NASA TECHNICAL MEMORANDUM

NASA TM-82460

MANAGEMENT AND CONTROL OF SELF-REPLICATING SYSTEMS: A SYSTEMS MODEL

By Georg von Tiesenhausen
Program Development

February 1982

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

(NASA-TM-82460) MANAGEMENT AND CONTROL OF SELF-REPLICATING SYSTEMS: A SYSTEMS MODEL (NASA) 36 p HC A03/MF A01 CSCL 12B

N82-25892

Unclas
G3/66 27923

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TM-82460	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Management and Control of Self-Replicating Systems: A Systems Model		5. REPORT DATE February 1982
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Georg von Tiesenhausen		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by Program Development.

16. ABSTRACT

In 1980, a conceptual engineering approach to self-replicating systems was achieved by von Tiesenhausen and Freitas. Their designs are based on von Newmann's kinematic version of self-replicating automata. This report expands on the systems management and control and the organization of the control elements. After developing the functional requirements of such a system, a hierarchy of three management and control levels is described. These are an autonomous, an external, and an intelligent management and control system. Systems recycling, systems specialization, and information replication are discussed.

17. KEY WORDS Self-replication Autonomous systems	18. DISTRIBUTION STATEMENT Unclassified — Unlimited

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	35	NTIS

MSFC - Form 3292 (Rev. December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22161

ACKNOWLEDGEMENTS

I am deeply indebted to Dr. Robert A. Freitas, Jr., Xenology Research Institute, Sacramento, California, for his advice and critique, his numerous suggestions and raising of key questions during the conception of this report. I am particularly grateful for his time and efforts in assisting to organize the material and for his editorial help. My great appreciation and thanks go to Professor Richard Laing, University of Oregon, for his review of the manuscript, his continual encouragements, and stimulating ideas and discussions on potential machine behavior. The work by H. von Ditfurth: "Der Geist Fiel Nicht vom Himmel" (The Evolution of our Mind) which describes the self-management and control of biological systems gave substantial stimulus to the development of the concept described in this report.

FOREWORD

In 1980, conceptual engineering approaches to self-replicating systems were achieved by von Tiesenhausen [1] and Freitas [2]. Their designs are based on von Newmann's [3] kinematic version of self-replicating automata. The references [1,2] describe the functional elements of such a system for the first time.

This report expands on a specific area involved in a self-replicating system according to Reference 1: the systems management and control and the organization of control elements. It is a very first approach to a rather complex problem solution. It is intended to provide only an outline of some of the aspects of the problem as presently conceived, and makes no pretense to be definitive or comprehensive.

It is hoped, however, that the presented approach will be of interest, provide comments, and stimulate further work in this area.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM

MANAGEMENT AND CONTROL OF SELF-REPLICATING SYSTEMS: A SYSTEMS MODEL

I. INTRODUCTION

This report addresses a concept for the management and control of Self-Replicating Systems (SRS). Discussions of the engineering feasibility of SRS have already appeared in the literature [1,2]. The purpose of the present work is to provide insight into the complex management and control requirements of such systems and to stimulate further work in this area.

The concept outlined here is based upon the SRS model developed in an earlier work [1]. This model, depicted schematically in Figures 1, 2, and 3, represents a fully autonomous, general-purpose factory which can be deployed on the surfaces of planetary bodies. Surface material is mined by excavation robots. The raw stock is delivered to a materials processing (MP) subsystem which generates and transports industrial feedstock to a parts production (PP) subsystem whose output is machines or additional components. These parts are then used either to produce useful output or are passed to a "universal constructor" (UC) subsystem for the construction of a duplicate factory complex nearby. Useful factory output is collected by the end product assembly system (EPS), and unitary energy systems (ES) provide electrical power.

SRSs behave much like biological systems, so the management and control systems described in this report have certain parallels with biological models (Fig. 4). A single SRS unit is a system that contains all elements required to maintain itself, to manufacture desired products, and to self-reproduce -- the analogue of a biological cell. An undifferentiated SRS field exists after self-replication has generated a number of identical replicas that manufacture identical products -- much like the structure of biological tissue. Finally, a differentiated SRS field consists of a number of undifferentiated SRS fields integrated to provide elements for a common end product -- analogous to biological organs.

II. SUMMARY OF FUNCTIONAL REQUIREMENTS FOR SRS

The functional requirements for the successful design, development, deployment, and operation of an SRS are many, but among the most basic are the need to process information, energy, and matter to permit both self-replication and useful industrial production. The following discussion presents a useful taxonomy of organizational levels for SRS factories and the required information, energy, and matter processing functions at each level.

NOMENCLATURE

MP – MATTER PROCESSING
MD – MATTER DEPOT
PP – PARTS PRODUCTION
PDR – PARTS DEPOT – REPLICATION
PDP – PARTS DEPOT – PRODUCTS
PF – PRODUCT FACTORY
PD – PRODUCT DEPOT
PRS – PRODUCT RETRIEVAL SYSTEM
UC – UNIVERSAL CONSTRUCTOR

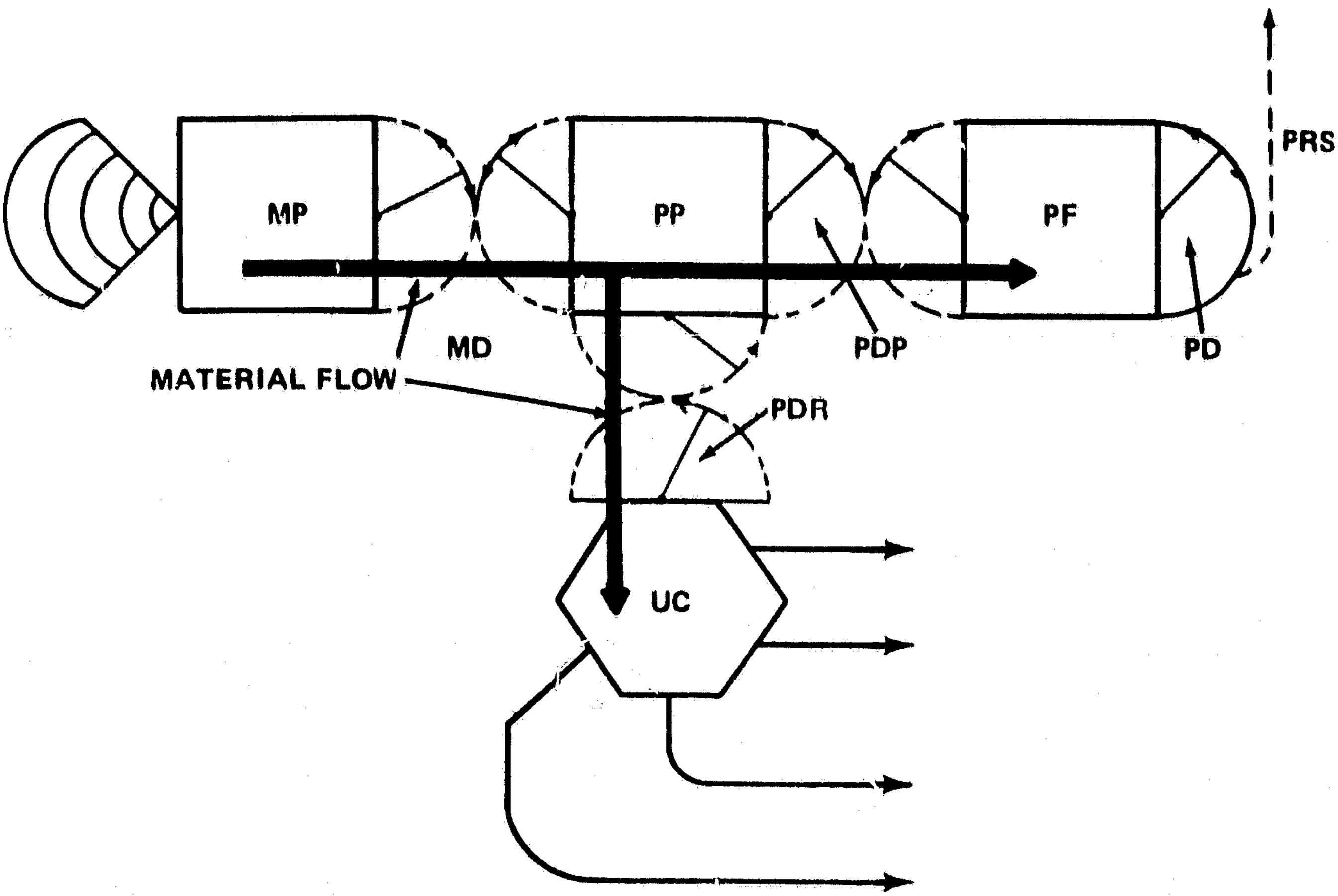


Figure 1. Schematic of a self-replication system [1].

