THE USE OF ARTIFICIAL INTELLIGENCE IN NUCLEAR ENGINEERING

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Many real time problems, such as plant control, require the ability to process a huge amount of data very quickly to determine the state of the system. To do this CANDU REACTORS use Digital Control Computers to monitor the reactor and algorithm based programs to perform tasks such as power-up and power-down. The problem with this system lies in the fact that when the operator most needs help, during an upset, the computer can not offer any real assistance since the task of determining the cause of a problem lacks the mathematically tractable core needed by most computer programs to function.

This paper will examine the use of Artificial Intelligence techniques, specifically expert systems, as an aid to operators in reactor control.

Presented at the 11th Simulation Symposium on Reactor Dynamics and Plant Control, Kingston, Ontario, April 22-23, 1985.

An expert system is a computer program that uses both knowledge and inference techniques to solve problems that normally require the specialized knowledge of a human expert to solve. These problems, by their nature, typically lack a mathematically tractable core and would prove unsolvable by normal computational techniques.

The components of an expert system include a knowledge base, an inference procedure and a working memory.

KNOWLEDGE BASE: The knowledge base of an expert system consists of both facts and heuristics. The facts are made up of a large number of rules which comprise the physical data relevant to the system such as limits on pressure and temperature. The heuristics are the methods of approach that characterize expertise in the field. They provide aid or direction in the solution of the problem but are otherwise unjustified except for the fact that they have been proven to work in the past.

INFERENCE PROCEDURES: The inference procedures are the control structure of the expert system which are used to apply the knowledge that the expert system has.

WORKING MEMORY: The working memory of an expert system is much like the memory of a human. It keeps track of the current status of the problem and the present state and history of any important variables.

There are many different ways of representing the required knowledge in an expert system. The most useful one for our purposes is known as a production rule type system. The control structure involves the use of both forward and backward chaining.

In forward chaining the system does not start with a particular goal defined for it. Instead, it uses the evidence at hand applying production rules to it until a particular conclusion is reached that satisfies all the available evidence. Forward chaining can be considered to be an event driven analysis of the problem, where the events dictate a conclusion.

The backward chaining type expert system can be considered to be goal directed. In backward chaining, the system is given a set of final goals that it must reach, the production rules are then applied to problems in a reverse manner. For example, if the production rules were of the "if..(condition) then..(conclusion)" type, the final goals that are given to the system are the conclusions that must be reached. The system then examines which conditions must be met such that the desired conclusion is reached from the present conditions without violating system parameters. In a nuclear reactor such a goal might be to reach a desired power level without producing large Xenon transients. The conditions the expert system generates in accomplishing this task would be the operating instructions to the operator.

Prediction systems infer likely outcomes to current or postulated situations. As in the interpretation systems, prediction systems can give numerical probability factors to all generated outcomes.

Diagnostic systems infer system malfunctions from observed data. There are two different techniques typically used in such systems to relate operational irregularities to observations, the first involves a simple table of associations between observations and their underlying cause. The other method uses knowledge of potential problem areas in design, operation or equipment to produce a list of malfunctions which are consistent with the observations.

Planning systems are generally used by the military to plan attack strategies. They could however be used to plan repair strategies so as to minimize exposure time in high radiation fields.

Monitoring systems perform much the same function as the computer system currently in use in CANDU REACTORS. However they use a knowledge based control structure as opposed to the algorithm control now in use.

APPLICATION OF PRODUCTION SYSTEM TO CANDU CONTROL

Although CANDU REACTORS use direct computer control of all major functions and systems, the operator is still required to monitor the operation of the plant and take corrective action during abnormal situations. Unfortunately, technology is progressing faster than the ability of humans to keep up with it. This has lead to each succesive plant design having greater quantities of instrumentation, to more accurately represent and monitor the behaviour of the reactor, while the operators are having more and more trouble learning the system and coping with all information that is being presented to them. This situation may not be so apparent under normal operating conditions. However, in the event of an upset, detailed information as to the nature of the alarm is sent to a 3200 line per minute alarm logging printer. The rate of information output at such times far exceeds the maximum rate of information processing capable by human operators. Furthermore, human memory and human response are not perfect, especially under pressure. It is due to these reasons that I would like to propose the creation of an expert system to serve as part of a man-machine partnership in the field of reactor control .

