A Radioactive Waste Transportation Package Monitoring System for Normal Transport and Accident Emergency Response Conditions*

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INTRODUCTION

Shipments of radioactive material (RAM) constitute but a small fraction of the total hazardous materials shipped in the United States each year. Public perception, however, of the potential consequences of a release from a transportation package containing RAM has resulted in significant regulation of transport operations, both to ensure the integrity of a package in accident conditions and to place operational constraints on the shipper. Much of this attention has focused on shipments of spent nuclear fuel and high level wastes which, although comprising a very small number of total shipments, constitute a majority of the total curies transported on an annual basis.

Shipment of these highly radioactive materials is made in what is described in the regulations as a Type B packaging. Type B transportation packages are designed to withstand a sequence of accident scenarios, including drop, puncture, fire, and immersion with virtually no release of contents. A bulk of the Type B packages currently in use are utilized in the transport of survey and well logging sources. These packagings, while extremely robust, are not large and move daily in general commerce. Large Type B packagings, or casks, are used to transport spent nuclear fuels and high level wastes.

Due to the quantities of spent fuel and high level wastes carried in Type B casks and the public perception and apprehension regarding the potential consequences of a release, involvement of a packaging containing spent fuel or high level wastes in any accident will result in a very cautious emergency response until it can be determined that the integrity of the cask is maintained. Typically this involves closure of the transport link or pathway, evacuation of all unnecessary personnel, diversion of traffic from the area, and subsequent investigative and mitigative procedures from trained specialists.

Cask integrity is not addressed without inspection, both visual and with radiation detection instruments. These actions are typically time consuming, due to the lack of first responders with specialized training in the mitigation of radioactive materials incidents and availability of specialized equipment. Detection instrument operational condition and calibration are also concerns, which,

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when combined with the lack of adequate training, have resulted in some states actually placing the equipment in a centralized storage area and relying on specialty responders for accident assessment. This results in long delays before normal transportation operations can be restored.

An "onboard" instrumentation/communications package has been developed that, when affixed to a spent fuel or high level waste cask, can monitor key indicators of the integrity of the cask and communicate these parameters to emergency responders. Entitled the Transportation Intelligent Monitoring System (TRANSIMS), this package links a monitoring system located inside the transportation cask with instrumentation and communications modules on the vehicle. The first responder can then monitor the status and integrity of the cask remotely, thus lessening the need to approach the container. Use of this unit also relieves the first responder of the necessity of mobilizing specially trained response units unless a release is indicated or some doubt about the integrity of the cask remains. This will effectively minimize transportation system downtime for all but the most severe accidents.

This paper addresses spent fuel and high level waste transportation history and prospects, discusses accident histories of RAM transport, discusses emergency responder needs and provides a general description of the TRANSIMS design.

BACKGROUND

It is estimated that 100 million packages classified as containing hazardous materials are shipped in the United States each year (U.S. Congress 1986). Approximately 2 million shipments of radioactive materials are shipped annually (Javitz et al. 1991), thus making radioactive materials about 2% of the total number of hazardous materials shipped each year. These radioactive materials are shipped in one of the following basic package types:

(1) Exempted packagings,
(2) Strong, tight containers,
(3) Type A packagings,
(4) Type B packagings, and
(5) Fissile material packagings.

Of the packaging types, the Type B packages must be demonstrated to be able to withstand test conditions designed to simulate severe hypothetical accident conditions. Specified by the United States Nuclear Regulatory Commission in 10 CFR 71, these test standards are:

(1) 30 foot drop onto a flat, unyielding surface so that the package's weakest point is struck,
(2) 40 inch drop onto a vertical steel rod at least 8 inches long, striking the package at its most vulnerable point,
(3) exposure of the entire package to an all-engulfing fire of at least 1475°F for 30 minutes, and
(4) total submersion of the package under at least 50 feet of water for at least 8 hours.

These Type B packages are typically used to transport radioisotopes, spent nuclear fuel, nuclear wastes, or similar highly radioactive materials. The majority of these shipments are made to transport radioisotopes, commonly used for surveying or well logging. Large Type B transportation packages typically range from 20 to 25 tons for legal weight transport and 70 to 100 tons for rail transport. These containers are typically used for transport of spent nuclear fuel and high level wastes. Between 1964 and 1989, a total of 2660 cask shipments of commercial spent nuclear fuel were made (Cashwell and McClure 1992). A small number of shipments of research reactor spent nuclear fuel and high level wastes were also made during this period. Averaging approximately 100 shipments per year, shipment activity fluctuates with the start-up and decommissioning of commercial storage and processing facilities. Requirements for shipments of commercially generated spent nuclear fuel to a Monitored Retrievable Storage (MRS) facility in 1998, as specified in the contractual agreements between the Department of Energy and the utilities, in conformance with the Nuclear Waste Policy Act, could result in 1000 to 6000 shipments per year (U.S. Department of Energy 1985).