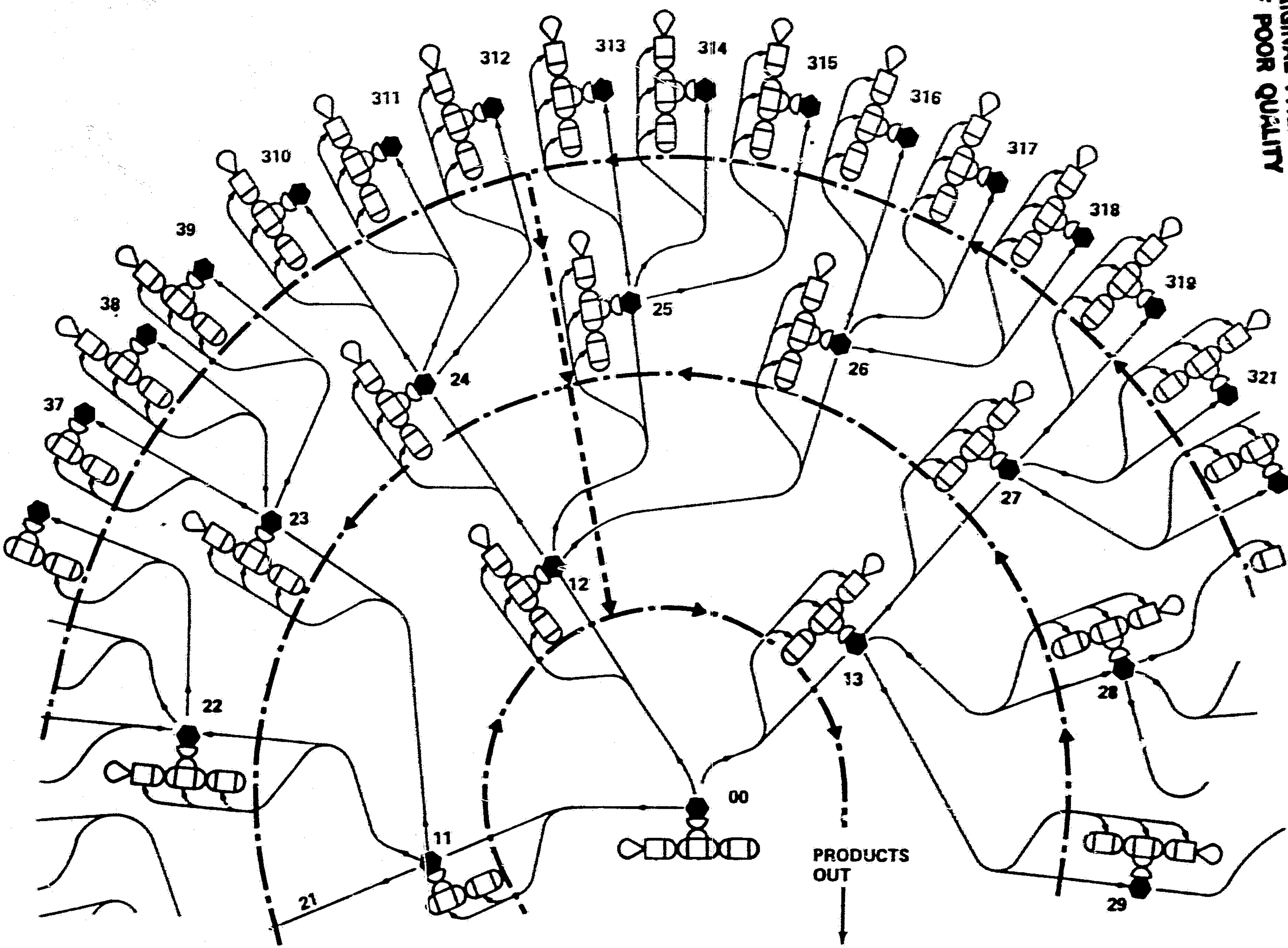


Figure 2. SRS growth plan (detail) [1].

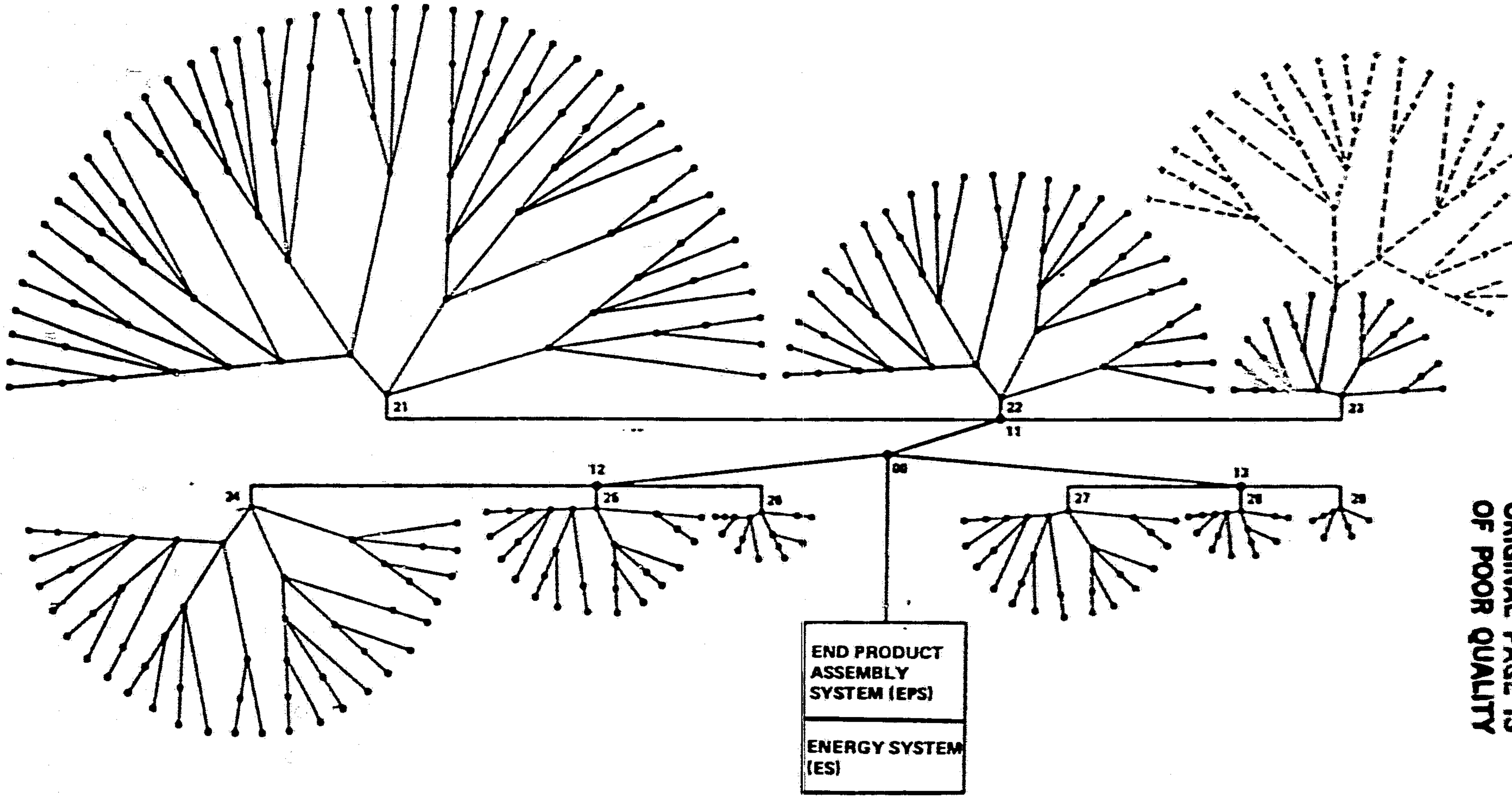


Figure 3. SRS growth plan (overview) [1].

SRS CONFIGURATIVE RELATIONS

SRS	BIO. SYSTEM
SINGLE UNIT	CELL
UNDIFFERENTIATED FIELD	TISSUE
DIFFERENTIATED FIELD	ORGAN

SRS FUNCTIONAL RELATIONS

SRS	BIO–SYSTEM	
	CELLS AND TISSUES	ORGANS
INFORMATION PROCESSING	DNA	BRAINSTEM — AUTONOMOUS FUNCTIONS UPPER MID BRAIN — ENVIRON. FUNCTIONS CEREBRUM — INTELLIGENT FUNCTIONS
ENERGY PROCESSING	ATP	ATP, MUSCLES
MATTER PROCESSING	RNA LYSOSOMES, MEMBRANES	DIGESTIVE SYSTEM

Figure 4. Biological analogy of SRS.

A. SRS Organizational Levels

The overall organizational structure of SRS fields has been divided into four Operational Levels as shown in Figure 5. Single SRSs are the simplest and belong to Level I. The SRS is an autonomous system which processes information and energy to convert raw material into products and into replicas of itself (Fig. 6). The fundamental responsibility of a Level I SRS management and control system is the maintenance of a fully functional SRS under all foreseeable circumstances. This requirement nominally overrides any other, depending on the degree of complexity of the particular SRS and on the available knowledge and predictability of the environment in which the SRS is to function.

LEVEL	ORGANIZATION	COMPOSITION
IV	SEVERAL DIFFERENTIATED SRS FIELDS	SEVERAL SYSTEMS OF LEVEL III
III	SINGLE DIFFERENTIATED SRS FIELD	SEVERAL SYSTEMS OF LEVEL II
II	UNDIFFERENTIATED SRS FIELD	NUMEROUS SYSTEMS OF LEVEL I
I	SINGLE SRS	

Figure 5. SRS field systems structure.

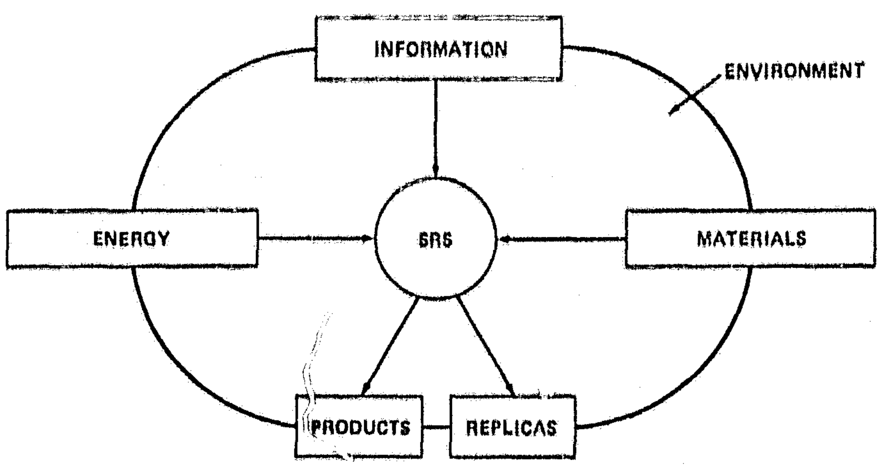


Figure 6. Basic SRS functions.

A field of identical SRSs is a Level II organization. The function of these fields consists of the combined individual functions of all SRSs comprising the field. These functions run essentially in parallel and independent from each other. The only connecting link between the individual SRSs are the End Product Collection System which gathers the individual, identical products at the collection point for further action, and the Energy System which is centralized and supplies all individual SRSs with electrical energy [1].

There can be several different Level II organizations, each one distinguished by a different product. Several of these can be combined into a differentiated SRS field which then forms a Level III organization (Fig. 7). These may consist either of individual SRSs, each of which manufactures a different product or subassembly of a larger product, or may consist of numerous undifferentiated SRS fields with different products or subassemblies coming from each -- products are either final output or they must be further assembled into larger entities.

These three Levels comprise the major forms of replicating systems organization involving individual SRSs, undifferentiated and differentiated fields (Fig. 8). One could also conceive of a Level IV organization that combines a number of Level III fields. Level IV is not covered here.

B. Three Basic SRS Functions

An SRS performs the following three basic functions:

1) Information processing

2) Energy processing

3) Matter processing.

These processes are interdependent and must be integrated with each other. They must be carried out on each Level but with a different scope of activity in each case (Fig. 9).

The heart of SRS management and control is information processing. This guides the processing of bulk energy and raw materials which is employed to achieve self-replication and useful production. Specific management and control information processing requirements for each organizational level are given in Figure 10.

