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DEVELOPMENT OF A DEPARTMENT OF ENERGY REPLACEMENT FOR THE 110-GALLON SPECIFICATION 6M SHIPPING CONTAINER

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ABSTRACT

The Department of Energy (DOE) has been shipping university reactor fuels and other fissile materials in the 110-gallon Department of Transportation (DOT) Specification 6M container for over 20 years. The DOT 6M container has been the workhorse for many DOE programs. However, packages designed and used according to the specification 6M (U. S. Code of Federal Regulations, 49 CFR 178.354; 2003) do not conform to the latest package safety requirements in the U.S. Code of Federal Regulations 10 CFR 71, especially performance under hypothetical accident conditions. For that reason, the specification 6M is being eliminated by the DOT. Packages designed to the 6M specification will no longer be allowed for in-commerce shipments after October 1, 2008.

The need for 6M replacements has been a major focus of the Secure Transportation and Packaging Steering Committee (STPSC) for several years. The STPSC is responsible for looking ahead at DOE future transportation needs and ensuring that those needs are met by the use of existing packages or the development of new packages. The STPSC was involved with developing a 55-gallon 6M replacement. After much deliberation, the DOE National Nuclear Security Administration (NNSA), Office of Defense Programs, in coordination with STPSC, provided funds for replacing the 110-gallon 6M.

Initially, two design agencies were asked to provide concepts for the new package. Both of these organizations, Savannah River National Laboratory and BWXT Y-12, have extensive experience with nuclear material shipping containers. After an evaluation, NNSA selected BWXT Y-12 for the project. The new container, designated the ES-4100 shipping container, will be a larger version of the ES-3100 container (USA/9315/B(U)F-96), designed by BWXT Y-12 and certified by the Nuclear Regulatory Commission in April 2006. The ES-3100 replaces the smaller 55-gallon 6M and is being used exclusively throughout the DOE complex. The ES-4100 will also be certified by the Nuclear Regulatory Commission.

The ES-4100 project began in September 2006 and the new container is expected to be operational in FY 2009. Details on the preliminary design features of this new container and the types of material to be shipped are discussed in this paper.

PACKAGE DESCRIPTION

The replacement package for the 110-gallon DOT Specification 6M container has been designated the Model ES-4100 container. This container will be a Type B package and has two major systems, a confinement assembly and a containment vessel. The confinement assembly (shown as a cutaway on Figure 1), will consist of an outer drum, insulation, an inner liner, and a drum lid. The containment vessel (CV) will consist of a pressure vessel with associated lid and O-ring seals. This package carries four CVs as opposed to the one CV the 6M carries. The multi-pack design concept will increase efficiency of the transport systems used to ship Type B quantities of highly enriched uranium and other fissile materials.

