14th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2004), Berlin, Germany, September 20-24, 2004

Paper # 108

NAC's Modular, Advanced Generation, Nuclear All-purpose STORage (MAGNASTOR) System: New Generation Multipurpose Spent Fuel Storage For Global Application

Charles W. Pennington

NAC International, Norcross, Georgia, USA

Multipurpose canister systems (MCS) have been designed, licensed, fabricated, constructed, and loaded over the last decade within the U.S. These systems are characterized as concrete-based storage overpacks containing transportable canisters utilizing redundantly welded closures. Canisters are designed and intended to be transferred into transport packagings for shipment off-site, and canister designs do not preclude their use in waste disposal overpacks.

Over the last decade, more than 325 MCS systems have been procured by U.S. utilities and more than 225 have been loaded with spent fuel and placed into Independent Spent Fuel Storage Installations (ISFSI) at reactor sites. To date, NAC multipurpose systems constitute some 40% of all loaded concrete MCS in the U.S.

The initial phase of MCS deployment in the U.S. is coming to a close, a phase characterized by procurements of first generation MCS for older plants with physical limitations, and for plants with near-term storage requirements and needing to preclude loss of full core reserve (FCR). The next phase of MCS procurements will be characterized by procurements for newer generation plants and for first-phase plants re-entering the market to improve their storage program.

NAC has learned a number of significant lessons in the deployment of its first generation MCS. During this period prior to the next procurement phase, NAC has developed a new generation MCS, incorporating the lessons learned from the first generation while considering the capabilities of the plants populating the next phase. The system is identified as the Modular, Advanced Generation, Nuclear All-purpose STORage (MAGNASTOR) system, and this paper addresses its unique design, fabrication, and operations features. Among these are:

- a unique developed cell basket design, under patent review, that increases spent fuel capacities and simplifies fabrication while providing high strength and heat removal efficiency
- a significantly enhanced canister closure design that improves welding time, personnel dose, and drying performance
- a low profile vertical concrete cask design that improves on-site handling and site dose rates, offers tangible threat limitations for beyond-design-basis events, and maintains proven and simple construction/operation features
- a simple, proven transfer system that facilitates transfer without excessive dose or handling
- a new approach to water removal and canister drying, using a moisture entrainment, gas absorption vacuum (MEGAVAC) system.

The paper includes design and licensing status of the MAGNASTOR system, and prototyping development that NAC has performed to date.

Introduction

Over the last decade, the use of multipurpose canister systems (MCS) in the U.S. has grown to the point where it is now the dominant technology for dry spent fuel storage. These systems are characterized as concrete-based storage overpacks containing transportable canisters utilizing redundantly welded closures. Canisters may be transferred into transport packagings for shipment off-site, and canister designs do not preclude their use in waste disposal overpacks. The U.S. Department of Energy drove this development by endorsing the use of MCS during the period of 1993 through 1997. More than 325 of these systems have been fabricated and constructed since the late 1990's, and more than 225 have been loaded with spent fuel and are in storage at Independent Spent fuel Storage Installations (ISFSI). NAC has been at the forefront of this deployment of first generation MCS in the U.S., with about 40% of the installed capacity of MCS being either NAC Multipurpose Canister (MPC) systems or NAC Universal MPC Systems (UMS).

The market for dry storage technology in the U.S. is presently undergoing a transition. The initial phase of MCS procurement in the U.S. is coming to a close, a phase characterized by procurements of first generation MCS for older plants with physical limitations, and for plants with near-term storage needs to preclude loss of full core reserve (FCR) in their spent fuel pools. The next phase of MCS procurements will be characterized by procurements for newer plants and for first-phase plants re-entering the market to improve their storage situation. The plants that will be entering the market for dry storage for the first time will be typically of newer design, with more space, more clearance and headroom, and higher cask crane lifting capacities.

NAC has learned a number of significant lessons in the deployment of its first generation MCS. During this period prior to the next procurement phase, NAC is developing a new generation MCS, incorporating the lessons learned from the first generation while considering the capabilities of the plants populating the next phase. The system is termed the Modular, Advanced Generation, Nuclear All-purpose STORage (MAGNASTOR) System. MAGNASTOR incorporates a number of features that improve its fuel coverage, its capacities, its thermal performance, its operational efficiency, and its installed cost per assembly, when compared to first generation technology.