For reasons of efficient self-replication, a central solar photovoltaic energy conversion system is assumed to exist, to which each individual SRS has contributed its share [1]. This system is supplemented with a chemical energy storage system. The distribution of electrical energy to the individual SRSs and within each SRS is by cable or microwave. Within each SRS the electrical energy is converted into the desired alternate energy forms -- whether mechanical, thermal, plasmic, or electromagnetic (Fig. 11). The specific management and control requirements for energy systems are outlined in Figure 12.

An SRS has a complex metabolism [1,2]. At one end raw material is gathered, followed by analysis which separates the desired elements and compounds from the incoming bulk material. Subsequent steps involve the synthesis of specific materials, the production of feedstock and parts, followed by the assembly of products and replicas. Systems maintenance and repair also use specific parts. Waste material is

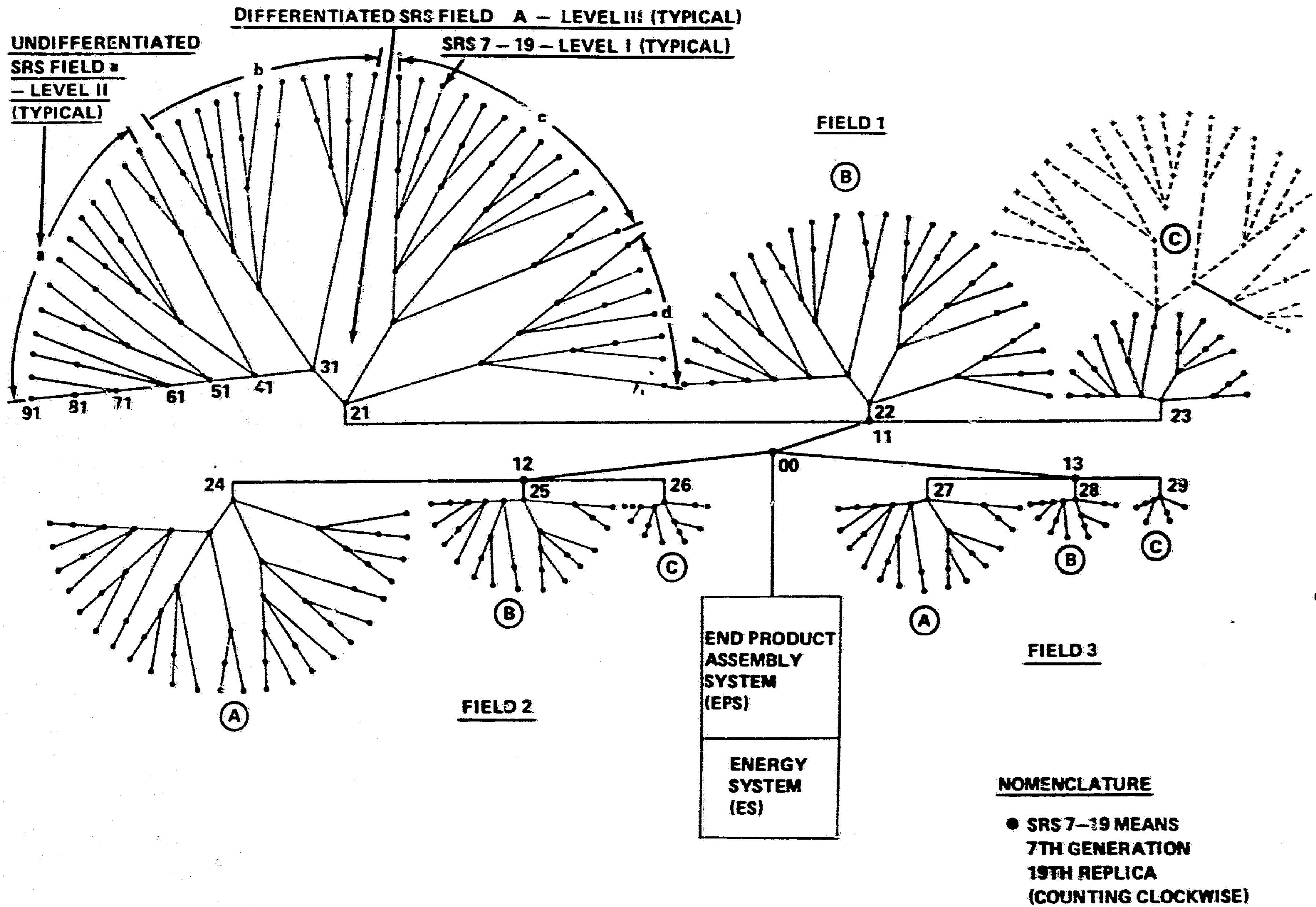


Figure 7. SRS field organizations.

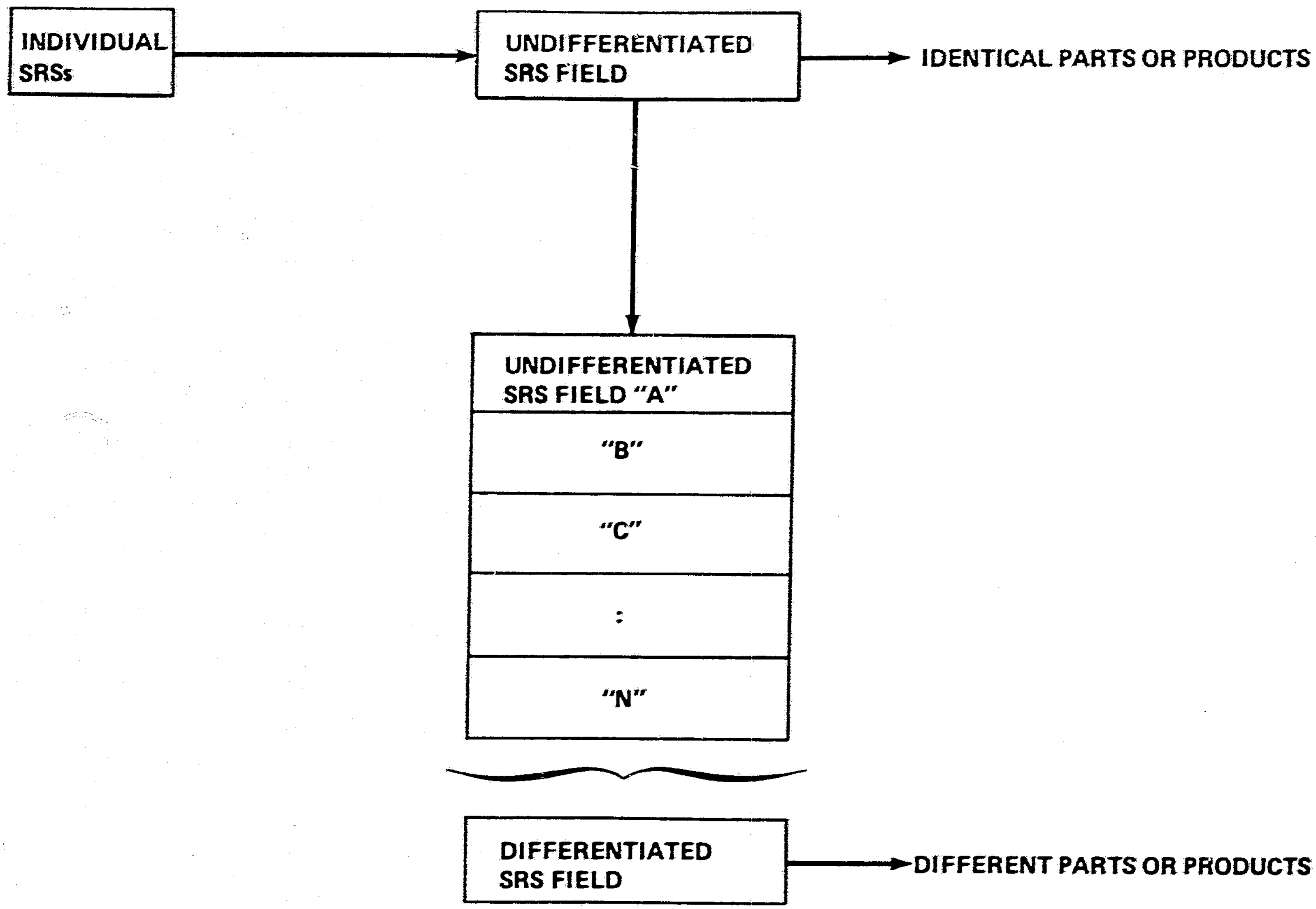


Figure 8. SRS organizations.