Historical accident rates for rail and truck transport are approximately 1.5 and 2.5 accidents per million vehicle miles (McClure 1981), respectively. Thus, while historically there have been no releases from a Type B cask carrying spent nuclear fuel, these shipments will be involved in accidents in which emergency response actions are taken. Although analysis of historical data indicates that the probability of a release is extremely low, emergency response actions and measures must be taken until the integrity of the cask and protection of the public is assured. The TRANSIMS concept will permit all interruptions to the transportation network to be minimized and will reduce the current necessity for undue delays for trained responders to answer all, even minor, accidents.

EMERGENCY RESPONSE

Most Type B shipments are routed whenever possible through rural areas, and the first responder to an accident will most likely be a local law enforcement officer or other public service volunteer. In the event of such an accident, the local first responder, having no package status information, must assume the worst case condition, i.e., a radioactive material release, and initiate an appropriate emergency response.

One of the primary functions of the emergency responder in the event of a hazardous material shipment accident is the protection of the general public. Using a conservative approach, dictated by the assumption of a RAM release, to protect the public, the responder would typically close the transport route, divert traffic, evacuate all unnecessary personnel, and wait for a response team trained in radiation assessment.

The TRANSIMS provides responders with immediate vital information on package integrity, external and internal temperature and radiation levels, and internal pressure. The pressure, temperature, and radiation level rates of change are also provided to allow the response team adequate warning of significant changes in the container condition. With this information, emergency responders can accurately assess the situation and implement an appropriate plan of action to protect the public and mitigate the emergency situation.

SYSTEM DESCRIPTION

The TRANSIMS consists of several independent modules. The first is the internal sensor and data processing module. This module measures the internal temperature, pressure and radiation level; logs the measurements; and transmits the data to the acoustic data transmitter/receiver module. The acoustic data transmitter encodes and transmits the digital data as acoustic energy through the package wall to the acoustic receiver, which decodes the signal for input into the microcontroller module. The microcontroller and external sensor module measures the cask external temperature and radiation level, receives internal sensor data, stores and mathematically manipulates all data, determines the appropriate response to emergency responder queries, maintains timing on all routines, and outputs the appropriate voice message. The last element of the system is the communications module. This module consists of a Citizen Band radio frequency transmitter and receiver, with associated decoding and encoding circuitry, and is the emergency responder/TRANSIMS interface. A diagrammatic representation of the TRANSIMS is shown in Figure 1.

