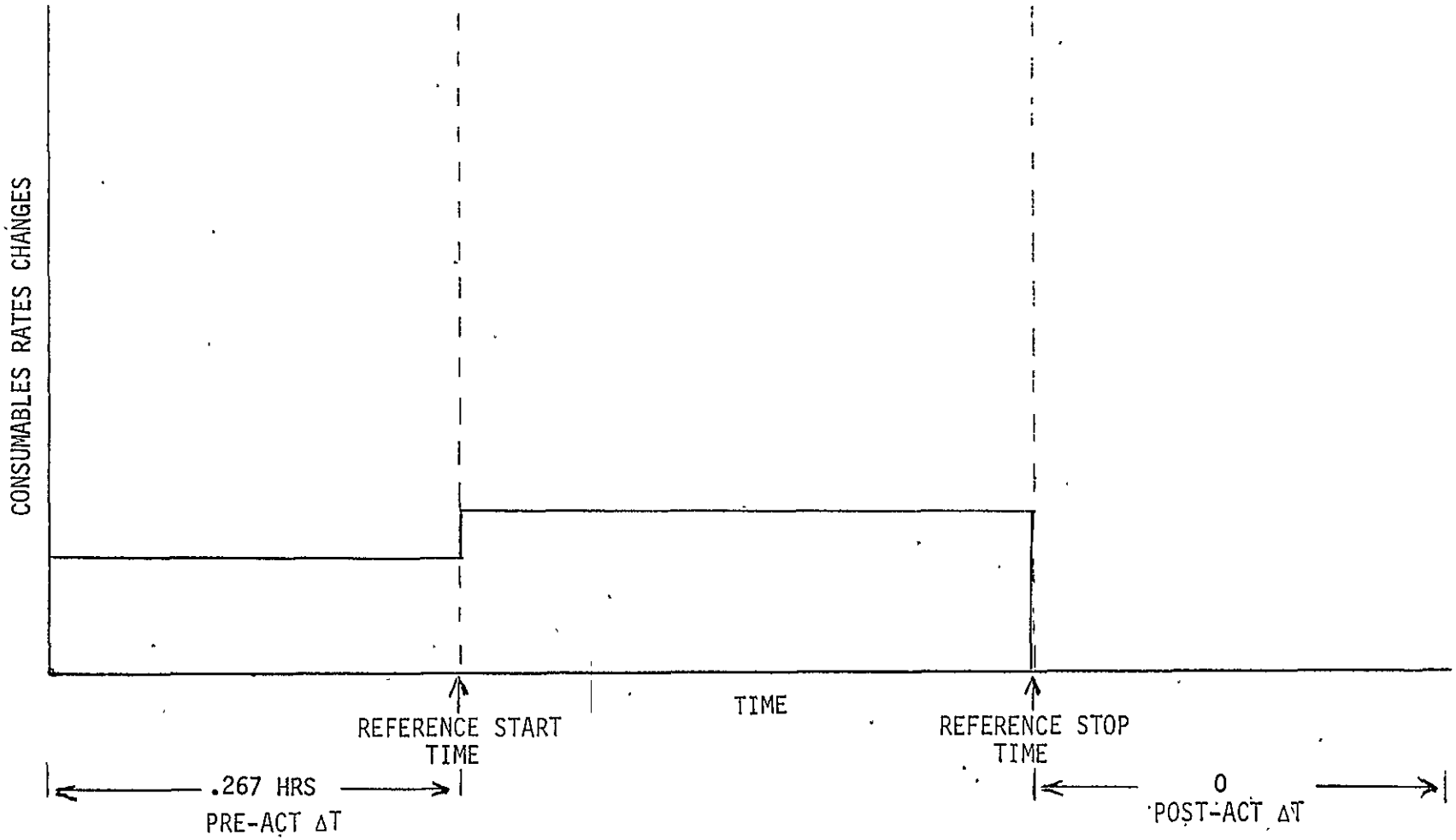
3.19.1 DESCRIPTION

The objective of this activity is to provide for the purging of impurities from the reactants used in the production of electrical energy. The activity is initiated with the activation of purge line heaters used to preclude the possibility of line freeze-up due to the accumulation of moisture, after which small quantities of oxygen and hydrogen are alternately expelled using vent valves to effect the purging. The influence variables for this activity are start time and stop time.

3.19.2 CONSUMABLES DATA

The consumables required for this activity consist of the electrical power required for the operation of the in-line heaters. A 0.267 hour preparation period constitutes the one ("K") operation followed by a 1.02 hour ("J") operation as shown in Figure 3-19. Table 3-XIX presents the consumables rates associated with the performance of this activity. The actual O_2 and H_2 quantities expelled during the purging operation are considered negligible and not included herein.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY FUEL CELL PURGE



NUMBER OF OPERATIONS: K 1 ; J 1 ; L 0 ; N 2 (TOTAL)

Figure 3-19. Fuel Cell Purge Profile

Table 3-XIX. Fuel Cell Purge Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY FUEL CELL PURGE

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			.267	97.35								
2		✓		1.017	97.35								

REMARKS:

3.20 EAT

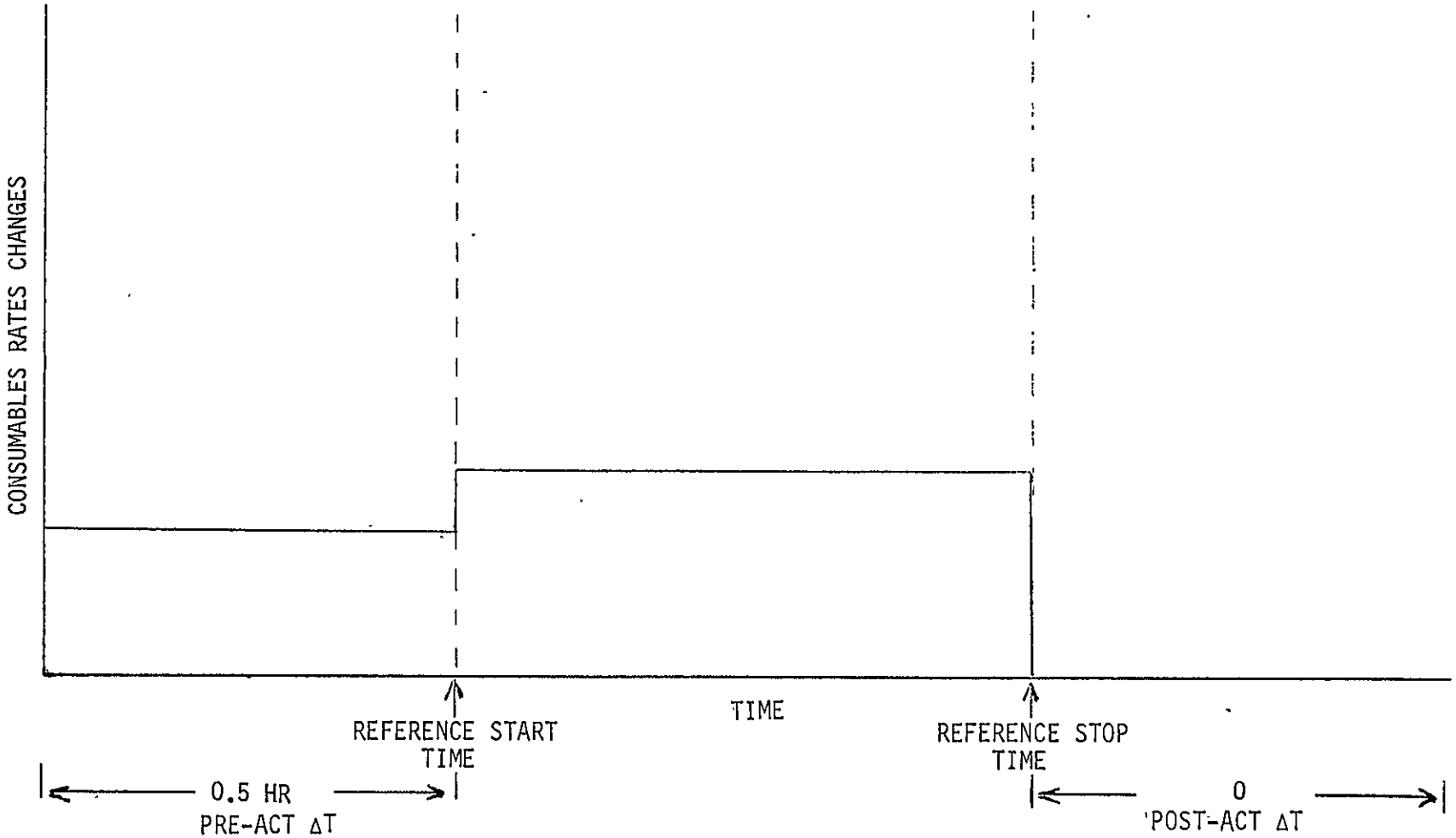
3.20.1 DESCRIPTION

The objective of this activity is to provide the food preparation facilities onboard the Shuttle Spacecraft. The activity is initiated by a short preparation period in which heaters are activated to heat up and maintain hot the food and water required for meal preparation. The activity is completed when the crew finish eating. The influence variables for this activity are start time and stop time.

3.20.2 CONSUMABLES DATA

The consumables required for this activity are the food, water, and electrical power required for meal preparation. The water and electrical power rate requirements are given in Figure 3-20 and Table 3-XX. The food is inventoried separately and not included as part of the consumables.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY EAT



NUMBER OF OPERATIONS: K 1 ; J 1 ; L 0 ; N 2 (TOTAL)

Figure 3-20. Eat Profile

Table 3-XX. Eat Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY EAT

N	K	J	L	ΔT (HRS).	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			0.5	466.66					-			
2		✓		1.0	466.66					0.66* M			

REMARKS:

*Where M is equal to the number of crew members eating

3.21 SLEEP

3.21.1 DESCRIPTION

The objective of this activity is to provide for the sleeping facilities for the crew onboard the Shuttle. The activity is preceded and followed by a 1.0 hour preparation and post-activity period allocated for personal hygiene. The influence variables for this activity are start time and stop time.