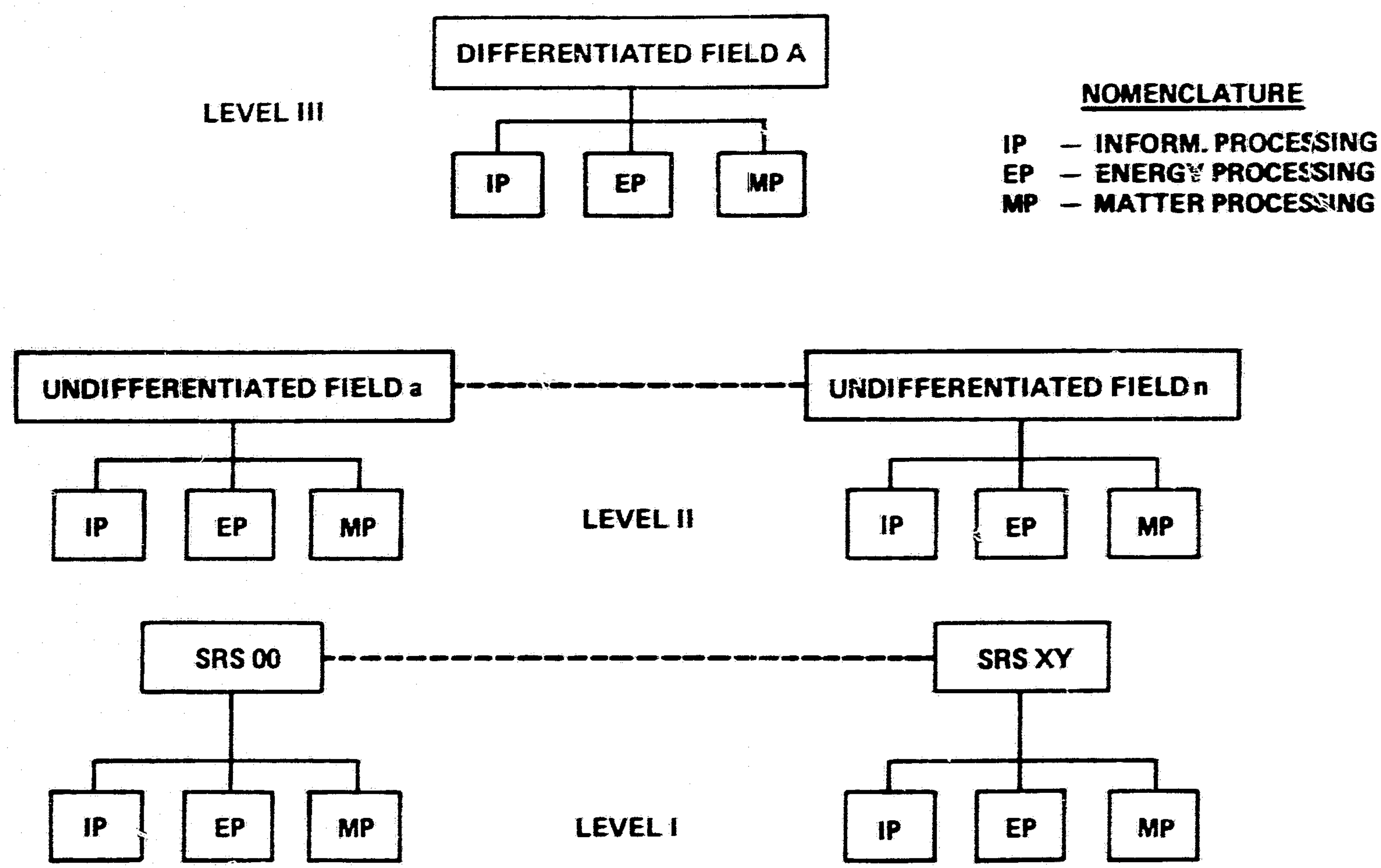


Figure 9. Functions within SRS organizational levels.

LEVEL I – THE INFORMATION THAT MUST BE AVAILABLE TO AN INDIVIDUAL SRS HAS TO FULFILL THE FOLLOWING REQUIREMENTS:

- FUNCTIONAL MANAGEMENT AND CONTROL OF ALL INTERNAL SRS SYSTEMS, SUBSYSTEMS, SEQUENCES AND FUNCTIONAL ELEMENTS, AND SYNCHRONIZATION AND BALANCING OF ALL SRS OPERATIONAL AND FUNCTIONAL CONDITIONS AND EVENTS. THIS INCLUDES SELF-MAINTENANCE AND REPAIR FUNCTIONS.
- PROPER RESPONSE TO CRITICAL EXTERNAL ENVIRONMENTAL SITUATIONS AND EVENTS AND THEIR COORDINATION WITH INTERNAL MANAGEMENT AND CONTROL FUNCTIONS. THIS INCLUDES THE REPRODUCTIVE CYCLE.
- OPTIONAL FOR SPECIAL CASES – AUTONOMOUS DECISION-MAKING AND PROBLEM-SOLVING IN UNPROGRAMMED SITUATIONS AND EVENTS AND COORDINATION WITH INTERNAL AND EXTERNAL CONDITION MANAGEMENT SYSTEMS.

THE INFORMATION PROCESSING SUBSYSTEM MUST BE CAPABLE OF SERVING EACH REPLICA DURING THEIR CONSTRUCTION PHASE UNTIL THEIR AUTONOMY HAS BEEN ESTABLISHED THROUGH THEIR OWN INFORMATION PROCESSING SUBSYSTEM.

LEVEL II – MANAGEMENT AND CONTROL INFORMATION WHICH MUST BE AVAILABLE IN UNDIFFERENTIATED SRS FIELDS INCLUDE THE FOLLOWING:

- RATE OF FIELD GROWTH AND INSTANTANEOUS NUMBER OF SRS'S CONTROL.
- PRODUCTION RATE GROWTH AND INSTANTANEOUS PRODUCTION RATE CONTROL.
- TERMINATION OF FIELD GROWTH WHEN PLANNED PRODUCTION CAPACITY HAS BEEN ACHIEVED.
- PROVIDE REPROGRAMMING SERVICE IF REPRODUCTION ERRORS (MUTATIONS) OCCUR IN INDIVIDUAL SRS UNITS.
- CONTROL OF THE ENERGY SYSTEM (ES) PARTS TRANSPORT FROM SRS ASSEMBLY.
- CONTROL OF THE EPS, INCLUDING PARTS TRANSPORT FROM SRS ASSEMBLY.
- POWER DISTRIBUTION TO EACH SRS.

LEVEL III – MANAGEMENT AND CONTROL INFORMATION NECESSARY FOR DIFFERENTIATED SRS FIELDS INCLUDES:

- BALANCING AND SYNCHRONIZATION OF THE DIFFERENT PART PRODUCTIONS AND THEIR TRANSPORT TO THE CENTRAL EPS.
- MANAGEMENT AND CONTROL OF THE CENTRAL EPS.
- COORDINATION OF ALL LEVEL II INFORMATION PROCESSING.

Figure 10. Management and control functions in information processing.

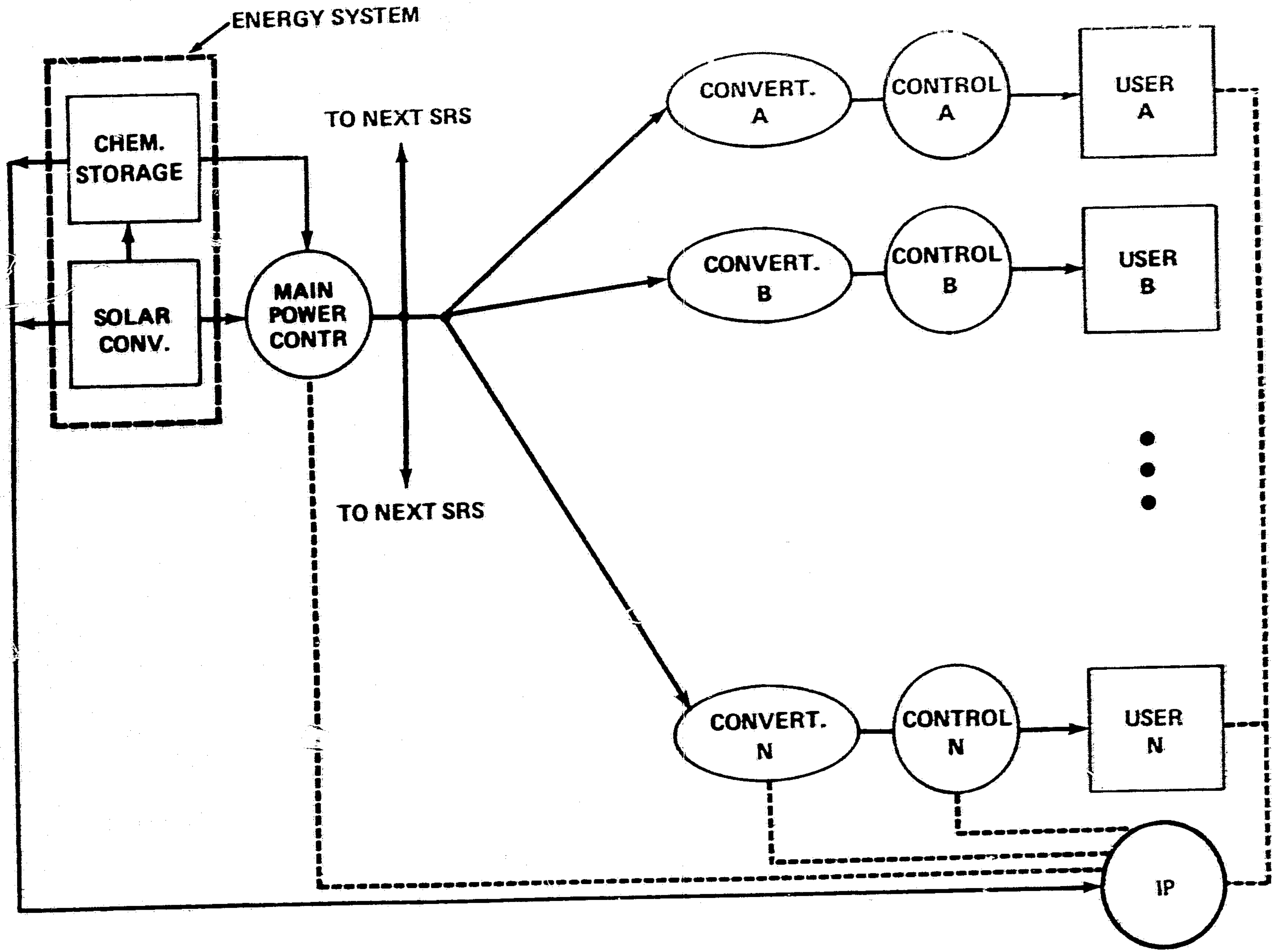


Figure 11. SRS energy processing (EP).

LEVEL I – SINCE EACH SRS RECEIVES POWER FROM THE CENTRAL ENERGY SYSTEM VIA A MAIN POWER CONTROL, THE LEVEL I REQUIREMENTS ARE:

- POWER RECEPTION, CONDITIONING, AND CONVERSION AND CONTROL AS REQUIRED BY THE VARIOUS SRS "USER" SUBSYSTEMS.
- POWER SUPPLY TO THE SRS REPLICAS UNTIL THEIR POWER RECEIVING STATION HAS BECOME OPERATIONAL.

LEVEL II – THE CENTRAL POWER SUPPLY MANAGEMENT FOR UNDIFFERENTIATED SRS FIELDS IS SITUATED AT THIS LEVEL.

LEVEL III – AT THIS HIGHEST LEVEL, THE POWER SUPPLY BALANCE IS COORDINATED AND CONTROLLED. IN A DIFFERENTIATED SRS FIELD, THERE IS ONE CENTRALIZED ENERGY PROCESSING SYSTEM FOR EACH UNDIFFERENTIATED SRS FIELD CONTAINED WITHIN IT.

Figure 12. Management and control functions in energy processing.

gathered and either discarded or recycled (Fig. 13). Management and control requirements are briefly outlined in Figure 14.

III. SRS MANAGEMENT AND CONTROL

In view of the considerable scope of functional requirements of individual SRSs and their fields, a broad new concept of management and control systems must be developed. The multitude of required SRS regulatory and feedback mechanisms will be of a vast complexity exceeding any artificial system heretofore conceived. The extraordinary demands that must be placed on the autonomous SRS management and control system are only partially recognized at this time. This report attempts to provide basic concepts for SRS management and control, starting from high-level aspects and progressing to concrete and describable functional elements. The basis of this approach is the requirement of total integration between the demands of internal SRS functions and the effects of the SRS environment on these functions, since the relations between an SRS and its environment are a crucial factor in successful operations.