The task of expert system design in the case of a CANDU nuclear power plant is made feasible due to the fact that most of the monitoring of the reactor is already done by a computer. This eliminates the need for complex interfacing between monitoring equipment and the computer supporting the expert system. The first generation expert system I propose will have along with recent problems with pieces of equipment. This last section would ideally be reprogrammable by the operator at any time by the use of simple questions and answers to allow for repairs being done and new problems that have developed.

In terms of the requirements that the task must meet in order for an expert system to be feasible, we must consider the following:

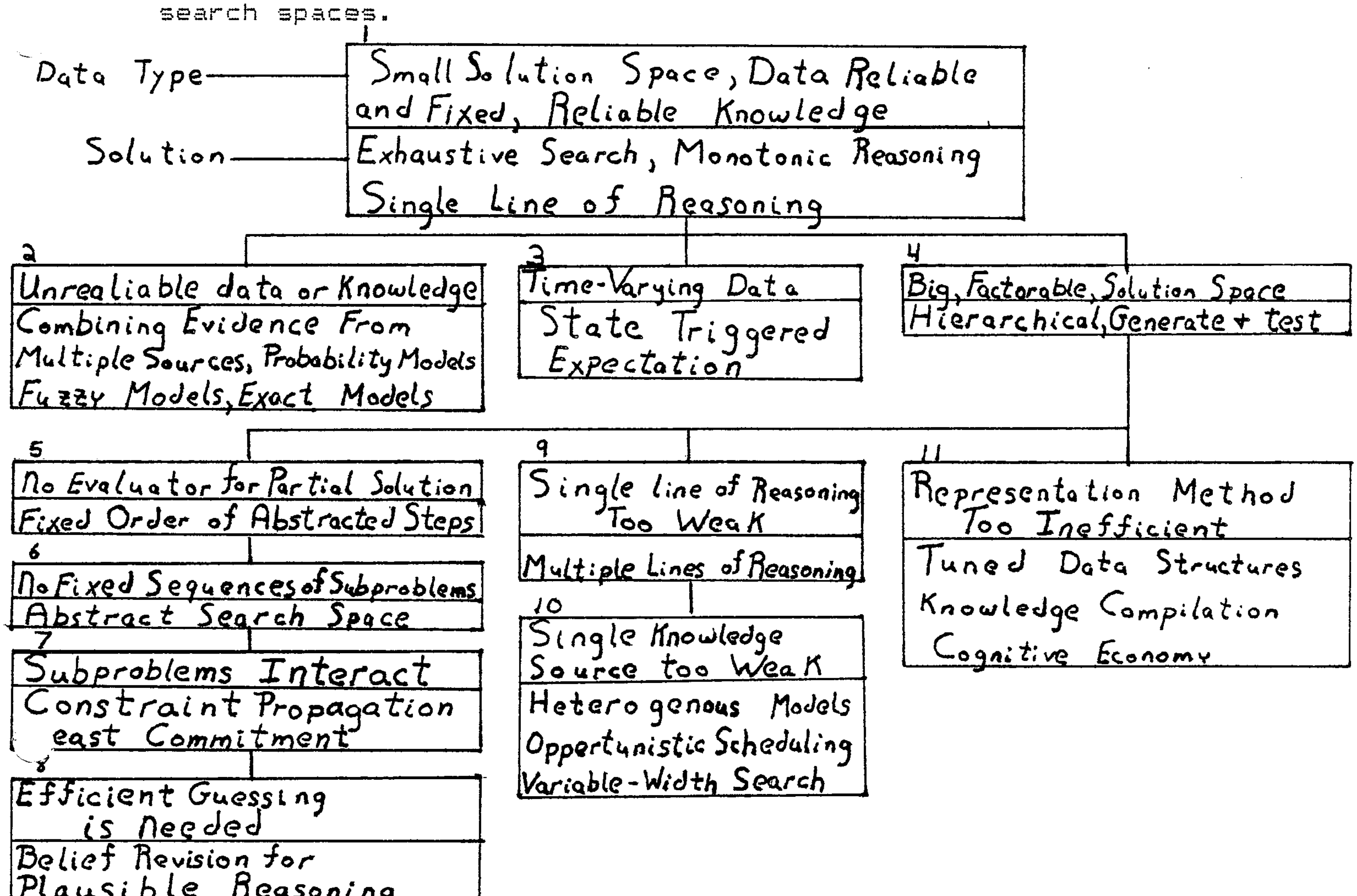
1: The need for experts who are good at the task. This requirement is quite easily met by simply finding the most experienced operators, an added benefit is that years of operator experience can be maintained even when people have retired. This first requirement might seem quite simplistic but when taken in conjunction with the next three requirements it becomes one of the hardest tasks to fullfill.