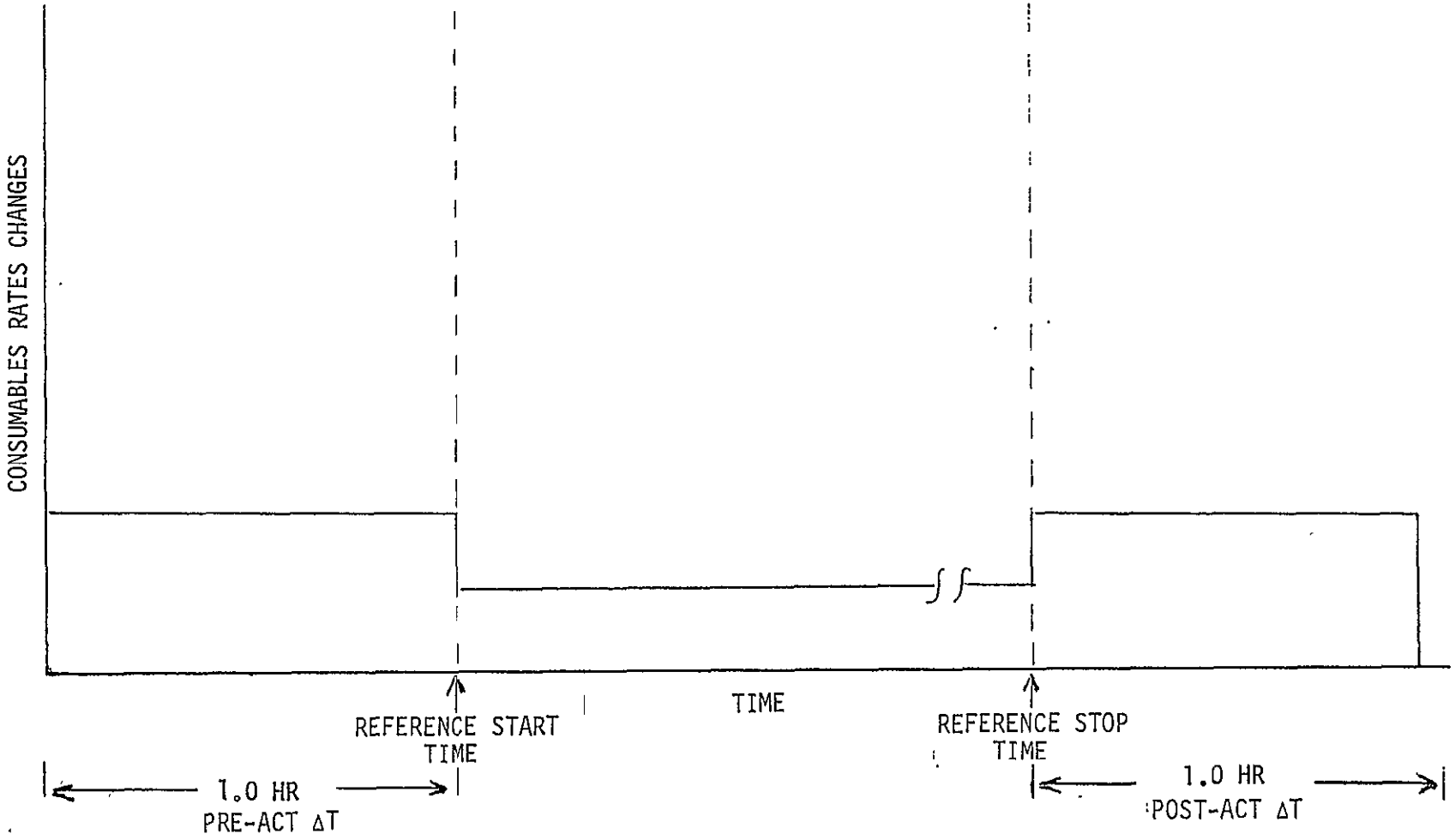
3.21.2 CONSUMABLES DATA

The consumables data for this activity are presented in Figure 3-21 which shows the preparation, activity, and post-activity operations K, J, and L, respectively. Table 3-XXI depicts the consumables rates which consist of:

EPS - The electrical power required for the operation of the waste management system prior to and at the completion of the sleep period, and also the operation of bunk and panel lights used during sleep.

ECS - A negative oxygen rate is included, corresponding to the difference in the metabolic consumption allocated for the duration of the mission in the Flight Common Activity and that actually used while the crew is asleep.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY SLEEP



NUMBER OF OPERATIONS: K 1 ; J 1 ; L 1 ; N 3 (TOTAL)

Figure 3-21. Sleep Profile

Table 3-XXI. Sleep Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY SLEEP

N	K	J	L	ΔT (HRS).	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1	✓			1.0	308.42			-					
2		✓		~	17.70			-0.01475*					
3			✓	1.0	308.42			-					

REMARKS:

*Δ between 450 to 360 BUT/HR metabolic O_2 consumption

3.22 WASTE MANAGEMENT

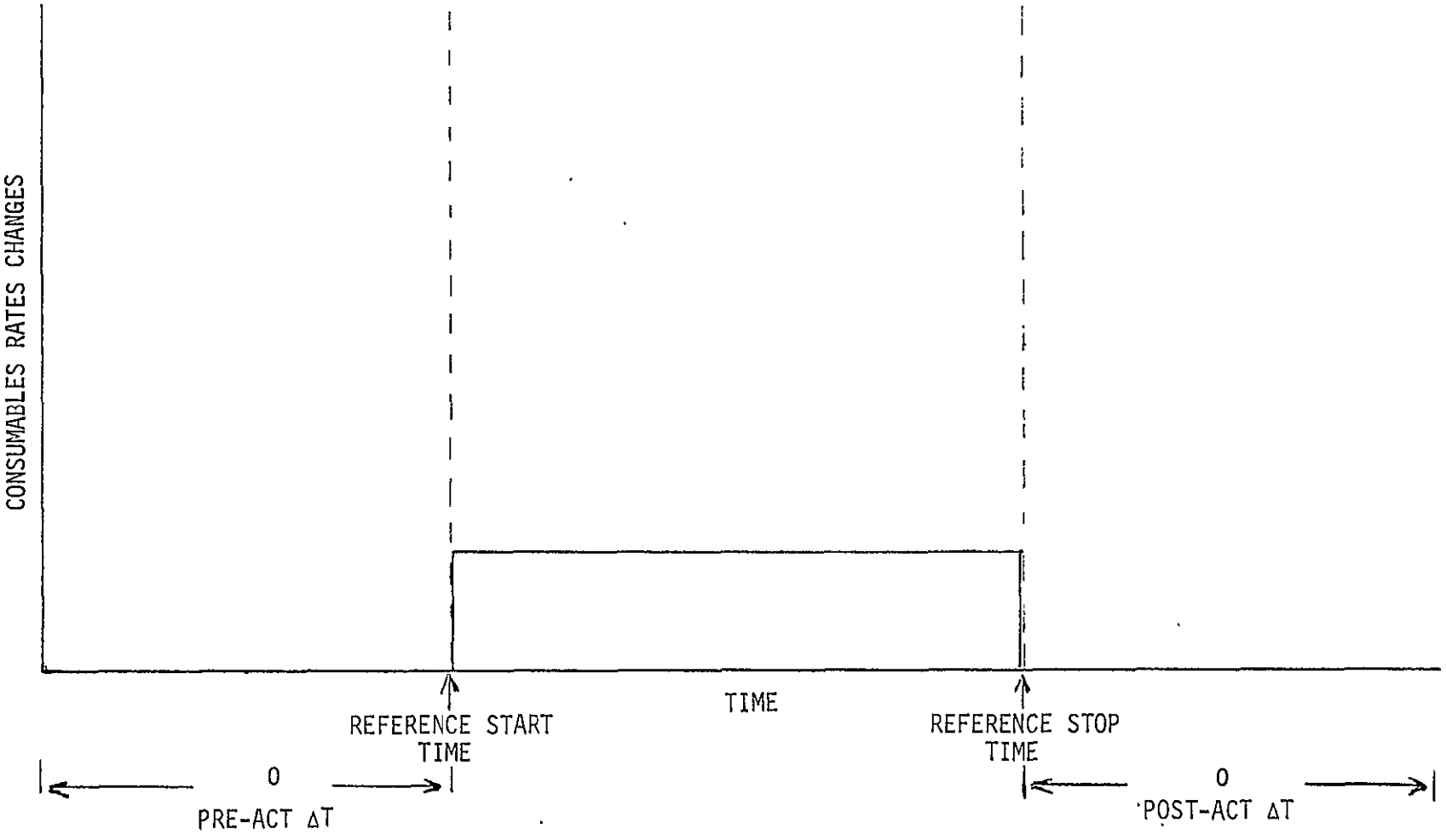
3.22.1 DESCRIPTION

The objective of this activity is that of providing for the waste management functions of the crew onboard the Shuttle. The influence variables for this activity are start time and stop time.