The following sections provide an overview of the MAGNASTOR system, its design features, capabilities, supporting ancillary equipment, anticipated licensing schedule, and prototyping development.

System Description

MAGNASTOR is a spent fuel dry storage system consisting of a concrete cask and a welded stainless steel transportable storage canister (TSC) with a welded closure lid to safely store spent fuel. The TSC is stored in the central cavity of a concrete cask and is compatible with the MAGNASTOR Transport Cask for future off-site shipment. The concrete cask provides structural protection, radiation shielding, and internal airflow paths that remove the decay heat from the TSC contents by natural air circulation. MAGNASTOR is designed and analyzed for a minimum 50-year service life.

MAGNASTOR provides for the long-term storage of spent fuel and subsequent transport using an MAGNASTOR transport cask. During long-term storage the system provides an inert environment, passive structural shielding, cooling and criticality control, and a welded confinement boundary. The structural integrity of the system precludes the release of contents in any of the design basis normal conditions and off-normal or accident events.

MAGNASTOR is designed to safely store up to 37 PWR or up to 87 BWR spent fuel assemblies in a TSC. These capacities, combined with enhanced operational features, assure that MAGNASTOR reduces the time and personnel dose required for placing spent fuel into dry storage, on a per assembly basis. Because spent fuel assemblies have different overall lengths, the PWR and BWR fuel assembly populations are each divided into two fuel length groups, which are accommodated by two different lengths of TSCs. A single height concrete cask and transfer cask design can accommodate both TSC lengths, reducing equipment costs for multiple-plant-type users.

System operations involve placing spent fuel into the TSC while it is in the transfer cask and positioned in the cask loading area of the spent fuel pool. The transfer cask provides radiation shielding during TSC closure and preparation activities. Maximum system handling weight on the crane hook is less than 115 tons (104 t). The loaded TSC is drained and dried, and the closure lid welded to the canister. The TSC is moved to the concrete cask using the transfer cask. The TSC is transferred into the concrete cask by positioning the transfer cask, with the loaded TSC, on top of the concrete cask, opening the shield doors, and lowering the TSC into the concrete cask. Figure 1 depicts the major components of MAGNASTOR in such a configuration.

The system design and analyses are in accordance with 10 CFR 72, ANSI/ANS 57.9, the applicable sections of the ASME Boiler and Pressure Vessel Code (ASME Code), the American Concrete Institute (ACI) code, and ANSI N14.6.

General Description of MAGNASTOR

The principal components of MAGNASTOR are:

- transportable storage canister (TSC)
- vertical concrete cask (CONCRETE CASK)
- transfer cask

Each of these components is briefly described below.

TSC

The TSC is designed for both storage and transport. Load conditions in transport produce higher stresses in the TSC than are produced during storage conditions. Consequently, transport load conditions establish the design basis for the TSC, and, therefore, the TSC design is conservative with respect to storage conditions.

The stainless steel TSC assembly holds the fuel basket structure and confines the contents. See Figure 2. The TSC is defined as the confinement boundary during storage. The welded closure lid prevents the release of contents under normal conditions and off-normal or accident events. The fuel basket assembly provides the structural support and a heat transfer path for the fuel assemblies while maintaining a subcritical configuration for all of the evaluated normal conditions and off-normal or accident events.

The TSC consists of a cylindrical stainless steel shell with a welded stainless steel bottom plate at its closed end and a 9-inch (229 mm) thick stainless steel closure lid at its open end having large vent and drain port penetrations. These large ports provide access for auxiliary systems to drain, dry, and backfill the TSC. The single lid closure represents a significant improvement in the welding required for canister sealing, thereby reducing operations time and personnel exposures.

Each TSC contains either a PWR or BWR fuel basket, which positions and supports the fuel. The basket uses a proprietary, developed cell technology, and a patent application for this technology is under review by the U.S. Patent Office. The basket design optimizes convective heat transfer from the fuel to the TSC outer shell using the pressurized helium backfill gas within the TSC. PWR and BWR basket configurations are similar. The structural components of both the PWR and BWR baskets are fabricated from low alloy steel with an electroless nickel plating to minimize corrosion and preclude significant generation of combustible gases during fuel loading. The designs minimize horizontal surfaces that could entrain water and provide free paths for water flow to the sump and drain tube in the bottom of the TSC. The lid port, internal drain system, and basket designs represent significant improvements to minimize and facilitate removal of retained water, thereby reducing the time required to dry the TSC to satisfactory storage conditions.