2,3,4: (2) The expertise the experts possess must come from special knowledge, judgement and experience. (3) They must be able to express their knowledge, judgement and experience in a quantifiable manner. (4) They must be able to explain the methods used to apply this knowledge and experience to a particular task. These three requirements deal with the ability of the experts to express their special knowledge, judgement and experience in a logical and quantifiable manner. It is the job of the knowledge engineer to extract from the operators the methods they use to determine the nature of the problem and the

DATA STRUCTURES AND SEARCH SPACES

As has already been mentioned the viability of the proposed expert system is directly related to the size of search space that must be dealt with. The larger the size of this search space the less helpful the expert system becomes in real time. Considering the complexity of a nuclear reactor control system, the search space would seem to large to be handled efficiently. There are, however, methods of breaking up the space into resonably sized segments, this section will deal with these methods.

The table below shows the accepted classes of data types and search spaces.



discrete component as a "window" into the working of the system. Comparing this windowed variable allows action to be taken to control the variable if its value is not optimum.

In situational calculus each action has associated with it a particular series of consequences. For example if the pressure in the heat transport system was too low and decreasing, the expert system would recommend increasing the pressurizer heater output. This action would have associated with it a consequence (ie. pressure increase). If this was found to be the case the function would be satisfied and no new action would be taken, provided no other conditions are violated. If, however, the pressure was still found to be low and decreasing, further action would be initiated and a search would be started to determine the cause of the problem.

CLASS 4

LARGE BUT FACTORABLE SOLUTION SPACE

In many cases it is vitally important to consider all possible explanations of the observed data. The direct approach would be to consider every possible combination of variables related to the observation. This method is known as reasoning by elimination. It is completely exhaustive and guarenteed to yield the correct solution. It is also completely useless for real time analysis since it is so slow.

The appropriate method of carrying out the search involves not only the use of heusistics that are designed to prune out inconsistent data early, but also a modular data structure that allows this pruning to have a maximum effect.

The following is an examination of the expert system written by Hitachi for Boiling Water Reactor start up. The task that the expert system is required to perform is to minimize transients in the core caused by Xenon build-up during reactor start-up. The method used by the system involves the application of both forward and backward chaining techniques to determine the correct start up procedure. In the backward chaining mode the operator would give the system the power level to be reached, the system would then work backward to determine the correct start up procedure. In the forward chaining mode the state of the reactor is analyzed and guidance is given in the form of operating instructions. The expert system uses its inherent knowledge of Xenon build up and decay along with the power history to estimate the current Xenon levels and thus offer the proper guidance. The techniques used, while not as accurate as numerical methods, are capable of "thinking" fast enough to operate in real time. The performance of the system is quite good despite the fact that it employs only 55 production rules. The rules that are used for this task are those of operating constraints, corrective action for constraint violation, Xenon transient state and heuristics for inference control.