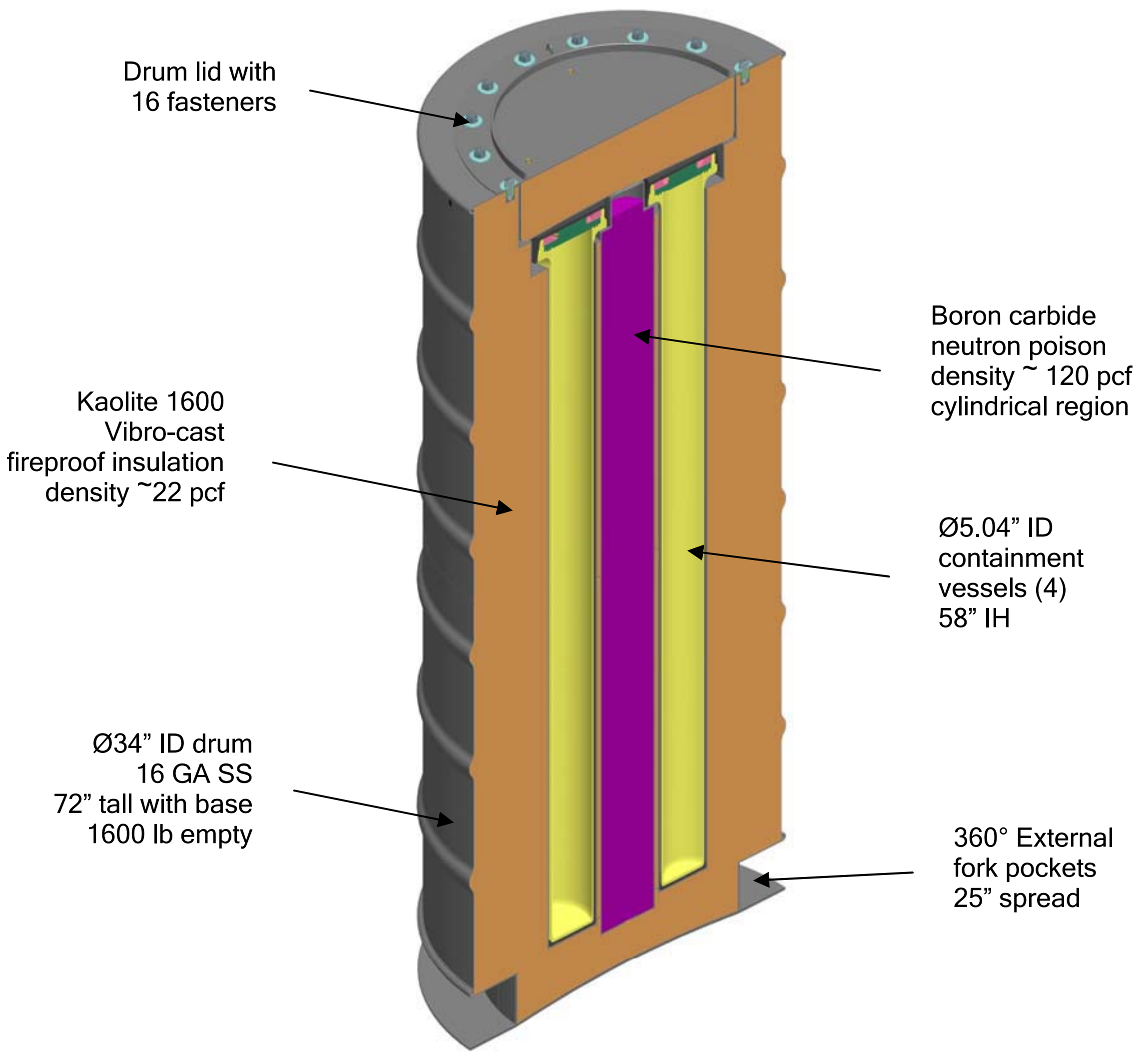

Figure 1. Section View of the ES-4100 Preliminary Design.

Confinement Assembly

The primary function of the confinement assembly is to ensure that the containment vessels remain confined under both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) as defined in 10 CFR 71 [1]. For HAC, the ES-4100 package must be able to withstand the rigors of a 9-m drop and a 1-m puncture test. The dynamic crush test, as defined in 10 CFR 71.73 (consisting of dropping a 500 kg steel plate from 9 m onto the package in its most vulnerable orientation) is not required for this Type B package because of the package weight.

The visible portion of the confinement assembly is a stainless steel drum. The current design employs a modified standard drum with a 34-in. outside diameter and a 72-in. height. Figure 2 is a depiction of the open drum showing the outside of the drum, the inner liner and cavities for the four containment vessels that the ES-4100 will carry. Also shown is the central region that contains the neutron poison material. The location of the drum-lid fasteners are shown on the inbound edge of the angle iron used to form the top portion of the drum liner. Along with the fasteners are two attachment points for tamper-indicating devices (TID).

The base drum is open at both ends. The modifications include the attachment of a drum top section and liner. The top surface will have flush-mounted nuts welded in place to accept lid bolts. Another modification has to do with a unique drum bottom attachment, which reduces deformation during structural testing.

A key design feature of the ES-4100 is the use of fully encapsulated insulation material. It should be noted that while it is referred to as insulation material, this material provides energy absorption during drop and puncture testing as well as thermal insulation during thermal testing. The use of an inner liner attached to the drum creates an annular space, which is subsequently filled with an insulating material. The insulating material is poured into this cavity through the open bottom of the drum. The insulation material is Kaolite 1600™. The application of this material in drum-type shipping packages has been patented by Y-12 [2]. Kaolite 1600™ is a mixture of Portland cement and expanded vermiculite, and has a cast density in the range of 22 lb/ft^3. Encapsulated insulation has been shown on other packages to reduce life-cycle costs by reducing package refurbishment and maintenance efforts over the life of the package.