Each fuel basket design is an arrangement of square fuel tubes held in a right-circular cylinder configuration using support weldments that are bolted to the outer fuel tubes. Fuel tubes support an enclosed neutron absorber sheet on up to four interior sides. Tubes are assembled in an array using a proprietary methodology, where the tubes function as independent fuel positions and as sidewalls for the adjacent fuel positions in what is called a developed cell array. Consequently, the total fuel storage positions are developed using significantly fewer tubes. The array is surrounded by weldments that serve both as sidewalls for some perimeter fuel positions and as the structural load path from the array to the TSC shell wall.

Concrete Cask

The concrete cask is the storage overpack for the TSC and its design is based on the highly successful UMS concrete cask. It provides structural support, shielding, protection from environmental conditions, and natural convection cooling of the TSC during long-term storage. The main body uses reinforced concrete attached to a structural steel inner liner and base. The reinforced concrete wall and steel liner provide the radial neutron and gamma radiation shielding for the stored spent fuel. Inner and outer reinforcing steel (rebar) assemblies are encased within the concrete. Refer to Figure 3. The reinforced concrete provides the structural strength to protect the TSC during events such as tornado wind loading, tornado missiles and during non-mechanistic tip-over events. The concrete surfaces remain accessible for inspection and maintenance over the life of the cask so that restoration actions may be taken to assure decades of license-compliant service.

The concrete cask provides an annular air passage to allow the natural circulation of air around the TSC to remove decay heat. The lower inlets are steel-lined penetrations in the concrete cask and each is covered with a screen. A baffle directs the air upward and around the pedestal that supports the TSC. The design of the air inlets and of the TSC pedestal support reduces the overall height of the concrete cask, giving it a low profile. Heat is removed by conduction and convection from the TSC shell to the air flowing upward through the annular air passage and exhausting through the air outlets. The concrete cask thermal design also maintains the bulk concrete temperature below ACI limits under normal operating conditions. The inner liner incorporates standoffs that provide a larger heat transfer surface and lateral support to the TSC in side impact events.

A carbon steel reinforced concrete lid is bolted to the top of the concrete cask. The lid incorporates the connecting points for lifting and the lift anchors for vertical handling of the loaded concrete cask. The lid provides the axial gamma and neutron radiation shielding, reduces skyshine radiation, and provides a cover to protect the TSC from the environment and postulated missiles. The design also allows the concrete cask to be moved outside the fuel building prior to lid installation, improving system egress (and ingress) through restrictive door openings.

Daily verification that the air inlets and outlets are free of blockage assures that airflow through the concrete cask meets design requirements. As an alternative to daily verification, the loaded concrete cask in storage may include remote temperature detector-mounted in air outlets, which are used to measure the exit air temperature.

Transfer Cask

The transfer cask provides biological shielding and structural protection for a loaded TSC, and is used to lift and move the TSC between workstations. The transfer cask is also used to shield the vertical transfer of a TSC into the concrete cask or transport cask. The transfer cask is designed, fabricated, and tested to meet the requirements of ANSI N14.6 as a special lifting device.

The transfer cask design incorporates three retaining blocks, pin-locked in place, to prevent a loaded TSC from being inadvertently lifted through its top opening. The transfer cask has retractable bottom shield doors. During TSC loading and handling operations, the shield doors are closed and secured. After placement of the transfer cask on the concrete cask or transport cask, the doors are retracted using hydraulic cylinders and a hydraulic supply. The TSC is then lowered into a concrete cask for storage or into a transport cask for offsite shipment. Refer to Figure 1 for the general arrangement of the transfer cask, TSC, and concrete cask during loading.

Penetrations at the top and bottom of the transfer cask body are available to provide a water or gas supply to and from the transfer cask annulus. Penetrations not used for supply or return are capped. The transfer cask annulus can be isolated using inflatable seals located between the transfer cask inner shell and the TSC near the upper and lower ends of the transfer cask. These penetrations can be used to minimize contamination of the canister in the pool and to cool the TSC using water or gas during closure operations.