3.22.2 CONSUMABLES DATA

The consumables required for this activity correspond to the electrical power required to operate the waste management equipment. These data are presented in Figure 3-22 and Table 3-XXII.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY WASTE MANAGEMENT



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-22. Waste Management Profile

Table 3-XXII. Waste Management Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY WASTE MANAGEMENT

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		0.667	215.21			TBS	TBS	TBS			

REMARKS:

3.23 APU CHECKOUT

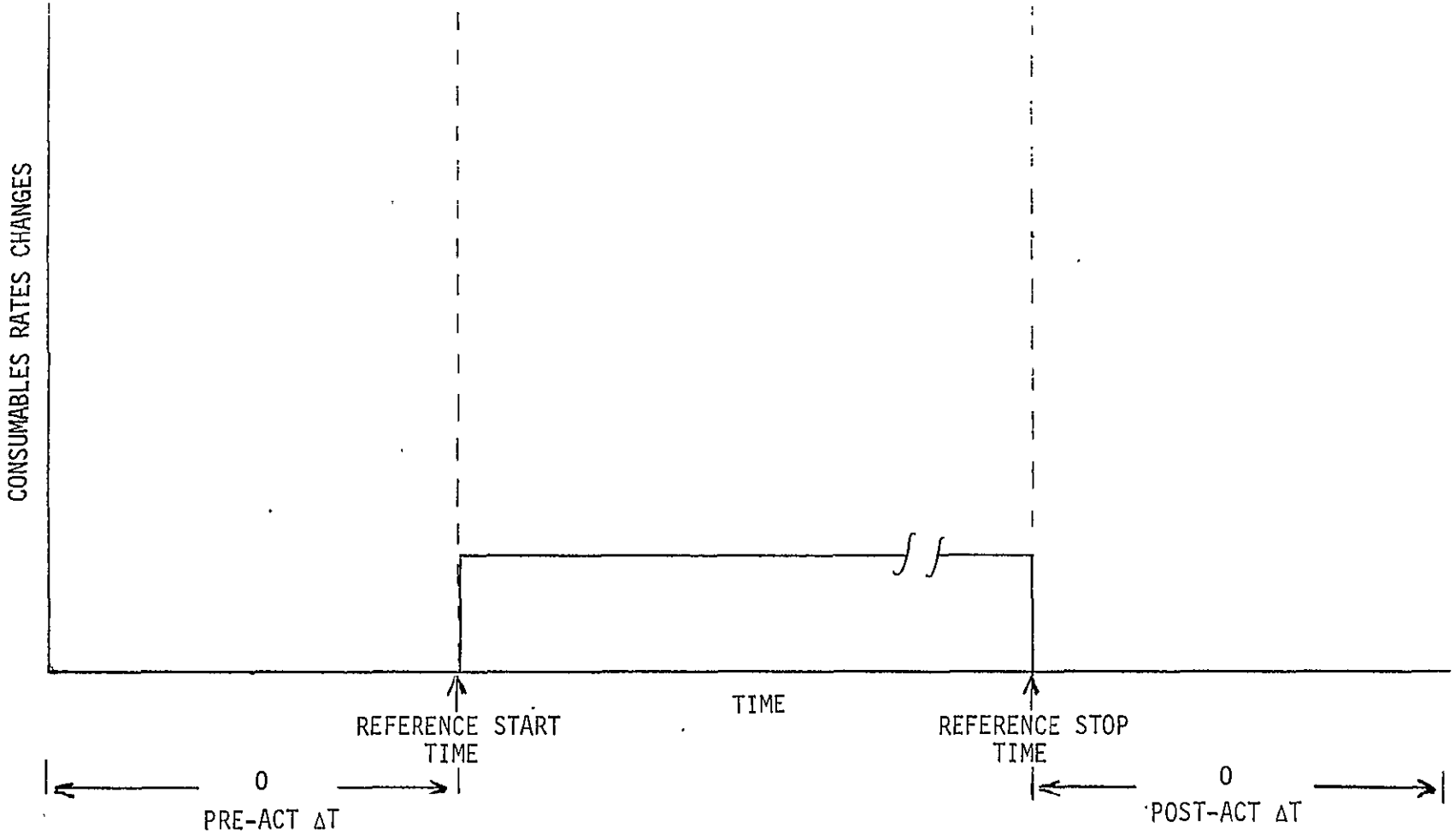
3.23.1 DESCRIPTION

The function of the Auxiliary Power Units (APUs) is to provide mechanical shaft power to drive hydraulic pumps for the operation of the aerosurface controls, main engine gimbal, landing gear, main wheel brakes, and nose wheel steering. The APUs are used during prelaunch, ascent, entry, and landing, and these operations are included in the Flight Common Activity. The objective of this activity is to provide for the checkout of the APU in addition to and independently of the operations already included in the Flight Common Activity. The influence variables for this activity are start time and stop time.

3.23.2 CONSUMABLES DATA

The consumables required for this activity are the fuel (hydrazine) used for the operation of the turbines and the water used in the water boiler required to control the hydraulic fluid temperature. Figure 3-23 and Table 3-XXIII present the activity profile and associated consumables rates.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY APU CHECKOUT



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-23. APU Checkout Profile

Table 3-XXIII. APU Checkout Consumables Rates

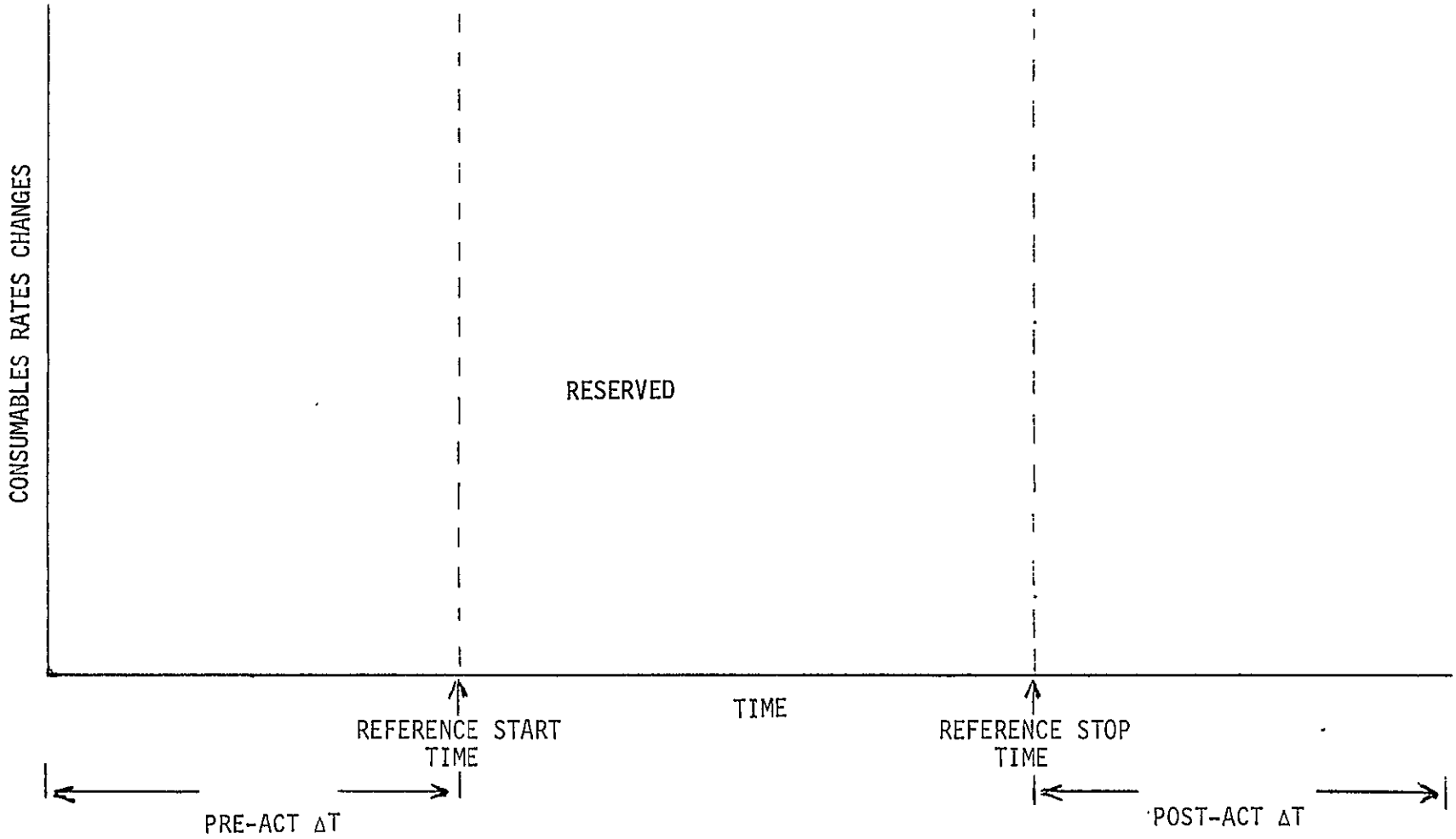
CONSUMABLES DATA SHEET
ACTIVITY APU CHECKOUT

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL :#/HR	H_2O #/HR
1		✓		~	TBS							TBS	TBS

REMARKS:

3.24 (RESERVED)

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY (RESERVED)



NUMBER OF OPERATIONS: K____; J____; L____; N____ (TOTAL)

Figure 3-24. (Reserved)

Table 3-XXIV. (Reserved)

CONSUMABLES DATA SHEET
ACTIVITY (RESERVED)

N	K	J	L	ΔT (HRS.)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
					RESERVED								

REMARKS:

3.25 FLIGHT COMMON

3.25.1 DESCRIPTION

The objective of this activity is that of providing the routine operational support functions to prepare, launch, insert into orbit, maintain in orbit, deorbit, and land the Shuttle Spacecraft. The activity covers the crew life support and subsystem operations from GSE disconnect during prelaunch to GSE transfer after landing.

To facilitate the specification and maintenance of the consumables data, this activity was subdivided into ten segments or sub-activities that represent discrete time periods associated with the performance of distinct mission functions. These sub-activities are:

1. COMMON (GSE to GSE)
2. PRELAUNCH (GSE to LIFTOFF)
3. ASCENT (LIFTOFF to MECO)
4. POST-ASCENT (MECO to INSERTION)
5. INSERTION (INSERTION to ORBIT)
6. ON-ORBIT (ON-ORBIT to DEORBIT PREP)
7. DEORBIT PREP (DEORBIT PREP to DEORBIT)
8. DEORBIT (DEORBIT to ENTRY INTERFACE)
9. ENTRY (ENTRY INTERFACE to SR)
10. LANDING (SR to GSE)

The start and stop times for each sub-activity are controlled by the block phase times BPT(I) specified in the Mission Planning Processor.