From a safety performance standpoint, Kaolite 1600™ is fireproof. This material is used on three other fully certified shipping packages at BWXT Y-12 (ES-2100, ES-3100, and DPP-2). On these other packages, no significant degradation of the insulating materials was observed during the HAC thermal testing [3]. Decomposition from an impact (cracking) can lead to heat transfer via mass transfer of hot off-gases, thereby leading to unpredictable and sometimes unacceptably high temperatures at the containment boundary. Under HAC conditions, the moisture within the Kaolite 1600™ is vaporized to steam, which then escapes from the package via vent holes in the drum. This results in heat dissipation and more protection of the containment boundary O-ring seals. The drum inner liner becomes a heat transfer barrier (convection and radiation) during the HAC, and based on past experience, will keep the temperature around the containment boundaries close to 212°F.

Another significant feature of the confinement assembly is a neutron absorbing system. The neutron absorbing system uses a cast material in a centrally located cylinder in a region between the four containment vessels. This neutron absorber is a noncombustible, cast material, which is composed of a high alumina concrete with about 4 wt. % boron carbide and a cast density in the range of 120 lb/ft3. The presence of the neutron absorber allows increased fissile mass loadings over other Type B packages. The use of a neutron absorbing layer in a drum-type package was first used in the ES-3100 package, which was certified by the U.S. Nuclear Regulatory Commission [USA/9315/B(U)F-96].

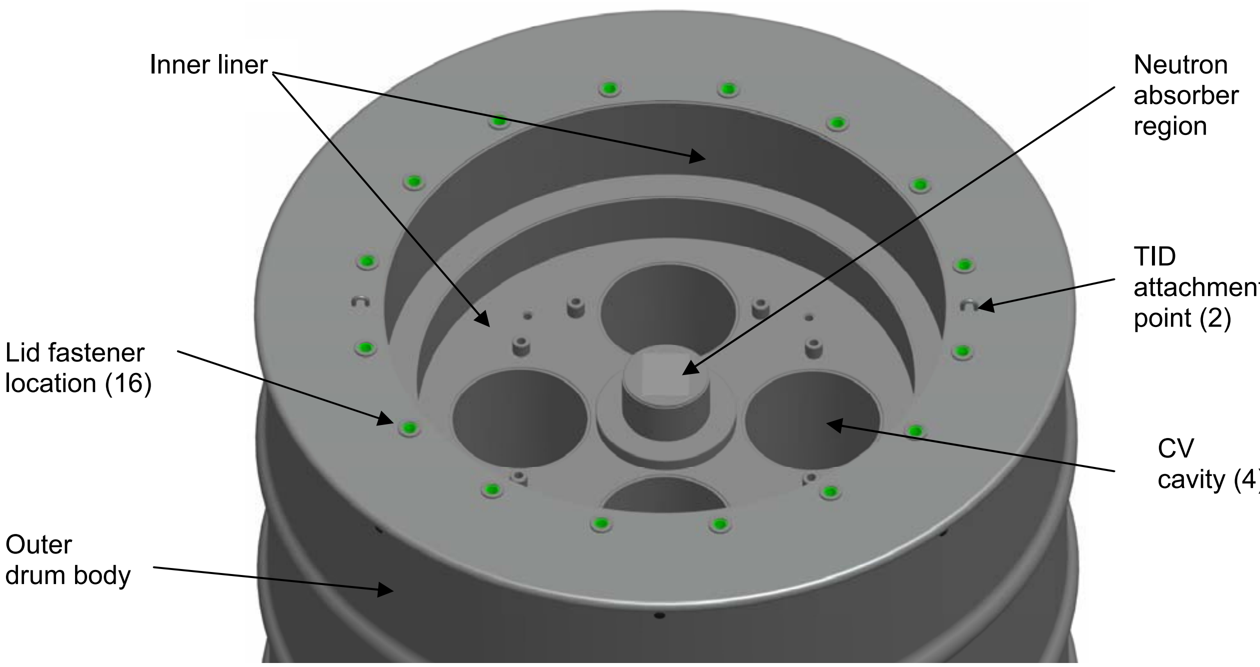

Figure 2. Open Drum Body.