Design Basis Fuel for Storage

The MAGNASTOR system has been designed to store and transport the spent fuel types, enrichments, and burnups that will be generated from the use of high burnup fuel cycle plans at global nuclear power plants over the next decade. The design objective for MAGNASTOR is that the system be able to store a significant fraction of spent fuel having burnups of 55 GWd/Mtu with cooling of about 6 years after its last criticality. Peak burnup limits are 70 GWd/MTU for PWR and 60 GWd/MTU for BWR fuel types.

Tables 1 and 2 provide the design bases for both PWR and BWR fuel.

Ancillary Equipment

The operation of the principal components of MAGNASTOR requires the use of associated ancillary equipment. The more significant items of ancillary equipment generally needed to operate the MAGNASTOR system are briefly discussed below.

- automated, remote, and /or manual welding equipment to perform TSC lid closure welding operations at the nuclear facility, along with weld inspection equipment;
- draining, drying, helium backfill, and water cooling systems for preparing the TSC and contents for storage; MAGNASTOR can use either vacuum drying or pressurized helium drying, depending on TSC heat loads; pressurized helium drying can be combined with vacuum drying to achieve a moisture entrainment, gas absorption vacuum (MEGAVAC) drying approach;
- hydrogen monitoring equipment to confirm the absence of explosive or combustible gases during TSC closure welding
- an adapter plate and a hydraulic supply system to align the transfer cask with the concrete cask or transport cask and to operate the transfer cask shield doors;
- a lifting yoke for lifting and handling the transfer cask and rigging equipment for lifting and handling other system components, such as lids;
- an engine driven or towed frame, or a heavy-haul trailer to move the concrete cask to and from the storage pad and to position the concrete cask on the storage pad.

In addition to these items, the system requires utility services (electric power, helium, air, clean and/or borated water, nitrogen gas supply, etc.), standard torque wrenches, tools and fittings, and other miscellaneous hardware.

Development and Licensing Status

The MAGNASTOR System has been under development at NAC for about 15 months. During this effort, licensing considerations and fabrication issues have dominated the development activities. In particular, the unique TSC basket technology, now under patent review, has driven most major development tasks. Once the approach to the basket design and its interconnecting tube assembly was mastered, elements of its safety analysis and its fabrication had to be defined, refined, and ultimately defended. Key among the analysis efforts involving the basket has been the thermal analysis approach, developed by NAC. That particular effort is addressed in other publications. A unique aspect of NAC's design development approach was to meet periodically with the staff of the U.S. NRC to discuss the MAGNASTOR development and licensing approach. Another unique aspect was to form a multidisciplinary design review team for MAGNASTOR, a significant component of which was comprised of engineers and plant management from potential customers. Their insights were beneficial, especially in optimizing design features and in identifying which particular design features were worth aggressively pursuing during the system-licensing phase.

The ability to fabricate the system with the quality, schedule, and cost, necessary for such technology was another determination of paramount importance, requiring extensive effort. NAC performed full-scale prototype work on basket components to assure fabrication, tolerance and assembly requirements could be met. Additionally, NAC worked with several fabricators on manufacturing reviews. These resulted in several design improvements to reduce fabrication costs and schedules. These reviews have clearly established appropriate costing and scheduling parameters, assuring that MAGNASTOR will be an extremely competitive dry storage system in the global marketplace.

The USNRC certification of the MAGNASTOR System is now underway. NAC recently submitted the application to the U.S. NRC and will be supporting post-application meetings with the NRC staff to maintain an efficient licensing process. The MAGNASTOR System is on track to receive NRC approval in 2006 based on recent NRC review and certification schedules. First delivery of the system is also expected in that same time frame. Transport certification will begin next year with the submittal of the transport licensing application, and the transport CoC is anticipated in late 2006.

Conclusions: Super Storage, Safe and Sure

NAC's MAGNASTOR System is based upon integrating proven technology and experience into a robust, economical, ultra-efficient, multipurpose system for the future. MAGNASTOR represents a new generation of dry MCS technology for use in the global market for spent fuel storage and transportation. Thanks to a focus on incorporating many lessons learned from NAC's extensive experience and on improving the economics of dry storage for its customers, NAC has developed a system that customers can be assured will be safe under any set of credible conditions, will be more efficient to load and operate than other designs, and will become a significant factor in improving the financial performance of their dry spent fuel storage programs.