3.25.2 CONSUMABLES DATA

3.25.2.1 COMMON (GSE TO GSE)

This sub-activity includes the consumables required to maintain the crew and spacecraft from the time the Shuttle goes to internal power during prelaunch to the time in which the transfer is made to GSE power after landing. The profile and consumables rates for this sub-activity are presented in Figure 3-25.1 and Table 3-XXV.1 and they include:

EPS - The electrical power required to operate that equipment associated with the crew life support functions, and to maintain the spacecraft operational. A load of 2556.42 watts is included as an average heater requirement. This figure, taken from Reference 1, will be updated as heater duty cycle data become better defined.

ECS

O_2: a) The oxygen required to make up the cabin leakage at the operating pressure.

b) The oxygen required for metabolic consumption.

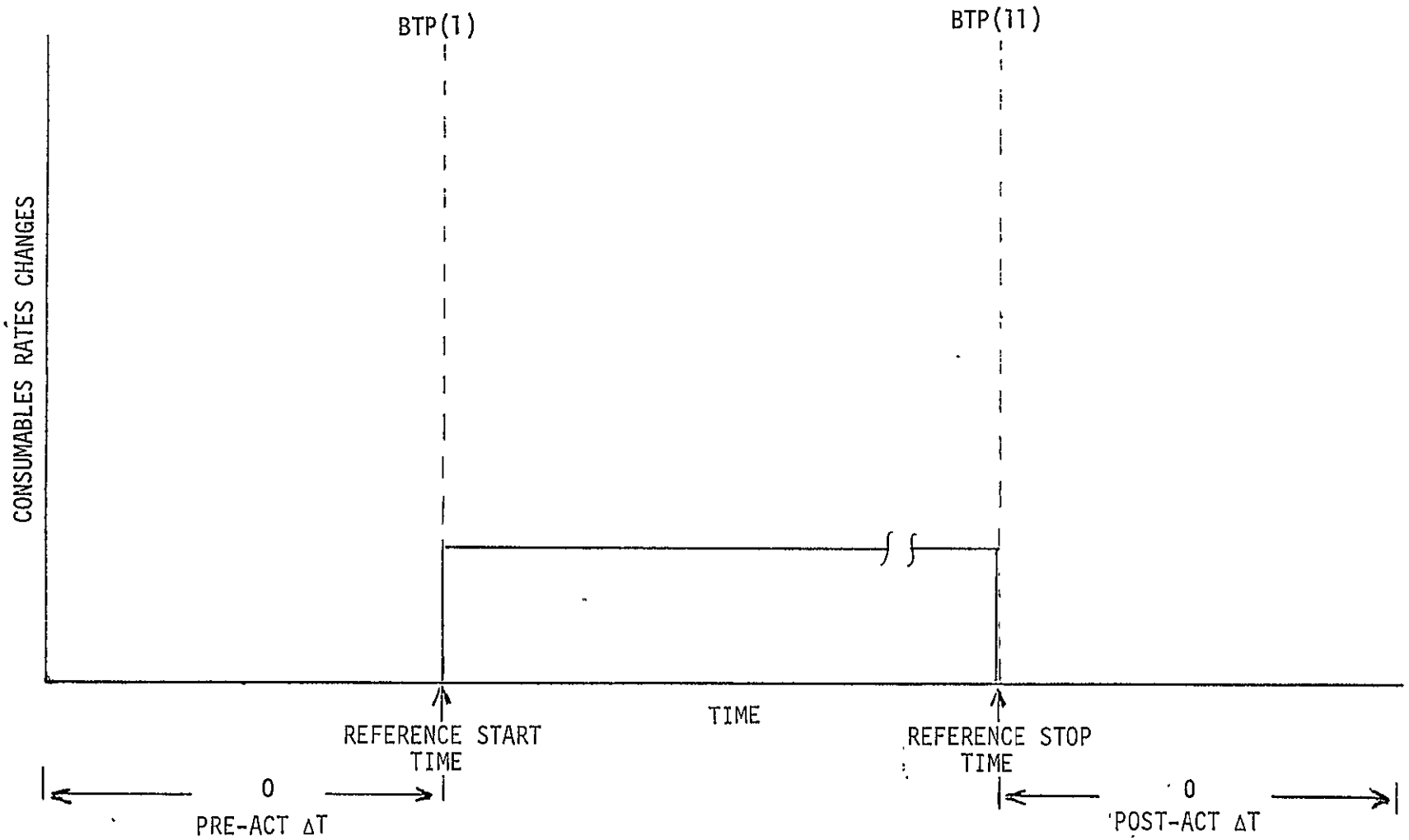
N_2: The nitrogen required for cabin leakage make-up.

H_2O: The water consumed or used by the crew for all functions except food preparation which is accounted for in the EAT activity.

LiOH: The lithium hydroxide cannisters required for the CO_2 removal from the cabin atmosphere.

C 5

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY GSE-GSE



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-25.1. Common Profile

Table 3-XXV.1. Common Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY FLIGHT COMMON

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		~	7326.10			.07+ .073*M	.2216	.558*M	.021*M		

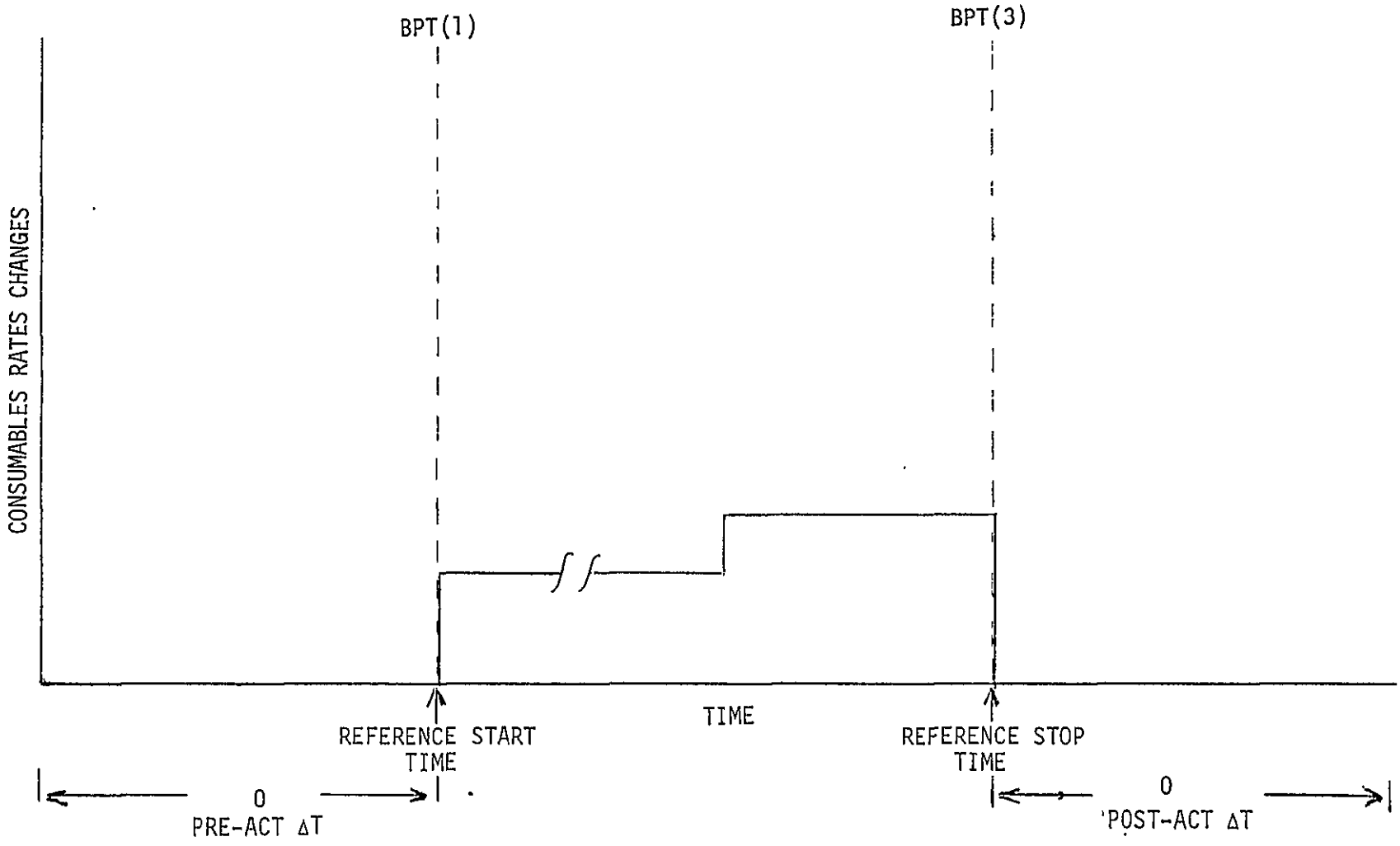
REMARKS:

*Where M is equal to the number of crew members

3.25.2.2 PRELAUNCH (GSE TO LIFTOFF)

This activity includes the activation of the majority of the spacecraft subsystems after transfer to internal power. The profile and consumables rates consisting of the electrical power requirements are presented in Figure 3-25.2 and Table 3-XXV.2. The consumables also include the fuel and water required for APU operation which is activated .083 hours prior to liftoff.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY GSE-LO



NUMBER OF OPERATIONS: K 0 ; J 2 ; L 0 ; N 2 (TOTAL)

Figure 3-25.2. Prelaunch Profile

Table 3-XXV.2. Prelaunch Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY PRELAUNCH