Figure 3 is a depiction of the open drum showing CVs loaded. The top of two CVs are exposed and the other two CVs are covered with silicone rubber caps that are installed for shipping. The silicone caps protect the CV heads during shipment. Also visible on Figure 3 are ball-lock pins. These pins engage the body of the CV and prevent it from rotating while the CV head screw is loosened and tightened, as can be seen in the top left CV position. When the ball-lock pins are not being used, they are stowed in holes in the liner (as shown). The inset in Figure 3 shows all four CVs covered with silicone caps in preparation for shipment.

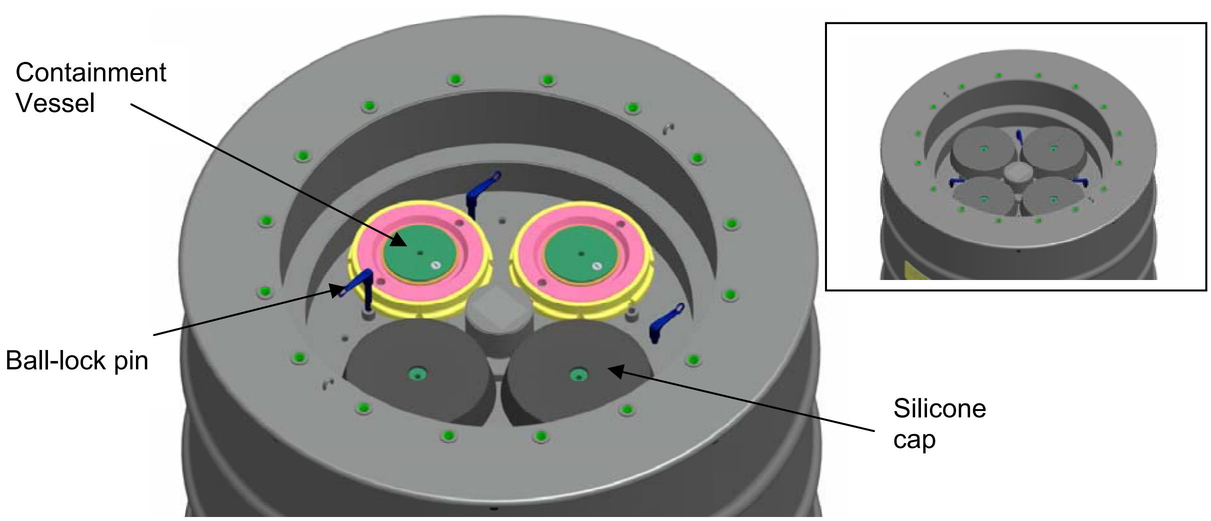

Figure 3. Open ES-4100 Showing Containment Vessels.

Containment Assembly

The primary function of the containment vessel is to maintain containment of the radioactive materials being shipped. This is accomplished through the use of a stainless steel vessel body and lid with an elastomeric O-ring seal (Figure 4). This containment vessel is leak testable. Leak rates on the order of 1×10^{-7} ref-cm^3/s are achievable with the seal design on the containment vessel, as demonstrated after HAC testing of the ES-3100 [4]. The ES-4100 CV is designed to operate with an internal pressure of up to 100 psig and will be manufactured in accordance with the ASME B&PVC, Section III, Subsection NB [5].