A highly organized and complex artificial system like SRS in an external environment with a relatively high degree of disorder requires an extremely selective exchange between internal and external environments in order to maintain system integrity. This requires insulation from all influences and external stimuli not of vital importance to SRS functioning. This basic design philosophy must be adopted regardless of the

IP — INFORMATION PROCESSING
EP — ENERGY PROCESSING
ES — ENERGY SYSTEM
EPS — END PRODUCT SYSTEM

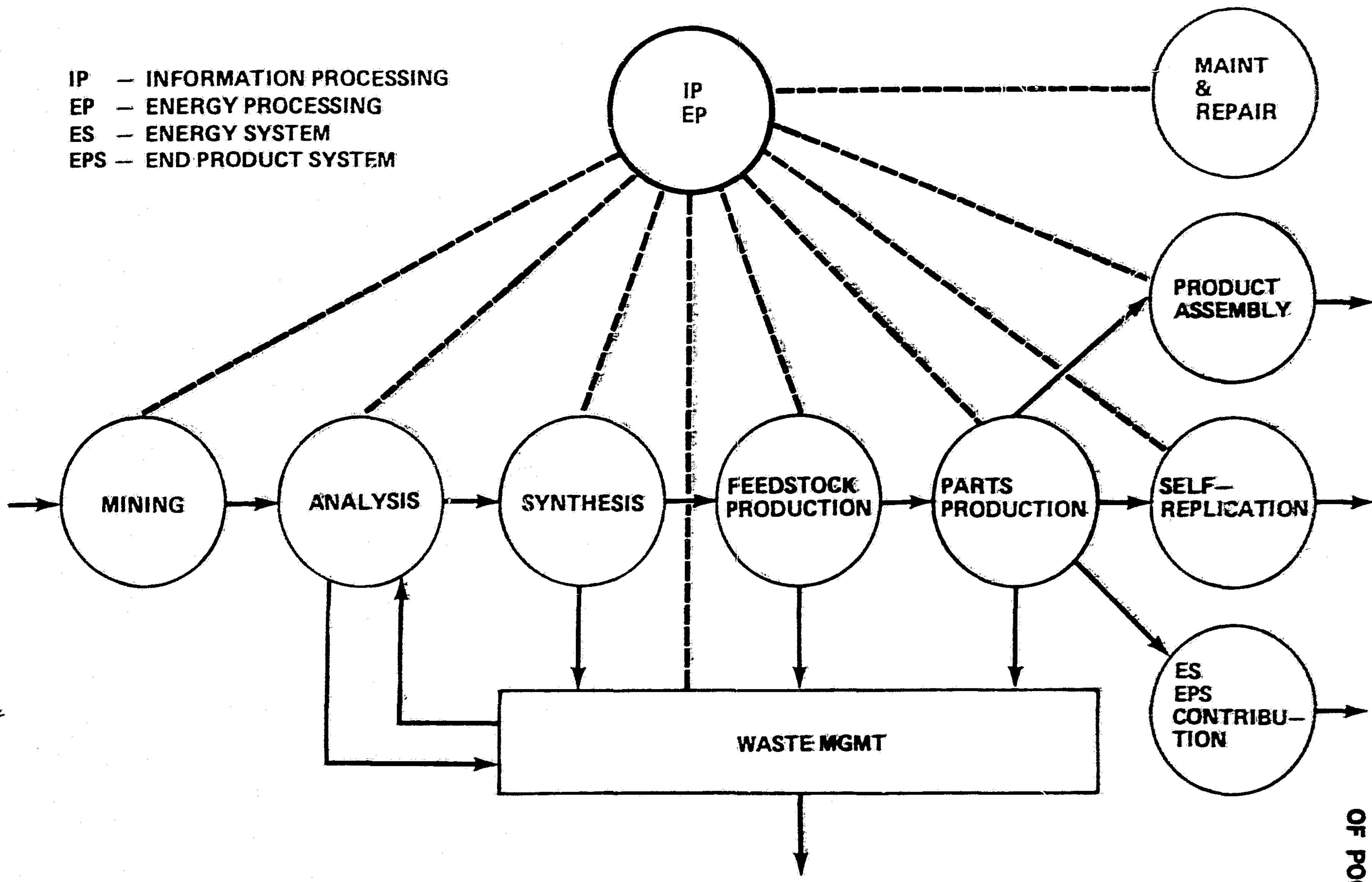


Figure 13. SRS matter processing (MP).

LEVEL I SYNCHRONIZATION, COORDINATION AND BALANCE OF NUMEROUS FLOW RATES RECYCLING AND WASTE MANAGEMENT MANAGEMENT AND CONTROL OF UNIVERSAL PARTS PRODUCTION MANAGEMENT AND CONTROL OF ACTIVITIES AND SCHEDULES OF THE UNIVERSAL CONSTRUCTOR COORDINATION AND MANAGEMENT OF INDIVIDUAL SRS CONTRIBUTIONS TO THE ES AND EPS WHICH ARE THEMSELVES MANAGED AND CONTROLLED BY THE LEVEL II ENERGY AND MATTER PROCESSING SUBSYSTEMS, RESPECTIVELY.
LEVEL II COLLECTION AND ORGANIZATION OF INDIVIDUAL SRS PRODUCTS IN THE EPS FOR FURTHER ASSEMBLY COLLECTION, TRANSPORTATION, AND FURTHER UTILIZATION OF FINAL PRODUCTS MANAGEMENT AND CONTROL OF THE ES ASSEMBLY (DURING THE SRS REPLICATION PERIODS) USING CONTRIBUTIONS FROM INDIVIDUAL SRSs MANAGEMENT AND CONTROL OF THE ES AND EPS
LEVEL III MANAGES AND CONTROLS THE MATERIALS BALANCE OF THE ENTIRE DIFFERENTIATED SRS FIELD.

Figure 14. Management and control functions in matter processing.

degree of environmental information available because it allows a more general-purpose approach while increasing SRS functional reliability by reducing the level of distraction.

Accordingly, we define a concept which postulates an internal system for autonomous management and control, supplemented by an externally oriented environment-monitoring system as a separate but coordinated unit, with an optional third "intelligent" system which may be required in especially chaotic environments (Fig. 15).

A. Autonomous Management and Control (AMC) System

In a completely defined and static environment an SRS could, in theory, operate with a fixed program of instructions which implements information, energy, and matter processing management exclusively without any direct external inputs (since the environment is presumed completely specified and unchanging). Such an entirely autonomous management and control (AMC) system is the basic building block for all operational SRS control. In some limited applications, an AMC system alone may suffice for essential completion of well-defined, simple tasks.

The AMC system constitutes the concentration of reactive regulatory systems for optimal management and control of all internal SRS functions with consideration of a very large number of conditions and requirements. The AMC system must itself be independent of all internal imbalances in order to be capable of reacting to achieve

ORIGINAL PAGE IS
OF POOR QUALITY

MANAGEMENT AND CONTROL SYSTEM	BASIC FUNCTIONS
AUTONOMOUS MANAGEMENT AND CONTROL SYSTEM (AMC)	REACTIVE REGULATORY FUNCTIONS FOR OPTIMAL MANAGEMENT AND CONTROL OF ALL INTERNAL SYSTEMS BY COMPARISON WITH A GLOBAL SYSTEMS MODEL
EXTERNAL MANAGEMENT AND CONTROL SYSTEM (EMC)	RESPONSE TO EXTERNAL SITUATION AND EVENTS THROUGH STORED PROGRAMS TO MAINTAIN THE FUNCTIONS OF THE SYSTEM IN A CHANGING ENVIRONMENT
INTELLIGENT MANAGEMENT AND CONTROL SYSTEM (IMC)	VOLUNTARY, INTELLIGENT ACTIONS, DECISION MAKING AND PROBLEM SOLVING IN NOVEL SITUATIONS THAT CANNOT BE PRE-PROGRAMMED.

Figure 15. SRS management and control approach.

the restoration of equilibrium. The AMC system is only indirectly affected by the environment as far as system performance is concerned and has no direct access to it.

In addition to its reactive functions, the AMC system must contain a substantial accounting package to coordinate all internal operations and transport movements, and to control the continuously changing status of all critical system elements. In order to oversee all functional performances, each AMC system requires a global model of its associated SRS or SRS field(s). This model carries an exact description of the SRS or field and its nominal functions, states, and equilibrium parameters. Incoming signals are continuously compared with the stored model. Any deviations indicating abnormal conditions will activate automatic remedies and compensations. These are initiated and maintained until the abnormal situation is rectified. This model or program is fixed for a specific SRS/field configuration.

As mentioned in Section III.A, in some limited applications, an AMC system alone may suffice for essential completion of well-defined, simple tasks. This includes product manufacturing and self-reproduction under limiting conditions. These two functions are ordinarily assigned to the EMC (Section III.B).

The responsibilities of the AMC system are outlined in Figure 16.

ORIGINAL PAGE IS
OF POOR QUALITY

LEVEL I

(1) INFORMATION
- COMPLETE INSTRUCTIONS PROGRAM AND PLAN
- ABNORMAL CONDITION FEEDBACK SYSTEM
- EMERGENCY READINESS

(2) ENERGY
(a) ENERGY SUPPLY
- CONVERSION SYSTEMS
- STORAGE
- DISTRIBUTION
- SUBSTATIONS
- BACK-UP SOURCES
- POWER CONDITIONING

(b) ENERGY BALANCE
- MATCHING SUPPLY AND DEMAND
- LOCAL ENERGY CONVERSION (MECHANICAL, CHEMICAL, ELECTRICAL, PLASMA, THERMAL)
- THERMAL BALANCE (TEMPERATURES)
- EMERGENCY READINESS

(3) MATERIAL
(a) MATERIAL FLOW
- ACQUISITION
- PROCESSING (CLOSED CYCLE)
- PRODUCT MANUFACTURING } FOR SRSs WITHOUT EMC ONLY
- SELF-REPRODUCTION }

(b) MATERIAL TRANSPROT SYSTEMS
- RAW MATERIAL
- FEEDSTOCK
- PARTS
- WASTE
- ASSEMBLY
- UNIVERSAL CONSTRUCTOR
- PIPES, VALVES

(c) EMERGENCY READINESS

LEVEL II

(1) INFORMATION
- SYNCHRONIZATION OF ALL SRS (LEVEL I) AMCs
- REPROGRAMMING INDIVIDUAL SRS INSTRUCTION PROGRAMS AND PLANS IN CASE OF PRODUCT CHANGES OR WHEN MUTATIONS OCCUR.