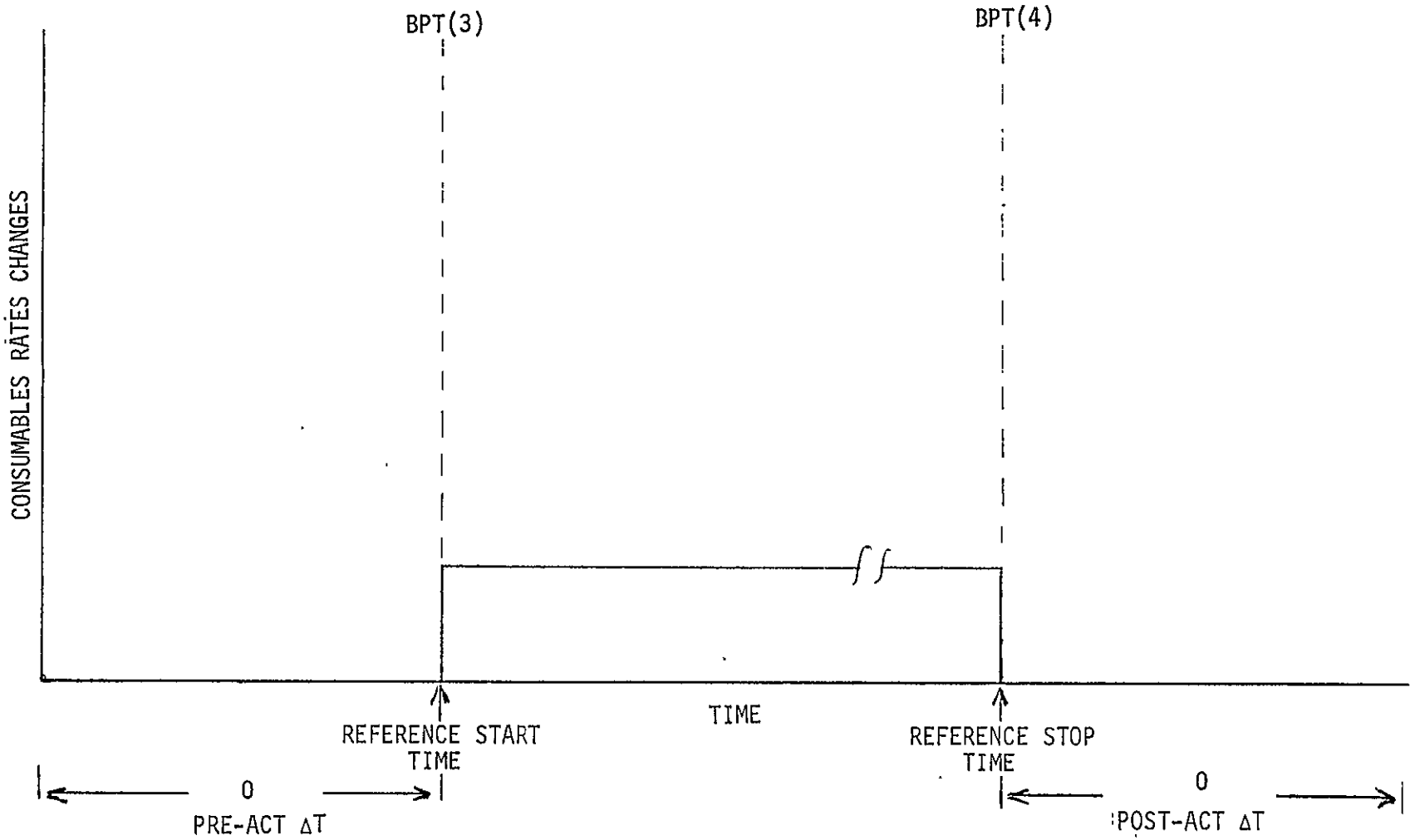
N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		≈	20,287.8							-	-
2		✓		.083	20,287.8							329.096	91.64

REMARKS:

3.25.2.3 ASCENT (LIFTOFF TO MECO)

This activity covers the operations from liftoff to Main Engine Cutoff and includes in the consumables the fuel and water required for the APUs operation in addition to the electric power. Figure 3-25.3 and Table 3-XXV.3 depict the profile and consumables rates for this sub-activity.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY LO-MECO



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-25.3. Ascent Profile

Table 3-XXV.3. Ascent Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY ASCENT

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		~	17,363.62							329.096	91!64

REMARKS:

3.25.2.4 POST ASCENT (MECO TO INSERTION)

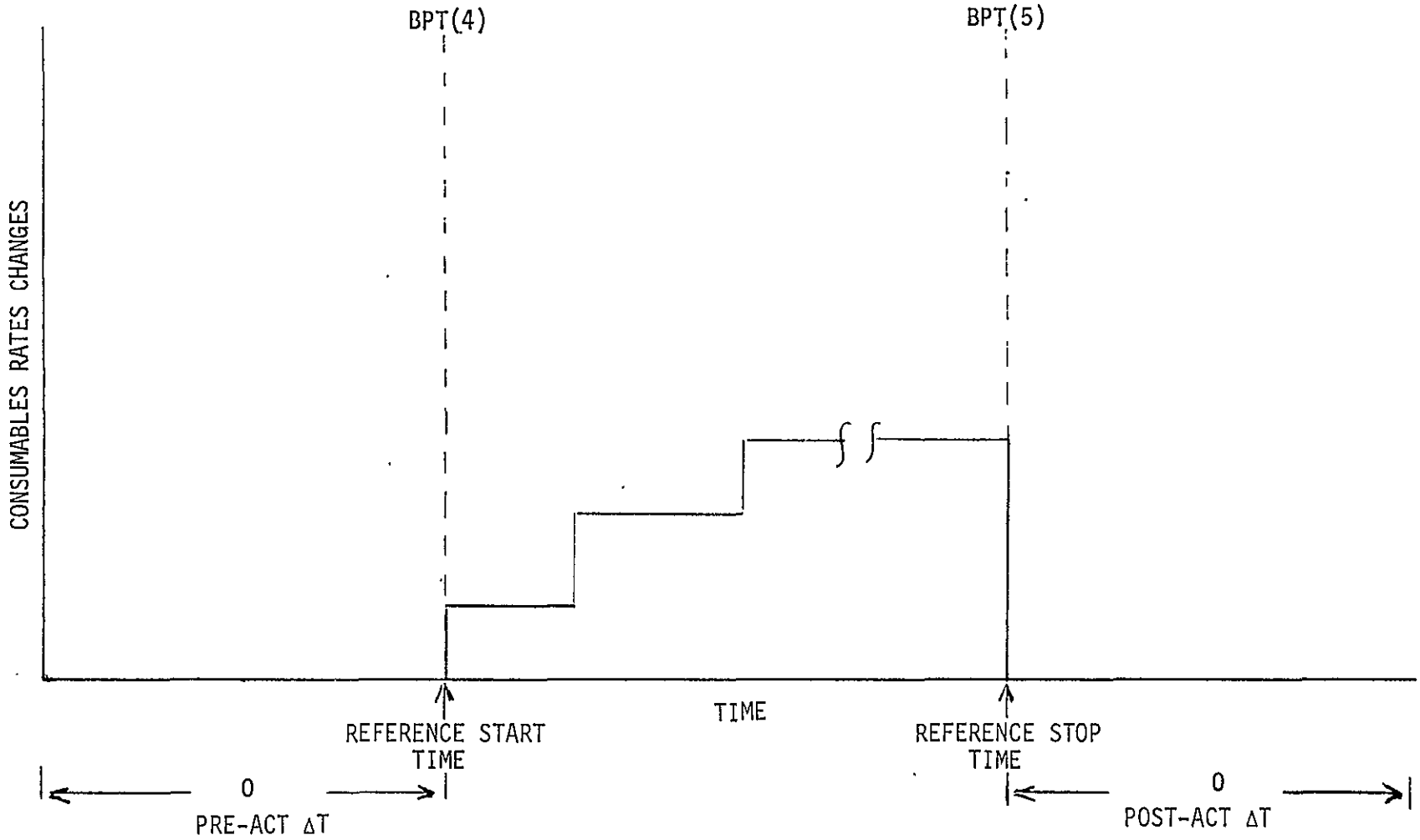
This activity spans from MECO to Insertion and includes the consumables requirements as given in Figure 3-25.4 and Table 3-XXV.4, which are:

EPS - The electric power required for the electronic equipment operation.

RCS - The propellant quantity required for ETS, 4 fps ΔV, is entered as an equivalent acceleration of 800 ft/(sec-hr) for a period of .006 hours.

APU - The fuel and water required to maintain operational the APUs during this time period.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY MECO-ETS



NUMBER OF OPERATIONS: K 0 ; J 3 ; L 0 ; N 3 (TOTAL)

Figure 3-25.4. Post Ascent Profile

Table XXV.4. Post Ascent Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY POST ASCENT

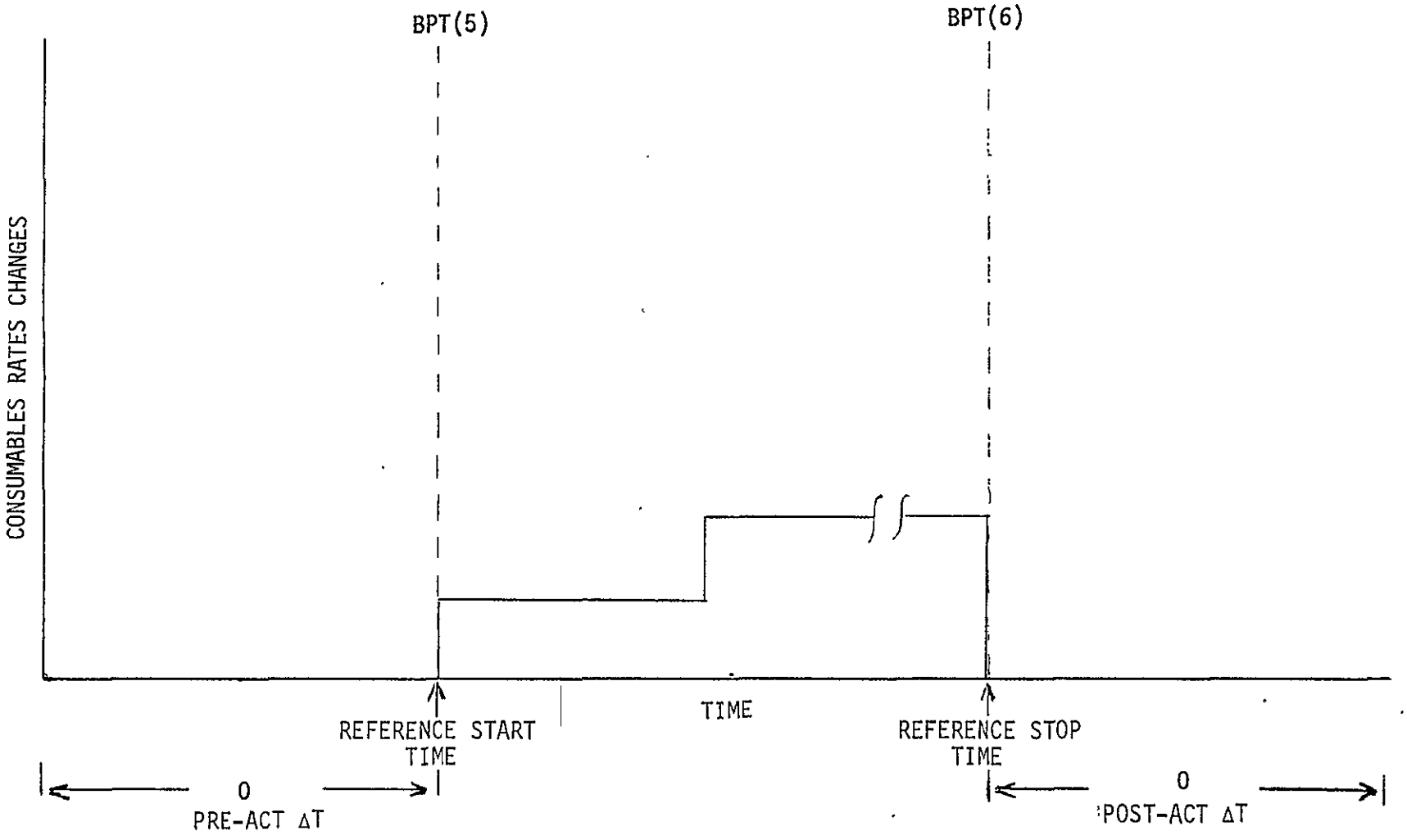
N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		.0144	17,805.12	-						329.096	91.64
2		✓		.006	17,805.12	800.0						329.096	91.64
3		✓		≈	17,805.12	-						329.096	91.64