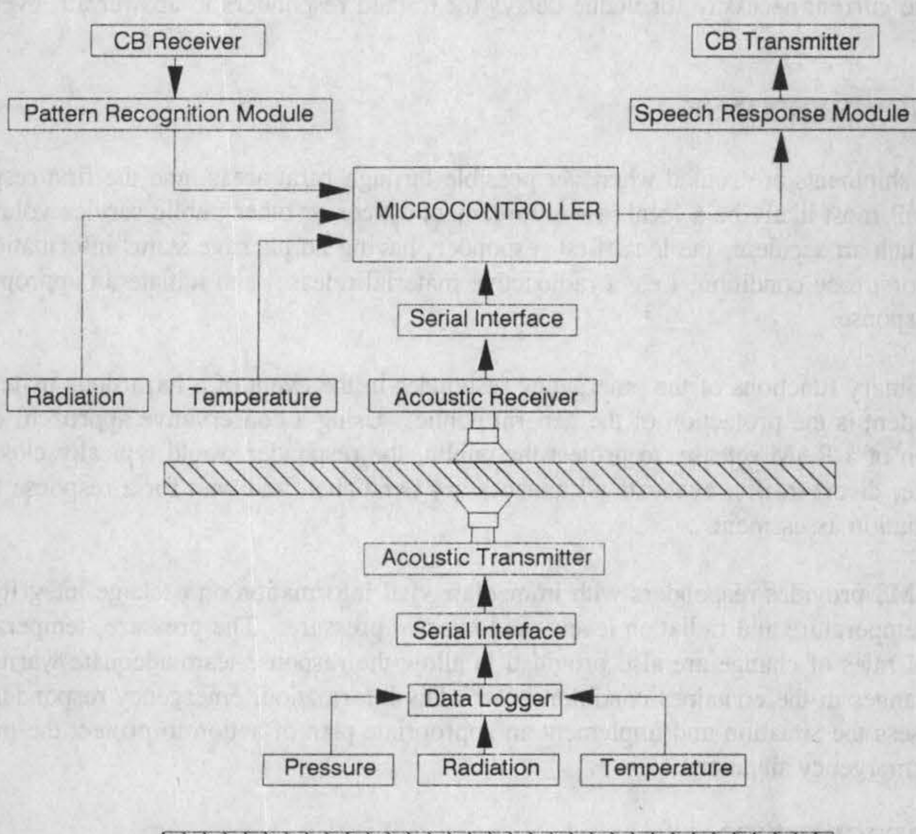

Figure 1. The Transportation Intelligent Monitoring System

As presently configured, the internal sensor module consists of a series of temperature probes, a pressure sensor, radiation sensors and accelerometers. The temperature and pressure sensor measurements are logged by a low power data logger at one second intervals. The accelerometer outputs are processed by a threshold detector which sets a flag high if a predetermined acceleration has been exceeded. These threshold flags are sampled at one second intervals and are used to determine normal or accident transport conditions. The radiation sensor outputs are continuously logged by two pulse count channels. All data are transmitted to the external microcontroller at 15 second intervals.

Data transmission from the internal package cavity to the external environment poses some unique problems. Primarily, the Type B certification is invalidated if any modifications affecting package integrity are made. Such a modification would be a new package penetration for data signal conductors. A novel approach is taken to transmit data and avoid the certification issue, i.e., ultrasonic acoustic transmission of digitized data through the existing package wall. The acoustic transmitter is attached at any point inside the package that has metal to metal contact with the main cask body, and the acoustic receiver is attached at a convenient point on the external wall of the transportation cask. The attachment points are welded to the existing surfaces and do not affect the package certification.

The digitized data are used to pulse width modulate the 220 Khz carrier frequency of the ultrasonic transmitter. The modulating pulse width varies between approximately 0.8 and 6.4 milliseconds, depending on the data bit pattern being transmitted. The original digitized data stream is restored after demodulation by the acoustic receiver.

Two potential problems in data transmission have been identified as: (1) acoustic noise and (2) data synchronization. The frequency range of acoustic noise, introduced by rail or truck transport vehicle vibration, is reported to be less than 2 Khz (Magnuson and Wilson 1977). The ultrasonic receiver transducer responds poorly to these frequencies, and very little vibrational energy at these frequencies is converted into electronic noise. Additionally, active electronic filters in the receiver circuit eliminate any low frequency electronic signal that may be present. The data synchronization problem is solved by placing a unique bit pattern at the beginning of each data frame to ensure proper timing in the decoding of the transmitted data stream.

The microcontroller module accepts input from the following sources: (1) the external sensors, (2) the internal data logger, and (3) the pattern recognition module. All incoming sensor data from both the external and internal sensors is stored and manipulated by the primary control algorithm. Rates of change are calculated using the most current data set.

The primary control algorithm responds at two levels. The first level simply notifies the requestor that package integrity has been maintained and that the external radiation levels are not above the established background. The second level is for more highly trained responders and provides details on internal temperatures and pressures, including rates of change. This enhanced response level provides emergency responders with the necessary information to properly assess the effectiveness of a specific course of action.

A TRANSIMS response is initiated by the transmission of a predetermined click pattern over a Citizen Band radio link. A pattern recognition module decodes the emergency responder request and activates the proper response algorithm in the microcontroller. Originally a speaker independent speech recognition scheme was proposed. However, the current technology for speaker independent recognition is expensive and gives less than 90% recognition, so to provide reliable operation, a pattern recognition scheme is used. The TRANSIMS responds using synthesized speech which is transmitted to the emergency responder via the Citizen Band radio link.

CONCLUSION

Based on the historical RAM transport accident rate, at least one surface transportation accident involving spent fuel or high level waste can be expected each year. Initial response to the accident will most likely be by personnel untrained in the mitigation of a RAM incident. Due to the lack of immediate cask integrity information, the worst case situation, a radioactive material release, will be assumed by the emergency responder. A conservative and possibly costly emergency response will be initiated and followed until specialized radiation assessment teams arrive.

A new approach to RAM transport accident assessment is the Transportation Intelligent Monitoring System (TRANSIMS), an "onboard" cask status monitor. This system provides the emergency responder with the ability to remotely monitor package status information, accurately assess the situation, and initiate the appropriate response in a timely and cost-effective manner.

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