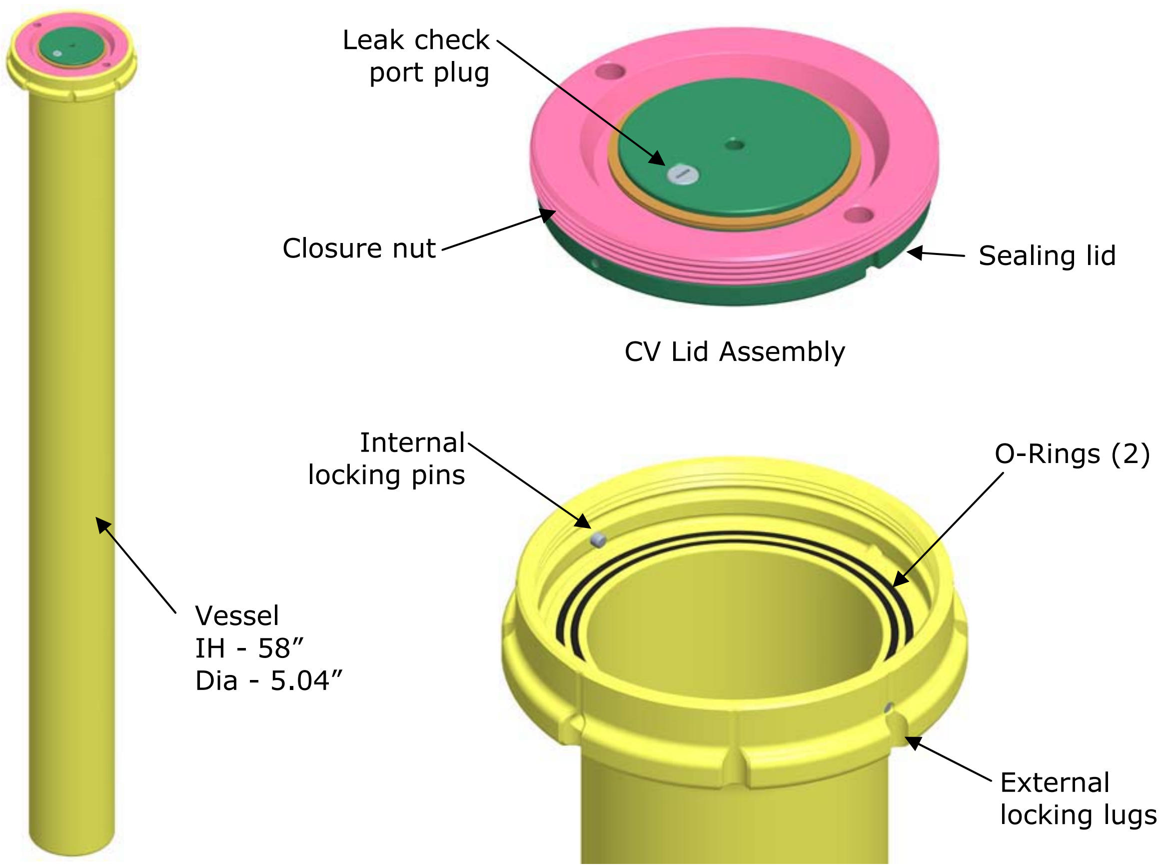

Figure 4. Containment Vessel Details.

The sealing mechanism for the ES-4100 CV involves a single nut that engages a threaded flange on the CV body. This single nut applies pressure to the top lid, thus providing adequate pressure on the O-rings to maintain a seal. A torque of 120 ft-lb is required to completely engage the nut. The CV body of this package, the upper threaded region, and the unique lid sealing mechanism are illustrated on Figure 4.

A key design feature of the ES-4100 is the size of the CV. Both the diameter and height of the CV have been optimized for HEU fuel shipments while also taking into account other fissile materials. The ES-4100 conceptual design specifies a 5.06-in. inside diameter CV (with a tolerance of ±0.04 in.). There is clearance outside the CV to allow for a slightly larger CV for other applications.

For payload efficiency, the ES-4100 will contain four CVs. With six ES-4100s per truck, this configuration allows the shipment of 24 CVs per load versus 20 CVs per truck load with the current DOT 110-gallon specification 6M container.

REGULATORY COMPLIANCE

The package will comply with the NRC requirements in 10 CFR 71 and also comply with International Atomic Energy Agency requirements (TS-R-1) [6] for international Type B shipments. Specific requirements for safety that were stressed in the new design are:

- Meet all regulatory requirements, including normal and accident conditions tests for Type B packages.

- Ease of certification, relying on state-of-the-art, but defensible, technology and experience in licensing Type B packages.

To protect the health and safety of the public, shipments of radioactive materials made in the ES-4100 are assured to be safe because of packaging that is designed, fabricated, assembled, tested, procured, used, maintained, and repaired in accordance with the regulations cited above. The ES-4100 Safety Analysis Report (SAR) will address structural and thermal responses to NCT (10 CFR 71.71) and HAC (10 CFR 71.73), and the ES-4100's ability to contain the radioactive materials when subjected to these requirements. A shielding evaluation will be conducted to ensure adequate nuclear radiation shielding. Criticality evaluations that are unique to the contents will be conducted to ensure nuclear subcriticality.