REMARKS:

3.25.2.5 INSERTION (INSERTION TO ORBIT)

This activity covers the Insertion to Orbit period and includes in addition to the electrical power consumables, the fuel and water required for APUs operation. Figure 3-25.5 and Table 3-XXV.5 include this sub-activity profile and consumables rates.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY INSERTION



NUMBER OF OPERATIONS: K 0 ; J 2 ; L 0 ; N 2 (TOTAL)

Figure 3-25.5. Insertion Profile

Table 3-XXV.5. Insertion Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY INSERTION

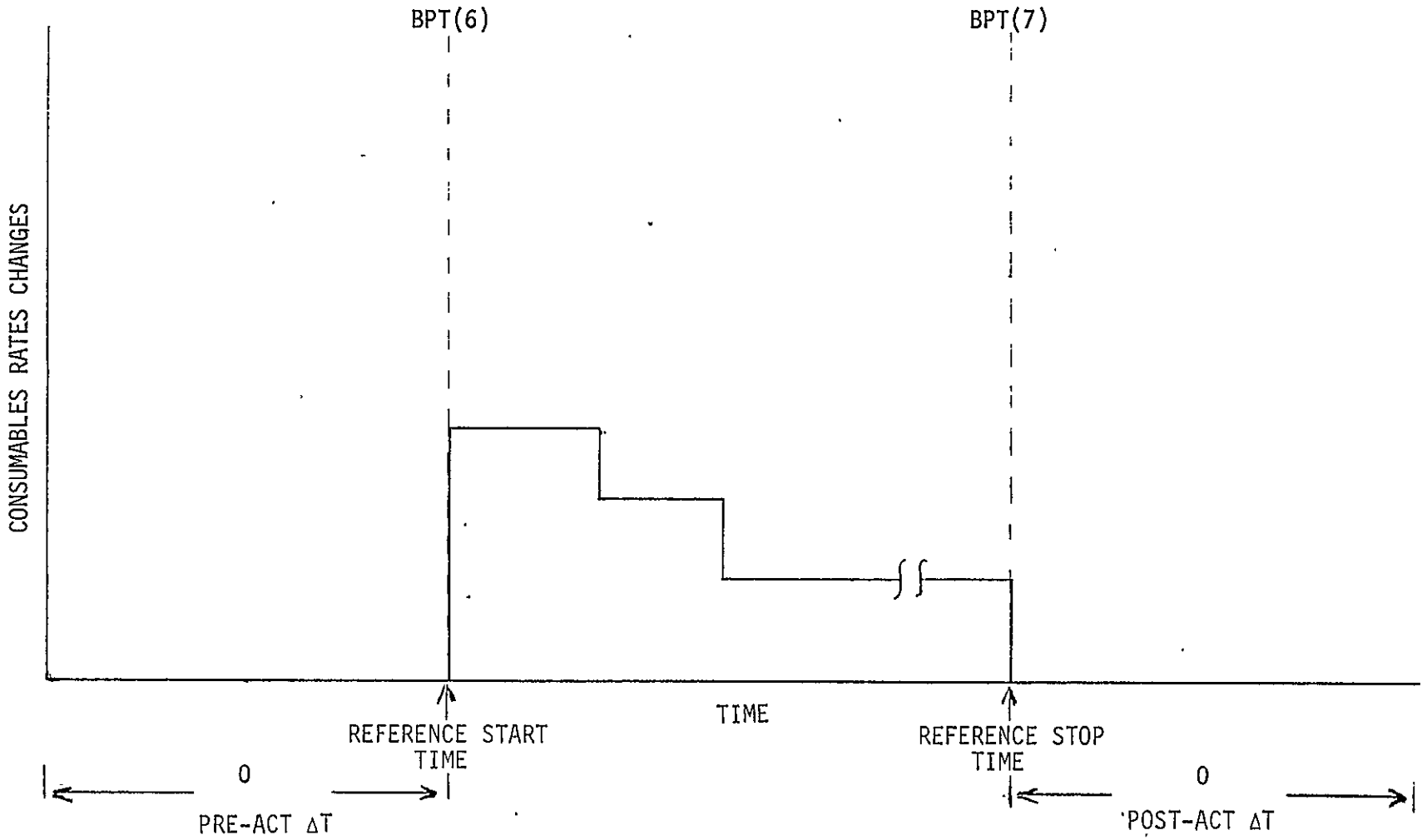
N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		0.33	10,996.46							329.096	91.64
2		✓		~	10,966.46							-	-

REMARKS:

3.25.2.6 ON-ORBIT (ON-ORBIT TO DEORBIT PREP)

The consumables requirements for this activity consist of the electrical power required to provide the crew life support functions and to maintain the spacecraft operational in conjunction with the Common activity (3.25.2.1). The profile and consumables rates are given in Figure 3-25.6 and Table 3-XXV.6. The decreasing power levels seen at the start of the activity correspond to the reconfiguration of the spacecraft subsystems at the completion of the Ascent and Orbit Insertion operations.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY ON-ORBIT



NUMBER OF OPERATIONS: K 0 ; J 3 ; L 0 ; N 3 (TOTAL)

Figure 3-25.6. On-Orbit Profile

Table 3-XXV.6. On-Orbit Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY ON-ORBIT

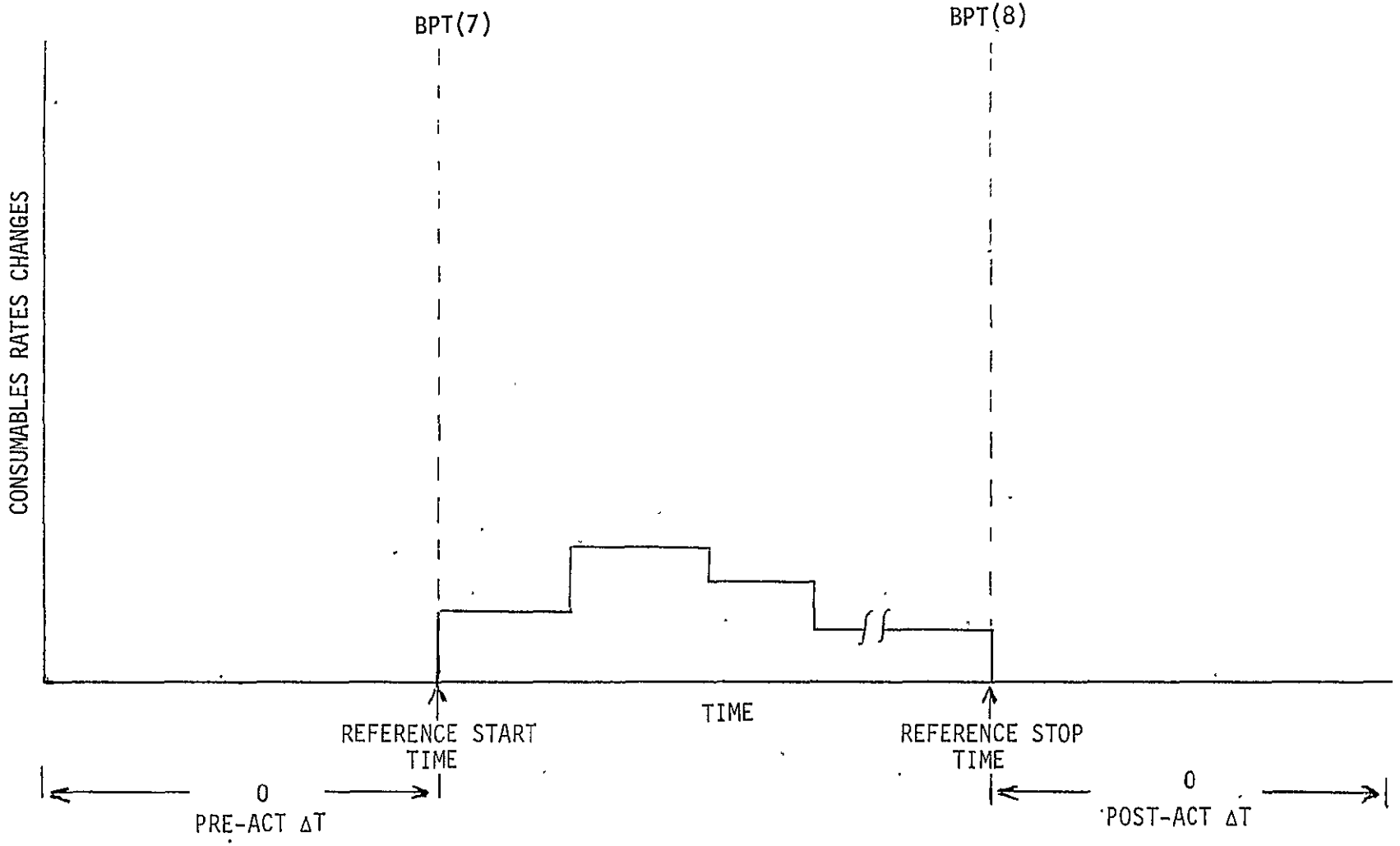
N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		.227	10,706.46								
2		✓		1.273	8,624.11								
3		✓		≈	3,889.88								