These rules include:

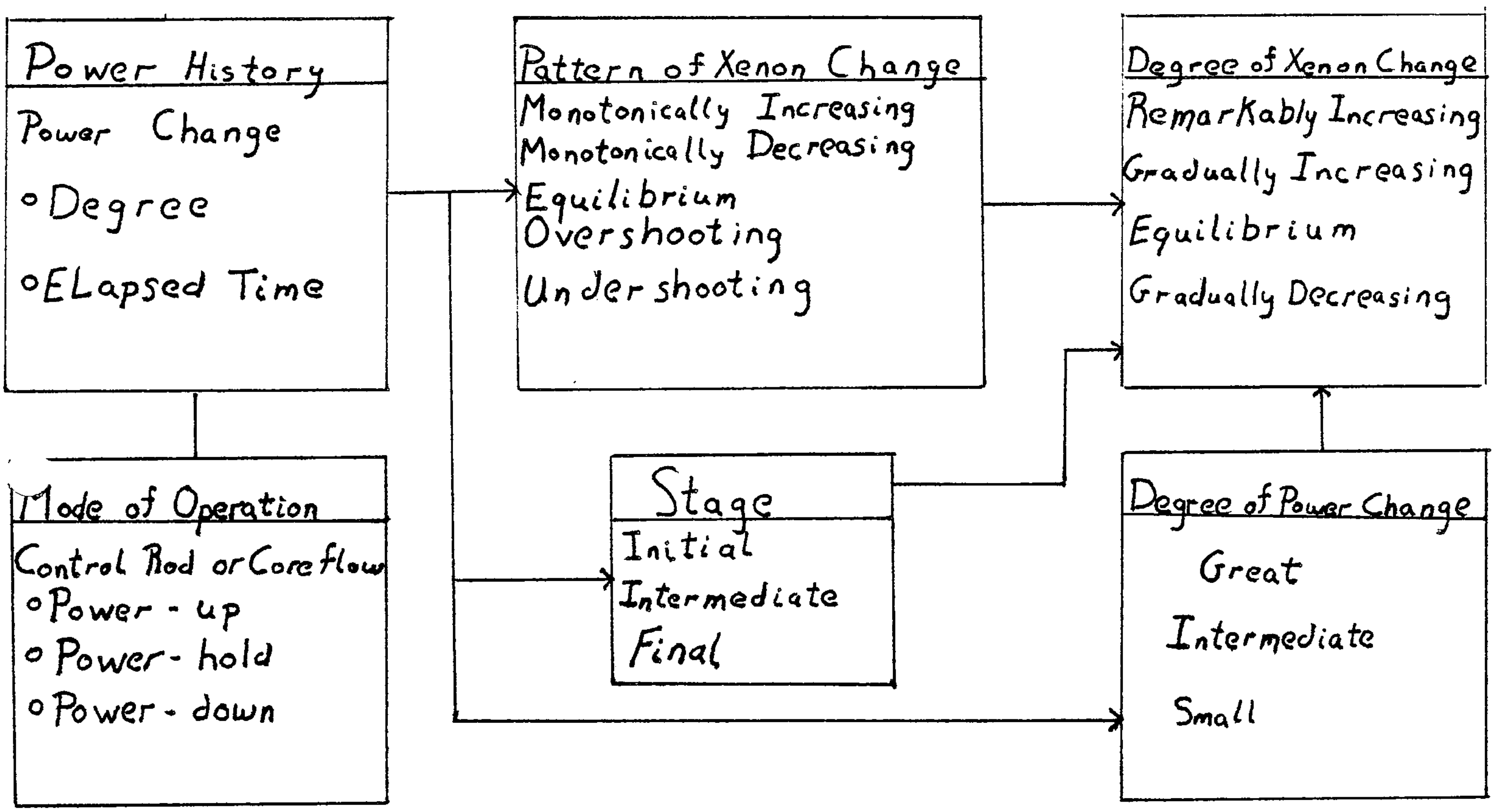
10- for operational constaints

20- for correctve action

20- for Xenon transients

5- heuristics for inference control

The structure of the knowledge base follows a standard format, an example using the twenty rules governing xenon transients is shown below.



The rules use the typical if then structure of all production rule type expert systems. An example of such a rule is shown below.