(2) ENERGY
- ES ASSEMBLY
- ES AUTONOMOUS OPERATION

(3) MATERIAL
- RESOURCE SURVEYS
- EPS ASSEMBLY
- EPS AUTONOMOUS OPERATIONS

LEVEL III

(1) INFORMATION
- SYNCHRONIZATION OF ALL LEVEL II AMCs
- REPROGRAMMING OF ALL LEVEL II AMCs IN CASE OF PRODUCT CHANGE OR GENERAL PLANNING MODIFICATIONS

(2) ENERGY
- ES COORDINATION

(3) MATERIAL
- EPS COORDINATION

Figure 16. Functional responsibilities of the AMC systems.

B. External Management and Control (EMC) System

An SRS constitutes a complex system which must maintain a high degree of internal order in its activities against the disordering influences of an often variable and sometimes chaotic external environment (Fig. 17). Minimal functional deviations within these activities, if allowed to continue and propagate unchecked, would cause a collapse of the delicate balance among the many interdependent sequences of events within an SRS or SRS field and destroy the countless individual activity rhythms that must be precisely tuned and synchronized.

TERRESTRIAL	GROUND	SURFACE
		UNDERGROUND
	OCEAN	SURFACE
		SUBMERGED
		BOTTOM
LUNAR	GROUND	SURFACE*
		UNDERGROUND
PLANETARY & SATELLITES	GROUND	SURFACE
		UNDERGROUND
	ATMOSPHERE	UPPER LOWER

*DESCRIBED IN REFERENCE 1 AND 2

Figure 17. Potential SRS environments.

The environment determines the characteristics of the SRS products and the specific type of SRS system elements and their basic design. Therefore, the nature of the SRS environment must be well-known. This is particularly important because during the SRS reproductive phase there is extensive mobility involved in seeking and moving towards new sites to be occupied by replicas. The paths toward these new sites and the sites themselves may have different environments than exist in the location of the primary system.

In order to deal with a variety of external situations and events, and to respond to foreseeable but unpredicted environment conditions and events, the SRS must have a set of stored, environmentally-sensitive programs which contain appropriate responses to supplement those provided automatically by AMC systems. These responses must be activated in case of external conditions which significantly diverge from an established norm. To protect the system from an infinitely large number of external stimuli and to maintain a practical minimum of exchange, inputs are required to exceed pre-established threshold values to initiate a response. In extreme cases where maximum response is needed at once, all other thresholds must be raised automatically until the original response is completed. Thresholding is controlled by a central information processing system with fixed response priorities.

Internal SRS functions and operations are constant or vary in known ways, whereas environmental events are at best periodically variable and at worst randomly variable in their effects upon SRS operations. AMC systems maintain SRS and SRS field internal integrity in the form of a synchronized closed unit of action and reaction, but these are not designed to maintain nominal functioning and internal stability in the face of significant environmental variations. This duty falls to the External Management and Control (EMC) system.

The principal functional responsibilities of the EMC system are:

1) To reduce the multitude of expressions of the environment to a maximum-likelihood limited number of standard situations to which an equal number of readily available reaction programs respond.

2) To generally characterize all objects within a specific scenario through a minimum of criteria that represent a particular object. In this process individual, identifying, and unique characteristics will be disregarded. This provides for maximum economy of necessary vital information acquisition because, as a consequence, all individual, concrete objects of the same type are now interchangeable and the proper automated responses can be accomplished.

3) To provide a program store for selected vital learning capabilities. Program memories are initially vacant to permit "imprinting" at the time the SRS encounters sensory inputs which indicate a situation the AMC system cannot handle alone. Learning capabilities remain vital through the SRS life cycle, becoming part of a fixed program within the EMC system.

In order to avoid saturation of the EMC system and to protect the integrity of an SRS or SRS field, not every external event will be registered or responded to; otherwise, the environment would generate a constant and potentially confusing bombardment of stimuli on SRS sensors. While AMC system sensors respond to abnormal conditions as compared to a fixed reference state model, the EMC system employs a threshold approach which blocks any external stimulus unless an established minimum or maximum threshold is exceeded. An added feature shall be the threshold level control which can lower or raise specific threshold values. This would allow concentration of resources when necessary to deal with selected priority inputs as triggered by unusual circumstances.

The specific tasks of EMC systems, generally and for each organizational Level, are summarized in Figure 18.

C. Intelligent Management and Control (IMC) System

The AMC and EMC systems are vital and should suffice for most SRS applications. However, circumstances may require more than the exercise of elementary functions for survival, production, and replication, and more than carrying out fixed program instructions and reacting to the environment within restricted limits. Occasionally a novel situation may require a recognition and understanding of an objective environment, leading to intelligent evaluations of situations that may have major effects on SRS functions and operations.

ORIGINAL PAGE IS
OF POOR QUALITY

GENERALLY

- CONTROL CENTER FOR ALL PROGRAMMED ACTIVITIES AND MOTIONS
- PROCESSING OF ENVIRONMENTAL INFORMATION
- PRIMARY CONTROL OF BALANCED SYSTEMS ACTIVATION
- PROGRAMMED RESPONSES TO ENVIRONMENTAL EVENTS AND SITUATIONS
- COMPLETE PROGRAMMING OF COMPOSITE ACTIONS COORDINATION (e.g., MAINTENANCE, STOP-AND-GO OF SUBSYSTEMS)
- ENVIRONMENTAL ADAPTATION OF PROGRAMS
- READY ACTION PROGRAMS
- MANAGEMENT OF RELATIVELY LIMITED NUMBER OF STORED, PREFABRICATED PROGRAMS FOR REST, MATERIALS GATHERING, MAINTENANCE, EMERGENCY, REPLICATION, INTER-SRS COMMUNICATIONS, SPATIAL ORIENTATION, AND SOLUTIONS TO ANTICIPATED EXIGENCIES.
- FINE TUNING OF THRESHOLD FUNCTIONS TO ALLOW PRIORITIZATION OF OPERATING PROGRAMS DEPENDING ON THE CHANGING DEMANDS OF THE EXTERNAL ENVIRONMENT.
- THRESHOLD REGULATION AND ACTIVATION
- PASSING ON CRITICAL ENVIRONMENTAL SENSORY DATA TO THE AMC FOR CONTROL
- INTEGRATION OF EXTERNAL INITIATING STIMULI WITH STORED PROGRAMS (EACH OF WHICH CONTAINS SPECIFIC REACTIVE PATTERNS OF ACTION)

LEVEL I

(1) INFORMATION

- ENVIRONMENTAL INFORMATION
  - ELECTROMAGNETIC RADIATION SENSING
  - TOUCH SENSING
  - AUDIO SENSING
  - MATERIAL SENSING
  - OPERATIONAL SENSING
- OPERATIONAL COORDINATION
- SELECTIVE LEARNING
- PRIORITY SETTING
- PROCESS CONTROL
- INFORMATION INTEGRATION
- ENVIRONMENTAL INFORMATION CONTROL

(2) ENERGY

- THERMAL CONTROL

(3) MATTER

- MAINTENANCE (SELF)
- MATERIAL INPUT SUPPLIES
- REPLICATION
- PRODUCT MANUFACTURING

LEVEL II

(1) INFORMATION

- TOTAL FIELD ENVIRONMENTAL STATUS INFORMATION
- FIELD GROWTH PLAN
- NEW EXPANSION AREA EXPLORATION
- SELECTED LEARNING
- SENSOR RE-CALIBRATIONS
- NEW SENSOR REQUIREMENTS

(2) ENERGY

- OVERALL FIELD ENERGY AND THERMAL BALANCE

(3) MATTER

- EXPANSION AREA MATERIAL ANALYSES

LEVEL III

(1) INFORMATION

- TOTAL ENVIRONMENTAL STATUS INFORMATION

(2) ENERGY

—

(3) MATTER

—

Figure 18. Functional responsibilities of the EMC systems.

This would require the capability to take voluntary, non preprogrammed intelligent actions and to make decisions and solve problems. Therefore, a third class of management and control system requiring machine intelligence may be necessary, called the Intelligent Management and Control (IMC) system. The IMC system is capable of providing an objective, rational view of the environment which maximizes SRS resource utilization in response to external conditions and situations.

The IMC system must operate with a minimum of interference with the vital activities of AMC and EMC systems. Access to the AMC system should be blocked, and access to the EMC system should be on a coordinating and amplifying basis only. The functions of the IMC system are largely in the information acquisition and generation area. Energy- and matter-oriented functions would be affected indirectly only through communication with the information processing subsystems. An IMC system should only be available at the highest organizational level, either Level II or Level III. This helps to preclude inconsistent or conflicting actions among the various systems involved.

Specific functions of the IMC system include:

1) Learning

2) Memorizing

3) Reasoning

4) Judgment

5) Problem-solving

6) Decision-making

7) Objective sensory perception of the environment

8) Non-preprogrammed action capability and control within priorities set by the EMC system.

The IMC requires the following components:

1) Environment input systems

2) Store of factual beliefs and knowledge

3) Storage capability of resources (e.g., a dictionary and past experiences)

4) Catalogue of resources

5) Motivational store

6) Process-purpose index (action-motive index)

7) Temporary structures associated with ongoing information processing

8) Central administrative process system

9) Set of monitoring process systems including permanent, general-purpose monitors and other, more specialized ones, set up temporarily according to needs

10) Retrospective analysis process system.