REMARKS:

3.25.2.7 DEORBIT PREPARATION (DEORBIT PREP TO DEORBIT BURN

The objective of this activity is the configuration of the Shuttle subsystems to perform the deorbit and entry operations. The activity includes a 0.133 hours checkout of the APUs required in preparation for the deorbit and entry phase, and an IMU alignment. The activity profile and consumables rates are given in Figure 3-25.7 and Table 3-XXV.7.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY DEORBIT PREP



NUMBER OF OPERATIONS: K 0 ; J 4 ; L 0 ; N 4 (TOTAL)

Figure 3-25.7. Deorbit Preparation Profile

Table 3-XXV.7. Deorbit Preparation Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY DEORBIT PREP

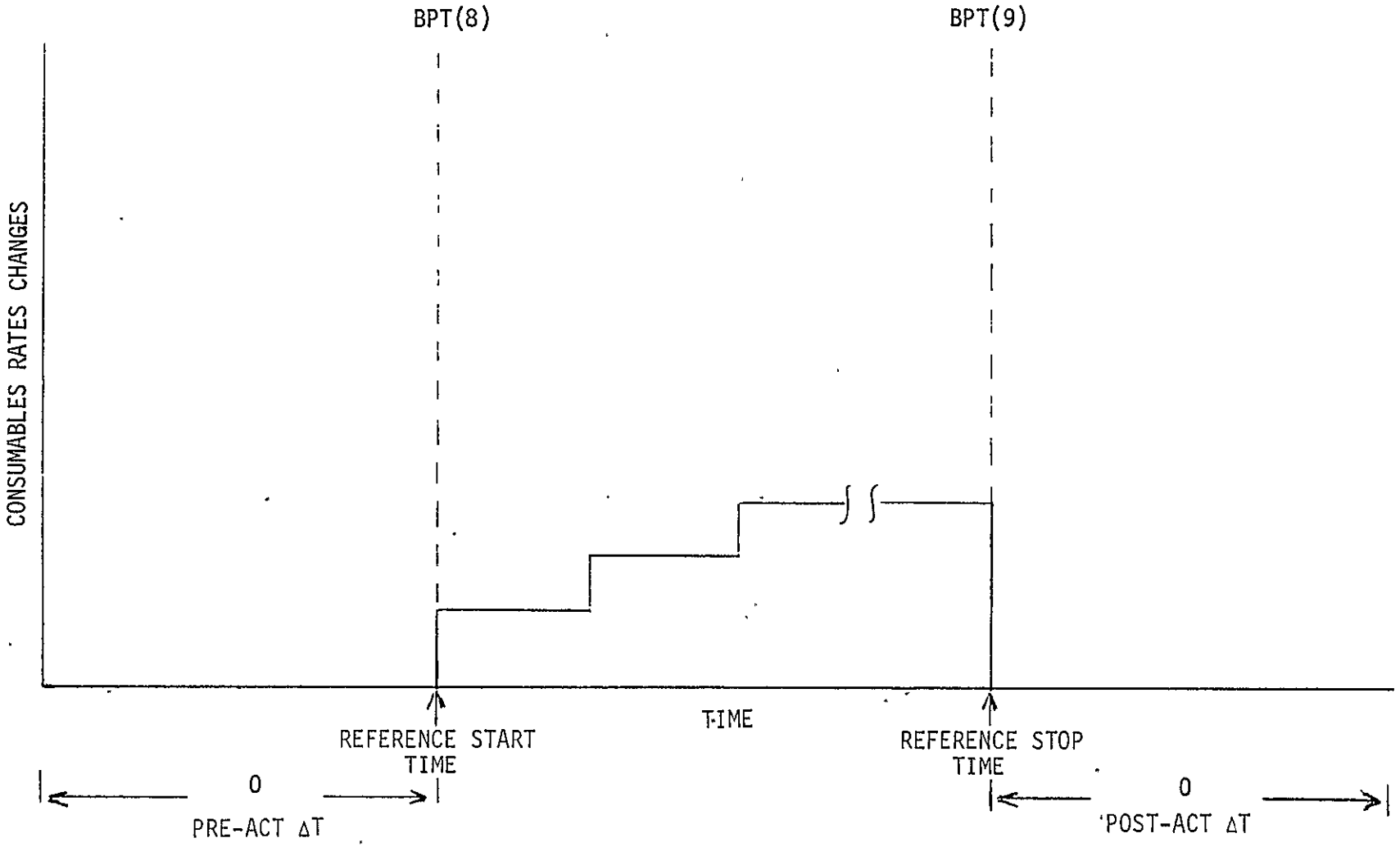
N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL :#/HR	H_2O #/HR
1		✓		.133	7990.12							853.76	264.85
2		✓		1.033	7990.12							-	-
3		✓		.13	7990.12							-	-
4		✓		~	7990.12							-	-

REMARKS:

3.25.2.8 DEORBIT (DEORBIT TO ENTRY INTERFACE)

The objective of this activity is to effect the deorbit of the Shuttle Spacecraft by the use of the OMS propulsion system. The activity includes in addition to the deorbit maneuver, the operation of the APUs systems in preparation of the entry phase. The consumables requirements and their associated rates are included in Figure 3-25.8 and Table 3-XXV.8. The OMS propellant quantity allocated for the deorbit burn will be calculated in the MPP from the ΔV specified by the user. The propellant requirements from the RCS system are entered as an equivalent acceleration of 9.58 ft/(sec-hr) for a period of .167 hours. The RCS system is used to place the Shuttle in the deorbit attitude.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY DEORBIT



NUMBER OF OPERATIONS: K 0 ; J 3 ; L 0 ; N 3 (TOTAL)

Figure 3-25.8. Deorbit Profile

Table 3-XXV.8. Deorbit Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY DEORBIT

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		.167	9494.56	9.58						-	-
2		✓		.202	9494.56	-						-	-
3		✓		~	9494.56	-						234.902	76.95

REMARKS:

3.25.2.9 ENTRY (ENTRY INTERFACE TO SR)

This activity includes the consumables requirements from entry interface to stop roll out and are constituted in addition to the electrical power to the fuel and water required for the APUs operation. Figure 3-25.9 and Table 3-XXV.9 present the profile and consumables rates.