Figure 1 - Major Component Configuration for Loading the Concrete Cask

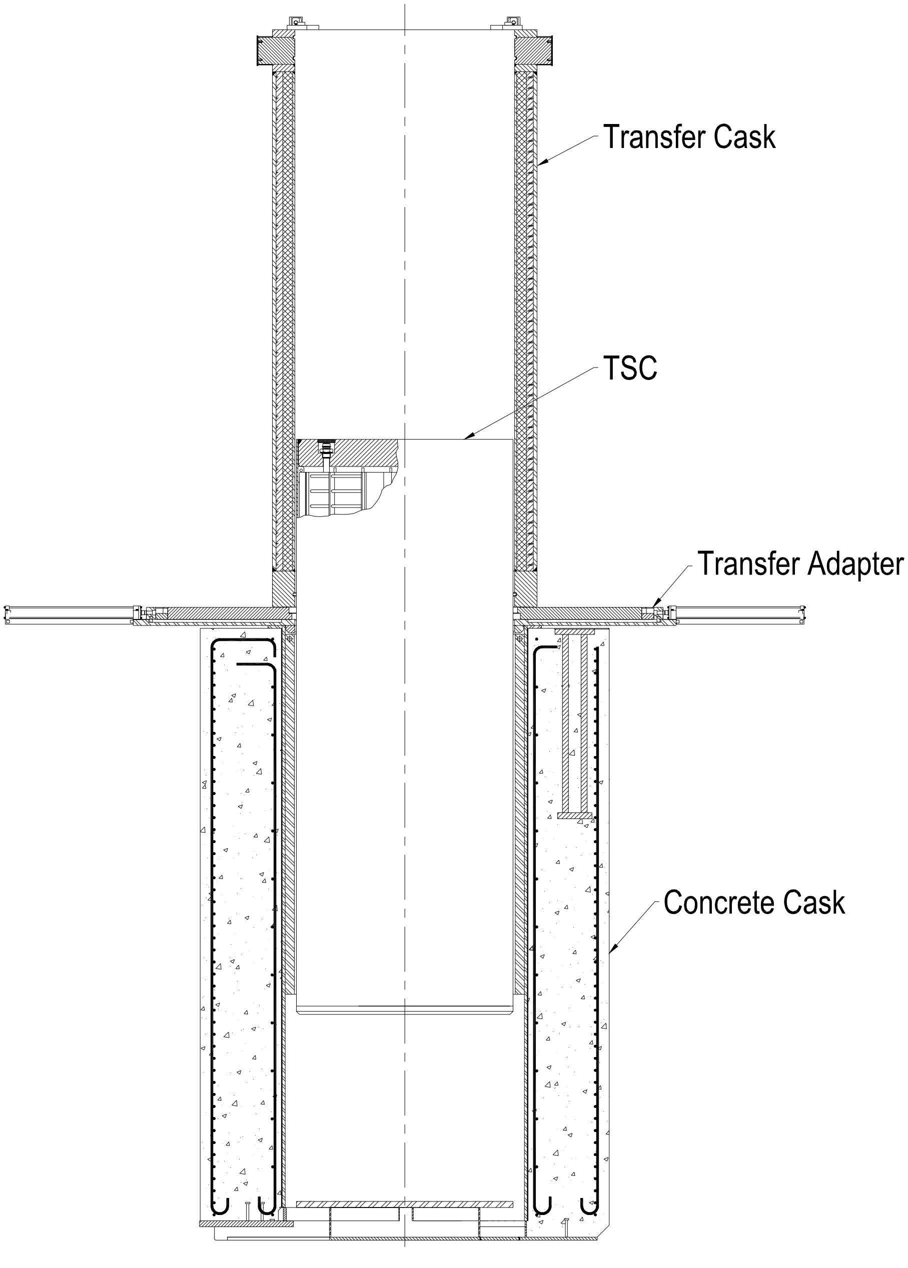

Figure 2 TSC and Basket

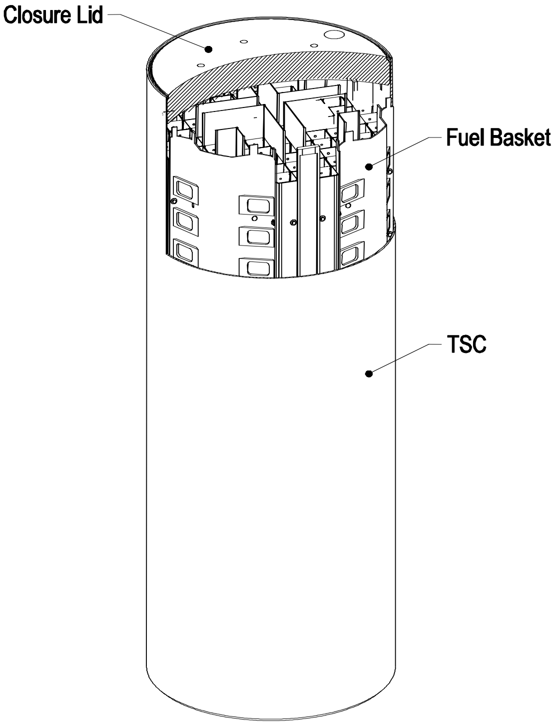

Figure 3 Concrete Cask

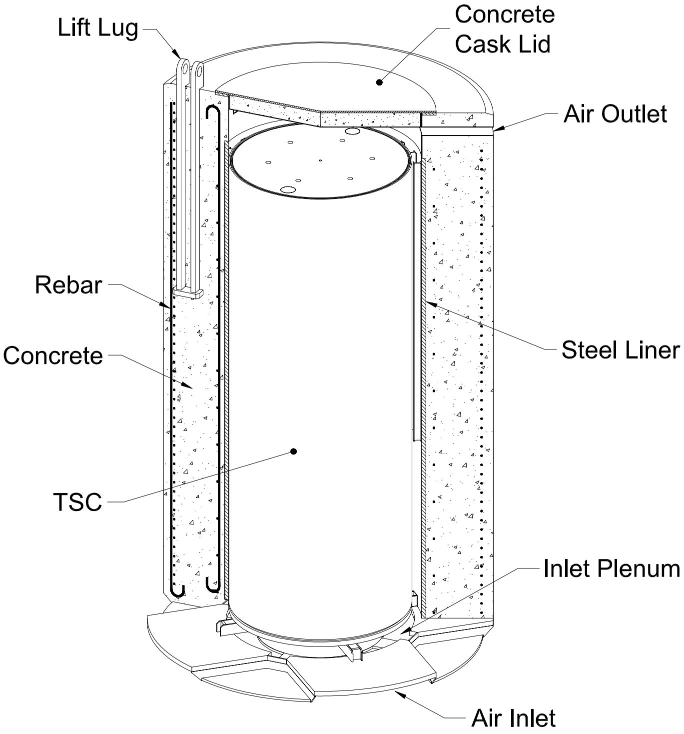

Table 1 - PWR Fuel Assembly Characteristics

Characteristic	Fuel Class					
	14×14	14×14	15×15	15×15	16×16	17×17
Max Initial Enrichment (wt % ^{235}U)	5.0	5.0	5.0	5.0	5.0	5.0
Min Initial Enrichment (wt % ^{235}U)	1.3	1.3	1.3	1.3	1.3	1.3
Number of Fuel Rods	176	179	204	208	236	264
Max Assembly Average Burnup (MWd/MTU)	70,000	70,000	70,000	70,000	70,000	70,000
Min Cool Time (years)	4	4	4	4	4	4
Max Weight (lb) per Storage Location	1,680	1,680	1,680	1,680	1,680	1,680
Max Decay Heat (Watts) per Storage Location	1,350	1,350	1,350	1,350	1,350	1,350

Table 2 - BWR Fuel Assembly Characteristics

Characteristic	Fuel Class			
	7×7	8×8	9×9	10×10
Max Initial Enrichment (wt % ^{235}U)	4.5	4.5	4.5	4.5
Number of Fuel Rods	48/49	59/60/61/ 62/63/64	72/74/76/ 79/80	91/92/96/100
Max Assembly Average Burnup (MWd/MTU)	60,000	60,000	60,000	60,000
Min Cool Time (years)	4	4	4	4
Min Average Enrichment (wt % ^{235}U)	1.3	1.3	1.3	1.3
Max Weight (lb) per Storage Location	704	704	704	704
Max Decay Heat (Watts) per Storage Location	437	437	437	437