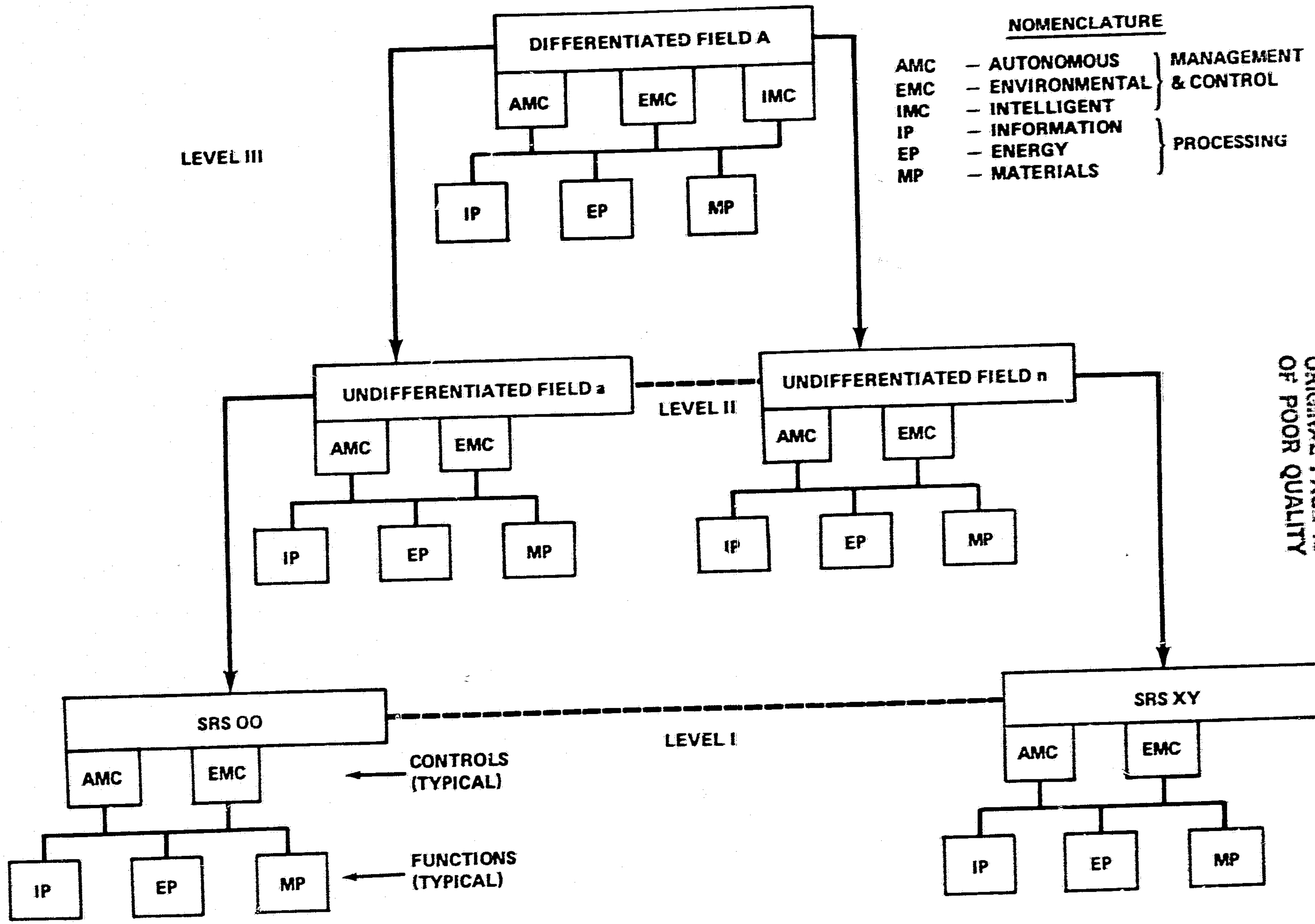
The AMC and EMC systems are required at each of the three organizational levels. The IMC system is a top level function only (Fig. 19). The levels of necessary communication to accomplish management and control are shown in Figures 20 and 21. Figure 20 shows, in addition to the Level I AMC and EMC systems, that each SRS element has its own sub-AMC and sub-EMC which regulates within its domain the local functions of the respective elements. The degree of coverage of these elements requires further study.

IV. SYSTEMS RECYCLING, SPECIALIZATION, AND INFORMATION REPLICATION

Since an SRS replication phase is limited through preprogrammed instructions, it could be practical and beneficial for each SRS to dismantle its reproductive mechanisms once they are no longer needed, and utilize the parts for production directly or, after reworking, back in the raw material or feedstock lines. Similarly, if additional replication or growth activities become necessary and these facilities are no longer available, part of the production plant could be converted to serve this purpose. Management and control systems must be able to adjust to any such new structural and functional configurations, optimizing their usage and retaining control over their deployment and operations at all times.

Inner field SRSs may eventually run out of raw material. While initially the quantity of material is almost unlimited and SRS operations would not significantly modify the environment, this may change rather dramatically as replication processes proceed. The quantity of readily available material could be reduced by many orders of magnitude. Because of this, interior-field SRSs may change their work scope and concentrate, for example, on parts production and assembly. The mining and raw materials processing facilities would be recycled and utilized elsewhere in the production loop. The feedstock or parts for final manufacturing would come from external SRSs which could either increase feedstock or parts production or would emphasize mining and new materials processing while reducing their own production in these areas. All management and control systems should be capable of directing and optimizing these changes in SRS fields.

The SRS management and control systems described in this report require the primary initial "seed" SRS to include all Level I and Level II capabilities in its instruction program (Fig. 22). During self-replication, an SRS passes on only the subordinate programs to the replicas while retaining its own supervisory program instructions. The initial SRS must contain complete instructions and information for the final organization of the entire differentiated or undifferentiated field which ultimately is to be constructed. This includes the master plan for the final layout and configuration of the various SRS fields and individual SRSs and for the various useful output products.



ORIGINAL PAGE IS OF POOR QUALITY

Figure 19. Levels of SRS management and controls.

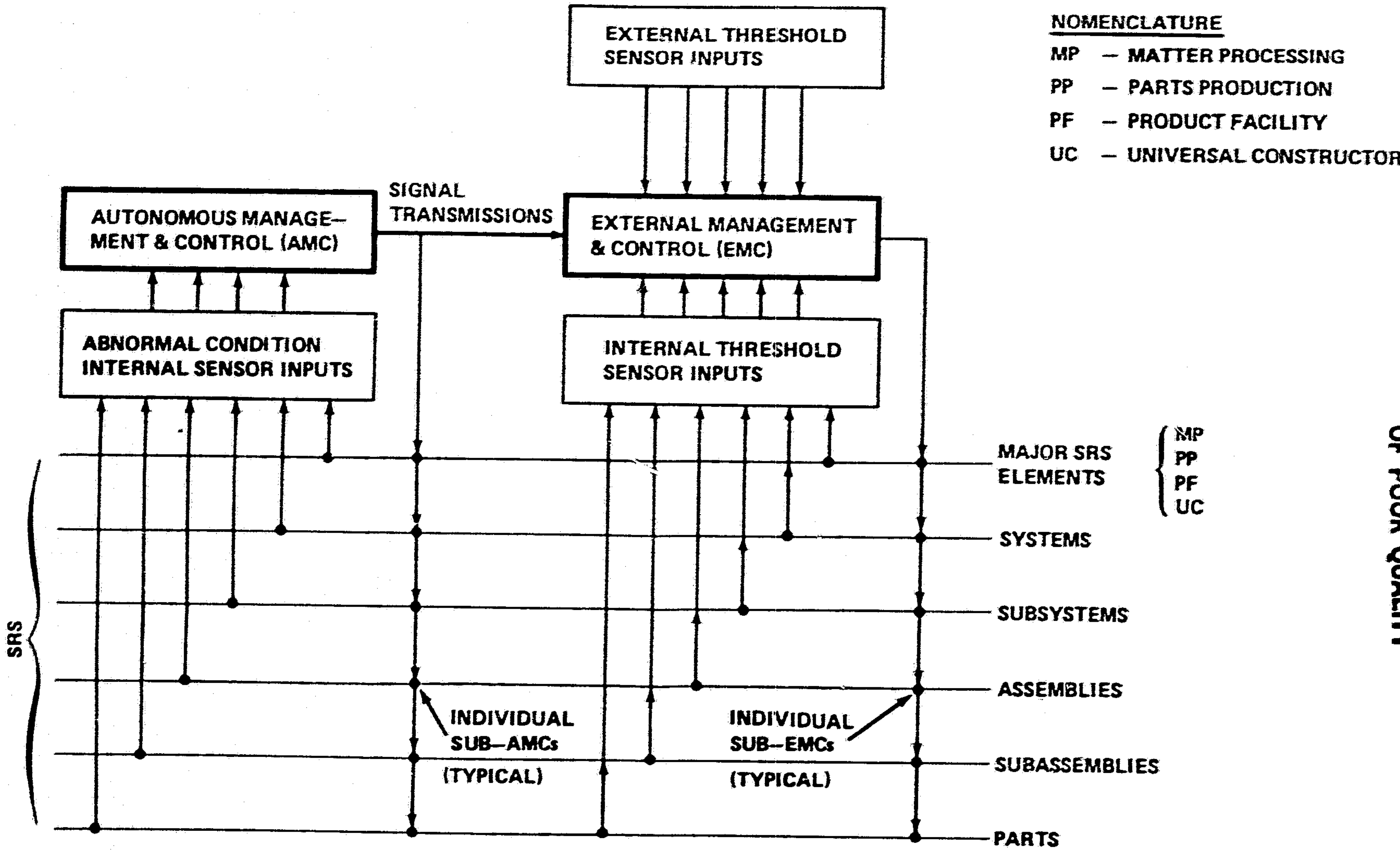


Figure 20. Level I management and control communications.