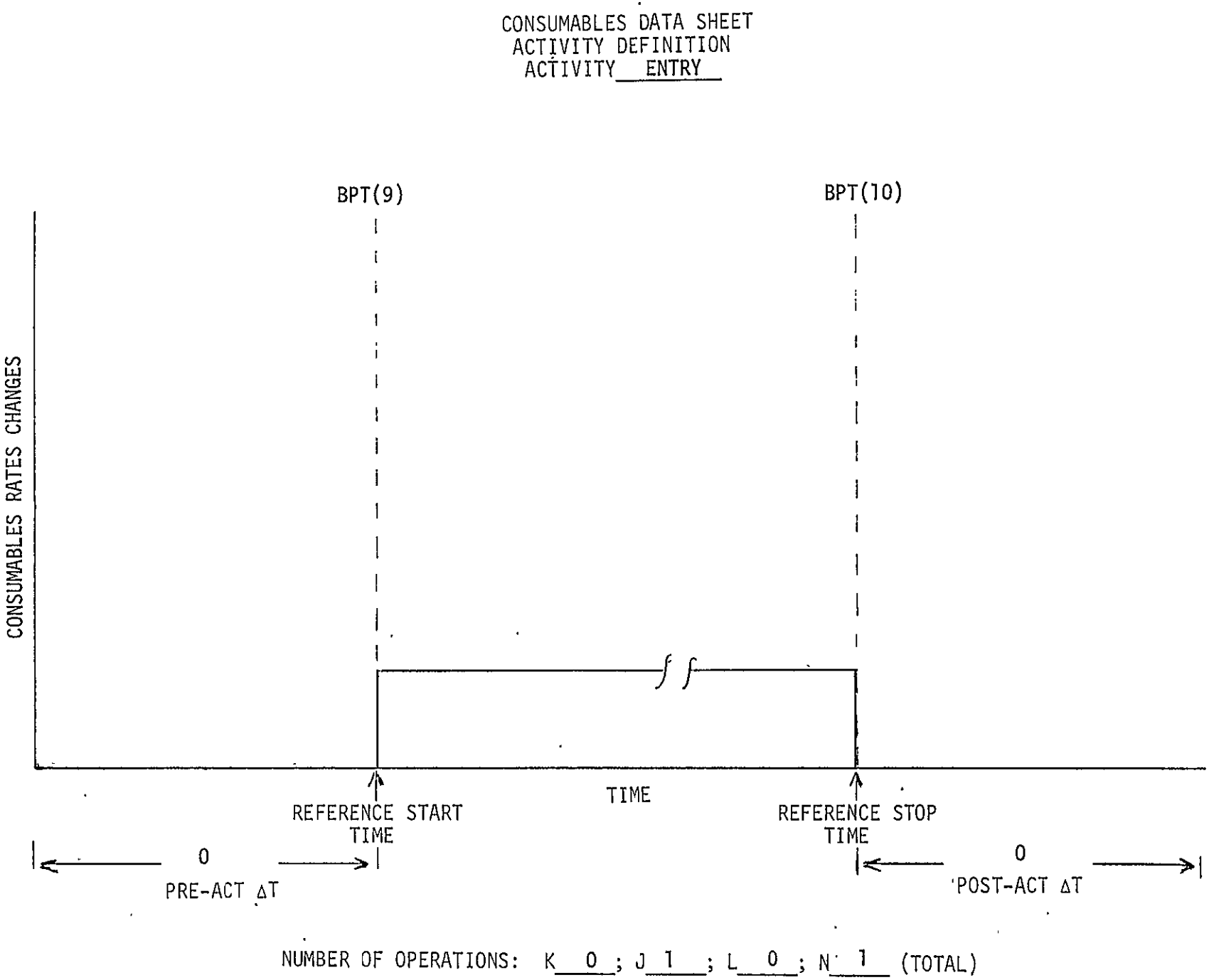


Figure 3-25.9. Entry Interface Profile

Table 3-XXV.9. Entry Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY ENTRY

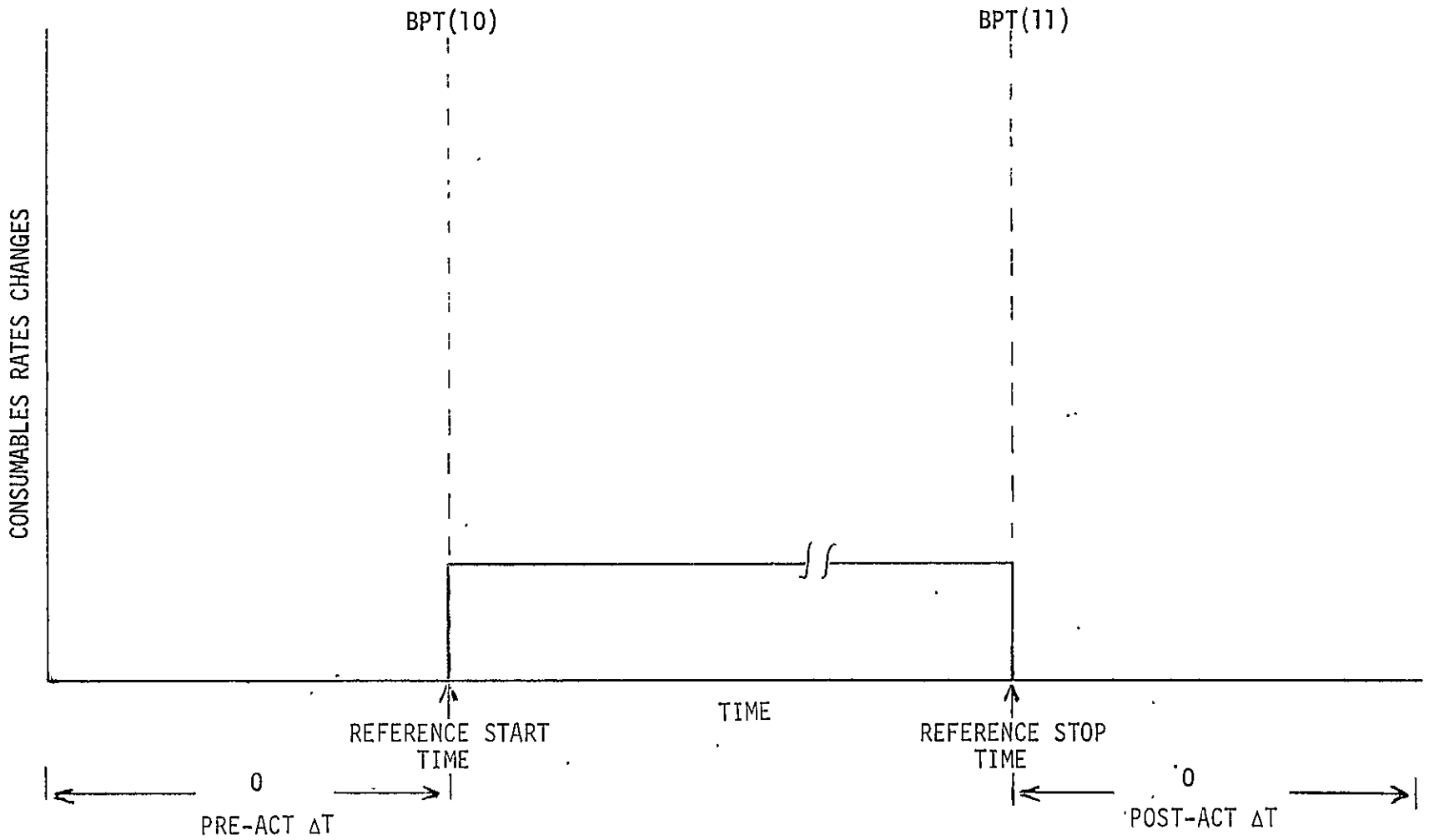
N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		≈	9529.56							234.902	76.95

REMARKS:

3.25.2.10 LANDING (STOP ROLL OUT TO GSE)

This activity includes the consumables for the last mission activity and spans from stop roll out to the transfer to the GSE power. The profile and consumables rates are included in Figure 3-25.10 and Table 3-XXV.10.

CONSUMABLES DATA SHEET
ACTIVITY DEFINITION
ACTIVITY LANDING



NUMBER OF OPERATIONS: K 0 ; J 1 ; L 0 ; N 1 (TOTAL)

Figure 3-25.10. Landing Profile

Table 3-XXV.10. Landing Consumables Rates

CONSUMABLES DATA SHEET
ACTIVITY LANDING

N	K	J	L	ΔT (HRS)	CONSUMABLES RATES								
					EPS	RCS	OMS	ECS				APU	
					WATTS	A FT/SEC-HR	A FT/SEC-HR	O_2 #/HR	N_2 #/HR	H_2O #/HR	LiOH CAN/HR	FUEL #/HR	H_2O #/HR
1		✓		~	14,446.41								

REMARKS:

4. DATA SOURCES

The data used for the development of the activities presented in Section 3.0 was derived from the following:

a) EPS - The activities profiles and EPS consumables rates were constructed using the activities definition contained in the SOURCE Data Base activity blocks (Reference 6), and the timeline information used for the development of the OFT-1 consumables analyses presented in Reference 7. Table 4-I is herein included as a cross reference of the activities as presented in this appendix and the referenced documents.

b) ECS - ECS consumables rates such as metabolic oxygen and water consumption, atmospheric leakage rates, etc., were taken from Reference 7.

c) OMS/RCS - The OMS/RCS consumables rates correspond to those developed in Reference 1.

Table 4-I. Activity Cross Reference

NO.	ACTIVITY NAME	SOURCE (REFERENCE 6) BLOCK ACTIVITY NUMBER
1	OMS MANEUVER	301, 407
2	RCS TRANSLATION	303, 305
3	ATTITUDE HOLD	309
4	RENDEZVOUS	409
5	STATION KEEPING	405
6	DOCK	411
7	UNDOCK	413
8	PTC	301
9	EVA	417, 419
10	IVA	415
11	MANIPULATOR OPERATIONS	451, 453
12	IMU ALIGNMENT	407
13	PAYLOAD BAY DOORS	435, 437
14	PAYLOAD CONSUMABLES	NOT DEFINED
15	COMPUTER	N/A
16	TV	421
17	DOWNLINK	N/A
18	UPLINK	N/A
19	FUEL CELL PURGE	431
20	EAT	423
21	SLEEP	427, 429
22	WASTE MANAGEMENT	425

Table 4-I. Activity Cross Reference (Concluded)

NO.	ACTIVITY NAME	SOURCE (REFERENCE 6) BLOCK ACTIVITY NUMBER
23	APU CHECKOUT	207
24	RESERVED	N/A
25.1	COMMON (GSE TO GSE)	101
25.2	PRELAUNCH (GSE TO LIFTOFF)	103, 201, 203, 207
25.3	ASCENT (LIFTOFF TO MECO)	103, 201, 203, 207, 121, 303, 205, 311
25.4	POST-ASCENT (MECO TO INSERTION)	103, 207, 121, 303, 205, 209, 307, 311
25.5	INSERTION (INSERTION TO ORBIT)	207, 121, 307, 105, 309, 401, 107, 403
25.6	ON-ORBIT (ON-ORBIT TO DEORBIT PREP)	121, 105, 309, 107, 403
25.7	DEORBIT PREP (DEORBIT PREP TO DEORBIT)	433, 507, 109, 301, 111, 121, 309
25.8	DEORBIT (DEORBIT TO ENTRY INTERFACE)	507, 109, 301, 111, 501, 503, 121
25.9	ENTRY (ENTRY INTERFACE TO SR)	507, 109, 111, 503, 509, 121
25.10	LANDING (SR TO GSE)	507, 109, 505, 121

REFERENCES

1.* Functional Requirements for Ground Support of Consumables Subsystem Management, Technical Report for Contract NAS 9-14264, October 1975, TRW Systems Group, Houston.

2. Study of Existing Analytical Models for STS Consumables Management, Technical Report for Contract NAS 9-14264, February 1976, TRW Defense and Space Systems Group, Houston.

3.* Formulation of Detailed Consumables Management Models for the Development (Preoperational) Period of Advanced Space Transportation System, Technical Report for Contract NAS 9-14264, May 1976, TRW Defense and Space Systems Group, Houston.

4. Formulation of Detailed Consumables Management Models for the Development (Preoperational) Period of Advanced Space Transportation System, Technical Report for Contract NAS 9-14264, August 1976, TRW Defense and Space Systems Group, Houston.

5.* A Suggested Classification System for Standard On-Orbit Shuttle Flight Phases, Technical Report for Contract NAS 9-14723, January 1976, TRW Defense and Space Systems Group, Houston.

6.* Orbiter Electrical Equipment Utilization Baseline, Draft, JSC IN 76-FM- , July 1976.

7.* EPS/ECLSS Consumables Analyses for the OFT-1 Conceptual Flight Profile, JSC IN 76-FM-32, May 1976.

* Referenced in this Volume