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(IF (AND (XENON-TRANSIENT OVERSHOOT)
         (POWER-CHANGE GREAT)
          (ELAPSED-TIME SHORT))(THEN XENON INCREASING REMARKABLY)
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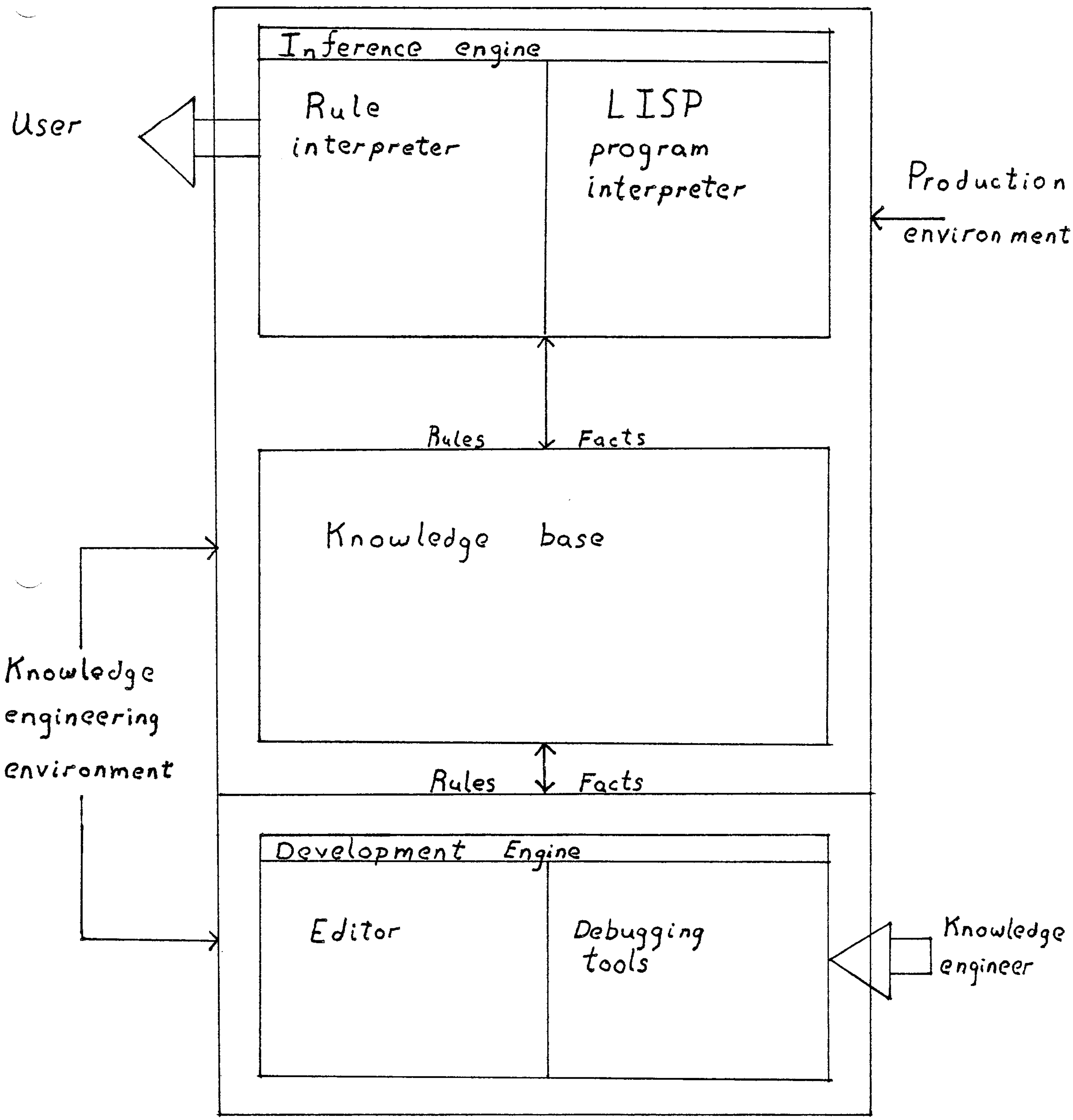
The system then suggests a corrective action:

CORRECTIVE ACTION: WAIT OUT POWER DOWN BY XENON



Inference engine
Rule interpreter
LISP program interpreter
User
Production environment
Rules
Facts
Knowledge base
Knowledge engineering environment
Rules
Facts
Development Engine
Editor
Debugging tools
Knowledge engineer

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