ORIGINAL PAGE IS OF POOR QUALITY

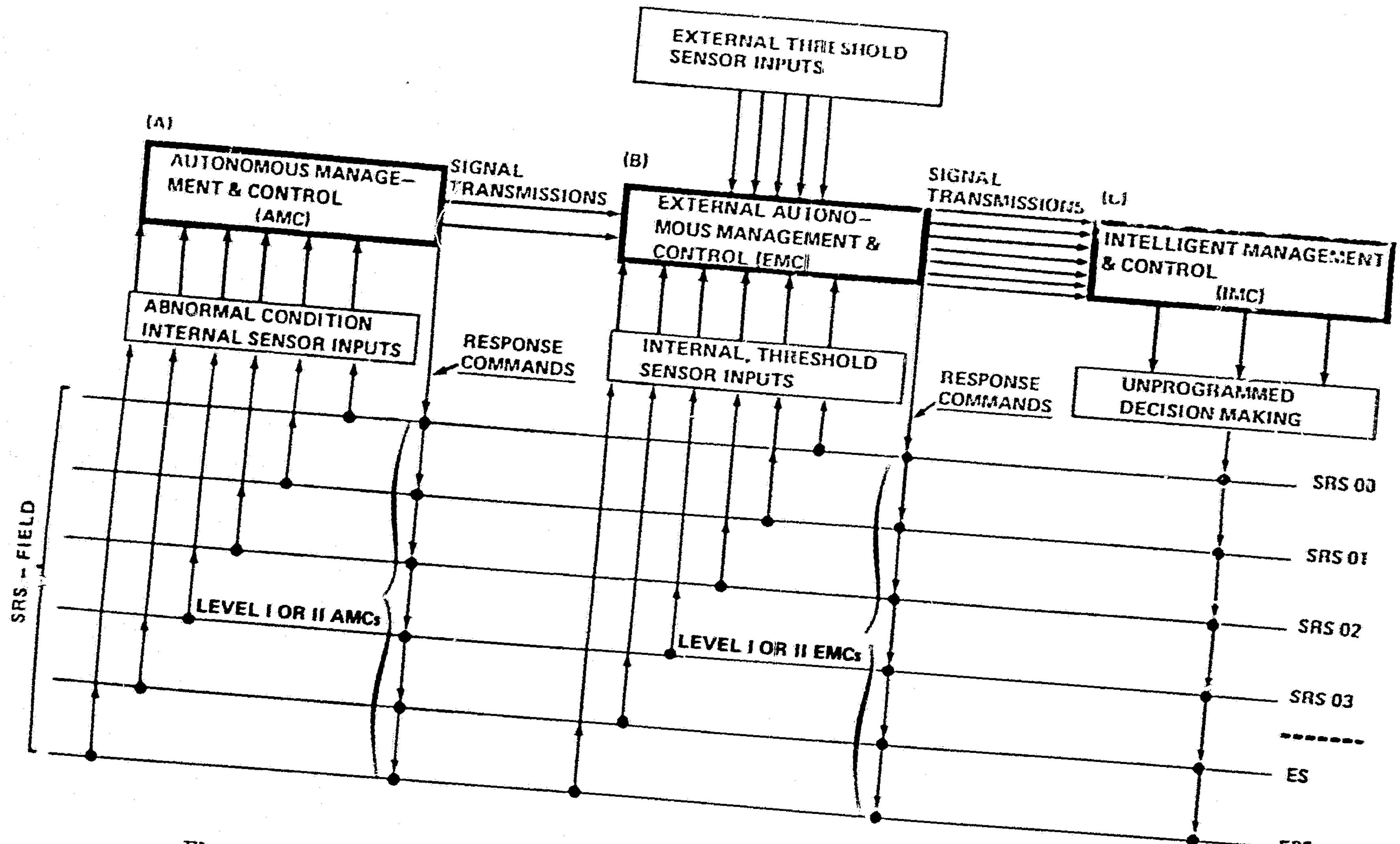


Figure 21. Level II or Level III SRS management and control communications.

ORIGINAL PAGE IS
OF POOR QUALITY

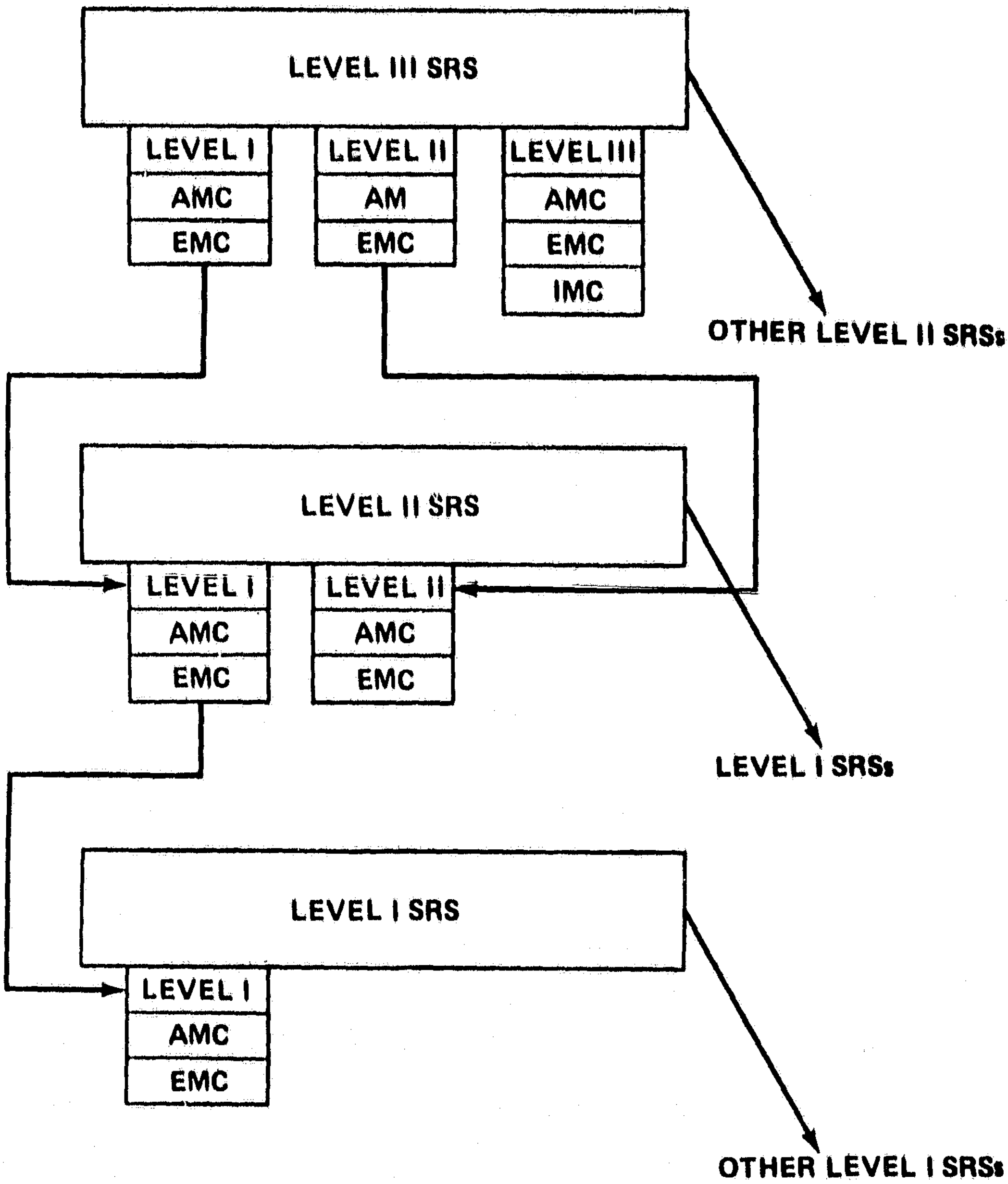


Figure 22. Information replication.

V. SELECTED AREAS REQUIRING ADDITIONAL WORK

After having established a basic SRS management and control model, it becomes apparent that certain closely related issues need definition. The following represents some of the questions to be answered:

1) The lowest level of management and control in this model is the individual SRS (Level I). How much lower must management and control penetrate the individual SRS building blocks and elements? What is the internal SRS distribution of AMCs and EMCs? How does the distribution differ between the two?

2) What are the physical and performance characteristics (at this time in gross terms) of the required computer soft and hardware based on the requirements outlined in this report? What order of magnitude information storage and processing is required?

3) What is the scope of human intervention in the operation of the three levels of SRS organization? At what points in the management and control systems would the intervention take place? In what forms would these interventions be carried out?

REFERENCES

1. von Tiesenhausen, Georg and Darbro, Wesley, A.: Self-Replicating Systems — A Systems Engineering Approach. NASA TM-78304, July 1980.

2. Freitas, Robert A., Jr.: A Self-Reproducing Interstellar Probe. Journal of the British Interplanetary Society, vol. 33, July 1980, pp. 251-264. See also: Freitas, Robert A., Jr. and Zachary, W.: A Self-Replicating, Growing Lunar Factory, paper delivered at the 5th Princeton/AIAA/SSI Conference on Space Manufacturing, May 18-21, 1981, Princeton University, 35 pp.

3. von Newmann, John: Theory of Self-Reproducing Automata. Edited and completed by Arthur W. Burks, University of Illinois Press, 1966.

BIBLIOGRAPHY

von Ditfurth, H.: Der Geist Fiel Nicht Vom Himmel (The Evolution of Our Mind). Hoffmann and Campe, Publishers, Hamburg 1976. The management and organization of biological systems, including humans, is discussed in this book.

Pask, Gordon: A Discussion of Artificial Intelligence and Self-Organization. Advances in Computer, 1964.

Saunders, P. T.: On the Increase in Complexity in Evolution II. The Relativity of Complexity and the Principle of Minimum Increase.

Miller, J. G.: Living Systems. McGraw-Hill Book Co., New York, 1978.

Laing, R.: Machines and Behavior, 1981.

Laing, R.: Personal Note on Sociobiology of Machines. August 11, 1980.

Laing, R.: Notes on problem areas in self reproducing automata. October 13, 1981.

Laing, R.: Self-Reproducing Automata. 1981, to be published.

Simmons, H. A.: Studying Human Intelligence by Creating Artificial Intelligence. American Scientist, Vol. 69, May-June 1981.

Simmons, G.: Are Computers Alive? Creative Computing. February 1981.

Freitas, R. A.: A Few Ideas on Implications of Replicating Systems. Notes dated August 13, 1980.

Darbro, W. A. and von Tiesenhausen, G.: Sequences Generated by Self-Replicating Systems. NASA-MSFC. Space Science Laboratory. Preprint Series No. 80-129, December 1980.

Taneja, V. and Walsh, P.: Growth Considerations of a Self-Replicating Field Dependent on External Factors. 1981, to be published, Western Illinois University.

Krone, R. M.: Advanced Machine Intelligence: NASA Research and Korean Implications. March 5, 1981. University of Southern California, Los Angeles.

Laing, R.: Personal notes on Machine Consciousness, Ultimate Human and Machine Intelligence, Information Processing Function in Self-Replicating Systems (SRS), Terraforming and SRS Master Machine Design and Construction System. December 1981.

Laing, R. A.: Automation Models of Reproduction by Self-Inspection. J. Theor. Biol., 66, pp. 437-456, 1977.

Laing, R. A.: Some Alternative Reproductive Strategies in Artificial Molecular Machines. J. Theor. Biol., 54, pp. 63-84, 1975.

Laing, R. A.: Machines as Organisms: An Exploration of the Relevance of Recent Results. Bio Systems, 77, pp. 201-215, 1979.

Laing, R. A.: Artificial Molecular Machines. Proceedings of the International Symposium on Uniformly Structured Automata and Logic, Tokyo, August 1975.

Laing, R. A.: Automation Self-Reference. University of Michigan, Computer and Communication Science Department, July 1977.

APPROVAL

MANAGEMENT AND CONTROL OF SELF-REPLICATING SYSTEMS: A SYSTEMS MODEL

By Georg von Tiesenhausen

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

for William C. Snoddy
WILLIAM R. MARSHALL
Director, Program Development

NASA—MSFC