The NRC will be the licensing agency for this package in the United States.

SCHDEDULE

The current project schedule shows the SAR and license application being submitted to the NRC in December 2008. Based on a standard NRC review period, certification is expected near the end of calendar year 2009. Since the ES-4100 is replacing the DOT 6M, which is being decertified in October 2008, there will be no service available for this type of package for at least one year. To minimize impacts of this gap to the extent possible, procurement of production ES-4100s may occur in parallel with the NRC review of the license application. While there is risk in this approach, it can be minimized by close tracking of the license application and subsequent questions by the NRC.

PROPOSED CONTENTS

The ES-4100 will initially be licensed to carry research reactor fuel containing HEU. Candidate fuel elements for the ES-4100 are currently:

1. Massachusetts Institute of Technology reactor
2. University of Missouri reactor
3. Training, Research, Isotope and General Atomics (TRIGA) reactors

4. General Electric Test reactor
5. Engineering Test reactor

These fuel elements will be shipped with one element per ES-4100 CV, or in some cases, loose fuel rods in a CV wrapped in polyethylene bags. Maximum fissile uranium per element will be less than 1 kg, so the maximum loading of the ES-4100 is expected to be in the 4 kg ^{235}U range. The ES-4100 has been designed and analyzed for at least twice this loading, but because of the neutron poison, will most likely be able to ship greater quantities of fissile materials, depending on the outcome of analyses for higher loadings.

SIZE COMPARISON

The ES-4100 is a relatively large package. Stability of a tall shipping package is an issue, so the ES-4100 was designed with a larger diameter than the DOT 6M and, with that larger diameter comes greater stability and also greater capacity. A size comparison of the ES-4100 against the existing ES-3100 package is shown in Figure 5. The ES-3100 is 19 in. in diameter by 43 in. tall. Figure 5 is roughly to scale, and shows the ES-4100 size as 34 in. in diameter by 72 in. tall.

ES-4100

34 in. dia
72 in. tall

ES-3100

19 in. dia
43 in. tall

Figure 5. ES-4100 Size Comparison.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the members of the Y-12 Packaging Engineering Group, the Y-12 Nuclear Criticality Safety Group, and the Y-12 Engineering Analysis Group for their efforts in developing new applications of materials for use in Type B, drum-type shipping containers. The materials new to this application (Kaolite™ and neutron absorber) enhance performance under accident conditions and allow greater capacity of individual containers than has been available in the past. BWXT Y-12 holds a U.S. patent for the use of a fireproof cast aggregate as insulation in drum-type shipping containers. The National Transportation Research Center of the Oak Ridge National Laboratory will perform all full-scale regulatory testing of this new shipping container.

DISCLAIMER

REFERENCES

1. U.S. Nuclear Regulatory Commission, Title 10, *Code of Federal Regulations*, Part 71, "Packaging and Transportation of Radioactive Material," Washington, D.C., 2004.

2. Byington, G. B., Oakes, Raymon E., Jr., Feldman, M. R., U.S. Patent, "Fireproof Impact Limiter Aggregate Packaging Inside Shipping Containers," Patent No. US 6,299,950 B1, US Patent Office, Washington, D.C., October 9, 2001.

3. Lockheed Martin Energy Systems, "Advantages of Using a Fireproof Inorganic Cast Refractory Material in Hazardous Content Shipping Packages," Y/LF-565, BWXT Y-12, LLC, Oak Ridge, TN, November 10, 1998.

4. BWXT, Y-12, L.L.C., "Safety Analysis Report, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents," Y/LF-717, Oak Ridge, Tennessee, February 25, 2005.

5. American Society of Mechanical Engineers, "Rules for Construction of Nuclear Power Plant Components," Sect. III, Div. 1, Subsection NB in <u>ASME Boiler and Pressure Vessel Code, An American National Standard</u>, New York, NY, 2002.

6. International Atomic Energy Agency, "<u>Regulations for the Safe Transport of Radioactive Material</u>," TS-R-1, Vienna, Austria, 1996.